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Original Research Article

Physicochemical and Functional Properties of Sabah Commercial Rice and Its Flour

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Abstract: This study explored the physicochemical and functional attributes of locally sourced rice flour from Sabah, covering grain morphology, proximate analysis, colour assessment, water absorption capacity (WAC), oil absorption capacity (OAC), foaming capacity (FC), foaming stability (FS), gelatinisation, and least gelation concentration (LGC). The analysis focused on three distinct brands of white rice varieties: SSS, SCA, and TKC. Findings indicated a range of grain characteristics: lengths varied from 6.23mm to 7.43mm, widths from 2.26 mm to 2.33 mm, length-to-width ratios between 2.71 to 3.35, and 1000-grain weights from 16.80 g to 20.20 g. Notably, SSS and SCA exhibited medium-sized grains, while TKC displayed elongated and slender shapes. Analysis of rice flour samples revealed moisture contents between 9.07% to 11.74%, ash contents from 0.31% to 0.36%, crude protein from 6.72% to 7.25%, crude fat from 0.56% to 0.79%, crude fibre from 0.21% to 0.36%, and carbohydrate content from 80.18% to 82.61%. Functional assessments demonstrated significant variations in WAC (ranging from 1.39g/g to 1.66g/g) across all samples, while OAC showed no significant differences (ranging from 1.28g/g to 1.43g/g). Regarding thermal properties, To, Tp, and Tc ranged from 75.31°C to 79.56°C, 75.31°C to 80.26°C, and 76.86°C to 81.68°C, respectively. SSS rice flour exhibited notably higher gelatinisation enthalpy (2.69J/g). Moreover, LGC varied from 11.33% to 15.33%, showcasing significant differences between SSS, SCA, and TKC. Overall, while there were substantial variations in the functional traits among the rice varieties, their proximate compositions remained notably consistent across the board.

Keywords: Rice morphology; rice flour; proximate analysis; functional properties

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1. Introduction

Rice stands as one of humanity's oldest and most vital crops, serving as a staple food for over half of the global population. *Oryza sativa*, commonly known as rice, dominates the Asian agricultural landscape, contributing to 90% of the world's rice production (Gnanamanickam, 2009). Belonging to the Poaceae family, rice encompasses two major domesticated species: *Oryza sativa*, referred to as Asian rice, and *Oryza glaberrima*, known as African rice (Nayar, 2014). The bulk of global rice cultivation occurs in tropical and subtropical regions of southern Asia and Southeast Africa, with countries like India, China, and other Asian nations leading in harvest volumes.

Considered one of the four primary crops responsible for nearly half of global agricultural production, rice holds immense dietary importance, particularly in Asia where per capita consumption averages 80 kg per year (Malaysia – Grain and Feed Annual, 2017). Malaysia reflects this trend, with rice consumption increasing from 2.75 million tonnes to 2.80 million tonnes in 2016/17, driven by population growth projections (Malaysia – Grain and Feed Annual, 2017). Rice serves as a vital energy source for more than half of the world's population, providing essential carbohydrates, proteins, minerals, vitamins, and fibre (FAO, 2022). Despite milling reducing non-carbohydrate constituents, rice retains its status as a staple food in Malaysian dietary guidelines. Moreover, rice is a popular source ingredient in food development (Ronie *et al.,* 2021; Ronie *et al.,* 2023)

In Sabah, rice plays a fundamental role as a staple food, with production rising from 71 MT in 2019 to 74 MT in 2020, driven by increasing local demand (Department of Statistics Malaysia, 2022). However, this growth does not parallel population increases, resulting in a decline in Sabah's self-sufficiency level (SSL) over the years. The SSL for Sabah rice was only 25% in 2019, further decreasing in 2020, indicating heavy reliance on rice imports (Khazanah Research Institute, 2022).

Despite rice's vast diversity, scientific studies exploring the physicochemical and functional properties of local white rice and its flour, especially in Sabah, remain limited. Compositional variations in rice contribute to differing chemical and physical properties, impacting factors like gelatinisation, retrogradation, and water absorption capacity (Jamal *et al.,* 2016). Given the scarcity of research on Malaysian local rice and rice flour, particularly from Sabah, this study aims to fill this gap by comprehensively examining the physical, chemical, and functional properties of Sabah's local rice.

2. Materials and Methods

2.1. Raw Materials

The materials were obtained from Bataras Hypermarket, Kota Kinabalu, Sabah, Malaysia. The brand of the rice was coded as SSS, SCA, and TKC, respectively. All three are locally available long-grain rice varieties sourced from Kota Kinabalu, Sabah, Malaysia.

2.2. Rice Grain Morphology

The weight of 1000 grains of rice was randomly selected and measured using an electronic weighing scale (Sartorius, Malaysia). Concurrently, physical properties such as kernel length and kernel width were determined using a sliding calliper. Subsequently, the length-to-width ratio was calculated.

2.3. Preparation of Rice Flour

The rice was ground into flour with a grinder. Grinding is repeated until the particle size of the flour can be filtered through the Easy Sieve AS 200 No. 60-mesh (250 µm). All samples were placed in containers and stored at room temperature (25°C) before analysis.

2.4. Proximate Analysis

Proximate analysis was carried out to ascertain the percentage of moisture, ash, crude protein, crude fat, and crude fibre, following the procedure outlined by the Association of Official Analytical Chemists (AOAC, 2000).

2.5. Colour

The colour of the rice flour was analysed by the colorimeter (Mamat *et al.*, 2023). Before measurements, a standard black glass and white tile were used for instrument calibration. The results were expressed in the CIE lab colour scale of L^*, a^*, and b^*. As stated by the Hunter Associates Laboratory Inc. (2012), L^* represents lightness and darkness; while a^* represents redness (+ number) or greenness (- number); b^* stands for yellowness (+ number) or blueness (- number).

2.6. Water Absorption Capacity (WAC)

The WAC of samples was determined based on the method described by Adeleke & Odedeji (2010). A total of 15 mL of distilled water was added to 1.00 ± 0.05 g of the sample in a weighed 25 mL centrifuge tube. The tube was agitated on a vortex mixer for 10 s every

5 min for 30 min total holding time. It was centrifuged at 4,000 rpm for 20 min. The clear supernatant was decanted and discarded. The adhering drop of water was removed and reweighed.

2.7. Oil Absorption Capacity (OAC)

The OAC of samples was determined based on the method described by Adeleke & Odedeji (2010). A total of 15 mL of oil (sunflower oil) was added to 1.00 ± 0.05 g of the sample in a weighed 25 mL centrifuge tube. The tube was agitated on a vortex mixer for 10 s every 5 min for 30 min total holding time. It was centrifuged at 4,000 rpm for 20 min. The clear supernatant was decanted and discarded. The adhering drop of water was removed and reweighed.

2.8. Gelatinisation Properties

The gelatinisation properties of samples were measured using a differential scanning calorimeter (DSC) according to the method described by Hasjim *et al.* (2013). A 2 mg sample was weighed into a DSC aluminium pan and 6 µL of distilled water was added to give the flour-to-water ratio of 1 to 3. The pan was sealed, and the sample was allowed to equilibrate for 1 h. In the DSC, the sample was held at 10°C for 1 min followed by heating from 30 to 120°C at a rate of 10 °C/ min. Indium was used for calibration. An empty pan was used as the reference pan. The following parameters were calculated and recorded: onset temperature (T_o), peak temperature (T_p), end temperature (T_c), and gelatinisation enthalpy (ΔH_{gel}).

2.9. Least Gelation Concentration (LGC)

The LGC properties of samples were determined using the method described by Thomas *et al.* (2014). The suspensions were made by mixing rice flour in distilled water (concentrations ranging from 2 to 20%) to make 100 mL total volume. Further, each suspension (10 mL) was transferred into clean test tubes and heated in a boiling water bath for 1 h. After this, the samples were cooled for 2 hs in a refrigerator at 4°C. After 2 h, the samples were taken out and allowed to be put inverted in a rack. The concentration at which samples did not slide (or fall) on the inversion of the test tube was considered the least gelation concentration.

2.10. Statistical Analysis

The experiments were performed in triplicate, and subsequent data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) program, version

26.0. The data underwent One-Way Analysis of Variance (ANOVA) testing. Significant differences were determined using Duncan's Multiple Range Test at a significance level of 95% ($p<0.05$).

3. Results and Discussions

3.1. Rice Grain Morphology

The classification of rice grains plays an important and critical role in market value. Through classification of rice grains, it ensures that rice grains have met pre-quality control guidelines. The standardisation of grain quality also allows the marketing of better quality and fair rice between sellers and buyers. Besides, consumers are concerned with the look of milled rice, which is of foremost importance to producers and millers as well. In order to breed quality rice for commercial use, grain size and shape are the most important criteria.

Table 1 shows the physical properties of the three local rice brands, SSS, SCA, and TKC studied in terms of length and width dimensions, length/ width ratio, 1000-grains weight, size, and shape classification based on IRRI (2002). The results of the study have shown a significant difference ($p<0.05$) for the grain length of SSS rice and SCA with TKC. The TKC rice grain was seen to have the longest length while the SSS rice grain was the shortest in length. The range of length dimensions for the three brands of rice grains was 6.23 mm to 7.43 mm and the range of width dimensions of rice grains was 2.26 mm to 2.33 mm. There was no significant difference ($p>0.05$) among the three brands of rice grains in terms of grain width. The length/width ratio of both SSS and SCA showed a significant difference ($p<0.05$) from TKC in the ratio range of 2.71 to 3.35. Meanwhile, TKC has a high length/width ratio because its rice grain varieties have both maximum and minimum length and width dimensions.

In addition, the weight of the 1000-grains for three local rice showed a significant difference ($p<0.05$). SSS rice grains were the lightest while TKC rice grains were the heaviest. This is also because the TKC rice grains have relatively high length and width dimensions. Overall, TKC grains have relatively high length and width dimensions and was the heaviest rice grain weight among other rice varieties. Size and shape are parameters used to determine the marketability and commerciality of rice. So, local rice varieties can be marketed based on size and shape for consumer preference. The morphology of SSS, SCA, and TKC rice grains is observed in Figure 1.

Table 1. Morphology parameters of three local rice grains

Rice Brands	SSS	SCA	TKC
Length (mm)	6.23±0.64^{a}	6.39±0.67^{a}	7.43±0.54^{b}
Width (mm)	2.33±0.32^{a}	2.31±0.37^{a}	2.26±0.34^{a}
Length/ Width Ratio	2.71±0.44^{a}	2.84±0.57^{a}	3.35±0.56^{b}
1000-grains weight (g)	16.08±0.06^{a}	19.04±0.03^{b}	20.20±0.00^{c}
Size Classification	Medium	Medium	Long
Shape Classification	Medium	Medium	Slender

Values shown are mean ± standard deviation, number of samples (n=100) except 1000-grains weight (n=1000). Different letters (a, b, and c) on the same line indicate that there were significant differences (p<0.05) in the physical properties of rice grains.

(a) (b) (c)

Figure 1. Morphology of rice grains, (a) SSS, (b) SCA, (c) TKC

3.2. Proximate Analysis

Table 2 presents the proximate compositions of three local rice flours. The proximate composition of white rice varies from 6.72% to 7.25% protein, 0.56% to 0.79% fat, 0.21% to 0.36% crude fibre, and 80.18% to 82.61% carbohydrates.

Table 2. Proximate compositions of three local rice flour

Rice Brands	SSS	SCA	TKC
Moisture (%)	11.74±0.16^{a}	10.65±0.47^{b}	9.07±0.08^{c}
Ash (%)	0.35±0.07^{a}	0.31±0.02^{a}	0.36±0.03^{a}
Crude Protein (%)	6.72±0.16^{b}	6.74±0.16^{b}	7.25±0.07^{a}
Crude Fat (%)	0.79±0.34^{a}	0.56±0.30^{a}	0.56±0.30^{a}
Crude Fibre (%)	0.21±0.14^{a}	0.36±0.02^{a}	0.21±0.28^{a}
Carbohydrate (%)	80.18±0.49^{c}	81.38±0.30^{b}	82.61±0.60^{a}

Values shown are mean ± standard deviation and the number of samples (n=3).

Different letters (a, b, and c) on the same line indicate that there were significant differences (p<0.05) in the proximate composition of rice grains.

3.2.1. Moisture content

According to Table 2, there was a significant difference (*p*<0.05) in the moisture content among the three rice flours from different brands. The moisture content ranges from 9.07% to 11.74%, with SSS rice having the highest moisture content and TKC rice the lowest. These findings align with previous studies, where the moisture content of white rice ranged from 8.47% to 11.22% (Suresh, 2013; Ronie *et al.*, 2022), indicating genetic, weather, and agronomic factors influencing moisture levels.

Variations in post-harvest processing techniques, such as drying, storing, and milling, could also account for the observed moisture differences. Traditional drying methods, like sunlight drying, heavily rely on daily weather conditions, impacting moisture levels. Low drying temperatures can result in higher moisture content, affecting milling properties and taste, while excessively dry grains may become brittle and prone to breakage (Ramli *et al.*, 2021). The hot and humid climate of Malaysia, with 80.00% relative humidity, poses challenges for rice storage, necessitating moisture levels of 11% to 14% for optimal preservation (Rice Knowledge Bank, n.d.).

Higher moisture content in rice enhances colour and palatability while reducing hardness and gumminess indexes (Zheng *et al.*, 2011). Consequently, SSS rice, with its relatively high moisture content, is anticipated to exhibit lower hardness and gumminess in the final product compared to other varieties. Overall, all rice samples exhibit favourable moisture levels, promising improved shelf life.

3.2.2. Ash content

The ash content in rice provides insight into the mineral content present in rice flour. Analysis from Table 2 revealed no significant difference (*p*>0.05) in ash content among the three local rice varieties. The ash content ranges from 0.31% to 0.36%, with TKC exhibiting the highest ash content (0.36%) and SCA the lowest (0.31%). In a study by Juliano (1993) on rough rice and its milling fractions at 14% moisture, milled rice exhibited the lowest crude ash content (0.3 g to 0.8 g), while rice hulls had the highest (13.2 g to 21 g). Furthermore, variations in ash content among rice varieties could stem from differences in the shape of milled rice grains. Research by Sandhu *et al.* (2018) indicated that short-grain rice generally contained lower levels of ash, protein, lipids, etc., compared to long-grain rice. Each milling stage resulted in a reduction in ash, protein, and lipid content. Consequently, TKC rice, with longer grain length compared to SSS and SCA, exhibited the highest ash content, aligning with Sandhu *et al.* (2018) findings where short-grain rice typically has lower ash content than long-grain rice.

The slightly elevated ash content in TKC rice might be due to lesser bran removal compared to SSS and SCA, which warrants further investigation. Different rice manufacturers employ varying degrees of milling and processing methods, leading to differences in ash composition despite being the same variety of white rice. Ultimately, the milling process, particularly bran and germ removal, influences the amount of ash present in rice grains.

3.2.3. Crude protein content

Protein content plays a pivotal role in determining the eating quality of rice, with white rice typically containing around 5.9% protein, while protein levels exceeding 7% are considered high. Analysis from Table 2 indicates a significant difference (p<0.05) in protein content between SSS and SCA flours compared to TKC, with protein content ranging from 6.72% to 7.25%. TKC rice flour boasts the highest protein content, followed by SCA and SSS. These results align with previous findings by Jamal *et al.* (2016), Kraithong *et al.* (2018), and He *et al.* (2021), who reported white rice flour protein content ranging from 5.97% to 9.77%.

The lower protein content in SSS flour may stem from temperature-related factors during processing, such as excessive solar irradiance during rice grain development, which can reduce amylose and protein levels. Additionally, variations in protein content within varieties can be attributed to milling methods, as protein is predominantly found in the embryo tissue (aleurone layer), which is often removed during grain milling (Ronie & Hasmadi, 2022). SCA's higher protein content may result from less extensive milling compared to SSS flour. Genotype, environmental factors, growing conditions, and agricultural practices also contribute to differences in protein content among rice varieties. Studies by Jin *et al.* (2001) have shown that increased nitrogen fertilizer application or timing can significantly boost rice grain storage protein content. Moreover, increased nitrogen fertilizer application has been linked to higher total protein, albumin, gliadin, and gluten contents in rice grains. Factors like shorter growing periods, salinity, or soil fertility can further enhance protein content in rice grains (Lan *et al.*, 2021).

3.2.4. Crude fat content

Based on the data from Table 2, there was no significant difference (*p*>0.05) in fat content among the various rice flour varieties. However, SSS flour exhibits the highest fat content, followed by SCA and TKC. The fat content range observed in the studied rice varieties (0.56% to 0.79%) aligns with recent studies on Chai Nat 1 white rice, CMRF (0.77%), but is lower than Phitsanulok white rice (1.13%) (Kraithong *et al.*, 2018; Oppong *et al.*, 2021). Fat content is primarily concentrated in rice bran and germ compared to other parts of the rice grain. During white rice processing, a portion of the bran and germ is removed through milling, significantly reducing the fat content. This step is essential for producing white rice because the germ contains polyunsaturated fats that are prone to oxidation and can become rancid during storage. Removal of the germ improves the storage stability of the flour.

3.2.5. Crude fibre content

The study results regarding crude fibre indicate no significant difference (*p*>0.05) among the various rice flour samples, as outlined in Table 2. The range of crude fibre in rice flour fell between 0.21% and 0.36%, with both SSS and TKC exhibiting the lowest value, while SCA had the highest crude fibre content. Across all samples, the crude fibre content remained below 1%. These findings are consistent with recent studies, where fibre content ranged from 0.12% to 0.21% in white rice for both TQR and Bario Adan Halus (Ronie *et al.*, 2022), and 0.81% in Phitsanulok white rice (Kraithong *et al.*, 2018). The low fibre content (0.21% to 0.36%) observed in the studied rice flour may be attributed to the level of rice polishing or milling, particularly the removal of rice bran, which is rich in fibre. Crude fibre content plays a role in rice digestibility, as higher fibre content decreases digestibility. Consequently, white rice, with its lower fibre content, is easier to digest compared to other varieties such as brown rice (Qadir & Wani, 2023).

3.2.6. Carbohydrate content

Carbohydrates serve as the primary constituents in rice flour, and in this study, all varieties exhibited high carbohydrate content ranging between 80.18% and 82.61%, falling within the desired range (>80%). Thus, all varieties can be considered excellent sources of carbohydrates (Verma & Srivastav, 2017). Significant differences (*p*<0.05) were observed in the carbohydrate content among the rice varieties, with TKC displaying the highest carbohydrate content, followed by SCA and SSS. These findings align with those of Ronie *et al.* (2022), who reported carbohydrate contents of 83.12% for TQR and 82.04% for Bario Adan Halus. Variations in carbohydrate content among rice flour varieties may be influenced by other compositions containing higher percentages. For instance, the highest recorded moisture content (11.74%) and crude fat content (0.79%) in SSS may contribute to its relatively lower carbohydrate content compared to others. Conversely, TKC flour, with the lowest moisture content (9.07%), exhibited a relatively higher carbohydrate content (82.61%). The abundance of carbohydrates in rice provides a valuable source of energy and aids in synthesising lipids and proteins in the body.

3.3. Colour

The results of the colour analysis conducted using the Hunter Lab colorimeter for all rice flour samples are presented in Table 3. The L* value, indicating brightness, ranged from 94.44 to 95.15, with a significant difference ($p<0.05$) observed among all the rice flour samples. SCA rice flour exhibited the highest brightness value, while SSS rice flour had the lowest, indicating that SCA flour possessed the brightest colour among the studied samples. The high L* values for all rice flour samples correspond to their white appearance. These findings are consistent with a previous study by Ronie *et al.* (2022), where brightness values for TQR and Bario Adan Halus white rice were reported as 93.62 and 94.34, respectively.

Table 3. Physical and functional properties of three local rice flour

Rice Brands	SSS	SCA	TKC
Colour			
*L**	94.26 ± 0.07^{a}	95.15 ± 0.06^{b}	94.44 ± 0.11^{c}
*a**	0.07 ± 0.03^{a}	0.04 ± 0.01^{a}	0.26 ± 0.00^{b}
*b**	6.00 ± 0.02^{a}	5.16 ± 0.05^{b}	5.25 ± 0.05^{c}
WAC (g/g)	1.39 ± 0.02^{a}	1.66 ± 0.02^{b}	1.51 ± 0.01^{c}
OAC (g/g)	1.31 ± 0.04^{a}	1.28 ± 0.02^{a}	1.43 ± 0.13^{a}
Gelatinisation			
T_o (°C)	77.39 ± 1.71^{a}	75.31 ± 1.68^{a}	79.56 ± 0.00^{a}
T_p (°C)	75.31 ± 1.68^{a}	75.65 ± 1.62^{a}	80.26 ± 0.00^{a}
T_c (°C)	79.46 ± 1.13^{ab}	76.86 ± 1.89^{a}	81.68 ± 1.05^{b}
ΔH_{gel} (J/g)	2.69 ± 0.12^{a}	0.97 ± 0.56^{a}	2.53 ± 0.88^{a}
LGC (%)	15.33 ± 1.15^{a}	12.00 ± 0.00^{a}	11.33 ± 1.15^{b}

Values shown are mean ± standard deviation. Different letters (a, b, and c) on the same line indicate that there were significant differences ($p<0.05$) in the properties of rice grains.
WAC: water absorption capacity, OAC: oil absorption capacity, FC: Foaming capacity,
FS: Foaming stability, T_o: onset temperature, T_p: peak temperature, T_c: end temperature, ΔH_{gel}: gelatinisation enthalpy

3.4. WAC

WAC indicates a product's ability to mix with water under conditions of limited water availability (Klunklin & Savage, 2018). In this study, WAC values of the rice flours ranged from 1.39 g/g to 1.66 g/g, as depicted in Table 3. Significant differences ($p<0.05$) were observed among the WAC values of the samples. SCA rice flour exhibited the highest WAC value, while SSS rice flour displayed the lowest. Comparable WAC values for rice flour have been reported in previous studies, approximately around 1.20 g/g (Ronie *et al.*, 2022).

Differences in WAC among rice flour samples can be associated with their moisture content. Flour with higher moisture content, essentially already "water-rich," has limited capacity to absorb additional water, while drier flour tends to absorb more water. In this context, SSS rice flour, with the highest moisture content (11.74%) among the samples, exhibited the lowest WAC (1.39 g/g). Overall, the WAC of all rice samples was found to be relatively low.

Moreover, the protein content of rice flour may also influence its WAC. Salehifar *et al.* (2010) reported that water absorption of flour samples increased with higher protein content. Proteins in rice flour possess unique functional properties, capable of trapping water from the surroundings. Flour with high water absorption typically contains more hydrophilic constituents such as polysaccharides. Protein, being both hydrophilic and hydrophobic, can interact with water in foods. Additionally, Jamal *et al.* (2016) demonstrated that higher protein content strengthens hydrogen bonds, subsequently enhancing the water absorption capacity of rice flour. Therefore, higher protein content in rice flour generally correlates with better water absorption. For example, SSS rice flour, with the lowest WAC (1.39 g/g), also exhibited the lowest crude protein content (6.72%).

Furthermore, since bran has been removed from rice flour, much of the pentosan present in the bran, which has high water-absorbing capacity, has been lost. Pentosans in flour can absorb water up to 15 times their weight, despite their small presence (approximately 1.50% of the flour). Therefore, rice flour tends to have lower WAC due to the absence or low content of bran.

3.5. OAC

The OAC of the rice flours in this study ranged from 1.28 g/g to 1.43 g/g, as illustrated in Table 3. Comparatively, these values were lower than those reported for commercial rice flour (CMRF) (OAC = 2.49 g/g) by Oppong *et al.* (2021). No significant differences ($p>0.05$)

were observed among the OAC values for all samples. The highest OAC value was observed in rice flour made from TKC, while the lowest was found in SCA. These findings are consistent with those reported by Kraithong *et al.* (2018), who documented OAC values for rice flour ranging from 1.11 g/g to 1.34 g/g. The higher OAC values recorded in the rice flours may be attributed to the presence of more hydrophobic proteins with superior lipid-binding efficacy (Oppong *et al.*, 2021).

According to Chandra *et al.* (2015), the major chemical component influencing OAC in proteins comprises both hydrophilic and hydrophobic parts. Non-polar amino acid side chains can form hydrophobic interactions with hydrocarbon chains of lipids, thereby facilitating their interaction and binding with lipids. This correlation is evident in the studied results, as TKC had the highest protein content (7.25%) among all rice flour samples, and also exhibited the highest OAC (1.43 g/g). Furthermore, high OAC values contribute to improved mouthfeel, flavour retention, and palatability in food products. However, excessively high OAC values may accelerate rancidity in food products. Nevertheless, given the similar OAC values observed across all samples in this study, any of these rice flours would be suitable for use in food preparations requiring OAC, such as soups, cakes, and sausages.

3.5. Gelatinisation Properties

The gelatinisation process plays a crucial role in determining the cooking, textural, and digestion properties of starchy foods like rice, wheat, barley, and potatoes (Sichina, 2000). Generally, gelatinisation of rice flour occurs within the temperature range of 60 to 80°C in the presence of excess water during thermal treatment. According to Table 3, the gelatinisation onset temperature (T_o) ranged between 75.31 and 79.56°C. TKC rice flour exhibited the highest T_o value, while the lowest was observed in SCA rice flour. Peak temperature (T_p) was recorded between 75.31 and 80.26°C, and end temperature (T_c) ranged from 76.86 to 81.68°C. In this context, TKC demonstrated the highest values for both T_p and T_c. Conversely, SSS had the lowest T_p value, while SCA had the lowest T_c value.

However, the enthalpy of gelatinisation (ΔH_{gel}) of rice flour samples varied between 0.97 J/g and 2.69 J/g. Kraithong *et al.* (2018) reported a ΔH_{gel} of 1.04 J/g for Phitsanulok white rice flour. There were no significant differences ($p>0.05$) observed among the samples for T_o, T_p, and ΔH_{gel}. However, a significant difference ($p<0.05$) was noted in the combination of SSS and SCA with SCA and TKC. The thermal properties of rice flour are influenced by various factors including chemical makeup, starch source, moisture content, presence of additional biomaterials, processing, pre-treatment conditions, and environmental factors (Suklaew *et al.*, 2020). Moreover, the size of the grains is related to the gelatinisation temperature due to the amylose content. Rice with long grains typically contains more amylose and exhibits a higher gelatinisation temperature, along with a higher tendency to retrograde compared to rice with short grains (Cornejo & Rosell, 2015). For example, TKC, with long and slender grains in this study, showed the highest T_p and T_c values among all samples. This may be attributed to the higher amylose content in long-grain rice, which delays swelling and increases the gelatinisation temperature.

Furthermore, the variation in ΔH_{gel} can be roughly determined by examining the area under the DSC thermogram of gelatinised rice flour. A high ΔHgel indicates that a significant amount of energy is required to change the starch structure from its ordered (crystalline) to its disordered (amorphous) states, whereas a low ΔH_{gel} indicates the opposite (Ronie *et al.*, 2022).

3.6. LGC

When flour is combined with water and heated, the LGC signifies the minimum amount of flour needed to form a gel. LGC serves as an indicator of gelation capacity. In this study, the rice flour samples exhibited LGC values ranging from 11.33% to 15.33%. A lower LGC indicates a more efficient gelling capacity (Hasmadi *et al.*, 2020). Accordingly, TKC rice flour demonstrated superior gel formation at a lower concentration (11.33%), followed by SCA rice flour, and SSS rice flour. The results revealed a significant disparity ($p<0.05$) between SSS and SCA rice flour compared to TKC rice flour. However, some rice flours have reported even lower LGC values, ranging from 6% to 8% (Suresh, 2013; Oppong *et al.*, 2021). The observed variations in LGC among rice flour samples can be attributed to differences in protein, carbohydrate, and lipid levels. As elucidated by Kaushal *et al.* (2012), legume flour, with its high protein and starch content, experiences a physical competition between starch gelatinisation and protein gelation for water. Therefore, TKC rice flour, with the highest protein content (7.25%) in this study, exhibits the most pronounced gelation capacity.

4. Conclusions

Sabah's local commercial white rice varieties, including SSS, SCA, and TKC, each possess distinctive attributes. SSS and SCA share similarities in their medium-sized, medium-shaped grains, while TKC stands out with long and slender grains. Notably, SCA flour showcases a remarkably bright colour due to its highest L* value. TKC boasts the highest ash, crude protein, and carbohydrate content, while SSS records the highest moisture and crude fat content. Conversely, SCA leads in crude fibre content. Additionally, significant differences in water absorption capacity (WAC) were observed among all samples, with overall WAC levels trending low. These findings highlight the nuanced characteristics of Sabah's local white rice varieties and their flour, offering valuable insights for food processing and product development.

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