International Journal of Agricultural Technology 2022Vol. 18(4):1429-1444
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Relation between geometrical and physicochemical properties of various Thai rough rice

Chanlat, P. and Songsermpong, S.*

Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok, 10900 Thailand.

Chanlat, P. and Songsermpong, S. (2022). Relation between geometrical and physicochemical properties of various Thai rough rice. International Journal of Agricultural Technology 18(4):1429-1444.

Abstract Thirteen rough rice cultivars were evaluated for geometrical and physicochemical properties corresponding to correlation and hierarchical cluster analysis. The average dimensions were 9.62-11.8 mm for length, 1.73-3.30 mm for width, 0.93-2.06 mm for thickness, 2.93-6.30 for slenderness ratio and hundred-grain weight was 1.98-2.36 g. The arithmetic mean diameter was in range of 4.48 to 5.20 mm, geometric mean diameter was in range of 2.84 to 3.89 mm., equivalent diameter was in range of 1.93 to 2.47 mm. The sphericity values varied from 1.31 to 1.78, grain volume from 15.18 to 31.57 mm^3, ellipsoidal volume from 12.10 to 30.95 mm^3, surface area from 25.91 to 44.11 mm^2. Pasting and thermal properties were determined. Significant differences were presented among all cultivars ($p \leq 0.05$). Apparent amylose content was in range of 2.84 to 26.88 % and it did not show correlation in geometry ($p > 0.05$) but strong effect on pasting ($p \leq 0.01$) and thermal properties ($p \leq 0.05$) of brown rice flour. The hierarchical cluster analysis using rough rice geometry revealed that it could be classified by four groupings based on dimensional and geometrical characteristics, and three grouping by pasting and gelatinization of rice flour. This study might be used as index for designing the equipment and processing of rice.

Keywords: Amylose, Geometric, Hierarchical cluster analysis, Physicochemical, Rough rice

Introduction

Rice (*Oryza sativa* L.) is one of the economic crops of the world trade and is a major source of staple food for daily consumption of the global population. Rough rice or paddy consists of caryopsis (rice kernel) and husk. It can be processed to many kinds of products like brown rice, milled rice, parboiled rice, rice bran, starch and other products.

The information of physical, chemical and engineering properties of rough rice are important and necessary for designing proper process and equipment for process operations such as conveying, cleaning, sorting, packing and other processing operations such as milling and puffing processes. Shape and size are one of the important factors for sorting and separating and can be used to design the separation process. Furthermore, the dimensional size can be applied to calculate the surface and volume of

* **Corresponding Author:** Songsermpong, S.; **Email:** fagisrsp@ku.ac.th

grain by mathematical modeling (Bhattacharya, 2011; Kunze *et al*., 2004; Mohsenin, 1986).

Paste viscosity is an important key factor for starch and investigated by a Rapid Visco Analyzer (RVA). It was widely used for studying the starch changes while heating in water. The RVA parameters like peak, breakdown and setback were used as an index for evaluation of the quality of flour or starch. Pasting properties have been very useful to the food industry in food formulation, quality control and in designing processing systems (Bao and Bergman, 2004). Thermal properties of rice can be studied by using differential scanning calorimeter (DSC). Gelatinization properties of starch are useful to estimate the amount of heat and time for cooking. The RVA and DSC parameter are very relevant in rice cooking, noodle making and other heating processes(Bao *et al*., 2004).

Cluster analysis is a multivariate statistical analysis to classify the cases or objects into relative groups called cluster, used in many fields including biology, bioinformatics, medicines, agricultures, business and marketing research, food science and technology, sensory and consumer study. Hierarchical cluster analysis (HCA) is a method of cluster analysis which combined the similar objects into the same clusters or groups and usually presented by a tree-like diagram called dendrogram (Fielding, 2007; Granato *et al*., 2014; Jobson, 1992). Application of hierarchical cluster analysis has been applied in many crops such as sorghum, finger millet, oat, corn and rice, and useful for classification, characterization and evaluation (Gayin *et al*., 2015; Lee *et al*., 2012; Patindol *et al*., 2009; Patindol *et al.*, 2010; Sood *et al*., 2015).

Thailand is one of the rice leader countries having different agro-climatic conditions like soil type, humidity, temperature, rainfall intensity and cultivation methods. These are the reason for variation of rice cultivars in particular regional part of country. The utilization of these cultivars is necessary and important. Thus, it is necessary to study some geometrical and physicochemical properties of various rice paddy cultivars for its processing.

However, the study investigated the physicochemical properties such as thermal and pasting properties and geometrical characteristics of thirteen paddy cultivars and characterized the groups of accessions with similar characters using hierarchical cluster analysis and correlation was used for processing and product development.

Materials and methods

Rice materials

The following thirteen rough rice varieties obtained from the four different regions of Rice Research Centers, Ministry of Agriculture and

Cooperatives and Rice Science Center at Kamphaeng Saen campus of Kasetsart University, Nakhon Pathom, Thailand were used in this study. Eight different varieties are from the north, namely Leum Pua (LP), Phrae 1(P1), Phitsanulok 2 (PNL2), Rice Division 6 (RD6), Rice Division 10 (RD 10), Rice Division 14 (RD14), Rice Division 16 (RD16) and San Pah Tawng 1 (SPT1). Two different varieties are from the northeast, namely Niaw Ubon 2 (NUB2) and Rice Division 33 (RD33). Two different varieties are from the central, namely Rice Berry (RBR) and Rice Division 31 (RD31) and Niaw Dam Cham Mai Pai 49 (NCP49) is from the southern. The coded names are listed in Table 1.

The rough rice was sun-dried and cleaned manually to remove all foreign matters and immature grains. The initial grain moisture content was determined using a Rice Moisture Tester (model M-999 Series, Kett, Japan). The average moisture content was 11-12 % (wet basis). Apparent amylose content was determined by method of Juliano (1971).

Principal dimensions of grains

Fifty kernels of each cultivar of rough rice was selected randomly to determine the principal dimensions of grains. The length, width and thickness (T) were determined using a vernier caliper with 0.01 mm accuracy (Mitutoyo, Japan).

The slenderness ratio (SL) was calculated with Eq. (1) as described by IRRI (2013).

$$SL = \frac{L}{W} \tag{1}$$

Where, L is the length of grain and W is the width of grain.

Determination of geometrical characteristics

The arithmetic mean diameter (D_a), geometric mean diameter (D_g), equivalent diameter (D_e), sphericity (∅) and ellipsoidal volume (V_e) of each rough rice varieties were determined using following expression Eq. (2) - Eq. (6) as described by McCabe *et al.,* (1993) and Mohsenin (1986):

$$D_a = \frac{L+W+T}{3} \tag{2}$$

$$D_g = (LWT)^{\frac{1}{3}} \tag{3}$$

$$D_e = \left[L\left(\frac{W+T}{4}\right)^2\right]^{\frac{1}{3}} \tag{4}$$

$$\emptyset = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (5)$$

$$V_e = \frac{\pi}{6}(LWT) \quad (6)$$

Where, L is the length of grain, W is the width of grain and T is the thickness of grain.

The grain volume (V_g) and surface area (S) of each rough rice varieties were determined using following expression Eq. (7) – Eq. (8) as described by Jain and Bal (1997) and Mohsenin (1986):

$$V_g = 0.25\left[\left(\frac{\pi}{6}\right)L(W+T)^2\right] \quad (7)$$

$$S = \frac{\pi B L^2}{(2L-B)} \quad (8)$$

Where, $B = \sqrt{WT}$ is a function of width and thickness.

Hundred-grain weight

The hundred-grain weight was counted randomly and weighed carefully on electronic balance with accuracy of 0.1 mg (IRRI, 2013). The procedure was repeated three times and average values were taken.

Pasting properties

Pasting properties were studied with a Rapid Visco Analyzer (RVA-4, Newport Scientific, NSW, Australia) Brown rice flour (3.0 g, 12% mc) was weighed into RVA canister and 25.00 g of distilled water was added. The pasting profile was recorded under constant shear rate with 160 rpm and heating-cooling profile of 50 ℃ to 95 ℃ for 13 min. The RVA viscosity provided the following parameters: peak viscosity (PV), trough viscosity (TV), breakdown (BD), final viscosity (FV), and setback (SB) were expressed in centiPoises (cP). The temperature corresponding to the initial increases in viscosity was designed as pasting temperature. The breakdown is the ratio of peak to breakdown viscosity and setback is the ratio of final to trough viscosity (AACC, 2000).

Thermal properties

The differential scanning calorimeter (Pyris 1 DSC, Perkin Elmer, CA, USA) was used to measure the thermal properties of flour. Brown rice flour sample of 5 mg (dry basis) and 15 mg of distilled water was weighed into the stainless-steel DSC pan, and the pan was hermetically sealed and allowed to stand for 1 hour at room temperature (25˚C) before analysis. The sample was held at 25 ˚C for 5 minute and heated to 110 ˚C at rate of 10 ˚C/minute. Calibration was performed using Indium and empty pan was used as a reference. The onset (T_o), peak (T_p), and conclusion temperature (T_c) along with the enthalpy of gelatinization (ΔH) were determined from thermogram by using Pyris software version 12.

Statistical analysis

The data were analyzed statistically by using a IBM SPSS Statistics, version 22.0 (IBM Corp., NY, USA). All data are presented as the means ± standard deviation. Analysis of variance (ANOVA) was used to determine whether there is a significant difference followed by post- hoc by Duncan's new multiple range test (DMRT) at 95% confidence level ($p \leq 0.05$). Pearson's correlation coefficients were calculated based on their mean values from analyses.

The hierarchical clustering analysis method is based on the average linkage clustering and Euclidean distance calculating method between dependent variables of each cluster. The data were transformed into *Z*-scores to facilitate their representation on the scale (Fielding, 2007; Gayin *et al.*, 2015) by using a STATISTICA, version 12 (Statsoft Inc., Tulsa, OK, USA).

Results

Dimensional characteristics

The apparent amylose content of flour from thirteen rice varieties were found in range of 2.84 -26.88 % dry basis ($p \leq 0.05$) as shown in Table 1. The highest of apparent amylose content were founded in PNL 2 and RD 31 variety ($p > 0.05$) and the lowest was found in RD 10, LP and RD 16 variety ($p > 0.05$).

The principal dimensions of rough rice including length, width and thickness, a slenderness ratio and a hundred-grain weight of thirteen rough rice varieties were found to vary between varieties. The results are shown in Table 1. The dimensional size, slenderness and a hundred-grain weight were significantly different ($p \leq 0.05$) and Pearson's correlation coefficient *(r)* is in Table 3.

Table 1. The apparent amylose content, dimensions, slenderness ratio and hundred-grain weight of thirteen varieties of rough rice

Variety	Apparent amylose (%)	Dimensions (mm)			Slenderness ratio	Hundred-grain weight (g)
		Length	Width	Thickness		
LP	3.56±0.68^{ef}	11.18±0.75^{a}	2.79±0.09^{b}	1.64±0.16^{bc}	4.01±0.36^{cde}	2.29±0.01^{b}
NCP49	5.80±0.16^{c}	9.62±0.53^{d}	3.30±0.39^{a}	1.44±0.08^{d}	2.93±0.27^{f}	2.27±0.04^{bc}
NUB2	4.69±1.17^{cde}	10.22±0.40^{bcd}	2.05±0.03^{f}	1.60±0.21^{bcd}	4.97±0.26^{b}	2.18±0.06^{de}
P1	5.36±0.58^{cd}	10.40±1.05^{abcd}	2.91±0.17^{b}	1.45±0.06^{d}	3.59±0.57^{e}	2.36±0.06^{a}
PNL 2	26.25±0.41^{a}	10.43±0.24^{abcd}	2.54±0.05^{cd}	2.00±0.06^{a}	4.09±0.10^{cde}	2.25±0.04^{bc}
RBR	12.92±0.39^{b}	10.08±0.59^{bcd}	2.44±0.21^{de}	0.93±0.05^{e}	4.14±0.42^{cde}	1.98±0.01^{g}
RD6	4.79±0.50^{cde}	10.21±0.51^{bcd}	2.06±0.07^{f}	1.57±0.03^{bcd}	4.95±0.39^{b}	2.11±0.02^{f}
RD10	2.84±0.57^{f}	10.54±0.36^{abc}	2.51±0.13^{cd}	1.48±0.13^{cd}	4.19±0.25^{cd}	2.18±0.01^{de}
RD14	5.41±1.27^{cd}	10.76±0.57^{abc}	2.14±0.02^{f}	1.50±0.15^{cd}	5.01±0.28^{b}	2.18±0.05^{de}
RD16	3.76±0.88^{ef}	10.02±0.55^{cd}	2.24±0.21^{ef}	1.73±0.02^{b}	4.49±0.50^{bc}	2.26±0.04^{bc}
RD31	26.88±0.37^{a}	10.50±0.08^{abc}	2.73±0.04^{bc}	2.06±0.04^{a}	3.84±0.05^{de}	2.30±0.02^{b}
RD33	13.11±0.98^{b}	10.85±0.38^{ab}	1.73±0.17^{g}	1.70±0.05^{b}	6.30±0.75^{a}	2.14±0.02^{ef}
SPT1	4.20±0.64^{de}	10.21±0.49^{bcd}	2.13±0.03^{f}	1.63±0.22^{bc}	4.77±0.21^{b}	2.21±0.02^{cd}

Different letters in the same column differ significant difference ($p \leq 0.05$).

The grain length, width and thickness were ranged 9.62 – 11.18 mm, 1.73- 3.30 mm and 0.93-2.06 mm, respectively. The longest grain was found in LP and not different with P1, PNL2, RD10, RD14, RD31 and RD33 ($p > 0.05$). The shortest grain was found in NCP49 and not different with NUB2, P1, PNL2, RBR, RD6, RD16, and SPT1 ($p > 0.05$). The widest and the narrowest grain were found in NCP49 and RD33, respectively. The thickest was found in RD31 and PNL2 ($p > 0.05$) and the thinnest was found in RBR. The r value did not show correlation between length, width, and thickness ($p > 0.05$) (Table 3).

Slenderness is the ratio of length and width (L/W ratio). Slenderness was ranged from 2.93 - 6.30 ($p > 0.05$). The strong negative correlation between grain width and slenderness ratio ($r = -.863$, $p \leq 0.01$) is shown in Table 3.

Table 2. The geometrical characteristics of thirteen varieties of rough rice, Arithmetic mean diameter (D_a), Geometric mean diameter (D_g), Equivalent diameter (D_e), Sphericity (∅), Grain volume (V_g), Ellipsoidal volume (V_e), surface area (S)

Variety	Geometrical characteristics						
	D_a (mm)	**D_g (mm)**	**D_e (mm)**	**∅ (%)**	**V_g (mm^3)**	**V_e (mm^3)**	**S (mm^2)**
LP	5.20 ±0.22^{a}	3.71 ±0.13^{bc}	2.39 ±0.07^{a}	1.65 ±0.06^{bc}	28.82 ±2.66^{ab}	26.88 ±2.97^{bc}	41.58 ±2.88^{a}
NCP49	4.79 ±0.29^{cde}	3.57 ±0.22^{cd}	2.38 ±0.17^{ab}	1.68 ±0.07^{bc}	28.77 ±6.13^{ab}	24.18 ±4.46^{cd}	37.29 ±4.54^{b}
NUB2	4.62 ±0.13^{ef}	3.22 ±0.12^{gh}	2.04 ±0.06^{de}	1.48 ±0.05^{fgh}	17.97 ±1.79^{def}	17.63 ±2.06^{fgh}	31.95 ±2.13^{cd}
P1	4.92 ±0.30^{bcd}	3.53 ±0.07^{de}	2.31 ±0.03^{b}	1.61 ±0.03^{cd}	25.94 ±1.12^{b}	23.05 ±1.46^{de}	37.32 ±2.52^{b}
PNL2	4.99 ±0.08^{abc}	3.76 ±0.03^{ab}	2.38 ±0.02^{ab}	1.72 ±0.01^{ab}	28.31 ±0.93^{ab}	27.89 ±0.92^{b}	41.53 ±0.95^{a}
RBR	4.48 ±0.22^{f}	2.84 ±0.09^{i}	1.93 ±0.08^{f}	1.31 ±0.02^{i}	15.18 ±2.03^{f}	12.10 ±1.28^{i}	25.91 ±2.00^{e}
RD6	4.61 ±0.16^{ef}	3.21 ±0.04^{h}	2.03 ±0.02^{def}	1.48 ±0.00^{fgh}	17.71 ±0.63^{def}	17.39 ±0.70^{gh}	31.74 ±1.25^{d}
RD10	4.85 ±0.13^{bcde}	3.40 ±0.13^{ef}	2.19 ±0.08^{c}	1.55 ±0.06^{def}	22.20 ±2.55^{c}	20.71 ±2.53^{ef}	35.28 ±2.40^{bc}
RD14	4.80 ±0.17^{cde}	3.25 ±0.11^{fgh}	2.07 ±0.06^{de}	1.47 ±0.05^{gh}	18.79 ±1.71^{cde}	18.19 ±1.88^{fgh}	33.11 ±2.02^{cd}
RD16	4.66 ±0.18^{def}	3.39 ±0.11^{efg}	2.14 ±0.08^{cd}	1.57 ±0.05^{de}	20.87 ±2.53^{cd}	20.49 ±2.24^{efg}	34.48 ±2.39^{bcd}
RD31	5.09 ±0.04^{ab}	3.89 ±0.04^{a}	2.47 ±0.02^{ab}	1.78 ±0.01^{a}	31.57 ±1.06^{a}	30.95 ±1.05^{a}	44.11 ±0.93^{a}
RD33	4.76 ±0.10^{cde}	3.17 ±0.10^{h}	2.00 ±0.06^{ef}	1.43 ±0.05^{h}	16.85 ±1.71^{ef}	16.82 ±1.67^{h}	31.82 ±1.66^{d}
SPT1	4.66 ±0.17^{def}	3.28 ±0.16^{fgh}	2.08 ±0.09^{cde}	1.51 ±0.07^{efg}	19.11 ±2.53^{cde}	18.72 ±2.80^{fgh}	32.98 ±2.87^{cd}

Different letters in the same column differ significant difference ($p \leq 0.05$).

Table 3. Pearson's correlation coefficient (*r*) of dimensional and geometrical characteristics of rough rice

Parameters	Length	Width	Thickness	Slenderness	Hundred-grain weight
Length	1				
Width	-.264	1			
Thickness	.278	.007	1		
Slenderness	.400	**-.863****	.107	1	
Hundred-grain weight	.152	.383	**.561***	-.487	1
Arithmetic mean diameter	**.600***	.499	**.579***	-.359	**.754****
Geometric mean diameter	.208	**.565***	**.738****	-.526	**.857****
Equivalent diameter	.107	**.723****	.547	**.704***	**.839****
Sphericity	.041	**.620***	**.751****	**-.594***	**.845****
Grain volume	.095	**.742****	.535	**-.712****	**.821****
Ellipsoidal volume	.205	**.596***	**.722****	-.545	**.824****
Surface area	.296	.544	**.739****	-.487	**.837****

* and ** refer significant difference at *($p \leq 0.05$)* and *($p \leq 0.01$)* respectively.

A hundred-grain weight was ranged between 1.98-2.36 g. The heaviest and the lightest were found in P1 and RBR, respectively. The positive correlation (r = .561, $p \leq 0.05$) between grain thickness and grain weight indicates the size and weight correlation.

Geometrical characteristics

The geometrical characteristics were significantly different)$p \leq 0.05$(and shown in Table 2. Pearson's correlation is in Table 3. The arithmetic mean diameter, geometric mean diameter and equivalent diameter of all varieties were ranged from 4.48 - 5.20 mm, 2.84 - 3.89 mm and 1.93 - 2.47 mm, respectively. It showed positive correlation between arithmetic mean diameter with length (r = .600, $p \leq 0.05$) and thickness (r = .579, $p \leq 0.05$). Same relationship was observed between geometric mean diameter with width (r = .565, $p \leq 0.05$) and thickness (r = .738, $p \leq 0.01$). Equivalent diameter and width (r = .723, $p \leq 0.01$) were observed, respectively. The sphericity was ranged from 1.31-1.78 %. The correlation with width and thickness was observed of .620 ($p \leq 0.05$) and .751 ($p \leq 0.01$), respectively. The grain volume and ellipsoidal volume were ranged from 15.18 - 31.57 mm^3 and 12.10 - 30.95 mm^3, respectively. The correlation of grain volume was highly positive with width (r = .742, $p \leq 0.01$). Correlation coefficient of ellipsoidal volume with width and thickness were .596 ($p \leq 0.05$) and .722 ($p \leq 0.01$), respectively. Surface area of grain was ranged from 25.91- 44.11 mm^2. The highly positive correlation coefficient was observed with thickness (.739, $p \leq 0.01$).

Physicochemical properties

The pasting properties of brown rice flour from thirteen rice varieties were comparable in pasting profile parameters by the RVA. There was a significant difference in pasting properties ($p \leq 0.05$). A wide variation in all pasting parameters were plotted against apparent amylose content (Figure 1). The pasting temperature is the temperature at which the viscosity of the paste begins to rise. The pasting temperature ranged from 68.90 – 83.70 ℃. RD31 had the highest pasting temperature, when LP and NUB2 ($p > 0.05$) had the lowest values (Figure 1A). Peak viscosity (Figure 1B) was ranged 368 – 2,288 cP. RD33 and NUB2 ($p > 0.05$) were found the highest peak viscosity than the other rice varieties, while the lowest peak viscosity was found in RBR. Trough viscosity was ranged 238 -1,300.5 cP. RD33 was the highest, when LP was the lowest trough viscosity (Figure 1C). Breakdown was calculated from the difference of peak and trough viscosity that indicates susceptibility of cooked starch to devastation. Breakdown (Figure 1D) was ranged 55.5 – 1,368 cP. NUB2 was a highest, when RBR was a lowest breakdown. Final or cold viscosity (Figure 1E) was ranged 327.5 – 3,032 cP. PNL2 was highest when, LP was lowest. Setback from trough (Figure 1F) was ranged 89.5 – 2,045 cP. PNL2 was highest when, LP was the lowest values. The variation of pasting properties might be from various factors.

The thermal properties of brown rice flour from thirteen rice varieties were comparable in onset, peak and conclude temperature, and enthalpy of gelatinization by the DSC. There were a significant difference of thermal properties ($p \leq 0.05$) and linear relations were plotted against apparent amylose content are shown in Figure 2. The onset, peak and conclusion temperature (Figure 2A) were ranged 58.32 – 71.62 ℃, 66.13 – 75.80 ℃ and 73.01 – 82.64 ℃, respectively. PNL2 was found a highest value than the other rice varieties and RD31 ($p \leq 0.05$) was found in highest of onset temperature only, while a lowest value was found in LP. Enthalpy of gelatinization (Figure 2B) was ranged 5.13 – 10.77 J/g. The highest value was found in P1 and RD33 ($p \leq 0.05$), while LP and RD6 ($p \leq 0.05$) were found in the lowest value of enthalpy of gelatinization.

For the low-amylose group had low range of onset, peak and conclusion temperature but high range of enthalpy were 58.32 – 65.28 ℃, 66.13 – 72.12 ℃ and 73.01 – 78.44 ℃ and 5.13 – 10.77 J/g, respectively. Medium-amylose group had medium range which was 65.34 – 62.52 ℃, 71.72 – 75.55 ℃, 78.80 – 80.35 ℃, and 7.29 – 9.85 J/g, respectively. High-amylose group had high range of low onset, peak and conclusion temperature which were 70.25 – 71.65 ℃, 75.80 – 77.63 ℃, 82.64 – 85.37 ℃, respectively but medium range of enthalpy was 8.26 – 8.35 J/g .The coefficient of determination (R^2) between apparent amylose and onset, peak and conclude temperature were 0.754, 0.727 and 0.691, respectively. Otherwise, no correlation was observed in enthalpy (R^2 = 0.027).

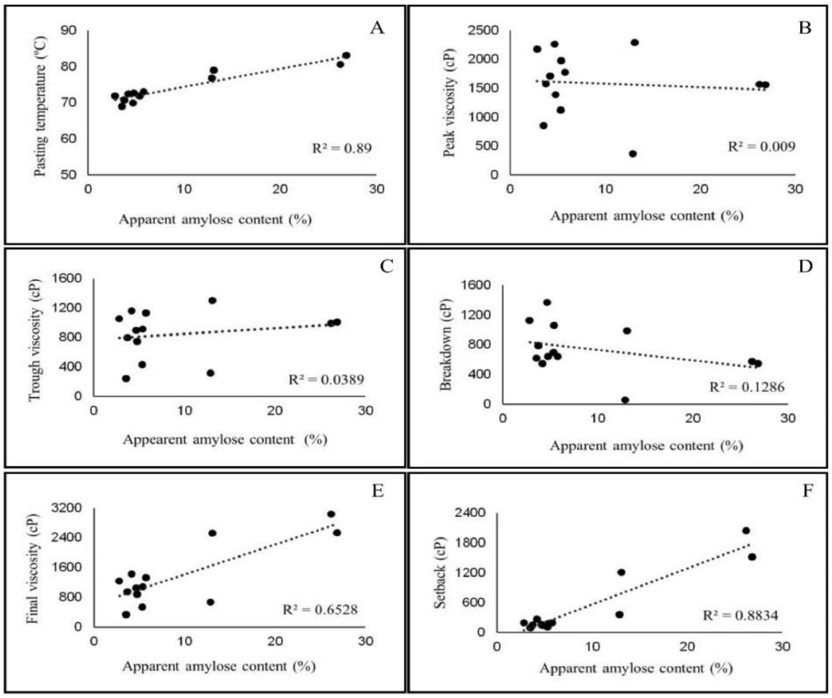


Figure 1. The relationship between pasting parameters as a function of apparent amylose content, pasting temperature (A), peak viscosity (B), trough viscosity (C), breakdown (D), final viscosity (E), setback (F)

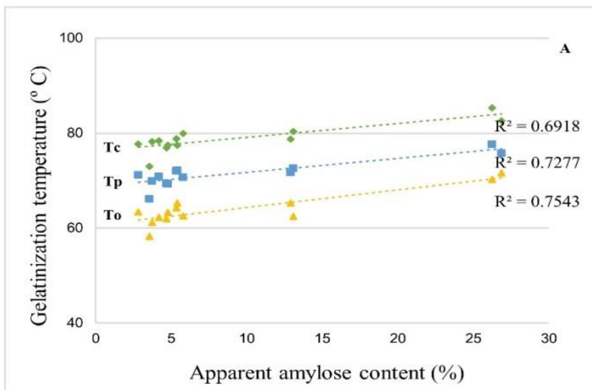
The correlation between thermal properties and apparent amylose content is shown in Figure 2. The onset, peak and conclusion temperature tend to increase with increasing amylose content and shown highly positive correlation (Figure 2A). This study is inconsistent with Ye *et al.*, (2016) that reported gelatinization temperature decreased with increasing amylose. The enthalpy of gelatinization from various rice are shown in Figure 2B. The enthalpy had a wide variation of different amounts of various rice cultivars.

Hierarchical cluster analysis

The hierarchical cluster analysis was applied to grouping. The dendrogram is shown in Figure 3. The relations of dimensional and geometrical characteristics were grouped into four clusters while, physicochemical properties were grouped into three clusters with Euclidean distance value of 5.474 and 5.915, respectively.

According to Figure 3A, the paddy was formed into four clusters by Euclidean distance value of 5.474. Cluster I (n=3) included LP, PNL2 and RD31. Cluster II (n=3) included NCP49, P1 and RD10. Cluster III (n=6) included NUB2, SPT1, RD6, RD16, RD14 and RD33. The RBR sample was subjected to cluster IV individually.

The dendrogram in Figure 1B provided three clusters: cluster I (n=3) included LP, P1 and RBR, cluster II (n=7) included NCP49, SPT1, RD16, RD6, NUB2, RD10 and RD14 and cluster III (n=3) included PNL2, RD31 and RD33.



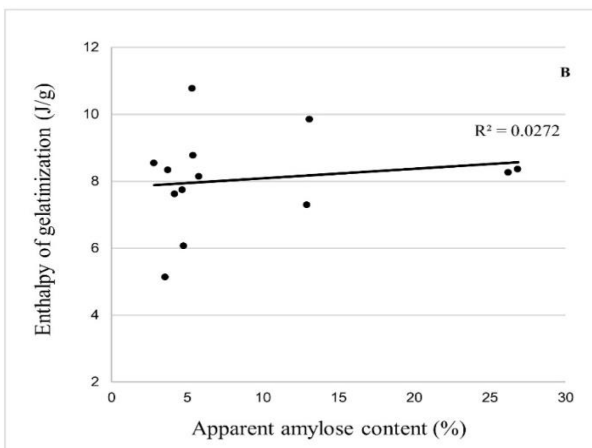


Figure 2. The relationship between gelatinization temperature (A) and enthalpy (B) as a function of apparent amylose content, onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c)

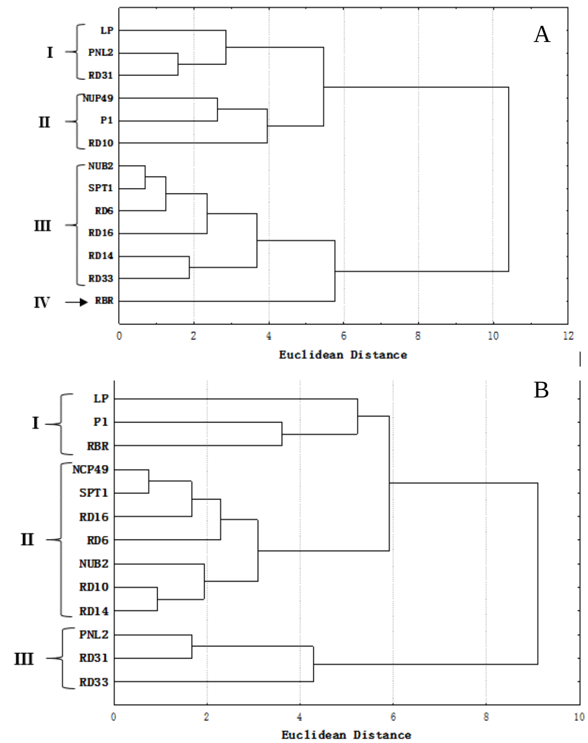


Figure 3. Hierarchical cluster analysis based on dimensional and geometrical characteristics of rough rice (A) and pasting and thermal properties of flour (B)

Discussion

Geometrical and physical properties of rice are importance in all activities of production and ultilization of rice. Several research papers discussed the characteristics of paddy depended on many factors, especially, cultivars, cultivation system and managements and environments (Bao *et al.,* 2004; Bhattacharya, 2011; Juliano and Villareal, 1993; Moldenhauer *et al.,* 2004). However, the dimensions of rice grains are primary important factors for designing equipment and food processing operation. Furthermore, the appearance of grain is the one of the important considerations by consumer (Bao, 2012; Meullenet *et al*., 2001). So, grain dimensions are one of the criteria for rice breeder to develop the new rice variety for consumer acceptance. In Thailand, cultivated rice belongs mainly *Indica* subspecies with slender type and medium- sized are preferred for consumption (Naivikul, 2007; Pitiphunpong and Suwannaporn, 2009).

Pasting temperature tend to be higher when apparent amylose increased. This phenomena have been observed, may be due to amylose inhibit water-swelling power in starch (Kong *et al.,* 2015). Peak viscosity indicates the water-binding capacity and ease which starch are disintegrated during cooking. This study found that the waxy and low amylose rice tend to have higher peak viscosity more than high amylose rice. Some researchers mentioned that amylose/amylopectin ratio, their molecular structure and interaction of other components like lipid and protein that affected on pasting of cereal flour (Sodhi and Singh, 2003; Varavinit *et al*., 2003). Trough viscosity indicates the intendancy of starch to breakdown during cooking. This study found that tend of waxy and low amylose rice had lower amylose. Breakdown is calculated from the difference of peak and trough. High breakdown indicates the low ability to resist heating and shearing during cooking. Waxy and low amylose rice showed high breakdown than high amylose rice. Final viscosity and setback indicate product stability after cooking. Low amylose rice showed highly positive correlation with final viscosity and setback. Waxy rice exhibited distinctive pasting behaviors compared with varieties belonging to different amylose content because of the amylopectin molecule retrograded slowly than amylose, resulting in lower final viscosity and setback (Kong *et al.,* 2015; Singh *et al*., 2006; Singh *et al.,* 2000).

The variation in gelatinization properties might be due to differences in the amounts of chemical compositions, starch granules and its fine structure (Singh *et al.,* 2000). The varieties in one cluster had mostly similar characteristics. The similar rice varieties are linked by gradually diminished criteria of similarity and represented by dendrogram (Patindol *et al*., 2009; Patindol *et al.*, 2010). The utility of cluster analysis had been demonstrated in many crops such as finger millet, sorghum, oat, corn and rice (Gayin *et al.*, 2015; Lee *et al*., 2012; Sood *et al*., 2015).

The dendrogram represents the relationship of similarity or difference (Fielding, 2007; Zhang *et al*., 2010). The X axis represents similarity, and Y axis represents the objects (variety). The four different clusters based on their dimensional and geometrical characteristics with Euclidean distance value of 5.474 and were arbitrarily designed as cluster I (n=3), cluster II (n=3), cluster III (n=6) and cluster IV (n=1). The RBR sample in cluster IV was characterized separately might be by a lowest hundred-grain weight, thickness, and geometric characters that showed significant difference in ANOVA. On the other hand, the physicochemical properties of rice were divided into three clusters with a Euclidean distance value of 5.915; this may be influenced by their compositions, particularly amylose and protein content, which have impact on RVA and DSC properties.

The information on geometrical and physicochemical properties of thirteen rough rice were presented. The results showed significant differences in principle dimensional and geometrical characteristics that were results of length, width and thickness of grains. The pasting and thermal properties of various rice cultivars were result of amylose content. Using amylose and/or physicochemical properties may not provide the cover results. The study was applied to the correlation and cluster analysis that provided an overview of the variation among rice varieties by incorporating geometrical and physicochemical characters. Hierarchical cluster analysis grouped thirteen rice varieties into four clusters based on geometrical properties and three clusters based on pasting and thermal properties. These results can be helpfully understood and used as grading and uniformity index for rice industry.

Acknowledgements

The authors acknowledge the financial support from the Research and Researcher for Industries (RRi) grant number PHD56I0071 under the Thailand Science Research and Innovation (TSRI). Rice sample from Bureau of Rice Research and Development, as well as Rice Science Center, Kasetsart University, Kamphaeng Saen Campus.

References

AACC (2000). Approved Methods of the American Association of Cereal Chemists., 10th edn. American Association of Cereal Chemists,Inc, Minnesota.

Bao, J. and Bergman, C. J. (2004). The functionality of rice starch. In: Eliasson A-C (ed) Starch in Food: Structure, Function and Applications. Woodhead Publishing, Boca Raton, pp 258-294.

Bao, J., Sun, M., Zhu, L. and Corke, H. (2004). Analysis of quantitative trait loci for some starch properties of rice (*Oryza sativa* L.): thermal properties, gel texture and swelling volume. Journal of Cereal Science, 39:379-385.

Bao, J. S. (2012). Toward understanding the genetic and molecular bases of the eating and cooking qualities of rice. Cereal Foods World, 57:148-156.

Bhattacharya, K. R. (2011). Rice Quality : A Guide to Rice Properties and Analysis Woodhead Publishing Limited, Cambridge.

Fielding, A. H. (2007). Cluster and Classification Techniques for the Biosciences. Cambridge University Press, Cambridge.

Gayin, J., Chandi, G. K., Manful, J. and Seetharaman, K. (2015). Classification of rice based on statistical analysis of pasting properties and apparent amylose content: The case of Oryza glaberrima accessions from Africa. Cereal Chemistry, 92:22-28.

Granato, D., de Araújo Calado, V. M. and Jarvis, B. (2014). Observations on the use of statistical methods in Food Science and Technology. Food Research International, 55:137-149.

IRRI. (2013). Standard Evaluation System for Rice. 5th edn. International Rice Research Institute, Manila Philipines.

Jain, R. K. and Bal, S. (1997). Properties of pearl millet. Journal of Agricultural Engineering Research, 66:85-91.

Jobson, J. D. (1992). Applied Multivariate Data Analysis. Springer-Verlag, New York.

Juliano, B. O. (1971). A simplified assay for milled-rice amylose. Cereal Science Today, 16:334-340.

Juliano, B. O. and Villareal, C. P. (1993). Grain Quality Evaluation of World Rices. International Rice Research Institute, Manila.

Kong, X., Zhu, P., Sui, Z. and Bao, J. (2015). Physicochemical properties of starches from diverse rice cultivars varying in apparent amylose content and gelatinisation temperature combinations. Food Chemistry, 172:433-440.

Kunze, O. R., Lan, Y. and Wratten, F. T. (2004). Physical and mechanical properties of rice. In: Champagne ET (ed) Rice: Chemistry and Technology. 3rd edn. American Association of Cereal Chemists,Inc., Minnesota, pp.193-221.

Lee, I., We, G. J., Kim, D. E., Cho, Y.-S., Yoon, M.-R., Shin, M.and Ko, S. (2012). Classification of rice cultivars based on cluster analysis of hydration and pasting properties of their starches LWT:Food Science Technology, 48:164-168.

McCabe, W. L., Smith, J. C. and Harriott, P (1993). Unit Operations of Chemical Engineering. 5th edn. McGraw-Hill, New York.

Meullenet, J. F., Griffin,V. K., Carson, K., Devis,G., Devis, S., Gross, J., Hankins, J., Sailer, E., Sitakalin, C.,Suwaansri, S. and Caicedo, A. L. V. (2001). Rice external preference mapping for Asian consumers living in the United States. Journal of Sensory Studies, 16:73-94.

Mohsenin, N. N. (1986). Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics and Mechanical Properties. 2 nd edn. Gordon and Breach Science, New York.

Moldenhauer, K. A. K., Gibbons, J. H. and McKenzie, K. S. (2004). Rice varieties. In: Champagne ET (ed) Rice: Chemistry and Technology. 3rd edn. American Association of Cereal Chemists, Inc., Minnesota, pp.49-75.

Naivikul, O. (2007). Rice: Science and Technology. 2nd edn. Kasetsart University Press, Bangkok.

Patindol, J., Gu, X. and Wang, Y. J. (2009). Chemmometric analysis of the gelatinization and pasting properties of long-grain rice starches in relation to fine structure Starch - Stärke, 61:3-11.

Patindol, J., Gu, X. and Wang, Y. J. (2010). Chemometric analysis of cooked rice texture in relation to starch fine structure and leaching characteristics Starch - Stärke, 62:188-197.

Pitiphunpong, S. and Suwannaporn, P. (2009). Physicochemical properties of KDML 105 rice cultivar from different cultivated locations in Thailand. Journal of the Science of Food and Agriculture, 89:2186-2190.

Singh, N., Kaur, L., Sandhu, K.S., Kaur, J. and Nishinari, K. (2006). Relationships between physicochemical, morphological, thermal, rheological properties of rice starches. Food Hydrocolloids, 20:532-542.

Singh, V., Okadome, H., Toyoshima, H., Isobe, S. and Ohtsubo, K. (2000). Thermal and physicochemical properties of rice grain, flour and starch. Journal of Agricultural and Food Chemisttry, 48:2639-2647.

Sodhi, N. S. and Singh, N. (2003). Morphological, thermal and rheological properties of starches separated from rice cultivars grown in India. Food Chemistry, 80:99-108.

Sood, S., Khulbe, R. K., Kumar, A. R., Agrawal, P. K. and Upadhyaya, H. D. (2015). Barnyard millet global core collection evaluation in the submontane Himalayan region of India using multivariate analysis. The Crop Journal, 3:517-525.

Varavinit, S., Shobsngob, S., Varanyanond, W., Chinachoti, P. and Naivikul, O. (2003). Effect of amylose content on gelatinization, retrogradation and pasting properties of flours from different cultivars of Thai rice. Starch - Stärke, 55:410-415.

Ye, L., Wang, C., Wang, S., Zhou, S. and Liu, X. (2016). Thermal and rheological properties of brown flour from Indica rice. Journal of Cereal Science, 70:270-274.

Zhang, C. h., Li, J. Z., Zhu, Z., Zhang, Y. D., Zhao, L. and Wang, C. l. (2010). Cluster analysis on Japonica rice (*Oryza sativa* L.) with good eating quality based on SSR markers and phenotypic traits. Rice Science, 17:111-121.

(Received: 22 December 2021, accepted: 30 June 2022)