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Relationships of sensory profile with instrumental measurement and consumer acceptance of Thai unpolished pigmented rice

Juemanee, A., Meenune, M. and *Kijroongrojana, K.

Department of Food Technology, Faculty of Agro-Industry, Prince of Songkla University, Songkhla, 90112, Thailand

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Abstract

Since being recognized for its health benefits, consumption of unpolished pigmented rice has increased markedly. The objective of this study is to investigate the sensory profile and the relationship between physical/chemical properties and consumer acceptance of 12 Thai unpolished pigmented rice samples (5 non-glutinous black rices, 3 non-glutinous red rices and 4 glutinous black rices). Descriptive analysis evaluated by 10 trained panellists showed that glutinous rice had higher intensities of sticky and smooth textures, mixed berry/popcorn odour and flavour as well as appearance characteristics including adhesion, plumpness, glossiness, darkness but lower intensities of hardness and husk flavour than non-glutinous rice ($p<0.05$). Physical property analysis revealed that both instrumental hardness of non-glutinous black rice and colour (L^*, a^*, b^*) of non-glutinous red rice were higher than those of glutinous black rice ($p<0.05$). However, glutinous black rice obtained higher values of size, weight, elongation index (EI), total anthocyanin content and total phenolic content than other rice samples ($p<0.05$). Multi Factor Analysis (MFA) demonstrated the relationship on the first three principal components (PCs1-3) with 79.61% of total variance. Appearance attributes (darkness, plumpness, adhesion, glossiness), sticky and smooth textures, sweet flavour, mixed berry/popcorn odour and flavour as well as physical properties (width, thickness, EI, weight, stickiness, hardness and colour) and some chemical properties (total anthocyanin content, total phenolic content, amylose content) were highly correlated on PC1 and associated with glutinous black rice. While musty and soil odours as well as husk flavour were associated with the red rice group. The results of the acceptance test showed that Thai consumers preferred unpolished pigmented rice with low intensities of hardness, glossiness, adhesion, plumpness and bursting as well as low values of width, thickness, weight and EI which were mainly found in MNS, HNU, RB, HNP and HNL.

Introduction

Rice (*Oryza sativa* Linn.) is a staple food for nearly half the world's population, accounting for 20 percent of the world's dietary energy supply (FAO, 2004). Most rice is consumed as whole kernels and the acceptance of specific sensory characteristics varies from country to country and even between regions within a specific country (Juliano, 1990; Suwansri *et al*., 2002). Generally milled rice is popular, whereas unpolished rice is considered a health food at this time due to its containing a large amount of vitamin B, minerals (Manganese, Phosphorus, Iron), essential fatty acids and dietary fibre. In addition, there are many special rice cultivars containing colour pigments, such as black rice and red rice, whose names refer to the colour of their bran layer and/or endosperm (black, red or purple). Various colours of pigmented rice contain anthocyanin in different kernel layers (pericarp, seed coat and aleurone); levels of the two main types (cyanidin-3-glucoside, peonidin-3-glucoside) are higher in black rices than in red rices (Ryu *et al*., 1998; Chaudhary, 2003; Abdel-Aal *et al*., 2006; Sompong *et al*., 2011; Yodmanee *et al*., 2011; Saikia *et al.,* 2012; Sutharut and Sudarat, 2012; Jantasee *et al*., 2014; Huang *et al*., 2016). Pigmented rice has been consumed in various parts of Asia and appears in food stores across the US, Australia and Europe. This popularity is due to its containing plenty of powerful disease-fighting antioxidants including phenolic acids, flavonoids, anthocyanins and proanthocyanidins, tocopherols and tocotrienols, γ-oryzanol, and phytic acid) (Itani and Ogawa, 2004; Suzuki *et al*., 2004; Yawadio *et al*., 2007; Sompong *et al*., 2011; Goufo and Trindade, 2014). Moreover, it contains a number of nutritional benefits over the more common milled rice such as vitamins, minerals, dietary fibre, protein (Suzuki *et al*., 2004; Savitha and Singh, 2011; Sumczynski *et*

*Corresponding author.
Email: *kongkarn.kij@gmail.com*

al., 2015). These nutraceutical contents of pigmented rice lead to numerous health benefits such as anti-inflammatory properties, heart disease, cancer and diabetes prevention as well as potentially supporting weight loss (Heber *et al*., 1999; Lila, 2004; Sun *et al*., 2010; Yang *et al.,* 2011; Wang *et al*., 2013; Shimabukuro *et al*., 2014).

The different physical properties and chemical compounds of rice cultivars generate distinct sensory properties which affect consumer acceptance. Limpawattana *et al*. (2008) reported that black rice samples were more intense in hay-like and barny flavours. The dark berry, smoky/burnt, medicinal, oily, astringent, brothy/meaty and bitter tastes of black rice were found in higher intensities than in red rice, which showed higher intensities of animal/wet dog, earthy, cardboard/musty and beany tastes (Bett-Garber *et al*., 2012). Odour and flavour of rice relates to various volatile compounds which can be measured by instruments (Yang *et al*., 2008 and 2010). According to the rice texture, the proportion of amylose and amylopectin play an important role in the texture of cooked rice (Juliano *et al*., 1981; Ong and Blanshard, 1995; Ramesh *et al.*, 1999; Singh *et al.*, 2005; Mestres *et al.*, 2011). A higher amount of fibre also results in a harder texture of rice (Mestres *et al*., 2011). Furthermore, the thickness of the aleurone layer results in hardness of cooked pigmented rice (Wu *et al.*, 2016)

However, round dimensions of sensory attributes (appearance, texture, odour, flavour and aftertaste) and the relationships among sensory characteristics, physical and chemical properties of Thai unpolished pigmented rice as well as consumer acceptance have not been reported. These relationships would lead to better methods to instantly evaluate and predict end-use qualities which will help to match rice with specific characteristics to populations that demand those attributes (Lyon *et al*., 2000). Therefore, the objective of the present study was to evaluate the sensory descriptive, physical and chemical properties of Thai unpolished pigmented rice and relation to consumer acceptance.

Materials and Methods

Rice samples preparation

Twelve unpolished pigmented rices, consisting of five non-glutinous black rices (B-NG) [Malinil-Surin (MNS), Riceberry (RB), Homnil-Payao (HNP), Homnil-Uttaradit (HNU), Homnil-LavoThani (HNL)], three non-glutinous red rices (R-NG) [Hommalidang-Uttaradit (HDU), Malidang-LavoThani (MDL), Sungyod-Phatthalung (SYP)] and four glutinous black rices (B-G) [NiawdumLeumpua-LavoThani (NLL), Kum-Doisaked (KD), Kum-Payao (KP), KumLeumpua-Payao (KLP)] were purchased from local rice farmers from different parts of Thailand not longer than 3 months after harvest. The rices were vacuum-packed in a Nylon Laminated with Polyethylene bag (Nylon/PE) and placed at room temperature (28 ± 2^{o}C) for not longer than 3 months.

Cooked rice was prepared using two hundred grams of rice grain for each sample. Rice was rinsed 2 times using a rice to water ratio of 1:2 and drained for 2 mins. Each rice was cooked using an electric rice cooker (Panasonic, 1.8L, SR-G181, Thailand) with a rice to water ratio of 1:2. All glutinous rice samples were soaked for 1 hour at room temperature before cooking. Both glutinous and non-glutinous cooked rice were allowed to remain in the cooker for 15 mins and warmed in a water bath (Memert, Model W350, Schwabach, Germany) at 60 ± 2^{o}C until used.

The rice flour used for chemical analysis was prepared by grinding 10 grams of rice grain using a grinder (Philips, HR2071, United Kingdom) which was stopped in 10 sec increments until the flour was able to pass through 60-mesh sieves.

Sensory evaluation of unpolished pigmented rice

The cooked rice samples were prepared for trained panellists, who used Generic descriptive analysis (GDA) (Lawless and Haymann, 2010). Ten panellists were screened for their perception of rice attributes (appearance, texture, odour and flavour), familiarity with unpolished pigmented rice and ability to determine differences between rice samples (ASTM Special Technical Publication 758, 1981; International Standard ISO 8586-1, 1993; Meilgaard, 2007).

The panellists attended weekly 2-hour training sessions for not less than 30 hours to develop their facility using descriptive terms for evaluating the sensory profiles of unpolished pigmented rice. Reference rice samples were selected by panellists from various rices with a high, medium and low intensity of each attributes. For example, the reference rices used for training the MBP odour were 3 cooked rices including NLL rice (high intensity), KLP (medium intensity) and SYP (low intensity).

Ten grams of each reference rice sample was pre-warmed 60 ± 2^{o}C in a small, transparent glass covered with aluminium foil. After testing the sample, panellists were asked to describe the appearance (A), odour (O), flavour (F), aftertaste (AFT) and texture (T) of each rice sample, using as many attributes as they could. They discussed each attribute in an open session until they reached a consensus on the final verbal definition. Panellists rated the intensities of individual attributes on a 150 mm unstructured scale, anchored at 15 mm of both ends with the terms 'not very' and 'very' with 3 rice reference samples for each attribute. Before testings, consensus criteria for evaluation was defined and practiced in training sessions for at least 30 hr before testing.

During testing, panellists evaluated the intensities of each of the attributes of 12 cooked rice cultivars in 3 sessions (4 samples per session) on a 150 mm unstructured scale. The tests were then replicated on different days. The rice samples were coded with 3-figure random numbers and given in random order to each panellist. Room temperature drinking water was provided to cleanse their palates between samples.

Physical measurement of unpolished pigmented rice

Grain weight was expressed in g/1,000 unbroken grains (Wadsworth *et al.*, 1982). Grain size was determined by measuring the length, width and thickness of 10 rice grains. Whereas the shape was determined by the length: width ratio of 10 rice grains (Adair *et al*., 1966). The shapes of rice grains were classified according to the research of Cruz and Khush (2000). The elongation index (EI) was calculated by the ratio of length/width of 10 cooked rice grains to that of the uncooked grains (Juliano and Perez, 1984).

Colour *(L^*, a^* and b^*)* of cooked rice was measured using Hunter-Lab (C04-1005-631 colourFlex, Reston, VA, USA) (Lamberts *et al.*, 2007). Hardness and springiness of cooked rice were measured according to a modified method of Leelayuthsoontorn and Thipayarat (2006) using Texture Analyser (TA-XTplus, Stable Microsystem, Surrey, UK).

Chemical analysis of unpolished pigmented rice

Protein and crude fibre content were determined with standard procedures according to A.O.A.C. (2000). Protein was estimated from total nitrogen using a conversion factor of 5.95. The amylose content was determined by an iodine colorimeter at 620nm using amylose from potato starch for preparing standard mixture (Juliano, 1971).

The extracted solution for total anthocyanin content (TAC) and total phenolic content (TPC) analyses were performed in duplicate using the method of Sutharut and Sudarat (2012). The total amount of anthocyanins was performed by the pH-differential with UV-vis spectrophotometer (Shimadzu, Kyoto, Japan) and was expressed as mg cyanidin 3-glucoside equivalent per 100g flour (Sutharut and Sudarat, 2012). Total phenolic content was assayed by the Folin-Ciocalteu colorimetric method (Sompong *et al*., 2011).

Consumer acceptance testing of unpolished pigmented rice

A total of 54 Thai consumers were selected between 18 to 65 years of age, all of whom were familiar with unpolished pigmented rice. They were 24% male and 76% female. Most of them work for a government service (68%) or study (18%). Family income of most selected consumers (68%) was in the range of 10,000 - 30,000 Bahts. The consumers evaluated the acceptance of 12 cooked rice samples (4 samples per session for 3 days) in partitioned sensory booths at Prince of Songkla University. A 9-point hedonic box scale from 'dislike extremely' to 'like extremely' was used (Meilgaard *et al*., 2007). The samples were coded and served as previously described in the sensory evaluation section.

Experimental design

Data was analysed using analysis of variance (ANOVA). The differences of mean comparisons carried out by Duncan's multiple range tests were considered to be at a significant level $p<0.05$ using Statistical Package for Social Science (SPSS for windows, SPSS Inc., Chicago, IL, USA.). The correlations among physical, chemical and sensory properties were determined using Multi Factor Analysis (MFA) computed by XLSTAT© (Addinsoft, New York, USA). The MFA determined the linear combination of initial variables that contributed the most to making the samples different from each other (Camo, 1999 cited by Suwansri *et al*., 2002).

Results and Discussion

Sensory characteristics of unpolished pigmented rice

Nineteen sensory characteristics were developed and described by 10 trained panellists as depicted in Table 1. Many sensory characteristics were similar to other reports of different unpolished pigmented rice cultivars. Earthy and sweet odours were found in Korean black rice (Limpawattana and Shewfelt, 2010), Thai KheowNgu black rice (Ajarayasiri and Chaiseri, 2008), and 3 other black rice cultivars (Bett-Garber *et al*., 2012). Bitter flavour described in the black rice samples was also reported by Ajarayasiri and Chaiseri (2008) and Bett-Garber *et al*., (2012). Straw odour from KheowNgu black rice (Ajarayasiri and Chaiseri, 2008) and musty odour from red pigmented rice (Bett-Garber *et al*., 2012) were also denoted. Nevertheless, our study reported

Table 1. Sensory definition of cooked rice attributes used in the generic descriptive analysis

Attributes	Definition and Evaluation	Scale range
Appearances (A)		
Burst	The degree of bursting of grain coating	0, no bursting 15, 100% bursting
Sticky	The degree to which the cooked grain sticks together in a mass	0, separate grain 15, compact grain
Plumpness	The degree of plumpness of cooked rice	0, slender 15, plumpness
Glossiness	The degree of glossiness on the surface of cooked rice	0, no glossiness 15, glossiness
Darkness	The dark colour of cooked rice	0, pale red 15, black
Odour (O)		
Soil/Earth	The odour reminiscent of soil/earthy	0, no odour 15, very strong odour
Musty	The odour associated with mustiness of old rice	0, no odour 15, very strong odour
Cocoa	The odour reminiscent of cocoa/malt	
StBL (Steamed-banana-leaf)	The odour reminiscent of steamed banana leaf	0, no odour 15, very strong odour
MBP (Mixed berry/popcorn)	The odour reminiscent of black glutinous rice, which is the mixed odour	0, no odour 15, very strong odour
Sweet ar (Sweet aroma)	The odour reminiscent of steamed sticky corn	0, no odour 15, very strong odour
Texture (T)		
Hard	The force required to compress the cooked rice, evaluated by compressing or biting 1-2 times with molar teeth	0, soft 15, hard
Sticky	The degree to which the cooked grain sticks together between chewing more than 5 times with molar teeth	0, loose grain 15, sticky grain
Smooth	The degree of smoothness of cooked rice between chewing	0, rough 15, smooth
Flavour (F)		
Husk	The flavour associated with husk/paddy/straw/hay	0, no flavour 15, very strong flavour
StBL (Steamed-banana-leaf)	The flavour reminiscent of steamed banana leaf	0, no flavour 15, very strong flavour
MBP (Mixed berry/popcorn)	The flavour reminiscent of black glutinous rice which is the mixed flavour of sweet aroma, cooked grain, starchy, pop-corn	0, no flavour 15, very strong flavour
Sweet	The flavour reminiscent of steamed sticky corn	0, no flavour 15, very strong flavour
Aftertaste (AFT)		
Bitter	The flavour associated with bitterness and harshness after	0, no flavour 15, very strong flavour

some additional characteristics, such as steamed-banana-leaf (StBL) and mixed berry/popcorn (MBP). MBP was the mixed odour of sweet aroma, cooked grain, starchy, pop-corn and dark berry. This odour was reminiscent of black glutinous rice odour and may be similar to the "black rice-like" odour reported by Yang *et al.* (2008).

The mean intensity ratings of sensory attributes obtained from different unpolished pigmented rice samples are presented in Figure 1. ANOVA performed on the sensory data (data not shown) revealed that all characteristics were significantly different across the cultivars ($p<0.05$). For appearance characteristics, the scores of adhesion, darkness, glossiness and plumpness of glutinous rices were 2-3 times higher than those of non-glutinous rices ($p<0.05$).

Concerning rice odour, the MBP of glutinous rice samples was six times higher than that of R-NG rice ($p<0.05$). This was in line with Bett-Garber et al. (2012) who reported that dark berry was more intense in black rice. The MBP may be related to many compounds such as guaiacol, 2-Acetyl-1-pyrroline, 2,3-butanediol found in black rice (Ajarayasiri and Chaiseri, 2008; Yang *et al*., 2008). Moreover, the StBL intensity of most cultivars was low (7.30-25.75), whereas RB exhibited the highest rating (69.20). Musty odour, perceived as being unpleasant, of R-NG rice was higher than that of other rice cultivars in agreement with Bett-Garber *et al*. (2012). Nevertheless, the values were present at very low levels (<21.05).

According to flavour characteristics, the MBP, StBL and sweet flavours exhibited similar trends to rice odours. Moreover, the husk score was rated highly in non-glutinous rice (15.8-108.35), except RB (4.50) ($p<0.05$).

With regard to texture attributes, the stickiness and smoothness scores of all samples ranged from

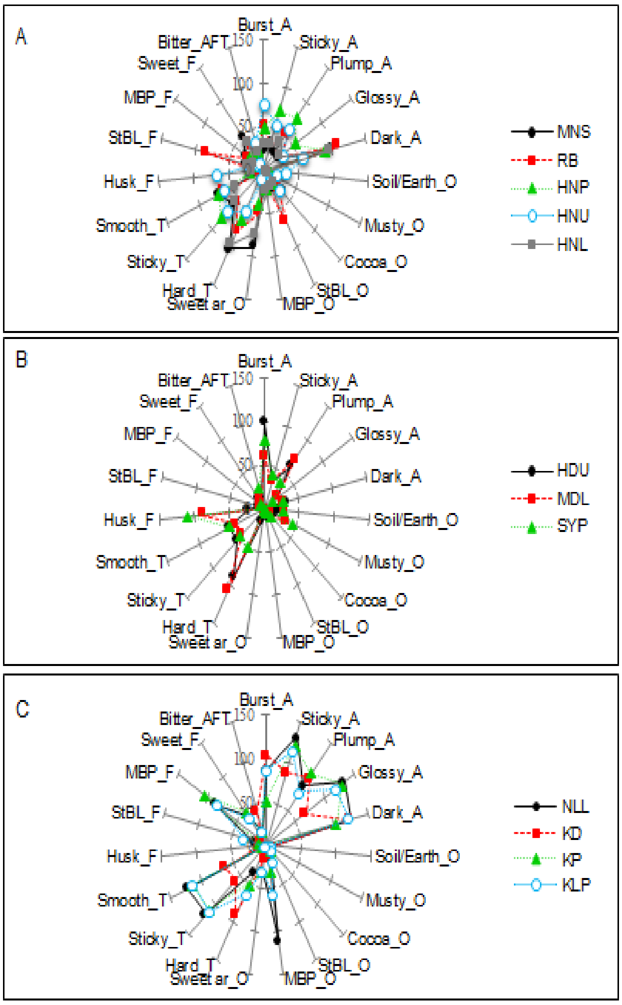

Figure 1. Sensory mean scores of non-glutinous black rice (A), non-glutinous red rice (B) and glutinous rice (C) from 10 trained panellists

47.45-116.35 and 43.05-121.50, respectively. Glutinous rice was approximately two times stickier than non-glutinous rice. In addition, glutinous rices, except KD, tended to obtain lower hardness scores than non-glutinous rices.

Table 2. Physical and chemical properties of 12 unpolished pigmented rice

Sample	Physical property										Chemical property				
	Size (cm)*			Wt*** (g)	Cooked rice colour**			EI*	Hard-ness*** (kg)	Stickiness***	Protein* (%)	Fibre* (%)	Amylose* (%)	TAC* (mg Cy-3-glc /100g db.)	TPC* (mg GAE /100g db.)
	W	L	Thk		L*	a*	b*								
Non-glutinous															
Black rice (B-NG)															
MNS	0.21^{cd}	0.73^{b}	0.156^{h}	17.44^{h}	16.08^{hi}	4.07^{a}	1.15^{e}	0.91^{bc}	12.59^{b}	-0.14^{de}	8.15^{f}	0.505^{c}	13.84^{e}	74.81^{f}	626.35^{d}
RB	0.20^{cd}	0.68^{cd}	0.173^{ef}	15.89^{j}	17.15^{fg}	3.21^{e}	-0.19^{f}	0.99^{ab}	10.11^{c}	-0.52^{ab}	9.61^{b}	0.436^{c}	17.52^{d}	128.70^{d}	744.57^{c}
HNP	0.22^{cd}	0.71^{bc}	0.171^{ef}	18.23^{g}	20.01^{d}	3.73^{e}	0.98^{e}	0.78^{d}	10.03^{c}	-0.67^{a}	7.66^{g}	0.319^{c}	26.96^{a}	50.27^{g}	511.71^{g}
HNU	0.21^{cd}	0.70^{bc}	0.166^{fg}	18.07^{g}	21.84^{c}	8.30^{c}	3.99^{d}	0.92^{bc}	6.76^{d}	-0.52^{ab}	9.50^{b}	0.644^{c}	14.53^{e}	22.92^{h}	400.43^{h}
HNL	0.20^{cd}	0.69^{cd}	0.176^{de}	18.15^{g}	16.85^{fgh}	5.02^{d}	1.72^{e}	0.90^{bc}	8.88^{c}	-0.36^{cd}	10.42^{a}	0.613^{c}	16.91^{d}	55.61^{g}	547.02^{f}
Red rice (R-NG)															
HDU	0.22^{cd}	0.76^{a}	0.178^{de}	22.98^{e}	28.85^{b}	13.54^{a}	12.51^{c}	0.93^{bc}	8.50^{c}	-0.06^{e}	7.59^{g}	0.152^{c}	23.70^{b}	16.03^{i}	584.06^{e}
MDL	0.21^{cd}	0.73^{b}	0.167^{fg}	19.46^{f}	31.35^{a}	12.54^{b}	15.26^{b}	0.87^{cd}	10.17^{c}	-0.02^{e}	8.56^{def}	0.236^{c}	20.77^{c}	8.41^{j}	498.03^{g}
SYP	0.18^{d}	0.67^{d}	0.162^{gh}	14.11^{i}	31.87^{a}	13.15^{ab}	17.08^{a}	0.87^{cd}	16.45^{a}	-0.01^{e}	9.27^{bc}	0.285^{c}	14.55^{e}	14.18^{i}	360.93^{i}
Glutinous black rice (B-G)															
NLL	0.47^{a}	0.69^{cd}	0.203^{a}	29.11^{b}	15.85^{h}	0.98^{f}	4.16^{d}	1.12^{a}	6.54^{d}	-0.52^{ab}	8.67^{de}	2.699^{a}	3.38^{h}	221.70^{a}	740.13^{c}
KD	0.29^{b}	0.79^{a}	0.187^{bc}	30.89^{a}	15.60^{i}	1.16^{f}	4.32^{d}	1.05^{ab}	9.69^{c}	-0.26^{cd}	8.28^{ef}	0.230^{c}	6.17^{g}	164.76^{c}	802.18^{b}
KP	0.26^{bc}	0.66^{d}	0.194^{b}	23.51^{d}	17.54^{ef}	3.34^{e}	4.58^{d}	0.98^{ab}	4.67^{e}	-0.50^{bc}	8.91^{cd}	0.231^{c}	3.29^{h}	100.83^{e}	644.65^{d}
KLP	0.28^{b}	0.78^{a}	0.183^{cd}	28.28^{c}	18.42^{e}	3.12^{e}	4.85^{d}	1.14^{a}	4.89^{e}	-0.56^{ab}	9.59^{b}	0.444^{c}	9.13^{f}	212.90^{b}	844.53^{a}

All values are means. For each run, three* or five** or ten*** determinations were conducted.

$^{a-j}$ In the same column, mean values followed by the different superscripts are significantly different (p<0.05).

Physical properties of unpolished pigmented rice

All physical properties of all rice cultivars were significantly different ($p<0.05$) as demonstrated in Table 2. The length of all varieties had a narrow range of 0.67-0.79cm. The width and thickness of glutinous rices tended to have higher values than non-glutinous rice. NLL (G) obtained the greatest width (0.47 cm), while others varied from 0.18 to 0.29 cm. According to the shape classification of rice (Cruz and Khush, 2000), only NLL was classified as bold shaped (length/width ratio < 2.0), while other glutinous rice samples were sorted as medium shaped (length/width ratio 2.1 – 3.0). All non-glutinous rice were slender shaped (length/width ratio >3). Furthermore, the weight of glutinous rices was also higher than that of non-glutinous rice ($p<0.05$). EI representing the expansion of rice after cooking was found to be higher in glutinous rice (0.98 – 1.14) when compared with non-glutinous rice (0.78 – 0.99).

The highest L^*, a^* and b^* were found in the red rice group with red tone colour, whereas the lowest values were obtained from glutinous rice samples which were dark purple colour ($p<0.05$). These results were concomitant with other reports (Shen *et al.*, 2009; Saikia *et al.*, 2012; Zhang *et al.,* 2015).

The non-glutinous rice group had approximately 1.4 - 1.7 times higher hardness, but 4 - 26 times lower stickiness when compared to the glutinous rice group ($p<0.05$) except RB, HNP, HNU and HNL which had similar stickiness to glutinous rice ($p<0.05$). The harder texture of unpolished pigmented rice might result from the barrier effect of the pericarp causing lower water absorption of the rice (Shobana *et al.*, 2011; Wu *et al.*, 2016).

Chemical properties of unpolished pigmented rice

The chemical analyses of the unpolished pigmented rice samples are depicted in Table 2. Pigmented rice is known to have high protein and fibre content which correlates to particular cooking and eating qualities (Blakeney, 1996; Martin and Fitzgerald, 2002; Savitha and Singh, 2011). In this study, protein and fibre contents of all cultivars were in the range of 7.66 - 10.42 and 0.12 - 0.77 %, respectively. The results were in agreement with other reports on unpolished pigmented rice cultivars (Resurreccion *et al.,* 1979; Somto, 2004; Yodmanee *et al.*, 2011; Sompong *et al.*, 2011).

Glutinous rice was classified as having very low level amylose content (3.29 - 9.12%) while non-glutinous rice was sorted as having low, intermediate and high amylose content (13.84 - 26.96%). Similar levels of amylose content were found in other pigmented glutinous rice (2.80 - 9.66%) and non-glutinous rice (18.30 - 41.95%) (Somto, 2004; Yodmanee, 2009; Sompong et al., 2011).

The TAC data showed that black purple glutinous rice contained the highest TAC (100.83 - 221.70 mg Cy-3-glc/100g dry basis), whereas the lowest content was found in red rice (8.41-16.03 mg Cy-3-glc/100g dry basis) ($p<0.05$). The amount of TAC varied greatly according to the species (Escribano-Bailón *et al.*, 2004). Anthocyanin content of red and light-purple rice was lower than that of black rice (Abdel-Aal *et al.*, 2006; Sangkitikomol *et al.*, 2008; Sompong *et al.*, 2011; Saikia *et al.*, 2012; Zhang *et al.*, 2015). The TPC of all varieties ranging from 360.93 to 844.53 mg FAE/100g was in line with TAC, for which black glutinous rice obtained the highest value (p<0.05). The result was in agreement with the report of other pigmented rices for which the values varied from 58.89 to 691.37 mg FAE/100g (Somto, 2004; Yodmanee, 2009; Sompong *et al*., 2011; Saikia *et al*., 2012). These high amounts of TAC and TPC in black rice are remarkable for their health-enhancing abilities due to being high in antioxidation properties (Itani and Ogawa, 2004; Suzuki *et al*., 2004; Yawadio *et al*., 2007; Sompong *et al*., 2011; Goufo and Trindade, 2014).

The relation among physical, chemical and sensory properties

The relationship between the 19 sensory attributes, 10 physical and 5 chemical properties of 12 unpolished pigmented rices is illustrated on the first three principal components (PCs1 - 3) from MFA with 79.61% of total variance (Figure 2). Most characteristics (12 sensory attributes, 8 physical and 3 chemical properties) were mainly related on the first PC (PC1) with 46.21% of total variance. Glutinous black rice (KD, KP, KLP and NLL) was highly represented at the positive end of PC1 which associated with darkness, glossy and adhesion appearance, sticky and smooth texture as well as MBP odour and flavour (Figure 2A). Whereas, the R-NG rice group (SYP, MDL and HDU) was positioned on negative end of PC1 associated with some sensory characteristics (husk flavour, musty odour) and some physical properties (L^*, a^*, b^*, hardness). PC2 explained 16.70% of total variance which three samples of B-NG rice (MNS, RB and HNL) were positioned at the positive end. These B-NG rice had negative correlation with bursting appearance and positive correlation with cocoa odour, sweet odour, StBL odour and flavour (Figure 2A). PC3 demonstrated by Figure 2B which showed the negative correlation of HNU and the length of rice.

According to PC1 and PC2, many sensory characteristics were associated with physical and chemical properties. The darkness had a negative relation to colour (L^*, a^* and b^*) and a positive relation with TAC as shown on PC1 (Figure 2A). Hiemori *et al.* (2009) reported that TAC related to cyanidin-3-glucoside and peonidin-3-glucoside of black rice sample (*Oryza sativa* L. japonica var. SBR). The darkness also related with TPC as well as MBP odour and flavour which may be related to the higher health-promoting abilities and intense odour/flavours of darker coloured rice. This was concomitant with Bett-Garber *et al*. (2012) who reported that dark berry were more intense in black rice.

Moreover, adhesion and glossy appearance were

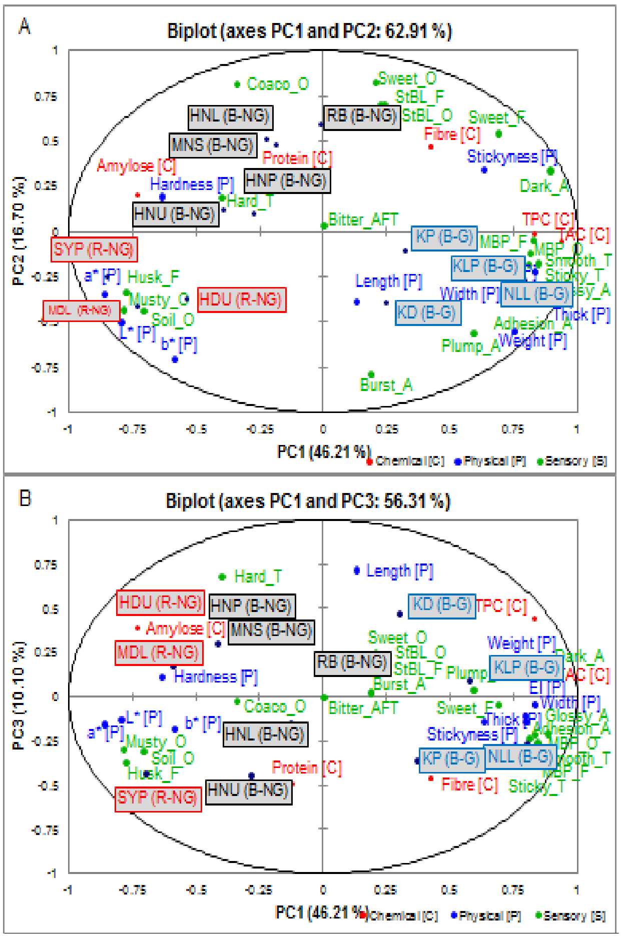

Figure 2. Products and attributes configuration of PC1-PC2 (A) and PC1-PC3 (B) obtained by MFA of 19 sensory characteristics, 10 physical properties [P] and 5 chemical properties [C] of 12 unpolished pigmented rices

associated with stickiness but inversely related to hardness in both sensory evaluation and instrumental measurement. These key textural characteristics also highly related with amylose content which was in agreement with many reports. Cooked rice containing high amylose or low amylopectin content associated with harder and less sticky than that with low amylose content (Juliano *et al.,* 1981; Ong and Blanshard, 1995; Ramesh *et al*., 1999; Singh *et al*., 2005; Leelayuthsoontorn and Thipayarat, 2006; Mestres *et al*., 2011). This was due to the fact that amylose absorbed less water than amylopectin (McWilliams, 2008) and leaching out of amylose during cooking generated a coating film on the surface of cooked grains (Ong and Blanshard, 1995; Leelayuthsoontorn and Thipayarat, 2006). In addition, the fibre content was found to be affected on hard texture of unpolished pigmented rice as reported by Bett-Garber *et al*. (2013). NLL (G) and KP (G), contained similar amount of amylose (approximately 3%), had different fibre contents and different hardness values as demonstrated in Table 2 (p<0.05).

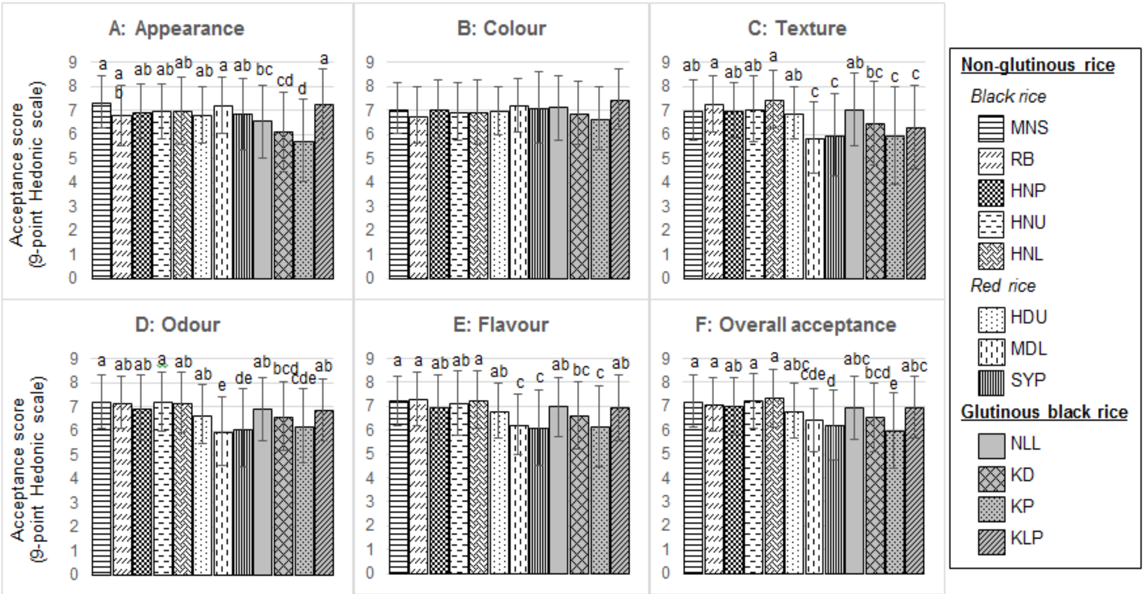

Figure 3. Acceptance scores of 12 unpolished pigmented rices evaluated from appearance (A), colour (B), texture (C), odour (D), flavour (E) and overall acceptance (F). Bars indicate standard deviation from 54 consumers. The different letters indicate significant different (p<0.05).

Consumer acceptance

The acceptance ratings from 54 consumers (Figure 3) showed small variation in acceptability of appearance, texture and flavour but large differences in odour and overall liking score among the 12 cooked rice samples ($p<0.05$). The acceptability rating of B-NG rice for all attributes except appearance and colour (acceptance score > 7) were higher than R-NG rice and glutinous rice (acceptance score < 7). MNS (B-NG) obtained the highest acceptance score of appearance and odour, whereas HNL (B-NG) obtained the highest acceptance score of texture and overall liking.

Of these, the appearance scores of most rice samples were higher than 7 except NLL (G), KD (G) and KP (G). This lower liking score of glutinous rice was due to the high intensity of glossiness, adhesion, plumpness and bursting appearance as well as the high values of some physical properties including width, thickness, weight and EI (Figures 2 and 3). In addition, consumers' colour acceptance was not mainly influenced by the darkness or colour (L^*, a^* and b^*) of samples.

Consumers did not favour (acceptance score < 7) the texture of R-NG rice (HDU, MDL and SYP) which had a harder texture than other rice samples. Furthermore, consumers also rated odour, flavour and overall acceptance of R-NG rice at lower levels. This might be due to high intensities of musty odour and husk flavour of the samples (Figures 2 and 3).

Conclusion

All rice cultivars differed from each other in terms of sensory profile, physical properties and chemical properties ($p<0.05$). The glutinous black rice obtained high intensities in most properties. The consumers favoured rices (e.g. MNS, HNL, RB, HNP, HNU) which had opposing characteristics to glossiness, adhesion, plumpness, bursting as well as hard texture. These properties had both positive and negative relations with physical and chemical properties of rice samples. It was interesting that the differences in colour were not mainly influential to consumer acceptance, even though, darker colour relates to high health-promoting abilities.

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