Effect of oil addition on *in vitro* starch digestibility and physicochemical properties of instant rice

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Abstract The most varieties of rice have high starch digestibility and glycemic index (GI), which is unsuitable for diabetics. The processes involved in the production of instant rice, not only make it more convenient for the consumer, but can also lower its starch digestibility and GI through the decrease in enzymatic accessibility to rice kernels. One way to control the enzymatic digestion of rice was increasing the amylose-lipid complex formation. The effect of oil addition during rice cooking on *in vitro* starch digestibility, GI and some physicochemical properties (thermal properties, X-ray diffraction patterns and pasting properties) of instant rice wasc studied. During rice cooking, 2 type of cooking oil, including coconut oil (C) and rice bran oil (R) at 2.5, 5 and 7.5% (w/w, on the basis of uncooked rice) were added to Sao Hai rice (SH), which had amylose content of 21.35 g/100g (dry weight basis, db). Thermal properties showed amylose-lipid complex dissociation peaks when rice was cooked with oil, and the highest enthalpy was found in the addition of oil at 2.5%. In X-ray diffraction patterns, cooked rice with oil which showed A+V type crystalline structure and the addition of rice bran oil at 2.5% exhibited the highest relative crystallinity (19.98%). The formation of amylose-lipid complex of cooked rice with oil reduced *in vitro* starch digestibility and eGI compared to cooked rice without oil. The addition of rice bran oil at 2.5% had the highest slowly digestible starch (SDS) and resistant starch (RS) contents, which were consistent with their lowest estimated glycemic index (eGI). The addition of oil to rice resulted in a lower peak viscosity (PV) and setback (SB), as compared to instant rice without oil.

Keywords: instant rice, amylose-lipid complex, starch digestibility and glycemic index

Introduction

Rice is one of the main foods in Asia, which mostly composed of starch. Rice starch is digested easily by amylases and represents a high glycemic index (GI) food (Frei *et al*., 2003). The glycemic index (GI) is based on the blood-glucose raise during the consumption of food consisting of carbohydrates (Kaur *et al*., 2016). The consumption of high GI foods (GI > 70) is one of the main causes for obesity, type 2 diabetes, cardiovascular disease and hyperlipidemia

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(Kaur *et al*., 2016; Nanri and Mizoue, 2014). Thus, low GI foods are more beneficial to consumers (Chang *et al*., 2014). The rate of starch digestion and glucose absorption in small intestine were correlated with GI value (Zhang and Hamaker, 2009). For the rate of digestion, starch has been classified into three fractions, including rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) (Englyst *et al*., 1992). The GI value was positively correlated with RDS content. In addition, SDS and RS caused slower glucose release, which led to lower GI value (Chang *et al*., 2014).

There are many studies that have attempted to reduce GI in rice for increasing health benefits. Kaur *et al*. (2016) reported that the processes that cause retrogradation such as parboiling could reduce GI value. Moreover, cooked rice stored in refrigerator caused increase in RS content through retrogradation, which resulted in a lower GI. During retrogradation, starch molecules are reorganized into more compact and stable structures, which led to increase in RS fraction (RS_3) (Benmoussa *et al*., 2007; Hsu *et al*., 2015; Park *et al*., 2009). Furthermore, the increase in amylose-lipid complex through rice production could decrease in starch digestion and GI of rice. Reed *et al*. (2013) reported that the various cooking methods also impacted on starch digestion of rice due to the formation of amylose-lipid complexes. Lipids can form inclusion complexes with starch, especially amylose (Putseys *et al*., 2010). These complexes naturally occur in starch (Putseys *et al*., 2010) or occur during gelatinization of starch with the presence of lipid (Kaur and Singh, 2000). The addition of lipid to starch upon cooking showed amylose-lipid complex dissociation peaks from DSC, indicating the existence of this complex. In addition, this complex restricted the swelling of starch granules leading to higher pasting temperature (PT) and lower peak viscosity (PV) (Ai *et al*., 2013). Annor *et al*. (2015) found that the type and amount of fatty acids affected amylose-lipid complex formation and this complex would impact on starch digestion. The reduction of starch digestion was found in a higher amount of fatty acid addition. The presence of unsaturated fatty acid was very effective on decrease starch digestion, particularly oleic acid. Moreover, Farooq *et al*. (2018) reported that the addition of oil to rice starch showed V-type peak in X-ray diffractograms, indicating the formation of amylose-lipid complex. This complex was resistant to enzymatic digestion, which reduced *in vitro* starch digestibility through the increase in type 5 resistant starch (RS_5).

Nowadays instant foods are more popular, especially in the city. Instant rice or quick-cooking rice is dehydrated precooked rice, which can be convenient for consumption by adding hot water within a few minutes (Lee and Wissgott, 2001). The processes of instant rice production consist of soaking, cooking and drying (Wongsa *et al*., 2016). Many researches have studied about

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the production process for enhancing instant rice quality (Huang *et al*., 2014; Le and Jittanit, 2015; Rewthong *et al*., 2011). In addition, the *in vitro* starch digestibility of instant rice affected by the production process, which reduced starch digestion through the optimal cooking condition and retrogradation (Hsu *et al*., 2015). Furthermore, Prasert and Suwannaporn (2009) reported that the instant rice production caused the increase in amylose-lipid complex, which might be impact on starch digestion of instant rice. Thus, for lowering starch digestion and GI of instant rice, the increase in amylose-lipid complex formation through instant rice production was interesting to study. Although, the effect of lipid addition on the digestibility and properties of rice starch have been widely reported (Farooq *et al*., 2018; Kaur and Singh, 2000; Shin *et al*., 2009; Zhou *et al*., 2007), but the effect of cooking oil on starch digestibility and physicochemical properties of instant rice are limited. Consequently, the objective of this research was to study the effect of cooking oil addition during rice cooking on *in vitro* starch digestibility, GI and physicochemical properties of instant rice. Two type of cooking oil, coconut oil and rice bran oil, were added to rice kernels during cooking for developing amylose-lipid complex. The outcome from this research will obtain instant rice with lower GI by the kitchen ingredient. This could be benefit and make impact for the real to the publics who are health concern.

Materials and methods

Materials

Sao Hai rice cultivar (SH) was used for the preparation of instant rice and their amylose content was 21.35 g/100g (dry weight basis, db). Rice sample was kept in polyethylene bags and stored at 4∘C until required. Coconut oil (C) (Brand: Naturel, Thailand) and rice bran oil (R) (Brand: King, Thailand) were purchased from a supermarket. Pancreatic α-amylase (EC 3.2.1.1., 3,000 U/g), amyloglucosidase (EC 3.2.1.3., 3300 U/mL) and glucose oxidase-peroxidase assay kit (K-GLUC, Megazyme, Ireland) were purchased from Megazyme International Ireland Ltd.

Sample preparation

One hundred grams of rice kernels were soaked for 1 h and then drained for 2 min. Coconut oil and rice bran oil at 2.5%, 5% and 7.5% (w/w, on the basis of uncooked rice) were blended with water (190 ml) by homogenizer (T25 digital ultra-turrax, IKA, Germany) for 2 min. Soaked rice were cooked with

oil-blended water in water bath at 82°C for 40 min. Then, cooked rice was packed in polyethylene bags and stored at 4°C for 1 day. Finally, cooked rice was dried at 50°C for 3 h, and then dried at 95°C for 1 h to obtain instant rice with final moisture content of 11% - 12%.

Thermal properties

Thermal properties of instant rice flours were determined with a differential scanning calorimeter (DSC 2 module, Mettler Toledo, Switzerland). Instant rice flour (3 mg, dsb) and deionized water ($3\times$, w/w, dsb) were loaded into an aluminum pan. The aluminum pan was hermetically sealed and equilibrated overnight at room temperature. Then, the sample pan was heated from 20°C to 120°C at a heating rate of 10°C/min. An empty pan was used as a reference. The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and the enthalpy (ΔH) were determined using STARe software (STARe system, Mettler Toledo, Switzerland).

X-ray diffraction analysis

X-ray diffraction patterns and degree of crystallinity of instant rice flours were determined using a X-ray Diffractometer (Bruker AXS model D8 discover, Karlsruhe, Germany). The diffractometer was operated at 40 kV and 40 mA with Cu Kα radiation (λ = 0.154 nm). The scanning range and speed were 5-40° (2θ) and 2°/min, respectively (Rewthong *et al*., 2011). The relative crystallinity of instant rice flours was calculated using following equation.
Relative crystallinity (%) = $100 \times A_c / (A_c + A_a)$
Where A_c and A_a are the areas of crystalline peak and amorphous peak, respectively.

In vitro starch digestibility and estimated glycemic index

Instant rice (5 g) was rehydrated by adding boiling water (250 mL) and leave for 20 min. Then, the water was drained for 2 min. The rehydrated samples were ground 3 times by a garlic press (Patindol *et al*., 2010). *In vitro* starch digestibility of instant rice was analyzed using the AACC method 32-40.01 (AACC, 2000) with minor modification. The ground sample (0.5 g) was incubated with pancreatic α-amylase (10 mg/mL) and amyloglucosidase (3.3U/mL) in 4 mL of 0.1 M sodium maleate buffer (pH 6.0) in a shaker water bath at 37°C. Rapidly digestible starch (RDS) was incubated for 20 min, slowly digestible starch (SDS) was incubated within 20 min and 16 h and resistant

starch (RS) was incubated for 16 h. The estimated glycemic index (eGI), was incubated at various times (30, 60, 90, 120, 150 or 180 min). After incubation, 4 mL of ethanol (95%) was added to each sample and centrifuged at 1,500 g for 10 min, then carefully decant the supernatants. The pellet was washed twice with 50% ethanol. Finally, the supernatants were combined, and their glucose content was measured using a glucose oxidase-peroxidase kit.

The kinetics of starch hydrolysis of the instant rice were calculated by the following equation (Goñi *et al*., 1997):

$$C = C_\infty (1 - e^{-kt}) \tag{1}$$

Where C, C_∞ and k were the percentage of starch hydrolyzed at time t (min), the equilibrium percentage of starch hydrolyzed after 180 min and the kinetic constant, respectively.

The hydrolysis curve area (AUC) was calculated by the following equation:

$$AUC = C_\infty (t_f - t_0) - (C_\infty / k)(1 - \exp(-k(t_f - t_0))) \tag{2}$$

Where t_f and t_0 were the final time (180 min) and the initial time (0 min), respectively. The hydrolysis index (HI) was calculated by dividing the area under the hydrolysis curve (0-180 min) of the sample by the area of a reference sample (white bread). The eGI was calculated by the following equation (Goñi *et al*., 1997):

$$eGI = 39.71 + 0.549HI \tag{3}$$

Pasting properties

Pasting properties of instant rice flours were analyzed using a Rapid Visco Analyzer (RVA) (RVA-4, Newport Scientific, Australia). Instant rice flour was weighed accurately (3.5 g) into the RVA canister. Then, 25 mL of deionized water was added to the sample. The sample was equilibrated at $50°C$ for 1 min, heated to $95°C$ for 3.42 min, and held there for 2.30 min, then cooled to $50°C$ for 3.48 min and finally, held at $50°C$ for 3 min (giving a total time of 13 min). Each sample was measured in duplicate. Pasting temperature (PT), peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BD), final viscosity (FV) and setback viscosity (SB) were measured using the RVA software.

Statistical analysis

All data were reported as the means ± standard deviation of triplicate measurements. In the case of XRD, only one measurement was performed. Analysis of variance (ANOVA) by Duncan's Multiple Range Test ($p < 0.05$) were carried out using the SPSS V.16.0 statistical software (SPSS Institute Inc., Chicago, IL, USA).

Results

Thermal properties

Table 1 shows thermal properties of SH instant rice (control) and instant rice that prepared by adding coconut oil and rice bran oil at 2.5, 5 and 7.5% (w/w, on the basis of uncooked rice). Two endothermic transitions were found in instant rice that prepared by adding oil during cooking, except the addition of rice bran oil at 7.5%. Instant rice was produced by cooking without oil (control) showed no observed endothermic peak at high temperature (90 - 120°C). The onset temperature (T_o) of peak I and II showed no statistically significant differences ($p \geq 0.05$) in all oil addition. However, the addition of rice bran oil at 2.5% exhibited the highest peak temperature (T_{p1}) and conclusion temperature (T_{c1}) of peak I ($p < 0.05$). Furthermore, the addition of oil at lower amount resulted in a higher transition enthalpy of peak I (ΔH_1). The highest ΔH_1 were found in the addition of coconut oil at 2.5% (0.23 J/g) and rice bran oil at 2.5% and 5% (0.22 J/g), whereas the ΔH_2 showed no statistically significant differences ($p \geq 0.05$).

X-ray diffraction

X-ray diffraction patterns and relative crystallinity of flours from instant rice (control) and instant rice produced by adding various oil content are presented in Figure 1. Instant rice without oil (control) showed diffraction peaks at 15.1°, 17.2°, 18.1°, 19.9° and 23.6° 2θ, which were related to a mixture of A and V type polymorphs. The addition of oil also exhibited A+V type diffraction patterns with strong reflections at 15.2°, 17.3°, 18.2°, 20°, 23° 2θ (Figure 1). The addition of rice bran oil at 2.5% displayed the highest relative crystallinity (19.98%). The relative crystallinity of instant rice with oil addition were higher than control, except 7.5% of rice bran oil.

Table 1. Dissociation of amylose-lipid complex of SH instant rice (control) and instant rice prepared with various oil content

Sample[1]	Peak I [2]				Peak II [2]			
	T_{o1} [ns] (°C)	T_{p1} (°C)	T_{c1} (°C)	ΔH_1 (J/g)	T_{o2} [ns] (°C)	T_{p2} [ns] (°C)	T_{c2} (°C)	ΔH_2 [ns] (J/g)
C 2.5	92.0 ±1.2	97.4[b] ±0.0	102.8[b] ±0.4	0.23[b] ±0.0	108.7 ±5.4	112.1 ±1.8	116.4[ab] ±1.3	0.12 ±0.0
C 5	93.3 ±2.4	97.2[b] ±0.0	100.7[a] ±1.5	0.08[a] ±0.0	106.9 ±0.0	110.7 ±0.3	114.4[a] ±0.7	0.06 ±0.0
C 7.5	92.3 ±0.0	98.0[c] ±0.1	103.4[bc] ±0.0	0.13[a] ±0.0	105.7 ±0.3	110.8 ±0.1	114.7[a] ±0.5	0.09 ±0.0
R 2.5	93.2 ±0.3	99.4[d] ±0.1	104.5[c] ±0.5	0.22[b] ±0.1	107.2 ±1.6	111.5 ±0.1	117.7[b] ±1.3	0.06 ±0.0
R 5	91.7 ±0.3	98.0[c] ±0.1	103.7[bc] ±0.1	0.22[b] ±0.0	106.8 ±0.9	111.0 ±0.6	115.9[ab] ±0.1	0.04 ±0.0
R 7.5	91.3 ±0.0	95.6[a] ±0.5	99.8[a] ±0.2	0.07[a] ±0.0	ND	ND	ND	ND
Control	ND[3]	ND	ND	ND	ND	ND	ND	ND

Data are means ± standard deviations (n =3). Values within the same column with different letters are significantly different ($p < 0.05$). [ns] Not significant for t-test at 95% level confidence.
[1] C: coconut oil; R: rice bran oil with 2.5, 5 and 7.5 % (w/w, on the basis of uncooked rice); Control: instant rice was prepared by cooking without oil.
[2] T_o: onset temperature; T_p: peak temperature; T_c: conclusion temperature; ΔH: enthalpy.
[3] ND: not detected.
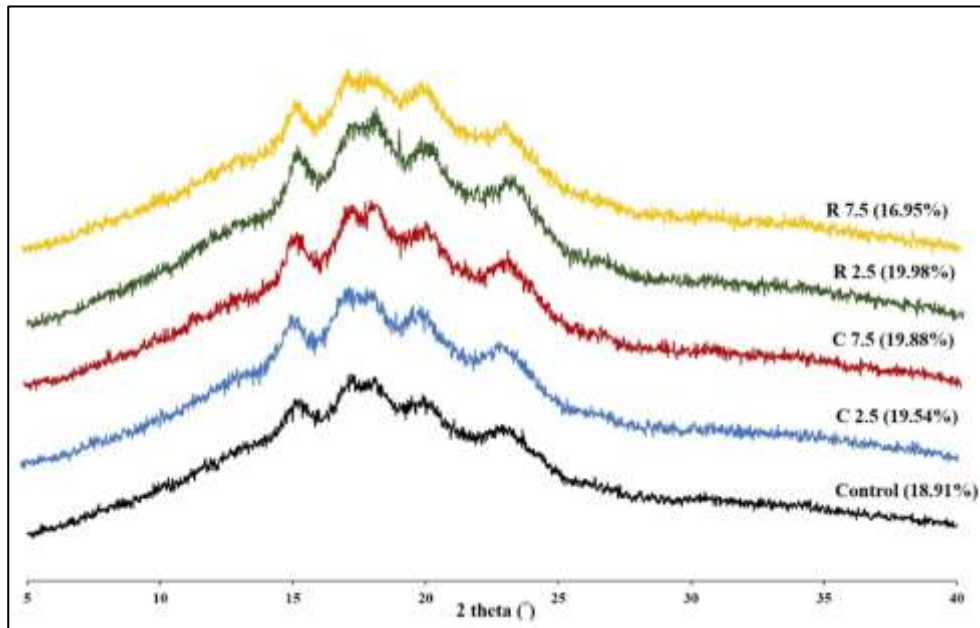
Figure 1. X-ray diffraction patterns and relative crystallinity (in bracket) (%) of flours from SH instant rice (control) and instant rice prepared with various oil content; C: coconut oil; R: rice bran oil with 2.5% and 7.5% (w/w, on the basis of uncooked rice)

In vitro starch digestibility and estimated glycemic index

In vitro starch digestibility of SH instant rice with and without oil addition are shown in Table 2. The RDS content of instant rice (control) was 30.98%, which was not statistically significant differences ($p \geq 0.05$) as compared to 2.5% oil addition. The SDS content of samples varied from 35.47-43.28% (Table 2). The addition of oil resulted in higher SDS content ($p < 0.05$), and moreover, RS content tended to increase as compared to the control. The SDS content tended to increase with the decrease in amount of rice bran oil (Table 2), addition of 2.5% rice bran oil showed the highest SDS content (43.28%). Moreover, the RS content of instant rice samples were slightly different, and the highest RS content was found in 2.5% of rice bran oil addition (5.94%). Furthermore, the instant rice without oil (control) had the highest estimated glycemic index (eGI) (67.61%), as compared to instant rice with oil addition ($p < 0.05$). The eGI value decreased with the decrease in amount of oil addition, especially rice bran oil. The addition of oil at 2.5% exhibited the lowest eGI value.

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Table 2. *In vitro* starch digestibility and estimated glycemic index (eGI) of SH instant rice (control) and instant rice prepared with various oil content

Sample [1]	RDS [2] (%)	SDS [2] (%)	RS [2] (%)	eGI [2]
C 2.5	31.66^c ±0.65	43.01^{cd} ±1.39	4.92^{ab} ±0.53	63.95^{ab} ±0.75
C 5	29.04^a ±0.46	41.19^c ±2.12	4.91^{ab} ±0.70	64.70^b ±0.34
C 7.5	30.11^b ±0.78	41.50^{cd} ±0.76	5.23^{bc} ±0.74	64.63^b ±0.24
R 2.5	30.73^{bc} ±0.38	43.28^d ±0.55	5.94^c ±1.43	63.18^a ±0.46
R 5	31.23^c ±0.35	41.56^{cd} ±0.87	4.35^{ab} ±0.42	64.06^b ±0.87
R 7.5	31.64^c ±0.87	37.33^b ±1.04	4.50^{ab} ±0.34	66.42^c ±0.37
Control	30.98^{bc} ±0.71	35.47^a ±1.30	3.88^a ±0.72	67.61^d ±0.48

Data are means ± standard deviations (n =3). Values within the same column with different letters are significantly different ($p < 0.05$).
[1] C: coconut oil; R: rice bran oil with 2.5, 5 and 7.5 % (w/w, on the basis of uncooked rice); Control: instant rice was prepared by cooking without oil.
[2] RDS: rapidly digestible starch; SDS: slowly digestible starch; RS: resistant starch; eGI: estimated glycemic index.

Pasting properties

The pasting properties of instant rice with and without oil addition are shown in Table 3. The instant rice without oil addition (control) showed a significantly higher trough viscosity (TV), final viscosity (FV) and setback (SB) ($p < 0.05$) compared to instant rice with oil addition. The decrease in amount of rice bran oil resulted in lower peak viscosity (PV), trough viscosity (TV), breakdown (BD), final viscosity (FV) and setback (SB). In contrast, a lower amount of coconut oil addition exhibited a higher PV, BD, FV and SB. The addition of rice bran oil at 2.5% had the lowest PV and SB ($p < 0.05$). Moreover, the addition of oil caused increase in pasting temperature (PT) as compared to control. The highest PT was showed in rice bran oil addition at 2.5% and 5% (Table 3).

Table 3. Pasting properties of flours from SH instant rice (control) and instant rice prepared with various oil content

Sample[1]	PV [2] (cP)	TV [2] (cP)	BD [2] (cP)	FV [2] (cP)	SB [2] (cP)	PT [2] (°C)
C 2.5	1108.5^d ±7.8	920.5^{bc} ±17.7	188.0^f ±9.9	1416.5^{cd} ±16.3	496.0^c ±1.4	91.2^{bc} ±1.1
C 5	1147.5^d ±86.9	969.0^c ±84.9	178.5^e ±2.1	1461.5^d ±118.1	492.5^c ±33.2	91.5^{bc} ±0.5
C 7.5	1024.5^c ±31.8	872.0^b ±31.1	152.5^c ±0.7	1319.0^c ±36.8	447.0^b ±5.7	90.5^{ab} ±1.1
R 2.5	841.5^a ±16.3	708.0^a ±19.8	133.5^b ±3.5	1068.5^a ±23.3	360.5^a ±3.5	92.5^c ±0.6
R 5	936.5^b ±14.8	774.5^a ±13.4	162.0^d ±1.4	1204.5^b ±31.8	430.0^b ±18.4	92.4^c ±0.5
R 7.5	1138.5^d ±17.7	975.5^c ±14.8	163.0^d ±2.8	1496.5^d ±10.6	521.0^c ±4.2	91.6^{bc} ±0.6
Control	1158.0^d ±32.5	1059.0^d ±31.1	99.0^a ±1.4	1711.5^e ±47.4	652.5^d ±16.3	89.2^a ±0.5

Data are means ± standard deviations (n =2). Values within the same column with different letters are significantly different ($p < 0.05$).
[1] C: coconut oil; R: rice bran oil with 2.5, 5 and 7.5 % (w/w, on the basis of uncooked rice); Control: instant rice was prepared by cooking without oil.
[2] PV: peak viscosity; TV: trough viscosity; BD: breakdown; FV: final viscosity; SB: setback; PT: pasting temperature.

Discussion

Thermal properties

In thermal properties, two endothermic transitions were observed that associated with the melting of amylose-lipid complexes. Peak I exhibited the dissociation of less ordered type I amylose – inclusion complexes, whilst peak II indicated the dissociation of semicrystalline type II amylose – inclusion complexes (Putseys *et al*., 2010). Farooq *et al*. (2018) also reported that amylose-lipid complexes exhibited two endothermic transitions with $T_p < 100°C$ and $100-125°C$, which were attributed to type I and type II amylose-lipid complexes, respectively. For instant rice without adding oil (control), the melting of amylose-lipid complexes was not observed, indicating the amount of amylose-lipid complex formed was too small to be detected by DSC. However, the addition of oil increased the formation of amylose – lipid complexes through the detection of endothermic transitions. Moreover, the addition of rice bran oil resulted in higher dissociation temperature than coconut oil, except at 7.5%. This could be attributed to that coconut oil contains high proportion of lauric acid (C12:0) (Bhatnagar *et al*., 2009), which was medium chain fatty acid resulting in decreasing hydrophobic interaction within the amylose helix (Ai *et al*., 2013; Marinopoulou *et al*., 2016). In addition, rice bran oil is rich in oleic (C18:1), linoleic (C18:2) and palmitic acid (C16:0), which were longer hydrocarbon chain than lauric acid (C12:0) (Gopala Krishna *et al*., 2006). Putseys *et al*. (2010) reported that the dissociation temperature of amylose-lipid complexes increased with the increase in carbon chain length of the lipid. The longer hydrocarbon chain caused more hydrophobic interaction inside the cavity of amylose helix leading to higher temperature was required to break these bonds. Thus, rice bran oil addition was more effective in increasing amylose-lipid complex than coconut oil, especially at lower amount of oil addition. Furthermore, the transition enthalpy (ΔH) is associated with the amount of amylose-lipid complexe and the degree of crystallinity within complex (Kawai *et al*., 2012). The higher ΔH_1 was found in lower amount of oil addition, indicating the higher amount of type I amylose-lipid complex. On the other hand, rice kernels were coated with oil throughly when increasing amount of oil, which decreased oil penetration to inside of rice and reduced the formation of complex. Therefore, ΔH_1 decreased as increasing the amount of oil. Furthermore, the amount of type II amylose-lipid complexs were not different with oil addition since ΔH_2 were not significantly different.

X-ray diffraction

In general, the native rice starch showed characteristic A-type crystalline structure with reflection peaks at $15°$, $17°$, $18°$ and $23°$ 2θ (Farooq *et al*., 2018). Moreover, the addition peaks at $13°$ and $20°$ 2θ were attributed to V-type pattern resulting from amylose-lipid complexes (Shin *et al*., 2009). Thus, all samples had an A+V type crystalline structure. The highest relative crystallinity was found in the addition of rice bran oil at 2.5%, which was related to a higher dissociation temperature and ΔH_1 in thermal properties. The addition of oil increased the relative crystallinity through the formation of amylose-lipid complexes, except rice bran oil at 7.5%. Shin *et al*. (2009) also reported that a higher relative crystallinity of citric acid-treated rice starch was attributed to the formation of these amylose-lipid complex. However, relative crystallinity of instant rice with oil addition was slightly different on instant rice with oil addition. This could be explained by thermal properties. The transition enthalpy of peak II (ΔH_2) showed no significant differences ($p \geq 0.05$), indicating that the amount of semi-crystalline structure was not difference and resulting in little change of relative crystallinity.

In vitro starch digestibility and estimated glycemic index

The increase in SDS and RS contents of instant rice related to the reduction of starch digestion. The addition of oil caused a lower starch digestion and eGI as compared with instant rice without oil (control). This was attributed to the formation of amylose-lipid complex, as previously studied (Farooq *et al*., 2018). During cooking, the addition of oil formed complexes with amylose in rice, which was resistant to enzymatic digestion. Annor *et al*. (2015) reported RDS and SDS of millet starch decreased, whilst RS content increased with the addition of fatty acids. In addition, the reduction in starch digestion of millet starch also depended on the amount of fatty acid. However, a lower *in vitro* starch digestibility of instant rice with oil addition was found in lower amount of oil added (2.5%). It could be due to the decrease in oil penetration to inside of rice through a higher amount of oil. Moreover, a higher amount of oil resulted in self-association rather than forming complexes with amylose helix (Tang and Copeland, 2007). Therefore, these effects reduced the formation of amylose-lipid complexes and increase in enzymatic digestion when increase amount of oil addition. The decrease in these complexes were also observed in thermal properties. With higher amount of oil, it showed a lower ΔH_1 and dissociation temperature, especially rice bran oil addition. The highest SDS and RS contents exhibited in 2.5% of rice bran oil addition. Rice

bran oil are rich source of oleic acid (Gopala Krishna *et al*., 2006; Sugano and Tsuji, 1997). Annor *et al*. (2015) found that oleic acid addition resulted in the lowest SDS and RS contents in millet starches, which was effective to reduce starch digestion. The eGI of instant rice was consistent with *in vitro* starch digestibility. The increase in SDS and RS of instant rice could lead to lower eGI. As the previously studied of Annor *et al*. (2015), the addition of fatty acid reduced starch digestion and eGI of millet starches, moreover, the unsaturated acid caused to lower starch hydrolysis compared to the saturated fatty acid . In this study, the lowest eGI showed in 2.5% of oil addition, particularly with rice bran oil. It might be attributed to a higher unsaturated fatty acid in rice bran oil as compared to coconut oil, which contains saturated lauric fatty acid.

Pasting properties

The addition of rice bran oil resulted in a lower PV as compared to coconut oil addition, except at 7.5%. The decrease in PV obviously showed in a lower amount of rice bran oil addition, which was due to the formation of amylose-lipid complexes. These complexes restricted swelling of starch granules, as previously reported (Ai *et al*., 2013). Becker *et al*. (2001) also reported that amylose-lipid complexes formed crystalline structures that hindered the swelling and prevent the leaching of amylose. Therefore, the formation of amylose-lipid complex through the rice bran oil addition was greater than coconut oil addition leading to a lower PV. This was supported by a higher dissociation temperature of instant rice with rice bran oil addition (Table1). Flour from instant rice with oil addition was more easily disrupted than instant rice without oil addition (control), which led to a higher BD. Conversely, Zhou *et al*. (2007) reported that BD decreased when lipid was added. However, when considering oil addition, a lower amount of rice bran oil showed the lowest BD. In addition, the increase in PT was attributed to amylose-lipid complexes formation (Kaur and Singh, 2000). Instant rice with oil had a higher PT as compared to without oil addition, indicating the formation of complexes with oil addition. This result was supported by thermal properties, which showed amylose-lipid complexes dissocation peaks in instant rice with oil addition (Table 1). Moreover, rice bran oil at 2.5% had the lowest PV and highest PT. It might be attributed to a higher amylose-lipid complexes formation, which supported by the highest relative crystallinity of 2.5% rice bran oil addition (Figure 1).

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