Asian J Agric & Biol. 2019;7(2):234-243.

AJAB

Original Article

Effects of cross linking on breadfruit starch and its batter properties

Yusnita Hamzah*, Revathi Subramaniam, Nor Hayati Ibrahim, Suhana Muhamad Hanidun
School of Food Science and Technology, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

Received:
September 03, 2018
Accepted:
March 31, 2019
Published:
June 30, 2019

**Corresponding author email:*
yusnita@umt.edu.my

Abstract

The characteristics of breadfruit starch after cross-linked using 2%, 5%, and 10% of a mixture of sodium trimetaphosphate (STMP)/ sodium tripolyphosphate (STPP) (99/1% w/w) and their feasibility in batter formulation were investigated. The concentrations of 2%, 5%, and 10% of STMP/STPP led to high (85.99%) medium (64.43%) and low (49.59%) cross-linking degree of breadfruit starches, respectively. Swelling power of native and high cross-linked breadfruit starches (CLBS) were significantly higher than that of medium and low CLBS. In addition, enthalpy of gelatinization (ΔH) of high cross-linked CLBS was the lowest (1.81 J/g) among the others. Different degrees of cross-linking did not significantly affect the appearances (size and shape) and crystallinity of breadfruit starches. Batters were prepared by combining wheat flour and native or CLBS (1:1). All batters behaved as shear-thinning fluids and batter with the highest cross-linking degree (CLBS with 2% STMP/ STPP) had the highest consistency (K, 0.46 Pas^n) compared to other CLBS formulations. Water retention capacity of batters containing native and high CLBS were significantly higher than batters containing medium and low CLBS. The pick-up of batter incorporated with low degree of CLBS (10% STMP/ STPP) was significantly lower than other batters. However, the cooking yield of batters containing native and different degrees of CLBS as well as their moisture and fat content were insignificantly affected. In summary, addition of 2% STMP/STPP as cross-linking agents obviously exhibited high degree of cross-linking in breadfruit starch without change most of the starch and batter properties. It uses in other food application are worth studied.

Keywords: Starch, Cross-link, Breadfruit, Batter, Frying

How to cite this:

Hamzah Y, Subramaniam R, Ibrahim NH and Hanidun SM, 2019. Effects of cross linking on breadfruit starch and its batter properties. Asian J. Agric. Biol. 7(2):234-243.

Introduction

In recent years, battered products have become the popular food products among consumers in Malaysia. Batter is normally used to coat food prior to deep fat frying in order to improve the palatability and appearance of fried food (Vongsawasdi, 2008) such as poultry, seafood, meat, fruits and vegetables. The rheology and adhesion properties of batter are affected by the types of starch used and in most commercial formulations, the combinations of flour and starches from wheat, tapioca, sago and rice have been used (Gamonpilas et al., 2013; Yusnita et al., 2007). Beside wheat, corn and rice starches, breadfruit starches have considerable economic potential to be used in making batter.

Breadfruit (*Artocarpus altilis*) belongs to the family Moraceae, which is growing throughout Southeast Asia and also most Pacific Ocean Islands. In Malaysia, this fruit is locally known as 'buah sukun'. Due to its high carbohydrate content, this fruit has become important staple food (Adebowale et al., 2005). Although the breadfruit is cultivated in over 90 countries throughout the wet tropics, however, it is still considered an underutilized crop in most locations (Jones et al., 2010).

Hence, there is an increased research interest in developing new value-added products from the fruits. For instance, biscuits, prawn crackers and fried chips have been developed from the breadfruits (Omobuwajo, 2003). Breadfruits are also employed in foods because of their good thickening and gelling properties and they are also good texture stabilizers and regulators (Adebowale et al., 2005). However, native breadfruits exhibit limited industrial applications. According to Adebowale et al. (2005), the fresh breadfruits have poor storage properties and they also possess low shear stress resistance and thermal decomposition. Besides that, the study done by Omobuwajo (2003) indicates that the fried prawn crackers and fried chips where breadfruit starches are incorporated into them, absorbed more oil compared to the commercial ones. However, these problems can be overcome by starch modification (Adebowale et al., 2005). Breadfruit starches have high amount of amylose in which the amylose will easily bind to lipid and then, forming amylose-lipid complexes. In food systems, the amylose-lipid complexes can affect the quality of the starch-based food products where they will lead to decreased swelling, solubilisation and thickening power of starch (Schirmer et al., 2013).

Among the various starch modifications, cross-linking is suitable to modify the breadfruit starch because cross-linking will make the native starch resistant to high temperature and high shear and it also improves the textural properties of the native starch (Yook et al., 1993). Cross-linking is one of the chemical modifications of starch which reinforces the hydrogen bonds in the starch granule with chemical bonds that act as bridges between the starch molecules (Nabeshima and Grossmann, 2001). Many cross-linking agents are allowed for food uses such as sodium trimetaphosphate (STMP), sodium tripolyphosphate (STPP), phosphoryl chloride (POCl3), and a mixture of adipic acid and acetic anhydride (Wongsagonsup et al., 2014). Among them, the STMP, which is one of the most important food additives with low toxicity, is an efficient cross-linking agent (Gui-Jie et al., 2006). In addition, there are numerous studies showed that cross-linked starches have better characteristics when they are incorporated into food products as compared to native starches. For example, cross-linked tapioca starches had less water retention capacity and also low oil absorption when incorporated into batter compared to the native tapioca starches (Gamonpilas et al., 2013). Other than that, the crust crispness of deep-fried battered food that is made from cross-linked wheat starch is improved compared to the battered food where native wheat starch is incorporated in (Primo-Martin, 2012). Thus, breadfruit starch can be modified by cross- linking to overcome its limited industrial applications. The objective of this study was to evaluate the effects of different degrees of cross-linking on breadfruit starch properties, characteristics of batter incorporated with breadfruit starch and properties of crust derived from batter incorporated with breadfruit starch.

Material and Methods

Raw materials

Mature breadfruits were bought from the supplier at Kampung Tengah Mengabang Telipot, Terengganu. The ingredients such as wheat flour, carrots, and cooking oil were bought from Giant Hypermarket, Gong Badak, Terengganu. The chemicals were purchased from Sigma-Aldrich Co. (Malaysia).

Sample preparations

Isolation and cross-linking of breadfruit starch

The breadfruit starch was isolated by using the procedures based on Omobuwajo (2003) and Adebowale et al. (2005) with some modifications. Firstly, the breadfruits were peeled, washed, and cut into pieces. In order to prevent browning, the breadfruit pieces were immersed into ice water. Then, about 4 kg of breadfruit pieces were blended with 5 L distilled water for 5 mins to make slurry. Then, the sedimentation process was carried out to remove impurities and it was repeated thrice by stirring the slurry with water. After that, the supernatant was decanted off while the obtained starch was dried at 40˚C for 24 to 48 hrs. The dried breadfruit starch was ground into powder. Finally, the breadfruit starch powder was sieved using Sieve Shaker (Octagon, England) and only the powder with particle size from 125 to 250 µm was collected.

The cross-linking of breadfruit starch was done according to procedure of Koo et al. (2010) with some modifications. Firstly, 50 g of native breadfruit starch powder was mixed with different amount (2, 5, and 10% (w/w), based on dry weight of starch) of a mixture of STMP/ STPP (99/1% w/w) and dissolved in 70 mL of water. Then, the pH of mixture was adjusted to 11.0 using 0.1 M NaOH and the slurry was kept at 45˚C for 3 hrs in a shaking water bath. After that, the suspension was neutralized to pH 6.0 with 0.1 M HCl, washed with distilled water and then, dried at 40˚C for 24 hrs in the oven. Finally, the dried samples were ground into powder. They were then sieved using Sieve Shaker (Octagon, England) and only the powder with particle size from 125 to 250 µm was used.

Batter preparation

Batter was prepared according to procedure of Gamonpilas et al. (2013) with some modifications. Firstly, 14.3% (w/w) of wheat flour, 14.3% (w/w) breadfruit starches, and 71.4% (w/w) water were mixed together using a magnetic stirrer. For breadfruit starches, they were replaced with either native breadfruit starch, cross-linked breadfruit starch (CLBS) with 2% STMP/ STPP, CLBS with 5% STMP/ STPP or CLBS with 10% STMP/ STPP. The batter was subsequently stirred at the speed of 250 rpm for 20 mins. The prepared batter was placed in the chiller for 30 min at 4˚C before using it.

Coating and frying of batter

Carrots for coating and frying were used as carriers (Akdeniz et al., 2006 with some modifications). Firstly, the carrots were peeled and cut into slices with size of 60 mm × 15 mm × 10 mm. Then, the carrot slices were dipped into the batter for 5s and allowed to drip for 10 s. After that, they were fried at 170˚C for 2 mins in the cooking oil of 250 mL. After frying, the fried carrot slices were removed and drained using a strainer. They were then cooled at room temperature before further analysis.

Analysis

Determination of the degree of cross-linking

The degree of cross-linking of modified breadfruit starches was determined according to the procedure of Li et al. (2008) and Koo et al. (2010) with some modifications. The peak viscosity of native and cross-linked starch slurries was measured using Hybrid Rheometer (Discovery HR-2) equipped with a cone and plate geometry. The native and CLBS slurries were prepared by dissolving the starch powder in distilled water (8.8% by weight) at room temperature. To obtain the peak viscosity, a programmed heating and cooling cycle was employed by loading the starch slurries between the cone and plate and it was equilibrated to 50˚C for 1 min at 200/s shear rate. The temperature was raised to 95˚C at 12˚C/ min and then, it was held at 95˚C for 2min 30s. After that, the paste was cooled to 50˚C at 12˚C/min and finally, it was held at 50˚C for 1 min. The shear rate was maintained at 200/s. The degree of cross-linking of the modified starches were calculated using Equation 1:

(Equation 1)

$$\text{Degree of cross-linking (\%)} = \frac{A - B}{A} \times 100$$

Where, A = Peak viscosity of control sample (native starch), B = Peak viscosity of the cross-linked starch

Determination of microstructural properties of starch

The microscopic evaluation of native and CLBS powder was done using Scanning Electron Microscope (SEM) (Jeol, USA) (Koo et al., 2010)

Determination of swelling power of starches

Firstly, the starch powder was suspended in distilled water at 1% (w/w) concentration using a magnetic stirrer. The suspension was cooked at 90˚C for 20 mins to allow complete gelatinization of the starch granules. Then, swollen suspension was cooled down and centrifuged at 25˚C under rotation speed of 9000 rpm for 15 min prior to remove the unabsorbed water. The remaining starch gel was weighed to obtain the wet weight. The weight of swelling ratio was calculated using Equation 2 (Caykara et al., 2003):

(Equation 2)

$$\text{Weight of swelling ratio} = \frac{Wwet - Wdry}{Wdry}$$

Where, Wdry = Weight of dry starch powder used in suspension, Wwet = Weight of centrifuged starch gel

Determination of crystallinity and gelatinization properties of starches

The crystallinity of native and CLBS was scanned (2θ range from 3 to 30˚) (Koo *et al.*, 2010) using X-ray Diffraction Image Processor (Mini Flex II, Rigaku, Japan) (analysis parameters of 50 kV and 90 mA, CuK radiation λ = 0.154 nm, nickel filter). While the gelatinization temperatures and the enthalpy (ΔH) of gelatinization for native and CLBS were determined using Differential Scanning Calorimeter (TA Q2000 Instrument, USA) (Wongsagonsup et al., 2014) with some modifications).

Determination of rheological properties of batter

The rheological properties of batter with native and CLBS were determined according to procedure of Gamonpilas et al. (2013) using Hybrid Rheometer (Discovery HR-2). Pre-shearing at shear rate of $10s^{-1}$ was performed for 30 s prior to flow test. Then, the shear stress was measured as a function of shear rate over the range of $0.01\text{-}100s^{-1}$ at 15˚C for 5mins. The obtained steady shear experimental data was fitted with a Power Law model (Equation 3):

$$\sigma = K \mathring{\gamma}^n \quad \text{(Equation 3)}$$

Where, σ = Shear stress (Pa), K= Consistency index (Pas^n), $\mathring{\gamma}$= Shear rate (s^{-1}), n = flow behaviour index ($n<1$, $n\approx1$,and $n>1$ indicate shear thinning, Newtonian and shear thickening characteristics, respectively)

Determination of water retention capacity of batter

Firstly, about 5 g of batter was placed in a 50 mL centrifuge tube. Then, the sample was centrifuged for 10 mins at 1400 rpm and 15˚C. The supernatant was removed. Then, the removed supernatant and the remaining dry matters (remaining residue after supernatant was removed) were weighed. The water retention capacity of batter was calculated using Equation 4 (Gamonpilas et al., 2013):

(Equation 4)

$$\text{Water retention capacity (\%)} = \frac{Wb - Ws - Wp}{Wp} \times 100$$

Where, Wb = Weight of batter, Ws = Weight of supernatant, Wp = Weight of dry matters

Determination of batter pick-up and cooking yield

Firstly, the carrot slice (60 mm × 15 mm × 10 mm) was dipped into the batter for 5s and allowed to drip for 10 s. Then, the battered carrot slice was weighed. The percentage of batter pick-up was calculated using Equation 5.

While to determine the percentage of cooking yield of batter, the battered carrot slice was fried. Then, the weight of fried battered sample was obtained after it was cooled down at room temperature. The percentage of cooking yield of batter was calculated using Equation 6 (Chen et al., 2008):

(Equation 5)

$$\text{Batter pick-up (\%)} = \frac{B - S}{S} \times 100$$

Where, B = Weight of battered sample, S = Weight of raw sample (without batter)

(Equation 6)

$$\text{Cooking yield (\%)} = \frac{C}{S} \times 100$$

Where, C = Weight of cooked battered sample, S = Weight of raw sample (without batter)

Determination of moisture and oil content of crust

After frying, the carrot slices were removed and only the crusts were used for determination of moisture and oil content (AOAC 2000).

Statistical analysis

All analysis were ran in triplicate and analysed using One Way Analysis of Variance (ANOVA) and Fisher's multiple comparison test was performed for the treatments with significant differences ($p\leq0.05$) to determine which treatment was different with others at 95% of confidence level. Statistical analysis was performed using MINITAB Release 14 Statistical Software.

Results and Discussion

Degree of cross-linking

Peak viscosity is defined as the maximum viscosity that occurs at high temperature prior to the initiation of sample cooling. In this study, the peak viscosity values of cross-linked breadfruit starches (CLBS) were significantly lower than that of native starch (control) (Table 1). Detduangchan et al. (2014) also showed lower peak viscosity of cross-linked rice starch than the untreated rice starch. This could be explained by the reduction of starch-water interaction during heating with the presence of cross-linking agent which led to lower peak viscosity in cross-linked starches (Detduangchan et al., 2014). Moreover, between CLBS samples, the peak viscosities of breadfruit starches were increased and the degree of cross-linking decreased with the increasing of STMP/STPP concentrations. Starch that was cross-linked with 2, 5 and 10% of STMP STPP showed 85.99%, 64.43%, and 49.59% degree of cross-linking, respectively. In this current study, using 5% and 10% STMP/ STPP yielded a significant lower degree of cross-linking compared to that of 2% STMP/ STPP. This would be possibly due to the excess concentration of the cross-linking agents causing the formation of bulky molecules of STMP/ STPP which coagulated and limited the cross-linking reaction in starch granules (Detduangchan et al., 2014). Furthermore, it had been reported that the effect of cross-linking could be depending on the botanical source of the starch and the cross-linking agent used (Mirmoghtadaie et al., 2009). For instance, in this study, using only 2% STMP/STPP led to high degree of cross-linking for breadfruit starch (85.99%) whereas for corn starch, 12% STMP/STPP was required to gain 99.1% of degree of cross-linking (Koo et al., 2010).

Table 1. Peak viscosity values, degree of cross-linking and swelling power of native and CLBS.

Starch	Peak viscosity (Pa.s)	Degree of cross-linking (%)	Weight of swelling ratio (g/g)
NBS	0.85 ± 0.001^{a}	0.00 ± 0.00^{d}	13.13 ± 0.20^{a}
CLBS-2	0.12 ± 0.001^{d}	85.99 ± 0.07^{a}	13.64 ± 0.19^{a}
CLBS-5	0.30 ± 0.008^{c}	64.43 ± 0.89^{b}	9.58 ± 0.08^{b}
CLBS-10	0.43 ± 0.001^{b}	49.59 ± 0.12^{c}	8.27 ± 0.02^{c}

NBS: Native breadfruit starch; CLBS-2, CLBS-5, and CLBS-10: CLBS with 2%, 5%, and 10% STMP/STPP, respectively. Means within the same column showing different superscript letter are significant difference ($p<0.05$).

Swelling power of starches

The swelling power of native and cross-linked breadfruit starches were expressed in terms of weight of swelling ratio (Table 1). The swelling ratios of native starch and cross-linked starch with 2% STMP/STPP were found to be similar ($p>0.05$). This finding was not in agreement with previous work reported by Xiao et al. (2012) who obtained higher swelling power of the cross-linked rice starch (13.9 g/g) as compared to its native counterpart (10.1 g/g). It was suggested that cross-linking is able to strengthen the bonding force within the starch granules, thus could resulted in an increase of swelling power (Xiao et al., 2012). However, this suggestion was relevant if the comparison was made between the treated breadfruit starches. Result showed that sample CLBS-2 which had been determined to have the highest degree of cross-linking (85.99%) exhibited the highest swelling power in hot water. This supports the idea suggested by Xiao et al. (2012) where the cross-linking itself manages to strengthen the starch granules, thus could allowed the granules to show extension swelling without rupture at condition tested.

Microscopic evaluation of starches

The scanning electron micrographs of native and CLBS prepared using different STMP/ STPP concentrations obtained at magnification of 2000x were presented in Figure 1. It can be seen that the native and CLBS granules were spherical and irregular in shapes, ranged from 4.06 to 9.80 µm with average size of 6.93 µm which indicated the native and cross-linked breadfruit starches had relative small particles.

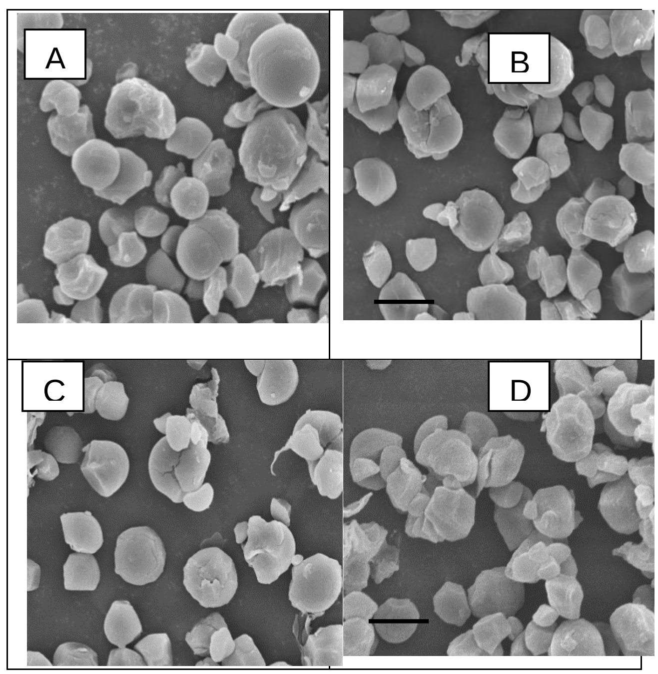

Fig. 1. Scanning electron micrographs (SEM) of native and cross-linked breadfruit starches (10 µm). Where A: Native breadfruit starch; B, C & D: CLBS with 2%, 5%, and 10% STMP/STPP, respectively.

The obtained granule characteristics were almost similar to those reported by Nwokocha and Williams (2011) where the native breadfruit starch granules were small and mostly indented with granule size range from 2.25 to 8.42 µm with average size of 4.34 µm. Therefore, cross-linking did not affect the appearance of breadfruit starch granules and this may due to their small granule size (Mirmoghtadaie et al., 2009).

Crystallinity of starches

The X-ray diffraction patterns of native and CLBS are shown in Figure 2. Native breadfruit starch gave strong diffraction peaks at 5.80, 17.02 and 22.64°, whereas CLBS with 2% STMP/ STPP gave strong peaks at 5.60, 17.15 and 22.56. In addition, strong diffraction peaks at 5.50, 17.31 and 22.34 were shown by the cross-linked breadfruit starch with 5% STMP/ STPP. While, cross-linked breadfruit starch with 10% STMP/STPP gave strong diffraction peaks at 5.61, 17.33 and 22.97. There was no obvious difference between crystallinity peaks of native and cross-linked starches as they showed almost similar diffraction patterns with typical characteristics of B-type starch. According to Nwokocha and Williams (2011), B-type diffraction pattern was common in tuber starches and has characteristics peaks at around 5.8, 15, 17, 23 and 24. These results indicated that cross-linking with STMP/STPP up to 10% did not dramatically alter the crystalline pattern of breadfruit starch. Theorically, this might because of cross-linking mainly took place in the amorphous regions of starch granule and did not change the crystalline patterns of starches (Hoover and Sosulski., 1986).

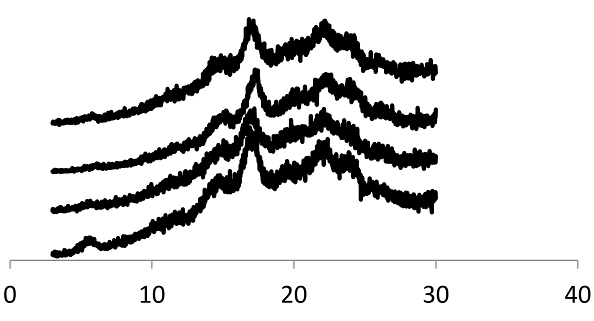

Fig. 2. X-ray diffractograms of native and CLBS. Where NBS: native breadfruit starch and CLBS-2, CLBS-5, and CLBS-10: cross-linked breadfruit starches with 2%, 5% and 10% STMP/STPP, respectively.

These observations were also in agreement with the findings of Koo et al. (2010) where cross-linking with STMP/STPP up to 12% did not dramatically alter the crystalline pattern of corn starch.

Gelatinization properties of starches

The onset (T_o), peak (T_p) and conclusion (T_c) of gelatinization temperatures and the gelatinization enthalpy (ΔH) of native and CLBS prepared using different STMP/STPP concentrations are shown in Table 2. The range of gelatinization temperature of native breadfruit starch was between 73.7˚C to 84.4˚C with peak gelatinization temperature of 76.31˚C. This was almost similar to the peak gelatinization temperature of breadfruit starch stated by Wang et al. (2011) with value of approximately 75.0˚C. Furthermore, the magnitudes of T_o, T_p, and T_c of cross-linked breadfruit starches were slightly higher than that of native breadfruit starch ($p>0.05$). This could be possibly due to formation of additional cross-linked covalent bonds tightened the molecular organization of starch molecules and thus reinforced the integrity of starch granules which made them resist to heat application (Wongsagonsup et al., 2014). However, the magnitudes of T_o, T_p, and T_c of cross-linked breadfruit starches were not considerably changed with three different concentrations of STMP/STPP and these were in consistent with previous work done by Mirmoghtadaie et al. (2009) in which two different concentrations of $POCl_3$ did not significantly changed the onset, peak and conclusion gelatinization temperatures of oat starch.

In contrast, the gelatinization enthalpy (ΔH) of cross-linked breadfruit starch with 2% STMP/STPP or high degree of cross-linked breadfruit starch (Table 2) was lower than that of native breadfruit starch. This result was in accordance with the research of Detduangchan et al. (2014) which indicated the decreasing of the endothermic heat flow of cross-linked rice starch films compared with untreated rice starch films. This may due to increase in the free volume in the starch chain in the presence of bulky groups of cross-linking agents (Detduangchan et al., 2014). Thus, less energy is required for dissociation of the starch granules. However, the ΔH of cross-linked breadfruit starches with 5% and 10% STMP/STPP were almost similar with that of native breadfruit starch and thus, the medium and low degree of cross-linking did not considerably changed the ΔH of breadfruit starch. Thus, similar energy required to dissociate the medium and low degree cross-linked starch granules as compared to native breadfruit starch.

Table 2. Gelatinization properties of native and cross-linked breadfruit starches prepared with different levels of STMP/STPP

Starch	T_o(˚C)	T_p(˚C)	T_c(˚C)	ΔH (J/g)
NBS	73.7 ± 3.1 [a]	76.3 ± 9.4 [a]	84.4 ± 5.6 [a]	3.1 ± 0.11[a]
CLBS-2	74.2 ± 5.7 [a]	77.5 ± 4.8 [a]	85.4 ± 7.1 [a]	1.8 ± 0.26[b]
CLBS-5	74.8 ± 4.5 [a]	77.6 ± 8.1 [a]	85.2 ± 9.7 [a]	3.1 ± 0.47[a]
CLBS-10	74.1 ± 6.1 [a]	77.7 ± 6.6 [a]	86.5 ± 8.3 [a]	2.9 ± 0.18[a]

T_o, T_p, and T_c are the onset, peak, conclusion gelatinization temperatures, respectively and ΔH is the gelatinization enthalpy. NBS: Native breadfruit starch; CLBS-2, CLBS-5, and CLBS-10: CLBS with 2%, 5%, and 10% STMP/STPP, respectively. Means within the same column showing different superscript letter are significant difference ($p<0.05$).

Batter characteristics after incorporated with different degrees of cross-linked breadfruit starches

Rheological properties of batters

The flow behaviour of the batters containing native and CLBS were studied by measuring the viscosities of the samples at shear rate of between 0.01 and 100s^{-1} at constant temperature of 15˚C. Table 3 shows consistency index (K), flow behaviour index (n), and R^2 values of batter containing native and CLBS prepared with different levels of STMP/ STPP. Based on Table 3, all batters behaved as shear thinning fluids as their 'n' values were less than 1 (Gamonpilas et al., 2013). Shear thinning fluid is fluid where its viscosity decreases as the shear stress increases.

Results from the steady shear experiments at shear rates between 0.01 and 100s^{-1} were fitted with Power Law model in order to determine the consistency parameter (K) and the flow behaviour index (n). The fittings of K and n assuming zero yield stress were very good with $R^2 \approx 1$ and showed that the batter with cross-linked breadfruit starches with 2% STMP/ STPP (high degree of cross-linked starch) had the highest consistency index as compared to other batter formulations (Table 3). This was mainly due to the strengthening effect of the cross-linked granules that make them resist deformation by the applied shear. The results were also in consistent with findings of Primo-Martin (2012) stating that the higher the degree of cross-linking of wheat starch, the higher was the viscosity of batter incorporated with the cross-linked wheat starch. According to Gamonpilas et al. (2013), high consistency of batter related to high batter viscosity. Viscosity is defined as the resistance of fluid to flow. The higher viscosity of cross-linked starch was mainly due to the high swelling power of the sample (Table 1) which caused breadfruit starch to absorb water well and expand, resulting in the decrease of the available free water in the batter system (Xue and Ngadi, 2006). According to Mukprasirt et al. (2000), this limited free water reduces particles lubrication; reduce flow and results in a higher viscosity value. Thus, the decreased free water caused to high viscosity of batter. In addition, the lowest viscosity was showed by the batter containing cross-linked breadfruit starches with 10% STMP/STPP. This was corresponding to the low swelling power of the cross-linked breadfruit starch (Table 2).

Table 3. Representative values of consistency index (K), flow behaviour index (n) and R^2 of batters containing native and CLBS prepared with different levels of STMP/STPP

Batter formulation	K (Pas^n)	n	R^2
NBS	0.44	0.51	0.9971
CLBS-2	0.46	0.54	0.9964
CLBS-5	0.37	0.56	0.9964
CLBS-10	0.28	0.55	0.9808

NBS: Native breadfruit starch; CLBS-2, CLBS-5, and CLBS-10: Cross-linked breadfruit starch with 2%, 5%, and 10% STMP/STPP, respectively.

Water retention capacity of batters

Water retention capacities of all batter formulations studied are tabulated in Table 4. Particularly, there was no significant difference between water retention capacity of batter with native breadfruit starch and CLBS with 2% STMP/ STPP. This could be because of the swelling powers of native and cross-linked starches with 2% STMP/ STPP were similar (Table 1). The ability of the starch granules to loosen and imbibe water in batter system was almost the same. In addition, water retention capacity of batters with CLBS with 5% and 10% STMP/ STPP (medium and low degree CLBS, respectively) were significantly lower than that of native and cross-linked starch with 2% STMP/STPP (high degree of CLBS) might also due to their low swelling power.

Pick-up and cooking yield of batters

The pick-up and cooking yield of batters containing native and CLBS prepared with different levels of

STMP/ STPP are shown in Table 4. Batter containing cross-linked breadfruit starch with 10% STMP/ STPP (low degree cross-linked starch) which had the lowest viscosity among the samples showed the lowest batter pick-up. This was supported by Primo-Martin (2012) who suggested significant linear relationship between batter pick-up and batter viscosity. According to Yusnita et al. (2007), the lower batter viscosity gave less coating adhesion to the substrate which finally reduces batter pick-up property. However, the other three batter samples containing native and modified breadfruit starches (2% and 5% STMP/STPP) resulted with similar batter pick-up even though their viscosities were different between each other. This was corresponding with study done by Chen et al. (2009) who reported that the viscosities of batter consisting wheat flour, corn flour and 1% wheat protein and batter consisting wheat flour, corn flour, and 1% soy protein were significantly different, however they had the similar batter pick-up. Thus, besides viscosity, there might be other factors that affect the adhesion properties of batter to substrate prior to frying.

Table 4. **Water retention, batter pick-up, cooking yield, moisture content (crust) and fat content (crust) of batters and fried batters containing native and CLBS prepared with different levels of STMP/STPP**.

Batter formulation	Water retention (%)	Batter pick-up (%)	Cooking yield (%)	Moisture content (crust) (%)	Fat content (crust) (%)
NBS	0.12±0.01ᵃ	29.9±2.3ᵃ	100.0±1.6ᵃ	38.2±5.1ᵃ	31.2±2.9ᵃ
CLBS-2	0.13±0.01ᵃ	33.8±2.4ᵃ	101.7±8.6ᵃ	37.9±5.2ᵃ	26.7±2.6ᵃ
CLBS-5	0.09±0.02ᵇ	32.8±2.0ᵃ	99.6±3.4ᵃ	36.6±4.8ᵃ	27.1±4.1ᵃ
CLBS-10	0.08±0.03ᵇ	22.1±2.1ᵇ	94.6±3.4ᵃ	31.8±4.4ᵃ	32.6±4.8ᵃ

NBS: Native breadfruit starch; CLBS-2, CLBS-5, and CLBS-10: CLBS with 2%, 5%, and 10% STMP/STPP, respectively. Means within the same column showing different superscript letter are significant difference (p<0.05).

Moreover, based on Table 4, there was no significant difference between the cooking yields of batters containing native and cross-linked breadfruit starches prepared with different levels of STMP/STPP. This was in corresponding to the previous work of Gamonpilas et al. (2013) where the values of cooking yield were insignificantly different among the batter formulations containing different degrees of cross-linked tapioca starches.

Moisture and fat contents of crusts

The moisture and fat content of crusts derived from batter incorporated with native and different degrees of CLBS are also shown in Table 4. The moisture content of the crusts containing native and cross-linked breadfruit starches showed no significant difference between them. This result was in contrast with previous work done by Primo-Martin (2012) where the moisture content of crust decreased with the use of highly cross-linked wheat starch.

The fat content was also similar in all samples (p>0.05). Their oil absorptions were in the range between 27.19% and 33.36% although the batters had different viscosity and consistency. This result was in contrast with findings of Primo-Martin (2012) stating the crust produced from batter with high and medium cross-linked wheat starch (high consistency and viscosity batters) had absorbed less oil compared to crust produced from batter with native and low cross-linked wheat starch (low consistency and viscosity batters). This could be possible because high viscosity batter only released low amount of water during frying which caused less porous coating (Gamonpilas et al., 2013). Hence, less porous coating produced during frying led to low oil absorption by the crusts.

Conclusion

The concentrations of 2%, 5%, and 10% of sodium trimetaphosphate (STMP)/sodium tripolyphosphate (STPP) produced 85.99% (high), 64.43% (medium) and 49.59% (low) degree of cross-linking of breadfruit starches, respectively. Hence, higher percentage of STMP/ STPP applied in breadfruit starch as cross-linking agents did not merely produce higher degree of cross-linking in the modified breadfruit starch. Even though the cross-linking degree value for CLBS-2 (cross-linked breadfruit starch with 2% STMP/ STPP) is considered high (85.99%), however, it did not have significant effect on most of the starch and batter properties. Thus, it is postulated that the selected percentages of STMP/STPP is not optimum enough to obtain much higher degree of cross-linking of breadfruit starch granules which could provide significant effect towards the starch and batter system. Hence, further optimization on the level of selected cross-link agent used should be carried out in order to gain more information with suitable applications of modified breadfruit starch in food industries.

Acknowledgment

The authors would like to thank School of Food Science and Technology, Universiti Malaysia Terengganu for the facilities and financial support in completing this study.

Contribution of Authors

Hamzah Y: Conceived idea, design the study, supervised the study and improvement of writing
Subramaniam R: Conducted the study and performed the statistical analysis, drafting article
Ibrahim NH: Helped with the rheological part and proof-read the article
Hanidun SM: Assist with technical parts of rheological experimental works

Disclaimer: None.
Conflict of Interest: None.
Source of Funding: School of Food Science and Technology, Universiti Malaysia Terengganu, Malaysia

References

Adebowale KO, Olu-Owolabi BI, Olawumi EK and Lawal OS, 2005. Functional properties of native, physically, and chemically modified breadfruit *(Artocarpus artilis*) starch. Ind. Crop. Prod. 21: 343-351.

Akdeniz N, Sahin S and Sumnu G, 2006. Functionality of batters containing different gums for deep-fat frying of carrot slices. J. Food Eng. 75: 522-526.

AOAC, 2000. Official Method of Analysis 920.39, 17th Ed., vol. 1. Association of Official Analytical Chemists, Inc. Maryland, USA.

Caykara T, Bozkaya U and Kantoglu O, 2003. Network structure and swelling behaviour of poly (acrylamide/crotonic acid) hydrogels in aqueous salt solutions. J. Polym. Sci. 41:1656–1664.

Chen HH, Kang HY and Chen SD, 2008. The effects of ingredients and water content on the rheological properties of batters and physical properties of crusts in fried foods. J. Food Eng. 88: 45–54.

Chen SD, Chen HH, Chao YC and Lin RS, 2009. Effect of batter formula on qualities of deep-fat and microwave fried fish nuggets. J. Food Eng. 95: 359-364.

Detduangchan N, Sridach W and Wittaya T, 2014. Enhancement of the properties of biodegradable rice starch films by using chemical crosslinking agents. Int. Food Res. J. 21(3): 1225 – 1235.

Gamonpilas C, Ponjaruvat W, Methacanon P, Seetapan, N, Fuongfuchat A and Klaikherd A, 2013. Effects of cross-linked tapioca starches on batter viscosity and oil absorption in deep-fried breaded chicken strips. J. Food Eng. 114: 262-268.

Gui-Jie M, Peng W, Xiang-Sheng M, Xing Z and Tong Z, 2006. Cross-linking of corn starch with sodium trimetaphosphate in solid state by microwave irradiation. J. Appl. Polym. Sci. 102: 5854–5860.

Hoover R and Sosulski F, 1986. Effect of cross-linking on functional properties of legume starches. Starch/Starke. 38: 149-155.

Jones AMP, Murch SJ and Ragone D, 2010. Diversity of breadfruit (*Artocarpus altilis,* Moraceae) seasonality: A resource for year-round nutrition. Econ. Bot. 64(4): 340-351.

Koo SH, Lee KY and Lee HG, 2010. Effect of cross-linking on the physicochemical and physiological properties of corn starch. Food Hydrocoll. 24: 619–625.

Li Y, Shoemaker CF, Ma J, Moon KJ and Zhong F, 2008. Structure-viscosity relationships for starches from different rice varieties during heating. Food Chem. 106: 1105-1112.

Mirmoghtadaie L, Kadivar M and Shahedi M, 2009. Effects of cross-linking and acetylation on oat starch properties. Food Chem. 116: 709-713.

Mukprasirt A, Herald TJ and Flores RA, 2000. Rheological characterization of rice flour-based batters. J. Food Sci. 65: 1194–1197.

Nabeshima EH and Grossmann MVE, 2001. Functional properties of pregelatinized and cross-linked cassava starch obtained by extrusion with sodium trimetaphosphate. Carbohydr. Polym. 45: 347-353.

Nwokocha LM and Williams PA, 2011. Comparative study of physicochemical properties of breadfruit (*Artocarpus altilis*) and white yam starches. Carbohydr. Polym. 85: 294 – 302.

Omobuwajo TO, 2003. Compositional characteristics and sensory quality of biscuits, prawn crackers and fried chips produced from breadfruit. Innov. Food Sci. Emerg. Technol. 4: 219-225.

Primo-Martin C, 2012. Cross-linking of wheat starch improves the crispness of deep-fried battered food. Food Hydrocoll. 28: 53-58.

Schirmer M, Höchstötter A, Jekle M, Arendt E and Becker T, 2013. Physicochemical and morphological characterization of different starches with variable amylose/amylopectin ratio. Food Hydrocoll. 32(1): 52–63.

Vongsawasdi P, Nopharatana M, Srisuwatchree W, Pasukcharoenying S and Wongkitcharoen N, 2008. Using modified starch to decrease the oil absorption in fried battered chicken. Assoc. J. Food Ag-Ind. 1(3): 174-183

Wang X, Chen L, Li X, Xie F, Liu H and Yu L, 2011. Thermal and rheological properties of breadfruit starch. J. Food Sci. 76(1): E55-E61.

Wongsagonsup R, Pujchakarn T, Jitrakbumrung S, Chaiwat W, Fuongfuchat A, Varavinit S, Dangtip S and Suphantharika M, 2014. Effect of cross-linking on physicochemical properties of tapioca starch and its application in soup product. Carbohydr. Polym. 101: 656-665.

Xiao HX, Lin QL, Liu GQ and Yu FX, 2012. A comparative study of the characteristics of cross-linked, oxidized and dual-modified rice starches. Molecules. 17: 10946-10957

Xue J and Ngadi M, 2006. Rheological properties of batter systems formulated using different flour combinations. J. Food Eng. 77: 334-341.

Yook C, Pek UH and Park KH, 1993. Gelatinization and retrogradation characteristics of hydroxypropylated and cross-linked rices. J. Food Sci. 58: 405-407.

Yusnita H, Wan Aida WM, Maskat MY and Aminah A, 2007. Processing performance of coated chicken wings as affected by wheat, rice and sago flours using response surface methodology. Int. J. Food Sci. Technol. 41: 535-542.