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DSC STUDIES OF THE EFFECT OF SODIUM CARBONATE, POLYOLS, AND EMULSIFIERS ON THERMAL PROPERTIES OF GLUTEN-FREE NOODLE DOUGH

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Abstract: Alkaline salt confers unique characteristics to noodles. Polyols and emulsifiers can be used to improve noodle quality and prolong their shelf life. However, there is no information regarding the effect of alkali in combination with polyols and emulsifiers on the properties of noodle dough. This research aimed to study the effects of emulsifiers [lecithin and distilled monoglycerides (DMG)] and polyols (glycerol and sorbitol) with or without sodium carbonate on the thermal properties of gluten-free noodle dough during gelatinisation and retrogradation analysed by DSC. Results showed that the addition of alkali increased the gelatinisation temperature of noodle dough (pH ~10). The effect of incorporating either emulsifiers or polyols on gelatinization temperature was significant in a neutral system compared to an alkaline system. The control presented the lowest onset temperature to melt the retrograded sample, indicating a less crystalline arrangement. Noodle dough in neutral pH had both type I and II ALCs, while alkaline noodle dough presented only type I ALCs. All retrograded samples presented only type I ALC. Polyol significantly decreased ALC formation. In conclusion, alkali had a significant effect on gelatinisation properties and proved effective in preventing the formation of crystals in starch containing DMG after cold storage.

Keywords: Amylose-lipid complex, DSC, emulsifier, polyol, sodium carbonate.
Abbreviations: Control sample containing alkali (ControlA), distilled monoglyceride (DMG), sample containing DMG and alkali (DMGA), glycerol (Gly), lecithin (Le), sample containing lecithin and alkali (LeA), sorbitol, (Sor).

Introduction

Noodles are a popular staple food in Asian countries. White Salted Noodles (WSN) and Yellow Alkaline Noodles (YAN) are two types of wheat-flour noodles distinguished by the absence or presence of salt (NaCl) or alkali (including Na_2CO_3, NaOH, or K_2CO_3) (Fu, 2008; Li *et al.*, 2018; Obadi *et al.,* 2022). YAN have pH values ranging from 9 to 11, depending on the alkaline agent (Cato, 2018). Japanese-style noodles, including udon and somen, are typically WSN, presenting a white colour with a smooth, soft and springy texture. However, YAN, such as ramen and wonton, show a yellow colour and chewy texture (Janto, 1997). Wheat noodles contain gluten, which is harmful to patients with celiac disease. Such patients must consume gluten-free food (Jnawali *et al.*, 2016). In addition, some healthy people avoid eating gluten-containing foods. Consequently, the demand for gluten-free foods has increased (Savarese *et al.*, 2021).

Gluten-free food based on rice, buckwheat and corn has been recommended for patients with celiac disease. Rice has been applied in gluten-free food products because of its low cost, hypoallergenicity and easy digestibility (Heo *et al.*, 2013; Thongthang & Ratanasumawong, 2019). The solubility of rice protein increases with alkalinity (Aldoury & Horax, 2018). However, rice protein does not have the functionality of gluten (Gallagher *et al.*, 2004). Therefore, developing gluten-free diets based on rice flour are challenging. The addition of hydrocolloids (Sanguinetti *et al.*, 2015; Cai *et al.*, 2016; Polsakda, 2016; Sutheeves *et al.*, 2020), glycerol in combination with an emulsifier (Prakaywatchara, 2016), and transglutaminase (Shahsavani Mojarrad *et al.*, 2017) could improve the quality of gluten-free noodle products.

Fresh noodles have high water activity leading to a short shelf life. Polyol (i.e., glycerol, propylene glycol, and sorbitol) reduces the water activity of food, which prolongs its shelf life (Suhendro *et al.*, 1995; Li *et al.*, 2011; Prakaywatchara, 2016), and inhibits the deterioration of the gluten network, thus maintaining noodle texture during storage (Ma *et al.*, 2019; Zhang *et al.*, 2021), and improves the pliability of bread dough and tortillas during storage (Hallberg & Chinachoti, 1992; Suhendro *et al.*, 1995). Nevertheless, polyols affect the properties of the food system. In starch-based gel, polyol increases gelatinisation temperature and enthalpy (Slade & Levine, 1987; Ahmad & Williams, 1999) and effectively slows down the retrogradation (Miura, 1992; Van Soest *et al.*, 1996) of rice gel (Ploypetchara *et al.*, 2015). Glycerol combined with an emulsifier effectively decreases the retrogradation of wonton dough (Prakaywatchara *et al.*, 2018).

The Amylose–lipid Complex (ALC) affects starch gelatinisation, thereby affecting food quality (Singh *et al.*, 2010). A complex of amylose and emulsifier decreases bread staling and stickiness of pasta (Krog, 1971) and increases noodle firmness (Kaur *et al.*, 2005). The ALC can also affect the swelling of starch granules by suppressing water absorption (Eliasson, 1994; Singh *et al.*, 2014) and reducing starch leaching during the cooking of noodles, thereby resulting in firm and cohesive noodles (Kaur *et al.*, 2016).

The effect of alkaline salt on Kongxin noodle qualities, gelatinisation properties (Wang *et al.*, 2021) and rheological properties of oriental wheat noodles have been reported (Wu *et al.*, 2006). The objective of this research was to investigate the effects of emulsifiers and polyols on the gelatinisation and retrogradation properties of noodle dough in neutral and alkaline conditions.

Materials and Methods

Rice flour and fresh eggs were obtained from Varavoot Industrial Co., Ltd. (Thailand) and Betagro Public Co., Ltd. (Thailand), respectively. Sodium carbonate (Food grade, Union Science Co., Ltd.; Thailand), xanthan gum (Ziboxan® F80, Inner Mongolia, China), glycerol (Chemipan Corporation Co., Ltd., Thailand), and sorbitol (Purechem Co., Ltd., Samutprakarn) were used. Lecico F 200 (Lecico GmbH, Hamburg, Germany) and distilled monoglycerides (DMG; Value Industrial Products Co., Ltd., Thailand) were the food-grade emulsifiers used.

Preparation of Noodle Dough

Sifted rice flour and xanthan gum were combined with a raw egg in a KitchenAid mixer (K5SS, USA). Before adding the sodium carbonate and salt, they were dissolved in water. The emulsifier and polyol mixture were then added. The mixing speed was set to number 2. A pasta machine (ATLAS 150, Marcato, Italy) was used to sheet the dough. Finally, it was freeze-dried (LyoQuest, Telstar) under vacuum (0.5 mbar) at an 80°C condenser temperature for 24 hours, ground (HR-2102, Philips), and sifted (Mesh No. 60). Table 1 lists all ingredients used in this study.

Thermal Properties of Freeze-dried Noodle Dough

A Differential Scanning Calorimeter (DSC8000, Perkin Elmer, USA) was used for thermal analysis. In hermetically sealed stainless-steel pans, the samples were prepared with distilled water (70% water content). The gelatinisation study was carried out by heating a sample at a rate of 10°C/min from 25°C to 130°C. As a reference, an empty stainless-steel pan was used. Subsequently, they were kept at 4°C ± 1°C for seven days to accelerate starch retrogradation.

Table 1: Formulation for preparing gluten-free noodle dough (unit: Gram)

Treatments[a/]	Polyol (dry solid amount) [b/]	Emulsifier	Alkali	Rice Flour	Xanthan gum	Salt	Water	Egg
Control	-	-	-	100	5	1.5	50	20
Le	-	1	-	100	5	1.5	50	20
Le Gly	10 (10)	1	-	100	5	1.5	50	20
Le Sor	10 (14.7)	1	-	100	5	1.5	45.7	20
DMG	-	1	-	100	5	1.5	50	20
DMG Gly	10 (10)	1	-	100	5	1.5	50	20
DMG Sor	14.3 (10)	1	-	100	5	1.5	45.7	20
ControlA	-	-	1.5	100	5	1.5	50	20
LeA	-	1	1.5	100	5	1.5	50	20
LeA Gly	10 (10)	1	1.5	100	5	1.5	50	20
LeA Sor	14.3 (10)	1	1.5	100	5	1.5	45.7	20
DMGA	-	1	1.5	100	5	1.5	50	20
DMGA Gly	10 (10)	1.0	1.5	100	5	1.5	50	20
DMGA Sor	14.3 (10)	1.0	1.5	100	5	1.5	45.7	20

[a/] Le = Lecithin, DMG = Distilled monoglycerides, Gly = Glycerol, Sor = Sorbitol, A = Alkali (sodium carbonate)

[b/] The data in parentheses showed solid content of each polyol. Glycerol used in this study is 100% dry solid, while sorbitol is 70% dry solid. Therefore, to control the amount of added wonton at 50 g in all samples, 70%sorbitol was added at the amount of 14.3 g.

The samples were then reheated at the same heating rate and temperature range as the first run. Pyris manager was used to evaluate the onset, peak, and end temperatures (To, Tp, and Te) of the DSC thermogram output, as well as the endothermic enthalpy (H).

Statistical analysis

All samples were done in triplicate. Statistical analyses were conducted via one-way analysis and Tukey's tests using SPSS 18.0 (SPSS Inc., Chicago, IL, USA).

Results and Discussion

Gelatinisation of Noodle Dough Systems

During gelatinisation, water moves into starch granules, resulting in swollen amylopectin. The crystalline structure of amylose and amylopectin collapses because of the breaking of hydrogen bonds (Yamaguchi *et al.*, 2019).

The gelatinisation properties of noodle dough are presented in Table 2. An increase in onset gelatinisation temperature (T_o), peak gelatinisation temperature (T_{p1}, T_{p2}; Figure 1), and end gelatinisation temperature (T_e) was observed in samples with alkaline addition, indicating the suppression of Na_2CO_3 gelatinisation (alkali) (Yamaguchi *et al.*, 2019). In the alkali system, Na^+ ions were produced and diffused into starch granule surfaces through small pores, causing starch granule stability related to electrostatic interactions between Na^+ ions and the hydroxyl group of starch. Consequently, the onset of gelatinisation was slightly delayed (Karim *et al.*, 2008; Nawaz *et al.*, 2016).

Gelatinisation enthalpy indicated the overall crystallinity of amylopectin (Fredriksson *et al.*, 1998). Results showed that the addition of alkali had no significant effect on the gelatinisation enthalpy of rice flour in the noodle model system ($P < 0.05$), which is consistent with the result obtained by Lai *et al.* (2002). Considering

Table 2: Effect of sodium carbonate, polyols and emulsifier on the DSC measurements for gelatinisation properties[a/] of noodle dough

Treatments	T_o (°C)	T_{p1} (°C)	T_{p2} (°C)	T_e (°C)	ΔH (J/g)
Control	65.39 ± 0.23^{i}	73.32 ± 0.01^{d}	83.43 ± 0.42^{b}	89.98 ± 0.14^{cd}	7.63 ± 0.10^{ab}
Le	65.46 ± 0.21^{hi}	73.18 ± 0.20^{de}	82.99 ± 0.07^{b}	90.15 ± 0.07^{cd}	7.54 ± 0.21^{ab}
Le Gly	66.07 ± 0.04^{gh}	73.94 ± 0.04^{c}	83.23 ± 0.27^{b}	89.74 ± 0.12^{d}	7.48 ± 0.12^{ab}
Le Sor	66.10 ± 0.04^{gh}	74.07 ± 0.22^{c}	83.34 ± 0.32^{b}	90.34 ± 0.18^{c}	7.16 ± 0.11^{abcd}
DMG	65.54 ± 0.10^{hi}	72.77 ± 0.40^{e}	82.83 ± 0.44^{b}	89.14 ± 0.30^{e}	6.36 ± 0.39^{d}
DMG Gly	66.58 ± 0.36^{fg}	74.05 ± 0.15^{c}	83.28 ± 0.13^{b}	89.88 ± 0.21^{cd}	6.70 ± 0.27^{bcd}
DMG Sor	66.93 ± 0.13^{ef}	74.01 ± 0.12^{c}	83.53 ± 0.23^{b}	90.16 ± 0.09^{cd}	6.26 ± 0.51^{d}
ControlA	68.02 ± 0.10^{bcd}	75.84 ± 0.05^{ab}	85.17 ± 0.24^{a}	91.94 ± 0.27^{a}	7.66 ± 0.25^{a}
LeA	67.76 ± 0.07^{cd}	75.71 ± 0.21^{b}	85.19 ± 0.37^{a}	91.37 ± 0.16^{b}	7.48 ± 0.03^{ab}
LeA Gly	67.98 ± 0.03^{bcd}	75.97 ± 0.15^{ab}	84.97 ± 0.13^{a}	91.81 ± 0.18^{ab}	7.64 ± 0.05^{a}
LeA Sor	68.38 ± 0.06^{abc}	76.31 ± 0.08^{a}	85.10 ± 0.42^{a}	91.93 ± 0.03^{a}	7.38 ± 0.11^{abc}
DMGA	67.43 ± 0.31^{de}	75.69 ± 0.12^{b}	84.70 ± 0.56^{a}	91.79 ± 0.14^{ab}	6.99 ± 0.07^{abcd}
DMGA Gly	68.51 ± 0.51^{ab}	76.16 ± 0.18^{ab}	84.89 ± 0.62^{a}	91.37 ± 0.12^{b}	6.42 ± 0.81^{d}
DMGA Sor	68.74 ± 0.17^{a}	76.36 ± 0.21^{a}	85.19 ± 0.38^{a}	91.96 ± 0.07^{a}	6.50 ± 0.20^{cd}

[a/] T_o = onset temperature; T_{p1} = peak1 temperature; T_{p2} = peak2 temperature; T_e = end temperature
Means with different small letters superscript in the same column are significantly different at $P < 0.05$

the effect of emulsifiers, the samples containing DMG had lower gelatinisation enthalpy than its control with less effect on the samples containing Le. This result is related to the formation of amylose–emulsifier (DMG) complex. Consequently, the destruction of some crystalline and amorphous portions of the starch and the loss of the double helix increase the distance between the molecular chain (Sciarini *et al.*, 2012) and the formation of the ALC. Considering the effect of polyol, the samples containing an emulsifier and polyol did not affect gelatinisation parameters compared with the samples containing only an emulsifier. In addition, the samples containing DMG presented a small peak at 55°C–65°C (Figure 1), which is the melting peak of DMG in freeze-dried samples.

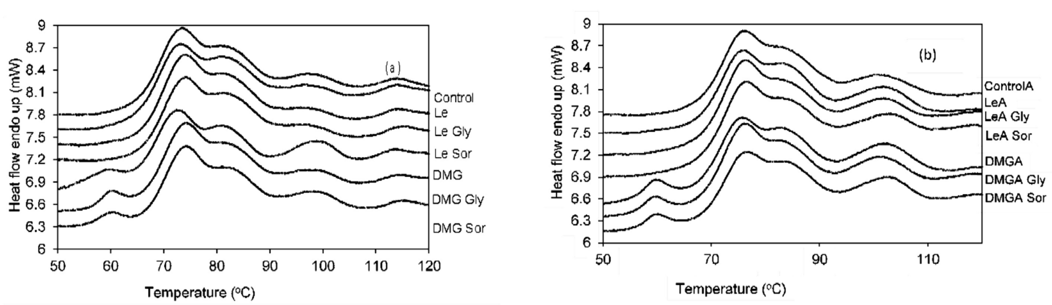

Figure 1: Effect of polyols and emulsifier on the DSC measurements for gelatinisation noodle dough (a) without and (b) with sodium carbonate

Retrogradation of Noodle Dough System

The enthalpy of retrogradation indicates the energy required to break down the crystal regenerated by the amylopectin rearrangement, which is known as an endothermic phenomenon (Kim *et al.*, 1997).

The onset temperature indicates the integrity of the crystal. The high onset temperature indicates an orderly arrangement of crystals (Eliasson, 2004). The results showed that the onset gelatinisation temperature was in the range of 65.3–68.74°C (Table 2), and the onset temperature to melt retrograded samples (Table 3) was in the range of 45.29–47.62°C, indicating that the crystals in initial starches had a more organised arrangement of crystals in which the starch molecular chain breaks the hydrogen bonds after gelatinisation. After storage, the amylopectin molecules realign themselves by hydrogen bonds, presenting in a less orderly arrangement because of their branched structure (Wang *et al.*, 2015).

Thermal properties of the gelatinised noodle dough after storage at 4°C are presented in Table 3. The onset temperature of control was the lowest, indicating that this sample had less crystalline arrangement than samples containing emulsifiers. Emulsifiers could block the penetration of water into starches. Consequently, the swelling of the starch was reduced, leading to a reduction of amylose elution from starches during heating and constrained amylose mobility. Therefore, during retrogradation, the amylose and amylopectin molecules move tightly together (Becker *et al.*, 2001), resulting in greatly dense retrograded samples. In addition, the LeA sample had the highest onset temperature. This result may be related to the starch–starch polymer movement because amylose–emulsifier complexes reduce the binding force among starch molecular chains (Kaur *et al.*, 2005). No statistical evidence was found in T_e of the control compared with the others having similar pH. This indicates that these samples had the remaining more stable double helices which melt at the same range (66.69–67.55°C for samples without alkali salt and 66.71–68.14°C for samples containing alkali salt).

Table 3: Effect of sodium carbonate, polyols and emulsifier on the DSC measurements for melting properties[a/] of noodle dough after storage at 4°C

Treatments	T_o (°C)	T_p (°C)	T_e (°C)	ΔH (J/g)
Control	45.29 ± 0.21[c]	56.20 ± 0.08[e]	67.31 ± 0.25[abcd]	2.42 ± 0.03[a]
Le	46.59 ± 0.29[ab]	57.85 ± 0.63[bcd]	67.07 ± 0.04[cd]	2.26 ± 0.16[a]
Le Gly	46.77 ± 0.20[ab]	57.31 ± 0.05[cde]	66.96 ± 0.13[cd]	2.37 ± 0.03[a]
Le Sor	46.56 ± 0.39[ab]	56.89 ± 0.64[de]	67.55 ± 0.33[abc]	2.19 ± 0.07[a]
DMG	46.50 ± 0.35[b]	58.23 ± 0.07[abcd]	66.69 ± 0.09[d]	2.10 ± 0.05[a]
DMG Gly	45.98 ± 0.52[bc]	57.04 ± 0.24[cde]	67.23 ± 0.27[cd]	2.07 ± 0.21[a]
DMG Sor	46.71 ± 0.24[ab]	57.79 ± 0.29[bcd]	67.42 ± 0.30[abcd]	2.38 ± 0.25[a]
ControlA	45.94 ± 0.27[bc]	57.74 ± 0.92[bcd]	67.43 ± 0.45[abcd]	2.47 ± 0.17[a]
LeA	47.62 ± 0.33[a]	58.34 ± 0.11[abc]	67.26 ± 0.09[bcd]	2.30 ± 0.17[a]
LeA Gly	46.67 ± 0.41[ab]	57.76 ± 0.48[bcd]	66.76 ± 0.29[cd]	2.45 ± 0.17[a]
LeA Sor	46.79 ± 0.33[ab]	58.23 ± 0.10[abcd]	68.08 ± 0.06[ab]	2.38 ± 0.01[a]
DMGA	46.35 ± 0.46[bc]	58.14 ± 0.85[abcd]	66.71 ± 0.52[cd]	2.06 ± 0.06[a]
DMGA Gly	46.32 ± 0.63[bc]	59.06 ± 0.13[ab]	67.45 ± 0.43[abcd]	2.05 ± 0.23[a]
DMGA Sor	46.67 ± 0.29[ab]	59.46 ± 0.10[a]	68.14 ± 0.11[a]	2.10 ± 0.40[a]

[a/] T_o = onset temperature; T_p = peak temperature; T_e = end temperature
Means with different small letters superscript in the same column are significantly different at $P < 0.05$.

A retrogradation factor in the samples containing lipid components was reported by Aytunda Arik Kibar *et al.* (2014). It was calculated as follows:

$$Retrogradation\,factor\,(\%) = \frac{\Delta H_{LD}}{\Delta H_c}\,x\,100$$

ΔH_{LD} = enthalpy of retrograded samples containing lecithin or DMG

ΔHc = enthalpy of retrograded samples containing no emulsifier (control or controlA)

The retrogradation factors were 93.39% (Le), 97.93% (Le Gly), 90.49% (Le Sor), 86.76% (DMG), 85.54% (DMG Gly), 98.35% (DMG Sor), 93.12% (LeA), 99.19% (LeA Gly), 96.37% (LeA Sor), 83.40% (DMGA), 82.99% (DMGA Gly), and 85.02% (DMG Sor). It indicated that the retrogradation was hindered in the samples containing Le or DMG. The alkali condition had a greater effect in preventing the formation of crystals in starch containing DMG than the neutral condition.

Thermal Properties of the ALC During Gelatinisation of Noodle Dough

ALCs are classified as type I and type II. Type I ALC has a melting temperature between 94–104°C, which is lower than type II ALC (115–121°C). A partially ordered structure with no distinct crystalline regions is found in type I ALC, whereas distinct crystalline/semi-crystalline structures are found in type II ALC (Biliaderis & Seneviratne, 1990; Panyoo & Emmambux, 2017). Wang *et al.* (2016) reported that ALCs in normal wheat and waxy wheat starches affected the decrease in solubility and swelling power. Moreover, they reduced starch retrogradation during low-temperature storage (D'Silva *et al.*, 2011; Panyoo & Emmambux, 2017). Factors affecting the formation of type I and type II ALCs include pH and the length of the fatty acid chain in rice starch, which is the main constituent of these samples in this experiment. The three main types of fatty acids in rice are linoleic acid (pKa = 9.24), palmitic acid (pKa = 8.80), and oleic acid (pKa = 9.85) (Kanicky & Shah, 2002), in which the three fatty acids belong to the long-chain fatty acid group (> 10:0). In this case, if pH > pKa, then ALCs are more readily formed into type I (Yotsawimonwat *et al.,* 2008; Wokadala *et al.,* 2012). In addition, the degree of polymerisation (DP) of amylose is another factor affecting the formation of type I and type II ALCs. Amylose DP exceeding 60 is required for the formation of type II complexes (Gelders *et al.*, 2004).

Samples containing alkali showed one endothermic peak of ALC during gelatinisation (Figure 1), which had a temperature range of 93.84–111.37°C (Table 4), indicating type I ALC. These samples have pH values ranging from 9.94–9.99, which were greater than the pKa values of fatty acids contained in rice starch. Therefore, samples with the addition of alkali formed type I ALC. The samples with no alkali had a pH in the range of 6.51–6.71, which was less than the pKa of fatty acids contained in rice flour resulting in less formation of ALC. The samples without alkali addition presented two endothermic peaks (type I found at 92.16–107.75°C and type II found at 108.71–121.70°C) of the amylose–lipid complex during gelatinisation.

Considering samples containing alkali, the onset, peak, and end temperatures of the ALC were in the range of 93.84–94.54°C, 101.62–102.66°C, and 108.72–111.37°C, respectively (Table 4). These parameters were significantly higher than those of the samples containing no alkali ($P < 0.05$). For the enthalpy of samples containing alkali, the DMGA had the highest enthalpy ($P < 0.05$) because DMG had a better structure to complex with amylose than with lecithin. Lecithin has a positive–negative polarity and large size, and it does not bind well with amylose strands (Eliasson & Wahlgren, 2004). Moreover, the addition of polyol decreased enthalpy because glycerol and sorbitol are plasticisers, thereby helping the macromolecules, which are fats that move extensively. They also reduce the hydrogen bonds among starch molecules, thereby creating a gap among the polymers (Ploypetchara *et al.*, 2015).

Table 4: Effect of sodium carbonate, polyols and emulsifier on the DSC measurements[a/] for melting amylose–lipid complex (ALC) during gelatinisation of noodle dough

Treatments	Peak 1				Peak 2			
	T_o (°C)	T_p (°C)	T_e (°C)	ΔH (J/g)	T_o (°C)	T_p (°C)	T_e (°C)	ΔH (J/g)
Control	93.13 ± 0.44^{bc}	98.59 ± 0.91^{bcd}	105.07 ± 0.66^{e}	0.38 ± 0.08^{fg}	109.15 ± 0.58^{bc}	114.02 ± 0.11^{bc}	120.75 ± 0.26^{ab}	0.39 ± 0.06^{ab}
Le	92.46 ± 0.44^{cd}	97.74 ± 0.25^{cd}	103.86 ± 0.10^{f}	0.30 ± 0.03^{fg}	108.71 ± 0.09^{c}	113.87 ± 0.01^{bc}	121.68 ± 0.38^{a}	0.41 ± 0.03^{a}
Le Gly	92.88 ± 0.02^{cd}	97.40 ± 0.47^{d}	102.98 ± 0.32^{f}	0.25 ± 0.02^{g}	108.85 ± 0.64^{c}	113.76 ± 0.31^{c}	121.01 ± 0.53^{ab}	0.33 ± 0.01^{bc}
Le Sor	92.71 ± 0.14^{cd}	97.29 ± 0.19^{d}	107.75 ± 0.20^{d}	0.21 ± 0.02^{g}	110.08 ± 0.07^{ab}	114.90 ± 0.12^{a}	121.70 ± 0.37^{a}	0.40 ± 0.02^{ab}
DMG	92.16 ± 0.08^{d}	99.20 ± 0.70^{bc}	105.85 ± 0.73^{e}	1.05 ± 0.09^{cde}	109.38 ± 0.14^{abc}	113.56 ± 0.59^{c}	120.49 ± 0.37^{b}	0.31 ± 0.02^{cd}
DMG Gly	92.36 ± 0.17^{cd}	99.36 ± 0.06^{b}	105.22 ± 0.22^{e}	0.71 ± 0.24^{ef}	109.71 ± 0.27^{abc}	114.23 ± 0.12^{abc}	120.49 ± 0.26^{b}	0.26 ± 0.02^{d}
DMG Sor	92.47 ± 0.15^{cd}	99.25 ± 0.32^{b}	105.15 ± 0.18^{e}	0.56 ± 0.12^{fg}	110.29 ± 0.24^{a}	114.59 ± 0.12^{ab}	121.20 ± 0.10^{ab}	0.31 ± 0.01^{cd}
ControlA	94.14 ± 0.14^{a}	101.79 ± 0.46^{a}	110.23 ± 0.19^{b}	1.21 ± 0.21^{bcd}	-	-	-	-
LeA	93.84 ± 0.23^{ab}	102.34 ± 0.73^{a}	109.52 ± 0.17^{bc}	1.32 ± 0.05^{bcd}	-	-	-	-
LeA Gly	94.20 ± 0.05^{a}	101.62 ± 0.52^{a}	108.72 ± 0.11^{cd}	1.01 ± 0.03^{de}	-	-	-	-
LeA Sor	94.54 ± 0.42^{a}	102.40 ± 0.47^{a}	109.13 ± 0.17^{c}	1.03 ± 0.02^{de}	-	-	-	-
DMGA	93.88 ± 0.06^{ab}	102.56 ± 0.31^{a}	111.37 ± 0.44^{a}	1.91 ± 0.19^{a}	-	-	-	-
DMGA Gly	94.06 ± 0.48^{a}	102.24 ± 0.53^{a}	109.14 ± 0.19^{c}	1.46 ± 0.18^{bc}	-	-	-	-
DMGA Sor	94.24 ± 0.24^{a}	102.66 ± 0.37^{a}	109.51 ± 0.29^{bc}	1.47 ± 0.26^{b}	-	-	-	-

[a/] T_o = onset temperature; T_p = peak temperature; T_e = end temperature
Means with different small letters superscript in the same column are significantly different at $P < 0.05$

Thermal Properties of the ALC in Gelatinised Samples After Storage at 4°C

Table 5 presents the parameters to melt the ALC in gelatinised samples after storage. They showed only one endothermic peak of amylose–lipid complex (Type I) in all samples (Figure 2). The melting temperature of the ALC after cold storage occurred in the range of 75.81–111.17°C. The peak temperature of these samples was higher than ALC during gelatinisation (Table 4) indicating that the complexes after retrogradation were more heat stable (Zhang *et al.*, 2012). The enthalpy of the amylose–lipid complex after 7 days of storage increased (Table 5), indicating the higher dissociation energy of the complex. This is because the amylose–lipid complex structure moved more closely and rearranged itself (Biliaderis *et al.*, 1985; Prakaywatchara *et al.*, 2018). The enthalpy of the amylose–lipid complex of retrograded starch of samples containing DMG had the highest value because DMG has a structure that can strongly interact with starches (Krog, 1971), which is more stable than lecithin; therefore, high energy is required to break the bond.

Table 5: Effect of sodium carbonate, polyols and emulsifier on the DSC measurements[a/] for melting amylose–lipid complex (ALC) of the gelatinised samples after storage at 4°C

Treatments	T_o (°C)	T_p (°C)	T_e (°C)	ΔH (J/g)
Control	79.70 ± 0.21^{f}	98.32 ± 0.04^{d}	106.54 ± 0.23^{f}	2.62 ± 0.19^{c}
Le	78.07 ± 0.35^{g}	97.54 ± 0.05^{de}	107.24 ± 0.47^{ef}	2.56 ± 0.21^{c}
Le Gly	75.81 ± 0.27^{h}	97.39 ± 0.32^{de}	106.76 ± 0.45^{f}	2.42 ± 0.05^{c}
Le Sor	75.88 ± 0.38^{h}	96.88 ± 0.09^{e}	106.60 ± 0.17^{f}	2.47 ± 0.05^{c}
DMG	84.60 ± 0.30^{c}	100.92 ± 0.56^{c}	107.69 ± 0.31^{e}	4.01 ± 0.51^{a}
DMG Gly	84.54 ± 0.42^{c}	100.45 ± 0.88^{c}	107.27 ± 0.07^{ef}	3.27 ± 0.61^{abc}
DMG Sor	82.34 ± 0.30^{d}	100.04 ± 0.69^{c}	108.66 ± 0.25^{d}	2.94 ± 0.26^{bc}
ControlA	81.59 ± 0.24^{de}	104.91 ± 0.02^{a}	111.17 ± 0.17^{a}	2.60 ± 0.28^{c}
LeA	80.04 ± 0.07^{f}	104.50 ± 0.31^{ab}	110.63 ± 0.26^{ab}	2.80 ± 0.23^{c}
LeA Gly	81.56 ± 0.49^{de}	103.52 ± 0.27^{b}	109.74 ± 0.26^{c}	2.40 ± 0.19^{c}
LeA Sor	77.36 ± 0.33^{g}	103.63 ± 0.20^{b}	109.61 ± 0.24^{c}	2.39 ± 0.10^{c}
DMGA	87.51 ± 0.32^{a}	105.26 ± 0.33^{a}	110.97 ± 0.22^{ab}	3.86 ± 0.43^{ab}
DMGA Gly	86.29 ± 0.22^{b}	104.25 ± 0.17^{ab}	110.20 ± 0.10^{bc}	3.07 ± 0.35^{abc}
DMGA Sor	81.40 ± 0.18^{e}	104.86 ± 0.10^{a}	110.80 ± 0.27^{ab}	3.25 ± 0.36^{abc}

[a/] T_o = onset temperature; T_p = peak temperature; T_e = end temperature
Means with different small letters superscript in the same column are significantly different at $P < 0.05$

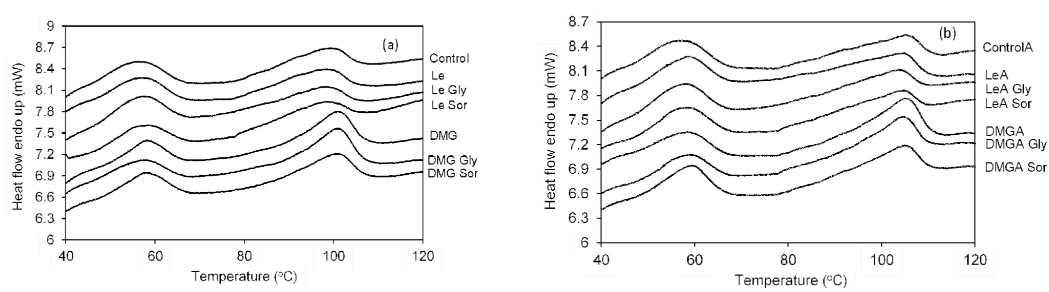

Figure 2: Effect of polyols and emulsifier on the DSC measurements for melting endotherms of noodle dough (a) without and (b) with sodium carbonate after storage at 4°C

Conclusion

Sodium carbonate in alkaline noodle dough had a significant effect on gelatinisation parameters and amylose-lipid complex formation. The effect of emulsifier and polyol on gelatinisation and retrogradation properties was observed in the neutral system rather than the alkaline system. The application of DMG had an effect on decreasing gelatinisation enthalpy rather than Lecithin. The incorporation of DMG and polyol increased the gelatinisation temperature compared to noodle dough containing only DMG. The enthalpy of ALC in samples containing polyol during gelatinisation and retrogradation was reduced. Polyol significantly decreased ALC formation. Finally, the treatment containing DMG in both neutral and alkaline systems presented less enthalpy which implies that those samples needed less energy for cooking the noodles. Additionally, the application of 10% glycerol in combination with 1% DMG in the alkaline system provided the lowest retrogradation factor, indicating less change in the molecular structure of starch molecules during cold storage.

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