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Effects of roasting conditions on anthocyanin, total phenolic content, and antioxidant capacity in pigmented and non-pigmented rice varieties

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Abstract

Roasting has been suggested to enhance the nutritional quality of many foods. The present work determined how roasting temperature (100, 150, and 200°C) and duration (10 and 20 min) affect anthocyanin, total phenolic contents, and antioxidant capacity in pigmented and non-pigmented rice. The concentration of anthocyanin in pigmented rice increased by 15% when roasted at 100°C for 20 min, but it dramatically decreased at higher temperature for longer time. The anthocyanin analysis profile showed that cyanidin-3-glucoside and peonidin-3-glucoside were found as the major compounds of pigmented rice, in which the first compound was about 14 folds higher than the latter, in both non-roasted and roasted rice. The concentration of cyanidin-3-glucoside slightly increased in the roasting rice but not for peonidin-3-glucoside. The total phenol concentration and antioxidant capacity in pigmented rice were not affected by the roasting treatments. In non-pigmented rice, total phenol concentrations and DPPH activity increased with increasing roasting temperature and duration. There were significant correlations between anthocyanin and total phenol concentrations in pigmented rice, and between total phenol concentration and antioxidant capacity determined by DPPH activity in non-pigmented rice. The optimum roasting temperature and time for maximising anthocyanin and total phenol was 100°C for 20 min for pigmented rice, and 200°C for 20 min for non-pigmented rice, as these treatments yielded the highest total phenol concentration and DPPH activity. The present work reveals that anthocyanin and total phenol concentrations of rice grains can be changed by roasting, but the direction and magnitude of the changes depend on the temperature and duration of the treatment as well as the rice variety.

Introduction

Food processing with positive impacts on nutritional quality is important, especially for food products consumed as staple such as rice. Many studies have reported positive impacts of food processing on the nutritional value of rice grain including parboiling, extrusion, and germination (Prom-u-thai *et al.,* 2009; Hu *et al.,* 2018; Owolabi *et al.,* 2019). However, a negative impact of processing has also been reported from soaking and cooking of both unpolished and polished rice (Yamuangmorn *et al.,* 2018). However, the effects of several traditional methods of rice processing such as popping and roasting remain unknown.

The roasting process consists of grain drying, heat application, and is usually followed by grinding into powder, with improvement in the sensory quality of traditional food preparations (Chen and Yan, 2016; Fikry *et al.,* 2019). In addition, the process has sometimes been suggested to increase nutrient bioavailability in some foods. For example, Tiwari and Awasthi, (2014) reported an increase in the bioavailability of calcium in oat flour after roasting at 97°C due to a decrease in phytic acid leading to the release of free calcium ions. Similar results have been found by Nkundabombi *et al.* (2015) and Singh *et al.* (2018), who observed that the roasting of millet and bean increased the bioavailability of minerals for human diets. Roasted rice flour is used in many products such as rice porridge, and is a common ingredient added to soups and other food preparations in Southeast Asia (Rechner *et al.,* 2002; Lee *et al.,* 2003; Wu *et al.,* 2013). The use of roasted rice in wine-brewing adds a new flavour to rice wine (Chen and Yan, 2016).

It has been reported that reactive oxygen species are the major cause of human health problems

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such as cancer and cardiovascular disease, and the risk from such diseases could be reduced by improving antioxidative properties in people's diets (Galli *et al.,* 2005). Roasting has been noted as a process which can improve antioxidant properties due to changes in the chemical composition and biological activity of cereal grains from thermal processing (Ferreira *et al.,* 2016). Recently, roasting has been proposed as the best processing method for enhancing total phenol and flavonoid contents in broomcorn millet as compared to other processing methods (steaming, puffing, and extrusion) (Kalam Azad *et al.,* 2019). Similarly, flavonoid and phenolic compounds were increased by roasting at 110°C for 16 min in pistachio, but not in almond or cashew (Ghazzawi and Al-Ismail, 2017). Total phenolic concentration and antioxidant activity were increased when fenugreek seed was roasted at 130°C for 7 min (Pandey and Awasthi, 2015). In contrast, microwave roasting decreased total phenolic content in barley flour resulting in the degradation of antioxidant activity and DNA damage (Baba *et al.,* 2016). A study in rice bran oil has reported an improvement in nutritional value for γ-oryzanol and DPPH antioxidant capacity when unpolished grain of non-pigmented rice was roasted at 60°C for 3 min (Ruen-ngam *et al.,* 2018). On the other hand, as roasting temperature and time increased, rice powder had lower contents of free amino acids (Lee *et al.,* 2003). However, little is known as to how nutritional quality is affected, and especially how rice genotypes with different bioactive qualities respond to roasting treatments. In general, to achieve the desirable colour and flavour of roasted rice, the required temperature ranges from 100 - 150°C depending on roasting time. The present work used temperatures from 100 - 200°C to evaluate the reaction of bioactive compounds at two roasting times.

The aim of the present work was to evaluate the effect of roasting temperature and duration on anthocyanin, total phenol, and antioxidant capacity, in pigmented and non-pigmented rice. The information gained from the present work should be useful for improving the nutritional quality of roasted rice products as well as for traditional food preparations, including in fermented fish products and cooking condiments.

Materials and methods

Rice variety and sample preparation

Two rice varieties were used in the present work. KH CMU was used as the representative of pigmented rice, and KPK as the non-pigmented rice. Both varieties were upland rice grown in the same aerobic condition with a similar management condition at Chiang Mai University. The seed samples were harvested at maturity, and sun-dried to 14% moisture content. Approximately 5 kg of paddy of each variety was de-husked with a laboratory husker (Ngenk Seng Huat Company, Model P1, Thailand) to produce unpolished grains.

Roasting procedure

About 200 g of each unpolished rice sample derived from the husking process above were roasted in an oven (Electrolux, Model EOT4805K, China) at 100, 150, and 200°C for 10 and 20 min at each roasting temperature. Unroasted sample served as control. The roasted samples were cooled at room temperature (29°C) before chemical analysis. Each roasting time and temperature were carried out for four independent replications.

Chemical analysis

Anthocyanin concentration

Anthocyanin concentration was determined by the modified pH-differential method of Abdel-Aal and Hucl (1999). Whole grain sub-samples (2.5 g each) were transferred into test tubes, each containing 24 mL acidified methanol (70% methanol and 30% of 1.5 mol/L HCl, v/v) with shaking at room temperature (29°C) for 1 h. After centrifugation, the liquid was filtered through Whatman No. 1 filter paper, and the supernatant was collected and added to the two buffer solutions (0.025 mol/L potassium chloride buffer with pH 1.0, and 0.400 mol/L sodium acetate buffer with pH 4.5). The absorbance was measured with a spectrophotometer (Biochrom Libra S22, England) at 520 and 700 nm. The absorbance of the anthocyanin pigment, expressed as cyanidin-3-glucoside, was calculated using Eq. 1:

$$\text{Anthocyanin concentration} = (A \times MW \times DF \times 1000) / \varepsilon \times L \quad \text{(Eq. 1)}$$

where, A = (A520 nm - A700 nm) pH 1.0 - (A520 nm - A700 nm) pH 4.5, MW = 449.2 g/mol for molecular weight of cyanidin-3-glucoside, DF = dilution factor, ε = 26,900 molar absorbance, and L = 1 cm for cell path length.

Total phenol concentration

Aliquots (2 g) of rice sub-samples were extracted with three-time changes of 20 mL 50% methanol for 60 min each time. The extraction mixture was centrifuged at 3000 rpm for 5 min, and the supernatants were pooled for the analysis of total

extractable phenol using the modified Folin-Ciocalteu colorimetric assay of Pengkumsri *et al.* (2015).

Antioxidant capacity

Antioxidant capacity was determined by free radical scavenging activity of 2,2-diphenyl-1-picryl-hydrazyl (DPPH) and ferric reducing antioxidant power (FRAP). Unpolished rice was ground and then dried at 75°C for 48 h; about 0.1 g of the rice flour was transferred into each test tube with 10 mL of the methanol solvent. The extract was shaken on an orbital shaker (IKA KS 250 B) for 30 min. The solution in each tube was separated by centrifugation at 3000 rpm for 10 min, and filtered through a 0.22 µm Nylon syringe filter. DPPH radical scavenging activity was evaluated following Amarowicz *et al.* (2004), with some modifications. Briefly, 0.3 mL of the sample extract was transferred into a test tube, and 1.6 mL methanol and 0.5 mL of 0.1 mM DPPH solution was added. Blanks of the extracts were performed using 2.1 mL of methanol, without DPPH solution. The mixtures were shaken, incubated in the dark at room temperature (~29°C) for 20 min, and measured with a spectrophotometer at 517 nm. The DPPH radical scavenging activity was calculated using a calibration curve made using Trolox concentrations. The DPPH radical scavenging activity (%) of samples and standard (Trolox) were calculated using Eq. 2:

$$\text{DPPH-scavenging activity (\%)} = [(AC - AS/AC) \times 100] \quad \text{(Eq. 2)}$$

where, AC = absorbance of control, and AS = absorbance of sample. The DPPH scavenging activity was expressed in terms of mg Trolox/100 g dry flour. For FRAP analysis, a modified method of Benzie and Strain (1996) was followed. Briefly, 2.0 mL of extracted solution was transferred into a 25 mL volumetric flask, and 20 mL of 0.1 M sodium acetate (pH 4.0), 0.5 mL of 0.5% (w/v) phenanthroline, and 0.5 mL of 0.3 mM Fe (III) were added. Blanks of the extracts were performed using samples as above, except 0.5% (w/v) phenanthroline was not added, and samples were diluted with 0.1 M sodium acetate (pH 4.0). After incubating in a 37°C water bath for 20 min, the absorbance at 510 nm was measured. The results were calculated from a standard curve prepared with known concentrations of Fe (II), and were expressed as µmol of Fe (II)/100 g of dry flour.

Anthocyanin profile by high performance liquid chromatography (HPLC)

Anthocyanin profile was determined by the

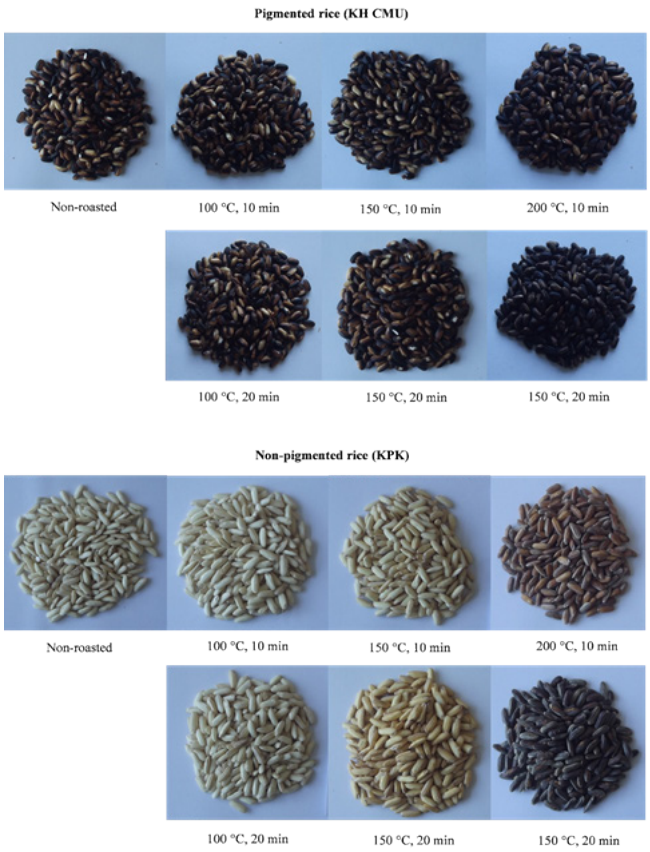

Figure 1. Appearance of non-roasted and roasted grains at different times and temperatures, in pigmented and non-pigmented rice varieties.

modified method of Ryu *et al.* (1998). Briefly, pigmented rice flour (5 g) was extracted with 20 mL of 0.5% trifluoroacetic acid (TFA) in 95% ethanol on a homogeniser for 1 min. The extract solution was centrifuged at 3000 rpm for 10 min at room temperature, and then filtered through 0.45 μm Nylon membrane before analysis. The HPLC analysis was performed on a Shimadzu LC-20A Series (Shimadzu, Japan) equipped with UV-Vis diode array detector and a 25 × 4.6 mm diameter column Allure C_{18} (reversed phase ODS C_{18}). The gradient elution program of the mobile phase A (0.1% TFA in H_2O) and mobile phase B (0.1% TFA in methanol) were as follows: 0 - 30 min, 0% B; 30 - 40 min, 100% B; 40 - 50, 0% B at a flow rate of 1.0 mL/min. The eight compounds of cyanidin-3-glucoside chloride, cyanidin-3-rutinoside chloride, peonidin-3-glucoside chloride, pelargonidin-3-glucoside chloride, cyanidin chloride, delphinidin chloride, and pelargonidin chloride were used as the standards for anthocyanin profile analysis. The absorbance was measured at 520 nm.

Statistical analysis

All statistical analyses were carried out using analysis of variance (ANOVA) (SX window) for a factorial experiment in completely randomised design, followed by LSD comparison tests, at $p < 0.05$. Correlation analysis were used to determine relationships between the total anthocyanin and phenol concentration in pigmented rice, and between DPPH activity and total phenol concentration in non-pigmented rice.

Results

The appearance of the two rice varieties at different roasting times and temperatures are shown in Figure 1. Increasing both roasting time and temperature resulted in a darker colour in both non-pigmented and pigmented rice.

The concentrations of total anthocyanin and total phenol

The total anthocyanin concentration in pigmented rice either increased or decreased, depending on the temperature and duration of the roasting treatment ($p < 0.05$). The total anthocyanin was not detected in non-pigmented rice, roasted or non-roasted (Table 1). In the pigmented rice, roasting at 100°C for 20 min increased total anthocyanin concentration by 14%, but had no effect with the shorter period of roasting of 10 min. The total anthocyanin concentration decreased when samples were roasted at higher temperature, with the effect accentuated with longer roasting time. Roasting at 200°C for 20 min decreased the total anthocyanin concentration in pigmented rice by 74%.

The total phenol concentration was also affected by the roasting treatments, and this differed between the rice varieties ($p < 0.01$) (Table 1). In non-roasted rice, the total phenol in non-pigmented rice was only 27% of the concentration in pigmented rice. The roasting treatments at 100°C for 10 and 20 min had no effect on the total phenol concentration in pigmented rice, but the concentration decreased by 11% in the 200°C for 20 min treatment. By contrast,

Table 1. Total anthocyanin and total phenol concentrations in non-roasted and roasted, pigmented and non-pigmented rice varieties at different roasting conditions.

Roasting condition		Anthocyanin (mg/100 g)		Total phenol (μg gallic acid/g)	
Temperature (°C)	Time (min)	Pigmented	Non-pigmented	Pigmented	Non-pigmented
Non-roasted		33.1^{b}	nd	198^{a}	54^{g}
Roasted					
100	10	32.6^{b}	nd	199^{a}	65^{f}
	20	37.7^{a}	nd	197^{a}	66^{f}
150	10	30.2^{bc}	nd	191^{ab}	66^{f}
	20	28.4^{c}	nd	182^{bc}	70^{f}
200	10	21.7^{d}	nd	186^{bc}	84^{e}
	20	8.6^{e}	nd	176^{c}	105^{d}
Variety × Roasting condition		**		**	
$LSD_{0.05}$		2.9		11	
CV (%)		14.6		5.8	

Data of the total phenol content were $\log_e$ transformed before subjected to analysis of variance, ** = significant at $p < 0.01$, nd = not detected. Different superscript lowercase letters indicate least significant differences within each column ($p < 0.05$).

Table 3. The antioxidant capacity determined by DPPH and FRAP methods in non-roasted and roasted, pigmented and non-pigmented rice varieties at different roasting conditions.

Roasting condition		DPPH (mg Trolox/100 g)		FRAP (µm Fe/100 g)	
Temperature (°C)	Time (min)	Pigmented	Non-pigmented	Pigmented	Non-pigmented
Non-roasted		186^{ab}	28^{f}	734^{ab}	495^{d}
Roasted					
100	10	184^{a}	37^{ef}	641^{c}	630^{c}
	20	185^{abc}	37^{ef}	707^{abc}	622^{c}
150	10	180^{bc}	34^{ef}	680^{abc}	499^{d}
	20	177^{c}	32^{ef}	665^{bc}	497^{d}
200	10	190^{a}	39^{e}	754^{a}	488^{d}
	20	180^{bc}	54^{d}	663^{bc}	482^{d}
Variety × Roasting condition		**		**	
$LSD_{0.05}$		9.2		87.7	
CV (%)		5.8		10.0	

All data were $\log_e$ transformed before subjected to analysis of variance, ** = significant at $p < 0.01$. Different superscript lowercase letters indicate least significant differences within each column ($p < 0.05$).

roasting increased the phenol concentration in non-pigmented rice, with effects varying by temperature and time from 20 to 94%, with the largest increase in the 200°C for 20 min treatment.

Anthocyanin profiles in pigmented rice

The HPLC analysis in pigmented rice showed that cyanidin-3-glucoside and peonidin-3-glucoside were the major compounds in non-roasted and roasted rice. The cyanidin-3-gluco side was found about 14 folds higher than peonidin-3-glucoside, while the other compounds were not detected in the profile analysis. The roasting treatment significantly affected the concentration of cyanidin-3-glucoside in pigmented rice ($p < 0.01$), but the effect was not found in the peonidin-3-glucoside ($p < 0.05$) (Table 2). Roasting at 100°C for 20 min increased cyanidin-3-glucoside concentration by 11% when compared with the non-roasted rice.

Table 2. Cyaidin-3-glucoside and peonidin-3-glucoside concentrations in non-roasted and roasted grain at 100°C for 20 min of the pigmented rice variety.

Roasting condition	Cyaidin-3-glucoside (mg/100 g)	Peonidin-3-glucoside (mg/100 g)
Non-roasted	61.5^{b}	4.2
Roasted	68.1^{a}	4.7
Roasting condition	**	ns
$LSD_{0.05}$	1.3	
CV (%)	0.2	1.3

** = significant at $p < 0.01$, ns = non-significant at $p < 0.05$. Different superscript lowercase letters indicate least significant differences within each column ($p < 0.05$).

Antioxidant capacity

The antioxidant capacity, determined by either DPPH or FRAP activity, was affected by roasting, but the effect differed with rice variety ($p < 0.01$) (Table 3). Overall, the pigmented and non-pigmented rice were more clearly differentiated by the DPPH than the FRAP values. In non-roasted rice, the antioxidant capacity of pigmented rice was more than six times that of the non-pigmented rice as determined by DPPH, but only 0.5 times higher whenmeasured by FRAP. In pigmented rice, the antioxidant capacity by DPPH was not affected by the roasting condition, except roasting at 150°C for 20 min which decreased DPPH activity by 5%. By contrast, antioxidant capacity in the non-pigmented rice significantly increased after roasting, and was markedly increased by 93% in the 200°C for 20 min treatment.

Interaction effects of rice variety and roasting conditions were also observed on the antioxidant capacity determined by FRAP ($p < 0.01$) (Table 3). Roasting treatment at 100°C for 10 min decreased FRAP activity of pigmented rice by 13%, while the other treatments had no significant difference in FRAP activity as compared to the non-roasted rice. FRAP activity in the non-pigmented rice significantly increased by 26% when roasted at 100°C for 10 or 20 min. Furthermore, higher roasting temperatures (150 and 200°C) did not alter FRAP activity in non-pigmented rice from the level in the non-roasted grain.

Correlation and regression analysis

There was a significant linear relationship between the anthocyanin concentration and total

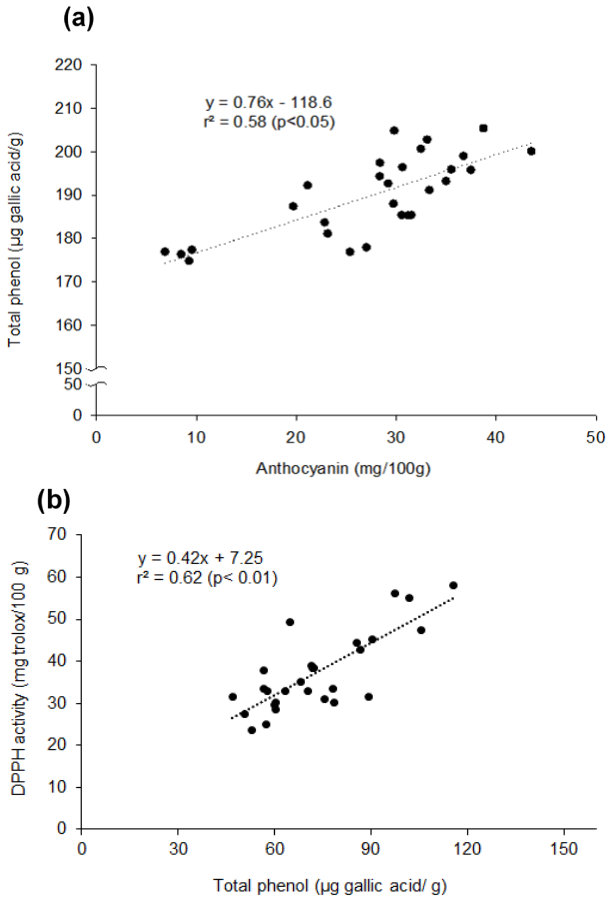

Figure 2. Relationship between total anthocyanin and total phenol concentrations in pigmented rice varieties (a), and relationship between DPPH activity and total phenol concentrations in non-pigmented rice varieties (b) at different roasting conditions.

phenol in the pigmented rice variety (y = 76.93x - 118.6, r^2 = 0.58, p < 0.01) (Figure 2a). No such relationship was established in the non-pigmented rice which had no anthocyanin. Parallel effects of roasting treatments on total phenol content and antioxidative capacity by DPPH of non-pigmented rice was confirmed by the highly significant relationship between the two parameters (y = 0.42x + 7.25, r^2 = 0.62, p < 0.01) (Figure 2b).

Discussion

The roasting treatments used in the present work are common in the preparation of some traditional food products. An optimal temperature is required to create the required flavour, cooking, and nutritional qualities (Lee *et al.,* 2003). Roasting alters the composition of bioactive compounds in rice grain, and this affects its antioxidative properties. However, the present results do not agree completely with previous negative effects of roasting on the antioxidant properties of rice. Furthermore, a significant finding was that antioxidant properties of pigmented and non-pigmented rice varieties were differently affected by roasting treatments. The oxidative property of plants can be depressed by thermal processing because anthocyanin is destroyed at high temperature (Patras *et al.,* 2010). However, the present work found that roasting rice grain at 100°C for 20 min induced higher total anthocyanin and cyanidin-3-glucoside concentrations than samples roasted at higher temperature and the non-roasted grain.

A previous study reported that bound anthocyanin combined with plant cell walls components could be released under the digestion process (Padayachee *et al.,* 2013). Moreover, the interaction between cyanidin-3-glucoside and ionic carbohydrates (pectin) has been drawn in the previous study (Fernandes *et al.,* 2014). The temperature may result in alerting of these compounds during food preparation, which could be one reason for the increase in anthocyanin compounds. Increasing the drying temperature from 50 to 80°C enhanced the total anthocyanin concentration by about 74% in purple potato flour (Ruttarattanamongkol *et al.,* 2016). In addition, steaming followed by air dehydration can enhance anthocyanin in purple-fleshed sweet potato powder through condensation of anthocyanin with phenolic compounds (Yang and Gadi, 2008). Nevertheless, anthocyanin can be destroyed at higher roasting temperature and longer drying times due to a breakdown of anthocyanin structure through the hydrolysis of glycosidic bonds (Sadilova *et al.,* 2007). On the other hand, the transformation of cyanidin-3-glucoside into phenolic acids (protocatechuic acid) was also found during heating (Ryu and Koh, 2017). However, the reduction of cyanidin-3-glucoside in roasted grain was not found in the present work. Other reports of negative effects of higher temperature on anthocyanin found that anthocyanin degraded by 44% with an increase in temperature from 100 to 140°C in black rice grain (Tanghiranrat and Anprung, 2015), and one that reported a loss of anthocyanin when glutinous rice powder was spray-dried at 160 to 180°C (Kanha and Laokuldilok, 2014).

It is interesting to note that anthocyanin in pigmented rice could be enhanced by heating depending on the temperature and duration of treatment. The magnitude of anthocyanin decrease from heating differs with rice varieties (Yamuangmorn *et al.,* 2018). This may be due to differences in anthocyanin composition and stability between genotypes. Changes in sensory properties of Maillard

reaction products of roasted grain should be explored further. Although, there was discrepancy between anthocyanin concentrations detected by spectrophotometer and HPLC methods (the higher concentration was found by HPLC method), but the results were associated between the two methods. In summary, the stability of anthocyanin compounds to heat treatment depends on the sensitivity of the rice variety, which may be caused by differences in anthocyanin concentration, localisation, composition, and stability between pigmented and non-pigmented rice grains, as well as the temperature and duration of roasting.

Roasting has been noted as a process which can increase the concentration of total phenol due to thermal changes in chemical composition (Carciochi *et al.,* 2016). A reduction in insoluble phenolic compounds and an increase in soluble compounds were observed in peanut seed after roasting in conventional (170°C) and microwave ovens (Ferreira *et al.,* 2016). Zhou *et al.* (2017) showed that roasting at 210°C for 30 min significantly decreased the total phenol concentration in black soybean, while increasing the roasting temperature to 230°C for 25 min did not show a significant difference before and after the roasting process. This is similar to the results of the present work where a reduction in total phenol was found in pigmented rice when roasted at 200°C, while it was not altered in the lower temperature treatments. However, drying rice flour at 140°C for 5 min has been reported to decrease the total phenol concentration in pigmented rice (Wiriyawattana *et al.,* 2018). Furthermore, the present work found an increase in total phenol in non-pigmented rice after roasting in all temperature and time treatments. This might be caused by the thermal destruction of protein, thus resulting in greater availability of polyphenols (Malik *et al.,* 2016). A similar finding of increased levels of phenolic compounds was found in black rice kernels after dry heating at 140°C for 25 min (Tanghiranrat and Anprung, 2015). However, there was no change in the total phenolic concentration in yellow soybean after roasting at 230°C for 25 min (Zhou *et al.,* 2017). In sesame seed, the production of phenoliccompounds was increased by increasing the roasting time from 30 to 90 min at 150°C, but it was decreased when the seed was roasted for a longer time (Rizki *et al.,* 2015). These results suggest that the chemical differences among plant genotypes, such as between pigmented and non-pigmented rice in the present work, affect roasting temperature responses such as polyphenol-protein interactions and the liberation of non-extractable phenolic compounds in the cell matrix.

The changes in antioxidant capacity for both DPPH and FRAP assays varied with the roasting treatment in pigmented and non-pigmented rice. A decrease in the DPPH activity in pigmented rice occurred in grain roasted at 150°C for 10 min, while the increase in DPPH activity was found in the higher roasting temperature. By contrast, in the non-pigmented rice, there was no change in DPPH activity in the beginning of roasting temperature at 100 or 150°C, but it increased at the higher roasting temperature of 200°C. Variation in antioxidant capacity may result from the production of new compounds (*e.g*., phenolic acid and γ-tocopherol) with potential antioxidant capacity or from the degradation under excess temperature and time (Jeong *et al.,* 2004; Jannat *et al.,* 2013). The results suggest that there could be a difference in antioxidant compounds and/or composition between non-pigmented and pigmented rice, and this might affect the response to roasting time and temperature as well as the extraction assay. In the case of non-pigmented rice, the positive effects of roasting treatments were confirmed by increases in both phenol concentration and antioxidative capacity by DPPH with increasing temperature, and the highly significant relationship between total phenol content and the antioxidative capacity by DPPH. This relationship confirmed that phenol is a major class of compounds with antioxidative properties in non-pigmented rice, while pigmented rice is more complex due to the presence of anthocyanin. In the pigmented rice, the present of anthocyanin improved the concentration of total phenol as observed from the relationship between the two groups of compounds. Anthocyanin are flavonoids within the large class of polyphenolic compounds.

Conclusion

The anthocyanin and total phenol in pigmented rice were stable when roasted at low temperature for a short time, but dramatically decreased at a higher temperature for a longer time. The optimum roasting temperature and time for maximising both anthocyanin and total phenol were 100°C for 20 min. In non-pigmented rice, total phenol and antioxidant capacity were affected by the roasting temperature and time; roasting at 200°C for 20 min yielded the highest total phenol and DPPH activity. Therefore, roasting has the potential to either increase or decrease the nutritional quality of rice. However, the possible interaction effects between rice variety and roasting condition need to

be further explored, especially with rice varieties containing a wider range of bioactive compounds.

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