Effects of Polishing and Cooking on the Phytochemical Properties and Antioxidant Activities of Selected Philippine Rice Cultivars

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This paper evaluated the effects of different polishing times and regular cooking on the phytochemical properties and antioxidant activities of black rice Bríllante, red rice Minaangkan, and white rice NSIC Rc 160. Rice samples were polished for 0, 15, 30, and 45 s, and were cooked using their optimum cooking water ratio. The samples were then characterized for their phytochemical properties [total anthocyanin content (TAC), total phenolic content (TPC), and total flavonoid content (TFC)] and antioxidant activities [DPPH-radical scavenging activity (DPPH-RSA) and ferric reducing antioxidant power (FRAP)]. Pearson’s correlation analysis (PCA) was employed to determine the strength of the linear relationship between the polishing times and different parameters tested. Results showed that the pigmented rice samples had significantly higher phytochemical properties and antioxidant activities than the white rice sample. Polishing of rice samples considerably reduced their TAC (4.8% to 52.7%), TPC (13.0% to 65.2%), TFC (11.2% to 61.5%), DPPH-RSA (35.0% to 79.9%), and FRAP (11.8% to 68.5%). Cooking also decreased their TAC (24.1% to 92.6%), TPC (14.3% to 78.0%), TFC (14.4% to 74.2%), DPPH-RSA (38.9% to 84.6%), and FRAP (37.0% to 92.8%). Moreover, PCA showed that the polishing time had a strong to very strong negative correlation with phytochemical properties (-0.8809 to -0.9846) and antioxidant activities (-0.8106 to -0.9763). This study concluded that the polishing and cooking significantly affected the phytochemical content and antioxidant activities of white and pigmented rice cultivars. The information generated can be used as a basis for selecting suitable processes to better preserve the antioxidants of pigmented rice.

Keywords: antioxidant activity, anthocyanin, cooking, phenolics, pigmented rice, phytochemical property, Pearson correlation analysis, polishing time

Abbreviations: DPPH-RSA—2,2'-diphenyl-1-picrylhydrazyl-radical scavenging activity, FRAP—ferric reducing antioxidant power, GAE—gallic acid equivalent, LSD—least significant difference, NSIC—National Seed Industry Council, RHE—rutin hydrate equivalent, TAC—total anthocyanin content, TE—trolox equivalent, TFC—total flavonoid content, TPC—total phenolic content, TPTZ—2,4,6-tripyridyl-s-triazine

INTRODUCTION

Pigmented rice is being cultivated because of its high resistance to pests and diseases, low nutrient input, excellent eating quality, and outstanding antioxidant properties. The majority of pigmented rice varieties in the country are brown, red, purple, and black; their color varies depending on the degree and type of pigmentation produced in their pericarp during seed development and maturation (Massaretto et al. 2022). The pigmentation is a product of chemical interactions and the intensity of anthocyanins in the grain (Bhat et al. 2020; Mackon et al. 2021). Rice pigments contain mostly of anthocyanin, carotenoids, γ-oryzanol, vitamin E, and other phenolic compounds (Bulatao et al. 2016; Bhat et al. 2020; Pradipta et al. 2020; Fracassetti et al. 2020; Arsha et al. 2021;
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The concentrations of phytochemicals are greatly dependent on the genotypic and phenotypic traits of pigmented rice. For example, some studies reported that black rice contains a higher amount of total phenolics, carotenoids, and anthocyanins compared to red rice (Bulatao et al. 2016; Choi et al. 2018; Gharemzadeh et al. 2018; Bulatao et al. 2020). On the other hand, red rice possesses stronger antioxidant activity than black rice (Kumar et al. 2020; Chen et al. 2022).

Rice phytochemicals have been reported to exhibit strong antioxidant activities and therapeutic properties. They can act as radical scavengers, electron donors, hydrogen donors, peroxide decomposers, singlet oxygen quenchers, enzyme inhibitors, and metal chelating agents (Pradipta et al. 2020; Sanyal et al. 2021). They were also reported to inhibit the formation of cell-damaging free radicals in the body which are associated with the occurrence of many degenerative and chronic illnesses such as hypertension, diabetes, and cancer (Teleanu et al. 2019; Kumar et al. 2020; Ohtsubo and Nakamura 2021; Massaretto et al. 2022). In vivo studies have shown that black rice could increase the concentration of high-density lipoprotein which corresponds to the reduction of atherosclerotic lesions and inflammation in rodents (Cicero and Derosa 2005; Joo et al. 2018; Kopeć et al. 2020). Isolated compounds from black and brown rice can inhibit aldose reductase activities that hamper the development of diabetic complications (Yawadio et al. 2007; Anjum et al. 2021). Moreover, the anti-diabetic properties of pigmented rice are mainly attributed to the synergistic effect of anthocyanin, proanthocyanidin, vitamin E, γ-oryzanol, and various flavonoids (Sanyal et al. 2021). Black rice bran extracts also showed strong antiproliferative activity against breast cancer cells (Ghasemzadeh et al. 2018; Kumar et al. 2020) and murine leukemic cells (Sanyal et al. 2021), while red rice bran extracts were reported to have an inhibitory effect on leukemia and cervical cancer cells (Sanyal et al. 2021). Furthermore, a human study involving 19 healthy individuals showed an increase in blood plasma polyphenols, flavonoids, and anti-radical activity after 60 min of consumption, confirming the effectiveness of black rice in diet-related health (Vitalini et al. 2020). This information establishes the fact that pigmented rice is indeed effective in improving the health and nutritional status of Filipino rice consumers.

To maximize the bioavailability and utilization of rice phytochemicals, it is important to know their chemical structures, properties, and behaviors (Fracassetti et al. 2020). For example, some phytochemicals such as anthocyanins and carotenoids are highly sensitive to temperature, oxidation, pH, and light (Kwak 2014; Sabuz et al. 2020; Ghosh et al. 2022). Therefore, cooking rice may degrade some of its water-soluble and heat-sensitive phytochemicals which may consequently lower its antioxidant activity upon consumption (Choi et al. 2017; Reddy et al. 2017; Da Silva et al. 2020; Putriani et al. 2020; Massaretto et al. 2022). Fracassetti et al. (2020) reported that cooking pigmented rice for 25 min can better preserve its bioactive compounds than boiling it for 1 hr. Furthermore, the distribution of phytochemicals in rice grain differs depending on the variety and milling degree (Sanyal et al. 2021). Since most of the phytochemicals are located in the pericarp layer, removing the bran during polishing may significantly reduce the antioxidant capacity of rice (Choi et al. 2017; Reddy et al. 2017; Choi et al. 2018; Bhat et al. 2020; Sanyal et al. 2021). However, polishing is done to improve its physical characteristics, eating quality, and shelf-life (Monks et al. 2013; Paiva et al. 2016; Reddy et al. 2017; Niharika et al. 2019).

This was the first paper to report the impact of polishing and cooking on the phytochemical properties and antioxidant activities of the commonly consumed ordinary and pigmented rice in the Philippines.

MATERIALS AND METHODS

Rice Samples

Black rice *Brillante* and red rice *Minaangan* were collected from Doña Remedios Trinidad, Bulacan and Banaue, Ifugao, respectively. The popular white rice variety NSIC Rc 160 (control) was purchased from the Business Development Division, Philippine Rice Research Institute (PhilRice), Maligaya, Science City of Muñoz, Nueva Ecija.

Polishing of Rice Samples

After collection, the rice sample was immediately cleaned and processed based on the protocol of the National Cooperative Testing Manual for Rice (NCT 2022). About 125 g of paddy rice was dehulled in a Satake THU-35A dehuller (Satake, Japan) to obtain the unpolished rice and then further milled at different polishing times such as 0, 15, 30, and 45 s using a McGill-type miller (McGill No. 2, USA). The physical appearance of rice samples at different polishing times was shown in Fig. 1.

Cooking of Rice Samples

The rice sample was cooked in a 100 g capacity automatic rice cooker (National Panasonic, Japan) based on its optimized cooking water requirement. Before cooking, the rice samples polished for 0 and 15 s were soaked in water at a 1:2 ratio for 40 and 20 min, respectively, while the samples polished for 30 and 45 s were directly cooked...
Total Phenolic Content

The total phenolic content (TPC) was measured using the modified Folin-Ciocalteu method (Singleton et al. 1999). About 500 µL of sample extract was transferred into a test tube and mixed with 7.5 mL of distilled water and 0.5 mL of Folin-Ciocalteau reagent. The mixture was allowed to stand for 10 min before measuring the absorbance at 755 nm using a UV-Vis spectrophotometer (DU-70, Beckman Coulter, USA).

Total Flavonoid Content

The total flavonoid content (TFC) of the rice sample was determined using an aluminum chloride colorimetric method (Bao et al. 2005). This method allows the aluminum chloride to react with the C-4 keto group and either the C-3 or C-5 hydroxyl group of flavones and flavonols in the sample to form an acid-stable complex. About 500 µL of the sample extract was transferred into a test tube containing 2 mL of distilled water and 0.15 mL of 5% sodium nitrite. The mixture was allowed to stand for 5 min before the addition of 0.15 mL of 10% aluminum chloride hexahydrate. After another 5 min, the solution was then added with 1 mL of 1N sodium hydroxide. The absorbance of the resulting solution was measured at 415 nm using a UV-Vis spectrophotometer (DU-70, Beckman Coulter, USA).

Determination of Antioxidant Activity

2,2′-diphenyl-1-picrylhydrazyl-Radical Scavenging Activity

The 2,2′-diphenyl-1-picrylhydrazyl-radical scavenging activity (DPPH-RSA) of the rice sample was determined using the modified procedure of Brand-Williams et al. (1995). This method entails the delocalization of DPPH electrons over the molecule to prevent dimerization which produces a deep violet solution. A mixture containing 500 µL of sample extract and 5 mL of freshly prepared 0.1 mM DPPH was incubated for 1 h in a dark room. After incubation, the absorbance of the sample was read at 517 nm using a UV-Vis spectrophotometer (DU-70, Beckman Coulter, USA).

Ferric Reducing Antioxidant Power

A ferric reducing antioxidant power (FRAP) working solution was prepared by mixing 300 µM of acetate buffer, 10 mM of 2,4,6-tripryidyl-s-triazine (TPTZ), and 20 mM of ferric chloride hexahydrate in a 10:1:1 ratio. About 300 µL of the diluted extract was added with 3 mL of the FRAP working solution. The mixture was incubated for 30 min at 37°C under dark conditions (Benzie and Strain 1999). The absorbance of the resulting blue color was read at 595 nm using a UV-Vis spectrophotometer (DU-70, Beckman Coulter, USA).
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Statistical Analysis

The statistical analysis of the data was processed using SPSS version 10.0 software for Windows (SPSS Inc., Chicago, Illinois, USA). Significant difference among means was determined using one-way ANOVA. LSD test was used to determine the effect of polishing on the phytochemical properties and antioxidant activities of the rice samples at 5% level of significance ($p < 0.05$). A dependent sample $t$-test was used to compare the significant difference in the phytochemical properties and antioxidant activities before and after cooking. Pearson’s correlation analysis (PCA) was used to assess the strength of the linear relationship between the polishing time and the phytochemical properties and antioxidant activities evaluated.

RESULTS AND DISCUSSIONS

Phytochemical Properties and Antioxidant Activities of Unpolished Rice Samples

There were significant differences observed in the phytochemical properties and antioxidant activities of rice samples (Table 1). Among the samples, black rice Brillante had the highest TAC (410.1 mg C3G/g), TPC (1.61 mg GAE/g), TFC (2.60 mg RHE/g), DPPH-RSA (1.31 mg TE/g), and FRAP (1.36 mg TE/g) while the control variety NSIC Rc 160 had the lowest (TAC: 8.3 mg C3G/g; TPC: 0.42 mg GAE/g; TFC: 0.90 mg RHE/g; DPPH-RSA: 0.18 mg TE/g; FRAP: 0.27 mg TE/g). The significantly higher phytochemical content and antioxidant activities of Brillante are attributed to its very high anthocyanin content which is the predominant antioxidant in black rice (Massaretto et al. 2022). Moreover, Sanyal et al. (2021) reported that the high TFC of black rice such as Brillante might be due to the presence of taxifolin-O-hexoside, quercetin-3-O-glucoside, and quercetin-3-O-rutinoside, the major flavonoids in rice that are only detected in black rice. Furthermore, significantly higher phytochemical

Table 1. Phytochemical properties and antioxidant activities of unpolished rice samples.

<table>
<thead>
<tr>
<th>Rice Sample</th>
<th>TAC (mg C3G/g)</th>
<th>TPC (mg GAE/g)</th>
<th>TFC (mg RHE/g)</th>
<th>DPPH-RSA (mg TE/g)</th>
<th>FRAP (mg TE/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSIC Rc 160</td>
<td>8.3$^b$</td>
<td>0.42$^b$</td>
<td>0.90$^b$</td>
<td>0.18$^b$</td>
<td>0.27$^b$</td>
</tr>
<tr>
<td>Minaangan</td>
<td>35.2$^a$</td>
<td>1.05$^a$</td>
<td>2.20$^a$</td>
<td>1.07$^a$</td>
<td>0.95$^a$</td>
</tr>
<tr>
<td>Brillante</td>
<td>410.1$^b$</td>
<td>1.61$^b$</td>
<td>2.60$^b$</td>
<td>1.31$^b$</td>
<td>1.36$^b$</td>
</tr>
</tbody>
</table>

*Means having different superscript within the column are significantly different with each other at $p < 0.05$ using LSD.

TAC-Total anthocyanin content; C3G-Cyanidin-3-glucoside

TPC-Total phenolic content; GAE-Gallic acid equivalent

TFC-Total flavonoid content; RHE-Rutin hydrate equivalent

DPPH-RSA-DPPH-radical scavenging activity; TE-Trolox equivalent

FRAP-Ferric reducing antioxidant power; TE: Trolox equivalent

Effects of Polishing on the Phytochemical Properties of Rice Samples

TAC

The TAC of rice samples at different polishing times was shown in Fig. 2. Polishing of rice samples up to 45 s significantly reduced the TAC of Brillante by 52.7%, Minaangan by 35.5%, and NSIC Rc 160 by 25.3%. The significant decrease in TAC of the rice samples is due to the bran removal during polishing (Choi et al. 2017). Since the majority of anthocyanins reside mainly in the bran layer, increasing the polishing time tends to remove more of the bran layers, thereby eliminating most of these compounds (Jin et al. 2012) and Ghasemzadeh et al. (2018). Anthocyanins are the major antioxidants in rice and are reported to exhibit antioxidative, anticancer, and anti-inflammatory activities (Ghasemzadeh et al. 2018; Bhat et al. 2020; Kumar et al. 2020). For the past few years, the popularity of pigmented rice rapidly increased due to their enormous therapeutic and functional health benefits brought about by the positive health effects of anthocyanins in the body (Bhat et al. 2020).

TPC

The major phenolic compounds in rice include proanthocyanidin, catechin, vanillic acid, protocatechuic acid, chlorogenic acid, ferulic acid, and coumaric acid (Sanyal et al. 2021) and are responsible for the strong antioxidant activities of pigmented rice (Shozib et al. 2021). Polishing of rice samples significantly reduced their TPC as shown in Fig. 3. Polishing reduced Brillante’s TPC by 13.0% for 15 s, 32.3% for 30 s, and 65.2% for 45 s. For Minaangan, its TPC was lowered by 21.0% for 15 s, 42.9% for 30 s, and 52.4% for 45 s. Despite its low

Fig. 2. TAC of the rice samples at different polishing times.
concentration, NSIC Rc 160 had a significant reduction in its TPC by 28.6% after polishing for 15 s, 45.2% for 30 s, and 61.9% for 45 s. Among the samples, the lowest reduction in TPC was observed in Brillante upon polishing for 15 and 30 s and Minaangan for 45 s. This implies that the loss of phenolic compounds upon polishing of rice differs depending on the variety. This observation was confirmed by Reddy et al. (2017) when they reported that the distribution of phenolic compounds in rice is dependent on its phenotypic and genotypic characteristics. Moreover, the current data shows that the loss of phenolic compounds can be minimized by polishing the rice samples in less than 15 s.

A reduction in TPC was also obtained by Walter and Marchesan (2011) upon polishing of pigmented rice variety Irga 157 from Brazil. Reddy et al. (2017) also reported an 85% to 90% decrease in the TPC of 3 pigmented rice varieties in Korea. Since the majority of phenolic compounds are loaded in the bran layer, extending the polishing time could result in the removal of more bran layers, thereby eliminating most of these compounds (Zaupa et al. 2015; Choi et al. 2018; Sanyal et al. 2021).

**TFC**

Fig. 4 illustrates the TFC of rice samples at different polishing times. It was reported that the major flavonoids in rice with strong therapeutic properties are quercetin, apigenin, catechin, luteolin, and myricetin (Ghasemzadeh et al. 2018). Upon polishing, the TFC of Brillante was reduced by 11.2% for 15 s, 30.0% for 30 s, and 61.5% for 45 s. For Minaangan, its TFC was reduced by 20.9% for 15 s, 44.1% for 30 s, and 56.4% for 45 s. The reduction in TFC of NSIC Rc 160 was 27.8% for 15 s, 34.4% for 30 s, and 48.9% for 45 s. Among the samples, Brillante retained most of its TFC upon polishing for 15 and 30 s, while NSIC Rc 160 had the lowest reduction after 45 s. These suggest that the distribution of flavonoids in rice grain is dependent on the variety. Moreover, the findings imply that the TFC was considerably affected by polishing since the majority of flavonoids are concentrated in the bran layer which was stripped out during polishing (Reddy et al. 2017; Choi et al. 2018). The reduction in TFC was consistent with the findings of Reddy et al. (2017) and Liu et al. (2015) upon polishing of pigmented rice varieties in India.

**Effects of Polishing on the Antioxidant Activities of Rice Samples**

**DPPH-RSA**

Fig. 5 shows the DPPH-RSA of rice samples at different polishing times. Among the samples, Brillante had the biggest loss in DPPH-RSA upon polishing of 73.9% for 15 s, 74.0% for 30 s, and 79.9% for 45 s. A similar trend was observed in Minaangan, wherein a 68.0% reduction in DPPH-RSA was recorded for 15 s, 72.0% for 30 s, and 75.6% for 45 s. The lowest reduction was noticed in the DPPH-RSA of NSIC Rc 160 with only 35.0% for 15 s, 51.4% for 30 s, and 70.0% for 45 s. In previous studies, about an 88–100% decrease in DPPH-RSA was obtained in a black rice variety (IAC 600) by Walter et al. (2013) and Paiva et al. (2014). Choi et al. (2018) also reported a decrease in antioxidant activity upon polishing of black rice varieties in Korea. Since most of the phytochemicals are removed during polishing, the capability of pigmented rice to scavenge free radicals in the body becomes weakened (Tuncel and Yilmaz 2011; Reddy et al. 2017). High concentrations of free radicals in the body may cause biological complications; thus, consumption of pigmented rice could be a good option to prevent health-related illnesses such as heart disease, cancer, and diabetes.
The FRAP of rice samples was significantly affected by different polishing times (Fig. 6). Among the samples, Brillante had the lowest reduction in FRAP, particularly during polishing for 15 s (11.8%) and 30 s (28.7%), while Minaangan had the lowest reduction for 45 s (58.9%). Despite its low FRAP, NSIC Rc 160 had the highest reduction in most of the polishing times, except for the 30 s where Minaangan had the highest reduction.

Effects of Cooking on the Phytochemical Properties of Rice Samples

TAC

Cooking is an integral part of food processing to improve the digestibility, palatability, and safety of food for human consumption. In this study, cooking was found to significantly decrease the TAC of all rice samples (Fig. 7). Among the samples, Brillante had the highest reduction in TAC after cooking in all the polishing time intervals (75.5% to 92.6%) while the lowest reduction was noted in Minaangan for 0 s (24.1%) and 15 s (49.9%) and NSIC Rc 160 for 30 s (53.2%) and 45 s (62.9%). It is quite expected that Brillante will have the greatest reduction since it had the highest initial TAC among the samples. With respect to different polishing times, unpolished rice samples (0 s) had the lowest reduction in TAC (24.1% to 75.5%), while samples polished for 45 s had the highest reduction (62.9% to 92.6%). In related studies, about a 100% reduction in TAC was reported by Saika et al. (2009) and Zaupa et al. (2015) after cooking of black rice Poreiton Chakhao variety from India and red rice variety from Italy, respectively. Hiemori et al. (2009) reported a 74.3% reduction in TAC upon cooking black rice from California. Fracassetti et al. (2020) recorded a 48.2% to 59.1% loss of TAC after cooking black rice varieties Artemide and Venere from Italy. Similarly, Massaretto et al. (2022) obtained a 51% to 56% decrease in TAC upon cooking commercial and Epagri black rice from Brazil. The reduction in TAC after cooking is due to the leaching of anthocyanins during washing and thermal degradation upon heating (Nayeem et al. 2021). Since anthocyanins are water-soluble, they can be washed out during the process prior to cooking, especially those located at the surface of the rice grain (Palermo et al. 2022).

Fig. 6. FRAP of the rice samples at different polishing times.

Fig. 7. TAC of (A) NSIC Rc 160, (B) Brillante, and (C) Minaangan at different polishing times before and after cooking.
The majority of anthocyanins are further degraded during the actual cooking. In this process, the anthocyanins are broken down into phloroglucinaldehyde and 4-hydroxybenzoic acid through deglycosylation. This reaction is primarily caused by oxidation reactions due to thermal processing (Patras et al. 2010).

**TPC**

The TPC of rice samples were considerably affected by cooking in all the polishing times tested (Fig. 8). The highest reduction in TPC was recorded in Brillante (64.6% to 76.4%) and Minaangan (66.7% to 78.0%) in all the polishing times while NSIC Rc 160 had the lowest (14.3% to 30.4%). With regard to the different polishing times, unpolished samples (0 s) had the smallest reduction in TPC (14.3% to 66.7%) while Brillante polished for 15 s (60.6%), NSIC Rc 160 polished for 30 s (30.4%), and Minaangan polished for 45 s (78.0%) obtained the highest reduction. Previous studies also reported a decrease in TPC upon cooking the following varieties: 63.4% for Keteki Joha (Saikia et al. 2012), 48.6% for Irga 157 (Walter et al. 2013), 27.3% for Ribe (Zaupa et al. 2015), 27.3% for Artimede and Venere from Italy (Fracassetti et al. 2020), and 60% to 62% for commercial and Epagri red rice from Brazil (Massaretto et al. 2022). The decrease in TPC might be due to the degradation of some phenolic compounds upon heating which was caused by the cleavage of esterified and glycosylated bonds when heated (Xu et al. 2007). Other biochemical reactions that could disrupt the phenolic compounds during cooking are polymerization, oxidation, and the release of bound forms (Palermo et al. 2014).

**TFC**

As shown in Fig. 9, the TFC of rice samples at different polishing times was significantly reduced upon cooking. Since the pigmented rice samples such as Brillante and Minaangan contained high initial TFC, it is expected that more flavonoids will be degraded from these samples after cooking. Brillante and Minaangan reduced their TFC by 32.7% to 74.2% and 44.5% to 73.2%, respectively, upon cooking. On the other hand, NSIC Rc 160 had the lowest reduction in TFC by 14.4% to 56.5%. Concerning the different polishing times, unpolished rice samples (0 s) had the lowest reduction in TFC upon cooking (14.4% to 44.5%), while samples polished for 30 s had the greatest reduction (55.9% to 74.2%). In similar studies, Nayeem et al. (2021) recorded a 30% decrease in TFC upon cooking of Indian pigmented rice while Fracassetti et al. (2020) reported a 53.0% to 72.8% reduction upon cooking of Artemide and Venere from Italy. Recently, Massaretto et al. (2022) obtained a significant decrease in TFC upon cooking of commercial and Epagri black rice (46% to 50%) and red rice (48% to 55%) genotypes from Brazil. Zhang et al. (2010) and Randhir et al. (2008) noted that most of the flavonoid compounds in pigmented rice are destroyed during heating. This observation was also
confirmed by Makris and Rossiter (2000), who found that flavonoids from pigmented rice are indeed degraded due to oxidation during heating. Aside from this, several researchers also reported that some water-soluble flavonoids were leached out during washing which consequently lowered the TFC of cooked rice (Tiwari and Cummins 2013; Wu et al. 2019; Nayeem et al. 2021).

**Effects of Cooking on the Antioxidant Activities of Rice Samples**

**DPPH-RSA**

The DPPH-RSA of rice samples at different polishing times was significantly weakened after cooking (Fig. 10). Among the samples, *Minaangan* had the highest reduction in DPPH-RSA in all the polishing times tested (67.6% to 84.6%). Cooking also considerably decreased the DPPH-RSA of *Brillante* (47.1% to 78.6%) and NSIC Rc 160 (38.9% to 66.7%). Although a significant number of antioxidants was destroyed during cooking, unpolished rice samples (0 s) were able to retain some of their antioxidants and consequently obtained the highest DPPH-RSA after cooking in all the polishing times tested. Nayeem et al. (2021) reported a 90% decrease in DPPH-RSA upon cooking of Indian pigmented rice. The low capacity of rice samples to scavenge free radicals after cooking might be due to the denatured phytochemicals during thermal processing. Most of the phytochemicals in rice are polyphenols which are water-soluble and heat-sensitive and can therefore leach out and be destroyed during cooking (Stevenson and Hurts 2007; Xu and Chang 2009; Saikia et al. 2012).

**FRAP**

Cooking significantly reduced the FRAP of all rice samples at different polishing times (Fig. 11). Among the samples, *Minaangan* had the highest reduction in FRAP ranging from 77.9% – 92.8%. A notable reduction in FRAP was also recorded in *Brillante* (62.5% – 87.6%) and NSIC Rc 160 (37.0% – 78.6%). Among the different polishing times, unpolished rice samples (0 s) obtained the lowest reduction in FRAP while the highest reduction was obtained in *Minaangan* polished for 15 s and in *Brillante* and NSIC Rc 160 polished for 30 s. The lower FRAP of rice samples might be due to the degradation of some heat-sensitive phytochemicals during cooking (Nagah and Seal 2005; Stevenson and Hurts 2007; Saika et al. 2012). This consequently affected the capability of antioxidants present in rice samples to chelate with metal ions such as iron to form a stable compound.

**Correlation of Polishing Times, Phytochemical Properties, and Antioxidant Activities of Rice Samples**

The correlation coefficient was used to evaluate the strength of the linear relationship between the polishing time and the different parameters tested. The strength of
the linear relationship was classified as follows: 0 — no correlation; 0.01 – 0.20 — very weak correlation; 0.21 – 0.40 — weak correlation; 0.41 – 0.60 — moderate correlation; 0.61 – 0.80 — strong correlation; 0.81 – 0.99 — very strong correlation; 1.00 — perfect correlation.

Tables 2–4 present the correlation coefficient of polishing time with the phytochemical properties and antioxidant activities of NSIC Rc 160, Minaangan, and Brillante. PCA showed that the polishing time had a strong to very strong negative correlation with phytochemical properties (-0.8809 to -0.9846) and antioxidant activities (-0.8106 to -0.9763). This implies that when the polishing time increases, the phytochemical properties and

Fig. 10. DPPH-RSA of (A) NSIC Rc 160, (B) Brillante, and (C) Minaangan at different polishing times before and after cooking.

Fig. 11. FRAP values of (A) NSIC Rc 160, (B) Brillante, and (C) Minaangan at different polishing times before and after cooking.
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Table 2. Correlation coefficient of phytochemical properties and antioxidant activities of NSIC Rc 160.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Polishing Time</th>
<th>TAC</th>
<th>TPC</th>
<th>TFC</th>
<th>FRAP</th>
<th>DPPH-RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polishing Time</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TAC</td>
<td>-0.9400*</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TPC</td>
<td>-0.9839*</td>
<td>0.9112*</td>
<td>1</td>
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<tr>
<td>TFC</td>
<td>-0.9457*</td>
<td>0.8557*</td>
<td>0.9718*</td>
<td>1</td>
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<td></td>
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<tr>
<td>FRAP</td>
<td>-0.9552*</td>
<td>0.8777*</td>
<td>0.9636*</td>
<td>0.9821*</td>
<td>1</td>
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<tr>
<td>DPPH-RSA</td>
<td>-0.9680*</td>
<td>0.8825*</td>
<td>0.9811*</td>
<td>0.9805*</td>
<td>0.9881</td>
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</tr>
</tbody>
</table>

Table 3. Correlation coefficient of phytochemical properties and antioxidant activities of Minaangan.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Polishing Time</th>
<th>TAC</th>
<th>TPC</th>
<th>TFC</th>
<th>FRAP</th>
<th>DPPH-RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polishing Time</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAC</td>
<td>-0.8809*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPC</td>
<td>-0.9846*</td>
<td>0.8377*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TFC</td>
<td>-0.9770*</td>
<td>0.8714*</td>
<td>0.9789*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRAP</td>
<td>-0.9763*</td>
<td>0.8169*</td>
<td>0.9591*</td>
<td>0.9709*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>DPPH-RSA</td>
<td>-0.8227*</td>
<td>0.7083*</td>
<td>0.8648*</td>
<td>0.8418*</td>
<td>0.8963*</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4. Correlation coefficient of phytochemical properties and antioxidant activities of Brillante.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Polishing Time</th>
<th>TAC</th>
<th>TPC</th>
<th>TFC</th>
<th>FRAP</th>
<th>DPPH-RSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polishing Time</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAC</td>
<td>-0.9836*</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPC</td>
<td>-0.9011*</td>
<td>0.9884*</td>
<td>1</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>TFC</td>
<td>-0.9674*</td>
<td>0.9626*</td>
<td>0.9541*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRAP</td>
<td>-0.9509*</td>
<td>0.9469*</td>
<td>0.9039*</td>
<td>0.9774*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>DPPH-RSA</td>
<td>-0.8106*</td>
<td>0.8187*</td>
<td>0.5479*</td>
<td>0.6794*</td>
<td>0.6633*</td>
<td>1</td>
</tr>
</tbody>
</table>

antioxidant activities of all rice samples decrease. On the other hand, strong to very strong positive correlations were obtained between the phytochemical properties and antioxidant activities (0.6794 – 0.9951) of all the rice samples, except for the relationship of DPPH-RSA with TPC (0.5479) in Brillante, which only had a moderate positive correlation. Furthermore, a very strong positive correlation was observed among the phytochemical properties (0.8377 – 0.9788) and a moderate to very strong positive correlation among the antioxidant activities (0.6633 – 0.9881).

CONCLUSION

This study provided important information on the impact of polishing and cooking on the phytochemical properties and antioxidant activities of ordinary white and pigmented rice cultivars in the Philippines. Pigmented rice samples had significantly higher phytochemical properties and antioxidant activities than the white rice sample. Polishing and cooking considerably reduced their phytochemical properties and antioxidant activities. PCA further showed that the polishing time had a strong to very strong negative correlation with phytochemical properties and antioxidant activities. On the other hand, strong to very strong positive correlations were obtained between the phytochemical properties and antioxidant activities of all the rice samples, except for the relationship of DPPH-RSA with TPC in Brillante, which only had a moderate positive correlation. Moreover, a very strong positive correlation was observed among the phytochemical properties while moderate to very strong positive correlations were noted among the antioxidant activities. Finally, this study concluded that polishing and cooking greatly reduced the phytochemical properties and antioxidant activities of ordinary white and pigmented rice cultivars. Hence, it is highly recommended to consume unpolished rice and avoid too much washing of rice before cooking to better preserve its antioxidants.

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