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PHYSICOCHEMICAL AND TEXTURE ANALYSIS OF TWO LOCAL GLUTINOUS RICE

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ABSTRACT

Glutinous rice (*Oryza Sativa var. glutinosa)* is known as waxy or sticky rice. It has an opaque and small grain size with distinct difference from common white rice. At the moment of writing, Malaysia only imports glutinous rice from Thailand, about 4% from total rice import into Malaysia. Thai glutinous rice is popular in Malaysia since cultivation in Malaysia has ceased late in the 1980's, creating a total dependency of imported glutinous rice. Subsequently, very few studies had been done on local glutinous rice cultivars. In parallel with the Malaysia's government of National Result Key Area (NKRA) policy, Langkawi was identified with the potential to become one of the local glutinous rice producer. Two different cultivar of local glutinous rice *Susu* and *Siding* were evaluated in this study while commercial *Susu* Thai act as the reference. The first objective of this project is to determine and compare the physicochemical properties of variety local glutinous rice whether it is superior as imported glutinous rice. The physical and morphological properties were determined by taking measurement of the rice kernel. The average length of local *Susu* cultivar is 6.63mm higher than *Susu* Thai and *Siding* cultivar. But, the average width of *Siding* cultivar is 1.98mm wider than local *Susu* cultivar. The other physical parameters does not significant between local *Susu* and imported *Susu* cultivar. Then, the rice kernel were grinded into powder to determine its chemical and thermal properties. The proximate composition between local and imported cultivar showed no significant difference. Finally, the glutinous rice were cooked in the rice cooker with different parameter of soaking time (0, 60, and 120 minutes). *Susu* Thai cooks faster than local cultivar due to the lower in amylose content, high in enthalpy of gelatinization and closely packed of morphological structure. Also, effect of soaking treatment gives high texture acceptability for *Susu* Thai cultivar compared to local cultivars. However, the result showed by *Susu* Thai cultivar gives no significant different to local *Susu* but slightly different with *Siding* cultivar. Thus, the physicochemical properties of local *Susu* was on par with the imported *Susu* Thai and suggested to soak the rice for the fluffy in texture properties.

ABSTRAK

Beras pulut (Oryza Sativa var. Glutinosa) dikenali sebagai beras lilin atau lekit. Ia mempunyai saiz butiran kecil dan legap dengan perbezaan yang berbeza dari beras putih biasa. Pada masa sekarang, Malaysia hanya mengimport beras pulut dari Thailand, sekitar 4% dari keseluruhan jumlah beras yang diimport ke dalam Malaysia. Beras pulut Thailand sangat popular di Malaysia kerana penanaman di Malaysia berhenti pada akhir tahun 1980-an, mewujudkan sepenuhnya kebergantungan beras pulut import. Selepas itu, sangat sedikit kajian yang dilakukan terhadap penanaman beras pulut tempatan. Selari dengan Bidang Keberhasilan Utama Negara (NKRA), Langkawi dikenal pasti berpotensi menjadi salah satu pengeluar beras pulut tempatan. Dua jenis kultivar beras pulut tempatan Susu dan Siding dinilai dalam kajian ini sementara Susu Thai komersial bertindak sebagai rujukan. Objektif pertama projek ini adalah untuk menentukan dan membandingkan sifat fizikokimia beras pulut tempatan sama ada lebih unggul daripada beras pulut yang diimport. Sifat fizikal dan morfologi ditentukan dengan mengambil ukuran biji beras. Panjang purata kultivar susu tempatan adalah 6.63mm lebih tinggi daripada kultivar Susu Thai dan Siding. Tetapi, purata lebar kultivar Siding adalah 1.98mm lebih lebar daripada kultivar Susu tempatan. Parameter fizikal yang lain tidak signifikan antara kultivar susu tempatan dan import. Kemudian, biji padi dikisar menjadi serbuk untuk menentukan sifat kimia dan haba. Kadar nutrisi antara kultivar tempatan dan import tidak menunjukkan perbezaan yang signifikan. Akhir sekali, pulut dimasak di dalam periuk nasi dengan parameter masa rendaman yang berbeza (0, 60, dan 120 minit). Susu Thai memasak lebih cepat daripada kultivar tempatan kerana kandungan amilosa yang rendah, entalpi gelatinisasi tinggi dan struktur morfologi yang padat. Juga, kesan rendaman memberikan penerimaan tekstur yang tinggi untuk kultivar susu Thai berbanding kultivar tempatan. Oleh itu, sifat

fizikokimia susu tempatan setara dengan susu Thai yang diimport dan dicadangkan agar rendam beras untuk mendapatkan tekstur beras yang gebu.

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L/B	Length to Breadth ratio
TWK	Thousand Weight Kernel
TPA	Texture Profile Analyzer
LPP	Lembaga Pengurusan Peladang
BERNAS	Padibernas Nasional Berhad
FAO	Food Agricultural Organization
IRRI	International Rice Research Institute
NKRA	National Key Result Area

CHAPTER 1

INTRODUCTION

1.1 Background

Rice (*Oryza sativa L.*) is one of the leading food crops of the world and is a staple food of more than half of the world's population. Thousands of rice varieties are available throughout the world and glutinous rice (*oryza sativa var. glutinosa*) is one of the most popular varieties. Commonly known as sticky rice or waxy rice. It has a type of short- or medium-grained rice that is especially sticky when cooked.

Glutinous rice has been growing in mainland Southeast Asia for at least 4,000 years (Ives, 2011). According to Food Agriculture Organization (FAO) (2018), global consumption of rice has been slightly increase about 490.27 million metric tons (MT) from 437.18m MT in 2008. From ricepedia, Asia account for 90% of global rice consumption and expected to continue to rise year by year. In Malaysia, about 2.7m MT was consumed in 2017. However, 1.8m MT of rice processed and remaining 821,869 MT of demand were fulfilled by importing rice (Khazanah Research Institute, 2019).

According to FAO statistics (2018), the worldwide top three of biggest rice exporters were from Thailand followed by Vietnam and then Cambodia. While in Malaysia, as reported by Khazanah Research Institute (2019), from the reported value 20% were consisted of speciality rice such as *basmathi,* glutinous, fragrance rice and others. 4% from them were consisted of glutinous rice which is about 38,880 MT of imported glutinous rice annually.

Preference towards glutinous rice based on Malaysian people can be categorized as seasonal where the highest demand is during *Hari Raya* festival making of *ketupat palas, lemang, wajik, bubur pulut hitam,* and others. As stated by Padiberas Nasional Berhad (BERNAS) (2017), 80% of Malaysian preference chose for white rice remaining 20% for import speciality rice. From 20%, only 4% of glutinous rice is preferred by Malaysian people in sufficient with the total of importing glutinous rice.

Besides that, there are many varieties of rice and each type has its own characteristics. Unlike other cereals, rice is consumed as a whole grain. In conclusion, physicochemical characteristics of rice are the determinant factor. This fact has been proved from previous studies and researches (Singh et al., 2003; Sing et al., 2005; Yadav et al.,2007). Hence, the aim of this study is to determine and compare the physicochemical properties of local glutinous rice whether it is on par with the imported glutinous rice cultivar to reduce our dependency from importing glutinous rice.

1.2 Benefit of glutinous rice

Rice is used mainly for human nutrition. In addition, it is particularly valuable for use in medical and functional foods (Medealf, 2000). Besides being the main source of calories and protein, rice is an important cereal because it has the highest digestibility, biological value and protein efficiency ratio (PER) among all the cereals (Kaul, 2001).

Different type of rice has different nutritional value and benefit towards consumer. Table 1.1 below shows the different nutritional value between white rice of which the most people consume and glutinous rice.

Table 1.1: Nutritional composition between white and glutinous rice

Nutrient Content	Composition (%)	
	White rice	Glutinous rice
Carbohydrate	80.14	78.89
Protein	5.96	**8.14**
Fats	1.24	1.12
Ash	0.39	0.82
Dietary fiber	7.07	7.47
Moisture content	12.08	11.23

Source : (Thomas, Wan-Nadiah & Bhat, 2013)

From table 1.1, the nutritional value between glutinous rice and white rice does not differ much for each nutrient contents. However, protein content of glutinous rice is significantly higher compared to white rice. Glutinous rice significantly has higher protein levels, 8.14% than white rice, 5.96% (Thomas, Wan-Nadiah & Bhat, 2013; Singh et al., 2003). This is because protein composition highly relative to the free amino acid composition. Thus, protein rich in glutinous rice compared to white rice.

Moreover, according to Organic Facts (2019), glutinous rice also various in vitamin B's, selenium, zinc, magnesium, copper and phosphorous. The health benefits of glutinous rice include its ability to regulate diabetes, prevent chronic diseases, and reduce inflammation, and optimize digestion, among others. The health benefits is based on the vitamins and mineral contents inside glutinous rice to fight the diseases.

1.3 Problem statement

At the moment of writing, Malaysia only import glutinous rice from Thailand. According to Khazanah Research Institute (2019) about 38,880 metric tonne of glutinous rice imported into Malaysia. Glutinous rice has been cultivated in Malaysia around year 1970's and stopped during late year 1980's. Since then there were no publications about local glutinous rice cultivar published by Malaysian Agricultural Research and Development Institute (MARDI). To simplify, minimal studies of local glutinous rice were found since it is not a staple variety of rice that consume by people in Malaysia.

In Malaysia, majority of consumers more prefer to buy imported glutinous rice since there is no available local glutinous rice in the market. According to Harun et al. (2019), there is a great potential to cultivate glutinous rice locally which is viable in the present local rice market. Thus, at the end of 2019 Langkawi has been identified as one of the main producer of glutinous rice by year 2020. The cultivation of glutinous rice project by Malaysia's government in 2019 is expected to reduce dependency of imported glutinous rice from neighbouring country such as Thailand and Vietnam. In accordance, this research is to study the properties of local glutinous rice that was obtained from Langkawi and Kedah cultivation.

In addition, traditionally Malaysian people much likely to soak glutinous rice before cook. In contradict to current developing era, Malaysians more emphasize on convenience food which provide short cooking time to cope with busy lifestyle in a squeezed time. However, at the same time they highly consider on texture acceptability. Thus, the cooking and texture properties of cooked glutinous with different soaking treatment is measured.

Therefore, the objective of this research is to compare the physicochemical, and textural properties of local glutinous rice with imported Thailand glutinous rice.

1.4 Objectives

1. To determine and compare the physicochemical properties of local glutinous rice from varieties *Siding* and *Susu* on par with imported Thailand glutinous rice variety *Susu*.
2. To analyse and compare the texture properties of cooked rice with different parameter of soaking treatment.

1.5 Scope of study

This study focused on the properties of two different local glutinous rice cultivar (local *Susu* and *Siding*) and commercial *Susu* Thai glutinous rice cultivar acted as a benchmark. Both local glutinous rice cultivar were collected from Lembaga Pengurusan Peladang (LPP), Langkawi to observe the physical properties such as length, width, thickness, sphericity, porosity, bulk density, 1000 weight kernel, aspect ratio, angle of repose and colour of glutinous rice. The chemical behaviour of grounded glutinous rice was determined in term of their amylose content (UV-spectrophotometer), and proximate analysis (carbohydrate, protein, fat, ash, fiber, and moisture) using AOAC standard method. The thermal properties of glutinous rice were analysed by using differential scanning calorimeter (DSC) while the morphological properties were analysed by using scanning electron microscope (SEM). In completion for the second objective, the glutinous is cooked at varied soaking time (0, 60, and 120 minutes) to observe its cooking properties and texture properties. The cooking properties of rice such as cooking time, water uptake, elongation ratio, and l/b ratio. Lastly, the texture properties was analysed by using texture analyser (TA) in term of its hardness, adhesiveness, cohesiveness, and chewiness parameter.

CHAPTER 2

LITERATURE REVIEW

2.1 Glutinous rice

Glutinous rice *(oryza sativa var. glutinosa)* is one of the most popular varieties among thousands of rice varieties available throughout the world. Glutinous rice is commonly known as sticky rice or waxy rice. It is a type of short- or long-grained rice that is especially sticky when cooked (Kang, Rico & Lee, 2010). Glutinous rice has been growing in mainland Southeast Asia for at least 4,000 years (Ives, 2011). But glutinous rice is the primary staple in Laos parts of the five countries bordering it: China, Myanmar, Thailand, Cambodia, and Vietnam.

This type of variety mainly grown in Southeast and East Asia and the eastern parts of South Asia, which has opaque grains, very low amylose content, and widely consumed around Asia. It is also used in making rice wine, sushi, rice balls, and rice cakes (Wittenberg,2007).

Normally, Malaysian more preferred for white rice compared to the other type of rice available. Statistically, 80% of Malaysian people choose over white rice and the remaining 20% Malaysian prefer on speciality rice. From 20%, only 4% of glutinous rice is preferred by Malaysian (BERNAS, 2017). The glutinous rice highly demand at certain period of time such as during festival which people prefer to make *ketupat palas, lemang, wajik, bubur pulut hitam,* and others.

However, according to Food Agriculture Organization (FAO) (2018), Malaysia is one of the rice importing country. Based on year 2017 statistics, about 2.7 million metric tonne of rice is consume. But, 1.8 million metric tonne of rice is processed and remaining 821,869 metric tonne were fulfilled by importing rice from neighbouring country such as Thailand, Vietnam, Cambodia, Myanmar, and China Apart from the number of the rice imported, 15% from the total import is primarily of glutinous rice which majorly import from Thailand and Vietnam (Global Agricultural Information Network, 2017). This is due cultivation of glutinous rice has stopped during late 80's. According to the one of folk paddy farmer in Kedah, there were no specific reason cease in production of glutinous rice in Malaysia. It might be due to the demand and harvest period of once per year of glutinous rice. On the other hand, market price glutinous rice is higher than white rice which RM 8 per kilogram rather than white rice, RM 3 per kilogram. Thai glutinous rice cost about $1,500 per tonne which is higher than Thai which rice which remain at $1,200 per tonne (Arunmas, 2019). Table 2.1 shows the previous research studies on properties of glutinous rice.

Table 2.1: Previous research studies on properties of glutinous rice

References	Studies
(Husain, 1984)*	Study on the physical properties, proximate analysis, cooking, and textural properties
(Thomas, Wan-Nadiah & Bhat, 2013)	Proximate composition, physicochemical properties and cooking qualities
(Hassan & Ali, 1978)*	Physical characteristics, cooking and eating quality
(Kang, Rico & Lee, 2010)	Morphological, mineral content, free amino acid, fatty acid composition
(Thomas, Bhat & Kuang, 2015)	Mineral content, free amino acid, fatty acid composition

*MARDI research paper consist of different variety of rice (*Siding* and *Malaysia 1*)

Based on the Table 2.1, MARDI research paper about different variety of rice properties is published during year 1970 until late 1980. It is assured that production of glutinous rice in Malaysia already stopped during late year 80's. Other than that the rice sample is imported glutinous rice. A lot of research studies has been developed such as morphological, mineral content, free amino acid, and fatty acid composition. Therefore, this research is combining all of the properties of that have been done by using local glutinous rice sample.

Basically, according to Rice Science (2007), all type of rice has the same structure from the outer layer until the inner layer of the rice grain. The main component of rice structure are hull, bran, white rice, and germ as shown in the Figure 2.1. Rice hull basically protect the rice as its growing but are indigestible to human, so the rice must undergo a milling process in section 2.2. Then, the rice bran known as brown rice before polishing into white rice. The bran is the outer layer of rice grain, has high fiber content which also used for treating diabetes, high blood pressure, high cholesterol, and obesity problem (Carol, 2018). The white grain is the polished rice after removing the bran layer which this is one of the most people around the world consumed. Lastly, the germ is the rice endosperm where it contains 95% of the total tocopherols of the entire grain (George, 2009).

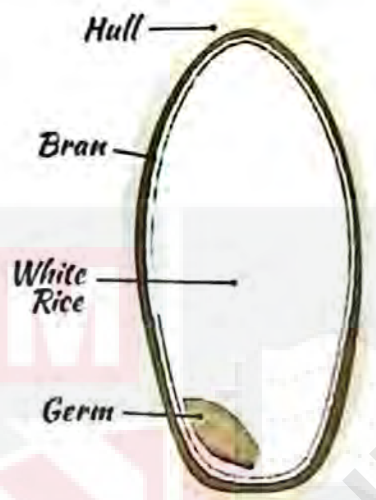


Figure 2.1: Structure of rice grain (source: Food and Agricultural Organization, FAO)

2.2 Milling process of rice

Milling is a crucial step in post-production of rice. The basic objective of rice milling system is to remove the husk and the bran layers, and produce an edible white rice kernel that is sufficiently milled and free from impurities (IRRI, 1990). Glutinous rice processing is similar as white rice processing since they have similar structure of rice grain. The different between glutinous rice and white rice is physically on the size of the grain. Figure 2.2 below shows the steps in process of rice milling starting from receiving paddy then goes to cleaning process, de-husking, paddy separation, polishing, grading and lastly sorting for the whole grain. These process are the basic process in mill.

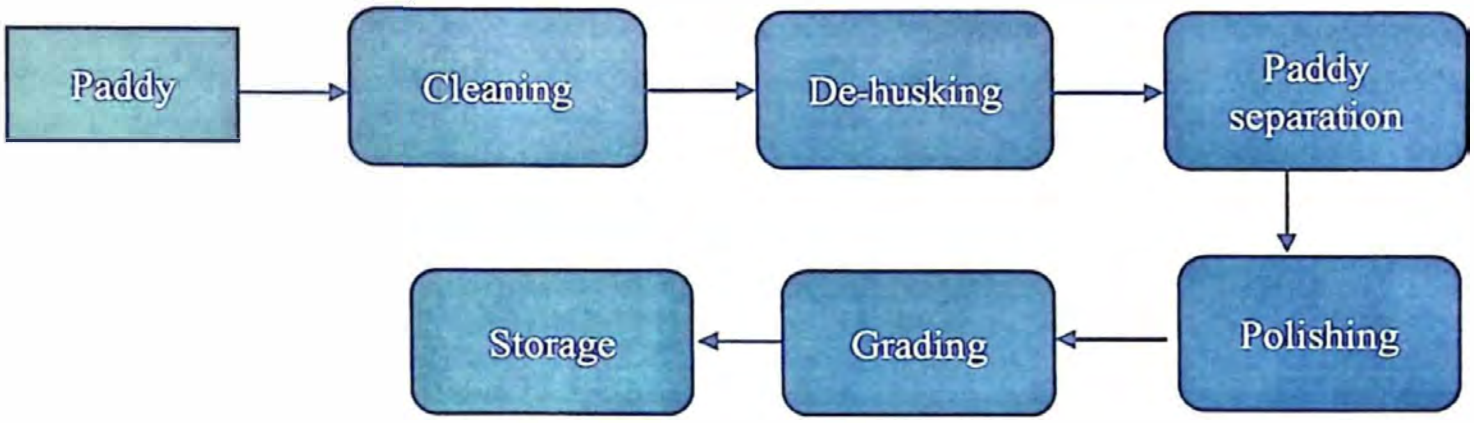


Figure 2.2: Flowchart of rice milling process

Based on Figure 2.2, firstly the received paddy must be dried within the range of moisture content from 13%-14% which is ideal for milling (IRRI,1990). If the moisture content is too low, high grain breakage will occur resulting in low head rice recovery. The function of cleaning process is to separate impurities from paddy. Use of paddy without impurities will ensure a cleaner and higher quality of end product. Then, de-husking process use rubber roll huskers to remove the husk from the grain. Next, paddy separation use to separate all paddy from the brown rice before whitening. This is to ensure only rice grain is allow until the end of process. Polishing also known as whitening process. It is to remove the bran layer from brown rice to get white kernel rice. Then, grading is a process of application using screen sifter to separate broken rice and head rice. The head rice is desired one for market while broken rice can be utilized to produce rice flour. Lastly, the graded rice is package in a jumbo bag for storage purposes. Figure 2.3 below shows the milled of glutinous rice.

Figure 2.3: Milled glutinous rice grain (Source: Mala Food community)

2.3 Physical Properties

Rice, unlike most other cereals, is consumed as a whole grain. Therefore physical properties such as size, weight (1000grain) and gruel loss, density, surface area, angle of repose, colour, and general appearance are utmost importance. Furthermore, because most of rice is milled, the important physical properties are determined primarily by milled endosperm.

2.3.1 Grain dimensions and shape

Rice varieties objectively classified into grain-type categories based upon two physical parameters: length and shape dimension is basically a measurable of the particular kind based on length (mm), width (mm), and thickness (mm) of the rice grain as shown in Figure 2.4.

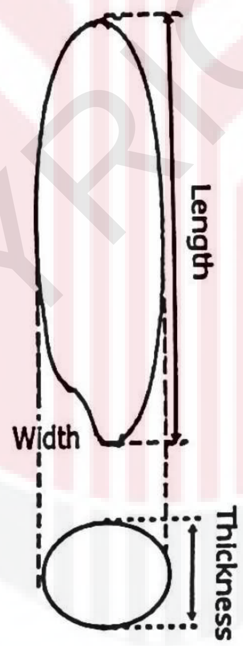


Figure 2.4: Dimension of rice grain

Grain size and shape can be visually classified, and more exact measurements are needed for a more critical comparison of varieties (Graham ,2002). Surface area (mm^2), aspect ratio, and sphericity (%) are function of the measured grain dimension.

Length, width, thickness are the prior parameter to determine the size and dimension of the rice grain. Length is longitudinal cross section of grain while width is the horizontal sectional of the grain of which extent from side to side. Thickness is distance through a grain, it is distinct from width and length where thickness is the smallest of three dimensions. The thickness of grains can be used for the measurement of the mass proportion of grains that pass through a sieve (Changming et al., 2006). The size of rice grain can be categorized as small, medium, and long-type rice grain. According to Houston (1972), the length value of rice grain indicated as small (maximum value 5.5 mm), medium (5.51mm – 6.6 mm) and long (6.61 mm-8.5 mm) grain rice accordingly.

Based on Table 2.2, the literature reported the mean value for length, width, thickness for Sorkheh cultivar was 8.45 mm, 2.36 mm, and 1.86 mm respectively. But, Sazandegi cultivar resulted 8.54 mm, 2.47 mm, and 1.83 mm respectively. Sazandegi has longer and wider but thinner size of grain compared to Sorkheh cultivar. However, both are categorized as long type of grain size.

The shape of rice grain is determined based on their l/b (length/breadth) ratio following the Food and Agricultural Organization (FAO) classification. L/B ratio is to determine the rice grain shape; rice grain can either be slender or bold shape. This parameter helps in milling rice recovery calculation where long or slender grains normally have greater breakage than short or bold grains and consequently have a lower milled rice recovery (IRRI, 1980). Grain size and shape are among the first quality criteria being considered in developing rice varieties for commercial production. They are primary factors in marketing, grading, and processing (Husain 1984). There were no significant differences in the l/b ratio for black, glutinous and basmati rice (Thomas et al., 2013). A length to breadth ratio of above 3 is generally considered as slender, below 3 can be judged as bold shape (IRRI,1980). Glutinous rice can be judged as slender except for basmati and brown rice, they classified as bold. Determining the rice grain shape and width are highly essential as both, cooking and eating properties are strongly influenced by these (McKenzie et al., 2001). The length and width of kernel grain is measure by using vernier calliper in unit millimetre.

2.3.2 Thousand weight kernel

One thousand rice kernels were randomly selected and weighed separately to determine thousand weight kernel (TWK) (Singh et al., 2003). TWK is the weight in grams of thousand seeds or grains. Grain weight provide information about the size and density of the grains. Uniform grain weight is important for consistent grain quality. This parameter also helps to measure the correlative amount of foreign substance in a designated bulk of raw rice and the number of shrink or unripe kernels, normally it based on the index of milling outturn.

Based on Table 2.2, TWK for Sazandegi cultivar is reported 8.54 g more heavier than Sorkheh cultivar which is 8.45g. The cultivar which possess higher value of TWK tendency have a high value of equivalent diameter of kernel (Iraj et al., 2013).

2.3.3 Surface area, aspect ratio, and sphericity

Aspect ratio is the ratio between width to length of the grain. Its distribution determination is important in classifying the varieties and determine the extent of off-size in market grade (Varnamkhasti et al., 2008). Also, it can identifies the grains will slide or roll on the flat surfaces. Equivalent diameter in millimetre consider as prolate spheroid shape for a rough rice grain (Mohsenin,1986). From the past result on Table 2.2, the aspect ratio ranges from 0.28 to 0.29 for Sorkheh and Sazandegi cultivar. The grains with higher aspect ratio will slide rather than roll.

The sphericity is defined as ratio of surface area of the sphere having the same volume as that of the grain to the surface area of the grain (Mohsenin,1970). This parameter functions to determine the rice grain shape either it is sphere or cylinder grain shape. Paddy grain with small sphericity will likely to be more difficulty to roll freely on a flat surface area (Sanusi, Akinoso & Danbaba, 2017). From literature report on Table 2.2, the sphericity of Sorkheh and Sazandegi cultivars were observed in the range of 37-46% and 37-43%, respectively. High sphericity for rounded grains and low sphericity for cylindrical grains (Charanjit, 2016).The sphericity values of raw rough rice fall within the range 0.32-1 reported by Mohsenin (1986) for most agricultural materials. For most of rice type will fall within that range. Sphericity is important for designing for storage in bulk of bin and silo.

Surface area of grain is the rate of heat transfer to material also significantly depends on heat transfer surface. Smaller the volume of material per unit surface, the better its condition for heat transfer (Varnamkhasti et al., 2008). Also, the ratio of surface area to volume affects drying time and energy requirements (Stroshine & Hamann, 1994). Basically, determination of surface is important for the heat transfer of rice during cooking and also important in designing of storage bin and silo. Based on Table 2.2 below, Sazandegi cultivar is highly preferable because it has large surface area for maximum and efficient heat transfer.

Table 2.2: Grain dimension and shape of rice kernel

Properties	Rice sample (white rice)	
	Sorkheh cultivar	Sazandegi cultivar
Length (mm)	8.45±0.36	8.54±0.41
Width (mm)	2.36±0.17	2.47±0.13
Thickness	1.86±0.01	1.83±0.12
Surface area (mm^2)	31.76±2.27	32.58±2.5

Volume (mm^3)	20.27±2.88	21.06±2.45
Aspect ratio	0.28±0.02	0.29±0.02
Sphericity(%)	39.71±1.5	39.88±1.37
1000 weight kernel (g)	8.45±0.36	8.54±0.41

Source:
(Varnamkhasti et al., 2007)

2.3.4 Bulk density, true density, and porosity

Bulk density is defined as the weight of the material including the intergranular air space in unit volume (Bhattacharya, 2013). The bulk density of grains is useful in design of silos and storage bins (Nalladulai et al., 2002). The larger value of bulk density, the bigger size requirement for the silo and bin design despite of their same weight. According to Thomas et al. (2013) findings, bulk density of glutinous rice (0.83g/ml) is just below brown rice (0.86g/ml) slightly higher than bario rice (0.82 g/ml). Based on Table 2.3, Sorkheh cultivar recorded lower bulk density value which it needs a bigger silo compared to Sazandegi cultivar,

While, true density is defined as the measurement is the particles that make up a powder or particulate solid. Cereal grain kernel densities have been of interest in breakage susceptibility and hardness studies (Morita et al., 1987).

The importance of determining weight, bulk density, true density, and porosity is because they have positive correlation to each other. Such as density, it is a function the rice mass and volume. In term of density, the air spaces inside the rice will determine its porosity, true, and bulk density of the particulate grain. Milled rice grain has high bulk density compared to paddy. Thus, a high bulk density is importance in packaging and transportation.

Table 2.3: Density and porosity of rice kernel

Properties	Rice sample (white rice)	
	Sorkheh cultivar	Sazandegi cultivar
Bulk density (kg/m^3)	2.36±0.17	2.47±0.13
True density (kg/m^3)	1.86±0.01	1.83±0.12
Porosity (%)	31.76±2.27	32.58±2.5

Source:
(Varnamkhasti et al., 2007)

2.3.5 Angle of repose

Angle of repose is defined as the angle with the horizontal at which the material will stand when piled. There were no marked differences in the angle of repose values between two different cultivars (Varnamkhasti et al., 2007). The individual material will affect the angle of repose, the size of particles is a factor for this properties. According to Breslin (2017), the coefficients of friction are dependent on the moisture content of the grain. In general, friction increases, often strongly, as the moisture content increases. Angle of repose is another important physical property used for characterization of the bulk of particulate foods mainly seeds, grains, flours, and grits. This angle is important for the design of processing, storage, and conveying systems of particulate materials. Materials with low angle of repose are highly flowable and can be transported using gravitational force or a little energy (Teferra, 2019). As Table 2.4 below shows the reported of past result by (Varnamkhasti et al., 2007), it shows that Sazandegi cultivar has low angle angle compared to Sorkheh cultivar. Thus, Sazandegi cultivar more flowable than Sorkheh cultivar.

Table 2.4: Angle of repose of rice kernel

Properties	Rice sample (white rice)	
	Sorkheh cultivar	Sazandegi cultivar
Angle of repose (°)	37.66±1.16	35.83±1.04

Source: (Varnamkhasti et al., 2007)

2.3.6 Colour appearance

Colour is refers to arise of sensation from the activity of the retina of the human eye which attached to nervous mechanism (Ranganna, 1998). Colour is an importance quality which attributes in foods and determines the acceptability of product by consumers. It gives an objective index of food quality.

The colour of rice often referred to as "general appearance". The importance of colur are that the lightness and whiteness of cooked rice has a positive effect on consumer acceptance. But, the degree of colour change majority occurred during steaming or retorting (Hapsari et al., 2016; Xu et al., 2019). This due to the colour changes more significant due to the increment of temperature and pressure. By using calorimeter, colour coordinates for the extent of lightness (L*), redness-greenness (a*), and yellowness-blueness (b*). The notation of L* is a light factor, a* and b* are the chromaticity coordinates which are more closely represents human eye sensitivity of colour. L* represents the difference between light (L*=100) and dark (L*=0). Then, a* represents the difference green (-a*) and red (+a*) while b* represents blue (-b*) and yellow (+b*) (Ladanyia & Ladaniya, 2010). A complete quantitative measurement is needed in order to express colour in numerical dimensions and values, including attributes of colour such as hue (red, blue, green); saturation or chroma (intensity or strength hue); and lightness (brightness or darkness) of the colour.

Chrome (C) is described as the purity or saturation which means the intensity of fundamental colour with the respect to the amount of white light that is mixed with it. For hue, it is defined as the visual sensation of the colour. Hue is the appearance of given area that is in comparison with one or proportion of two or more of perceived standard colour, like yellow, blue, red, and green. Normally, it is measured by plotting coordinate with respect to the angle (radians or degrees) in the colour wheel as shown in Figure 2.5 (Sun, 2011). Colour difference (ΔE) is a metric of the distance or difference between two colour (Win et al., 2015).

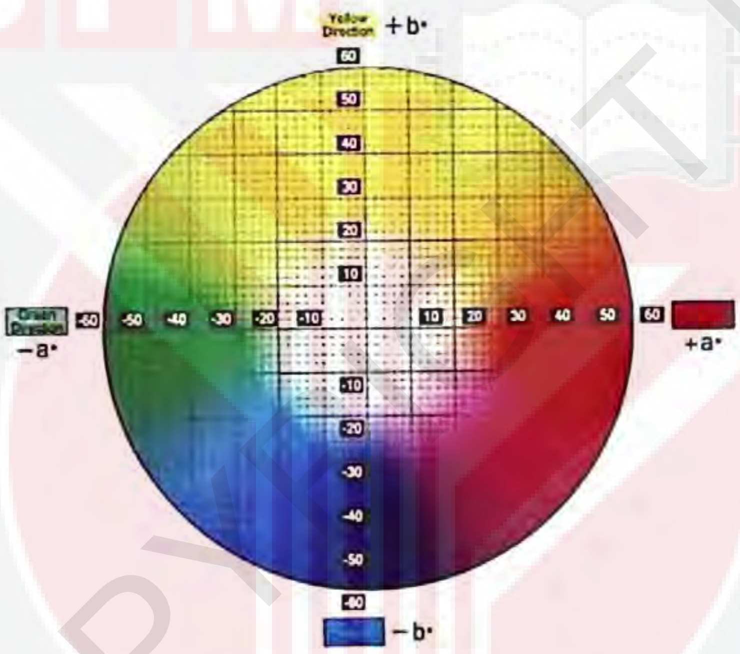


Figure 2.5: CIE lab colour chart

The nutritional profile of the speciality rice is high when compared to the white rice varieties. The colour deposition due to the anthocyanin pigments in the bran layer of the grain, is rich in phytochemicals and antioxidants (Priya et al., 2019). Table 2.5 shows colour L*, a*, and b* of glutinous (Korean) rice and japonica rice. Based on Table 2.5 below, the colour of rice sample before and after cooked shows significant difference. This is due to the gelatinization process effect the starch deformation and differ in colour appearance.

Table 2.5: Colour parameters of different glutinous rice cultivar

Rice samples	Before cooked			After cooked		
	L*	a*	b*	L*	a*	b*
Glutinous (Korean) rice	58.67± 0.14	4.85± 0.01	25.24± 0.08	54.06± 0.76	3.28±0.30	20.26± 0.81
*Japonica rice	80.02± 0.02	1.12± 0.10	6.49±0. 15	78.71± 0.54	-1.95±0.12	4.31±0. 29

Source:
(Hapsari et al., 2016) Glutinous (Korean) rice
*(Xu et al., 2019) Japonica rice

2.4 Chemical Properties

2.4.1 Amylose Content

Rice starch is composed of a major branched fraction, amylopectin, and a linear fraction, amylose. Amylose is made up of α (1→4) bound glucose molecules. Amylose content is considered to be the single most important characteristic for predicting rice cooking and processing behaviour (Juliano,2001). Overall, cooking, eating and pasting properties of a rice variety importantly depends on its amylose content (Adu-Kwarteng et al., 2003, Asghar et al., 2012). Apart from the amylose content, components such as; proteins, lipids, or amylopectin also affect the cooking quality of rice (Cai et al., 2011). According to Husain (1984), high amylose rice show high volume of expansion and a high degree of flakiness. Meanwhile, low amylose rice cook moist and sticky and are preferred for their tenderness, stickiness, and glossiness.

In a present study, most preferable of rice with intermediate amylose content since it results to cook moist and remain soft when cooled than one with high or low amylose contents. Rice is known to cook dry and fluffy due to high amylose content, but can become hard on cooling. This can be put down as retrogradation of the amylose molecules (Adu-Kwarteng et al., 2003). Glutinous rice differs from other types of rice in that the grain starch contains essentially no amylose and has high amount of amylopectin (Juliano, 1999), which is responsible for the sticky quality of cooked glutinous rice.

Amylose is important in plant energy storage. However, amylose is less readily digested than amylopectin but, because of its helical structure it takes up less space compared to amylopectin. In human digestion system, the digestive enzyme α-amylase is responsible for the breakdown of the starch molecule into maltotriose and maltose, which both of these molecules can be used as sources of energy. In addition, amylose also an important thickener, water binder, emulsion stabilizer, and gelling agent in both industrial and food-based contexts. Based on the Table 2.6, the amylose content of imported glutinous rice is higher than the local glutinous rice cultivar. This makes the local cultivar cooked stickier than imported cultivar.

Table 2.6: Amylose content of different glutinous rice cultivar

Rice samples	Amylose Content (%)
Glutinous (imported)	8.44±1.3
Glutinous (local) *Variety: pulut Malaysia 1*	*1.1
Glutinous (local) *Variety: pulut Siding*	*1.4
Glutinous rice (local) *Variety: pulut Masria*	**7.8

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties
** (Hassan & Ali, 1979) MARDI local rice with different varieties

2.5 Proximate Analysis

2.5.1 Moisture Content

Moisture content is one of the parameter that measures the good quality of rice and palatability of rice grains. Rice kernels contain dry matter and water. The dry matter translates to the actual value of rice. Moisture content of rice plays a significant role in determining the shelf life (Webb, 1985). Mostly all veriety of rice were found to possess the moisture content almost within the acceptable limit (12%-13%) for long term storage of rice (Adair et al., 1973). Moisture content of food can be determined by various method, such as oven drying, distillation with an immiscible solvent, and physical and chemical methods like infrared heating. Generally, drying method are used as they provide accurate results. In this method, it consists of measuring the weight loss of the foods which due to evaporation of water.

According to Thomas, Wan-Nadiah & Bhat (2013), the moisture content of local variety of rice vary between 10.04-12.88%. The obtained moisture content for glutinous rice is 10.04±0.1. The variation value percentage of moisture content depends on different type variety of rice yet the results achieved acceptable limit of moisture for long term storage of rice. Based on the past result shown in Table 2.7 below, it shows that the imported glutinous rice has low moisture content than local glutinous rice. This proves that the local glutinous rice recorded the moisture content within range.

Table 2.7: Moisture content of different glutinous rice cultivar

Rice samples	Moisture Content (%)
Glutinous (imported)	10.04±0.1
Glutinous (local) *Variety: pulut Malaysia 1*	*12.2
Glutinous (local) *Variety: pulut Siding*	*12.8
Glutinous rice (local) *Variety: pulut Masria*	**14.0

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties
** (Hassan & Ali, 1979) MARDI local rice with different varieties

2.5.2 Protein content

Proteins are macromolecules that consist of one or more polypeptides. Every polypeptide consists of a chain of amino acids which linked together by peptide (amine) bonds. It is an essential nutrients for the human body. Protein is nutrient needed by human body for growth and maintenance. They are one of the building blocks of body tissue and can also serve as a fuel source. During human digestion, protein are broken down to smaller polypeptide chains via hydrochloric acid and protease actions. Rice has small proportion of protein since rice has adequate amount carbohydrate percentage. Table 2.8 shows percentage of protein content of rice with different varieties. Based on the table, protein content of imported glutinous rice slightly higher than the local glutinous rice. However, the protein content were still in range as reported by (John, 2012).

Table 2.8: Protein content of different glutinous rice cultivar

Rice samples	Protein Content (%)
Glutinous (imported)	8.14±0.1
Glutinous (local) *Variety: pulut Malaysia 1*	*7.3
Glutinous (local) Variety: *pulut Siding*	*7.7

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties

2.5.3 Fat content

Fat is a macronutrient or large molecules that are composed of three fatty acid molecules bonded to a glycerol molecule. The fatty acid molecule is a long chain of covalently bonded carbon atoms with nonpolar bonds to hydrogen atoms all along the carbon chain with a carboxyl group attached to one end. According to "Fats and fatty acids in human nutrition" (2010), advantage of addition of oils and fats to such food will make these food more palatable and enable the consumer to meet energy requirements more effectively. However, excessive fat content is not recommendable. Fats must be present in the diet to absorb the fat-soluble vitamins A,D,E and K. Table 2.9 shows fat content for different varieties of local rice. Based on the table below, imported glutinous rice has slightly higher of fat content compared to local glutinous rice. This is because the high in fat content makes the appearance of cooked rice more fluffy and taste good (Meyer, 2009).

Table 2.9: Fat content of different glutinous rice cultivar

Rice samples	Fat Content (%)
Glutinous (imported)	1.12±0.2
Glutinous (local) *Variety: pulut Malaysia 1*	*0.5
Glutinous (local) *Variety: pulut Siding*	*0.4

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties

2.5.4 Ash content

Ash is one of the components in the proximate analysis for biological materials. It is a non-aqueous residue that remains after a sample is burned, which consists only metal oxide. Ash levels in food are required for calculation of total carbohydrate and dietary fibre (Fairulnizal et al., 2015). Moreover, the amount of ash present in a food sample plays an important role while determining the levels of essential minerals (Bhat & Sridhar, 2008). The main components of ash are usually phosphorus and calcium, but it also normally contains other mineral such as iron and zinc. The amount of ash is limited value, since the value represents the total ash and does not provide any insight into which specific minerals it represents. Reducing the amount of minerals in the diet can help to minimize certain growth and urinary tract problem (Cindy,2018). Table 2.10 shows ash content for different varieties of local rice. From the past result as shown on

Table below, the ash content imported rice cultivar slightly higher than local glutinous rice cultivar.

Table 2.10: Ash content of different glutinous rice cultivar

Rice samples	Ash Content (%)
Glutinous (imported)	0.82±0.1
Glutinous (local) *Variety: pulut Malaysia 1*	*0.7
Glutinous (local) *Variety: pulut Siding*	*0.5

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties

2.5.5 Fiber content

Fiber is a plant-based nutrient that is sometimes called roughage. It is a type of carbohydrate but unlike other carbs, fiber cannot be broken down into digestable sugar molecules. Dietary fiber consist of non-starch polysaccharides, such as cellulose, dextrins, inulin, lignin, chitins, pectins, beta-glucan, waxes, and oligosaccharides. There are two broad types of dietary fiber which are insoluble and soluble fiber. Fiber has its own advantages and speciality. Both type of fibers are present in all plant food but rarely in equal proportions. Soluble fiber dissolves in water and form gel that goes through the digestive tract. While, insoluble fiber repels water does not change form then goes through to the digestive tract. Rice is one of the source of soluble fiber that human can consume (Anonymous, 2019). Table 2.11 below shows fiber content for different varieties of local rice. Based on the past result below, the total diet fiber for imported rice cultivar slightly higher than local glutinous rice cultivar. This shows glutinous rice type provide sufficient fiber intake in our body.

Table 2.11: Fiber content of different glutinous rice cultivar

Rice samples	Fiber Content (%)
Glutinous (Imported)	7.47±0.4
Glutinous (local) *Variety: pulut Malaysia 1*	*6.8
Glutinous (local) *Variety: pulut Siding*	*7.2

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties

2.5.6 Carbohydrate content

Carbohydrate is consist of carbon, hydrogen, and oxygen atom. Usually with a hydrogen–oxygen atom ratio of 2:1 and thus with the empirical formula C□□. This formula holds true for monosaccharides. Rice is a staple food that most widely consumed for a large part of the world's human population, especially in Asia. Carbohydrate is one of the major component consist in rice grain. It is considered high in all varieties of rice and hence can be considered to be a good source of carbohydrate. Carbohydrate of rice mainly comprises of 85-90% starch (Houstan & Kohler, 1970) along with small portions of hemicelluloses, pentosans and sugars. Most important nutritional property of total carbohydrate is their easy digestibility in the small intestine (Devindra & Longvah, 2011).

According to Verma & Srivastav (2017), the carbohydrate content of all accessions (aromatic and non-aromatic rice) ranged from 75.87%-82.70%. All of the rice exhibited fairly higher amount of carbohydrate and somewhat similar and near about the desired range (80%) (Juliano,1999). For local variety of rice, findings show that carbohydrate content ranged from 78.21%-82.23%. Glutinous rice results about 78.89%±0.6 of carbohydrate content (Thomas et al., 2013). The results of local variety executed acceptable range of carbohydrate content. Based on the past result as shown in Table 2.12 below, carbohydrate content for local glutinous rice are higher than the imported rice cultivar. However, they are still within the acceptable range of carbohydrate content.

Table 2.12: Carbohydrate content of different glutinous rice cultivar

Rice samples	Carbohydrate Content (%)
Glutinous (imported)	78.89±0.6
Glutinous (local) *Variety: pulut Malaysia 1*	*87.6
Glutinous (local) Variety: *pulut Siding*	*84.0

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI *local rice with different varieties*

2.6 Thermal Properties

Rice thermal properties is widely determined by Differential Scanning Calorimeter (DSC). It is closely related to starch gelatinization to swell its structure due to high temperature of cooking. Also, thermal is positively correlated to amylose content and the texture of cooked rice. According to the analysis, it will execute onset temperature (T_o), peak temperature (T_p), conclusion temperature (Tc), and enthalpy of gelatinization (ΔH). Table 2.13 below shows the past result of thermal properties of white rice and basmati rice type. According to Singh et al., (2003), the higher transition temperature of chalky kernels than their translucent counterparts may be attributed to the presence of lower amylose and higher amylopectin contents. Lower amylose content of kernels can increase their gelatinization temperature and endothermic enthalpy (Sasaki, Yasui, &Matsuki,2000: Sodhi & Singh,2003).

Table 2.13: Thermal properties of different rice type

Rice Samples	**T_o (°C)**	**T_p (°C)**	**T_c (°C)**	**ΔH gel**
White rice	63.70	68.90	72.30	3.19
Basmati	68.70	74.30	84.80	6.16

Source: (Singh et al., 2003).

2.7 Morphological Properties

Microstructure of grain from different rice varieties differed significantly (Singh et al., 2003). The endosperm region is composed of cell wall materials and starch granules that clustered into amyloplasts or compound starch granules. Different varieties of grain showed different size of granules. From literature, based on Singh et.al, (2003), basmati had smaller granule than white rice. For the translucent kernel, the cells and amyloplast were observed tightly packed to each other. Closer observation on the starch granules revealed starch mainly composed of polyhedral and irregular-shaped granules which is typical of many rice starches (Kang, Rico & Lee, 2010). From literature, Sangnamchal and Seolhyanchaul apperared to have greater crystallization than the other varieties analysed, which were more loosely packed with larger air spaces between granules. Variation in starch granules morphology may be due to the biological origin and physiology of rice. Furthermore, variations in amylose and amylopectin content of rice could also affect the starch granule size and shape of the samples (Svegmark & Hermansson, 1993). Table 2.14 below shows the scanning electron micrographs of glutinous rice from Korean varieties. The granule size for Hwasunchal variety is more smaller than Dongjinchal variety. The size and structure of granule are vary depend on their varieties.

Table 2.14: Granular structure of different glutinous rice cultivar

Varieties	Scanning electron micrographs of glutinous rice grain (Lens x1000)	Scanning electron micrographs of glutinous rice grain (Lens x5000)
Hwasunchal		

Dongjinchal		

Source:
(Kang, Rico & Lee, 2010) korean rice with different varieties

2.8 Cooking Properties

Cooking properties is analyse on the rice that being cooked. This is highly related to cooking time, water uptake ratio of rice to water, volume expansion, elongation ratio, and gruel solid loss of rice. Meanwhile, the amylose and amylopectin contain has positive correlation towards cooking properties of rice.

2.8.1 Cooking time

Cooking time is to measure the optimum time of cooking for rice to cook which means that there is no free water left in the rice pot. Cooking time is important to optimize the ratio of rice to water quantity during cooking. Optimum of rice to water ratio results to optimum cooking time with a good of rice quality (Hapsari et al., 2016). The starch of the rice will start to gelatinize until its gelatinization temperature for it to turn soft and fluffy texture. When a disorganized cellular structure is present in the grain, soft cooked grain can be obtained (Lisle et al., 2000). High amylose cook dry, less tender, and hard upon cooling (Thomas et al., 2013). Cooking time of a rice grain is usually ascertained when an opaque center is no longer visible by 90% of the starch in the grain (Dipti et al., 2003). Based on the past result as shown in Table 2.15 below, the cooking time for imported glutinous rice is longer than local glutinous rice cultivar.

Table 2.15: Cooking time of different glutinous rice cultivar

Rice samples	Cooking time (min)
Glutinous (Imported)	20.5±0.0
Glutinous (local) *Variety: pulut Malaysia 1*	*15.0
Glutinous (local) *Variety: pulut Siding*	*15.5

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties

2.8.2 Water uptake ratio

Water uptake ratio is defined as the amount or weight of water absorbed by a given amount of rice in an arbitrarily fixed time period in boiling water. This is because water uptake is important parameter while cooking rice since any variety of rice needed water to gelatinize the starch structure during cooking at its starch gelatinization temperature. If the bulk density is higher, then correspondingly water uptake ratio will also be high. This has been attributed to the compact structure of a rice variety (Bhattacharya et al., 1971; Horigane et al., 2000). Disorganized cellular structure can enhance the probabilities for high water absorption during cooking and can lead to longer cooking time. According to Thomas et al. (2013), water uptake ratio of imported glutinous rice to be lowest which is 2.33 among other type of rice. Water absorption during cooking is influenced by the amylose content (Husain, 1984). Based on the past result shown on Table 2.16 below, the water uptake ratio for local glutinous rice cultivar slightly higher than imported rice cultivar. This may due the bulk density of local cultivar is higher than imported cultivar.

Table 2.16: Water uptake of different glutinous rice cultivar

Rice samples	Water uptake ratio
Glutinous (Imported)	2.20±0.8
Glutinous (local) *Variety: pulut Malaysia 1*	*2.55
Glutinous (local) *Variety: pulut Siding*	*2.25

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Husain, 1984) MARDI local rice with different varieties

2.8.3 Elongation ratio

Elongation ratio is the length expansion of rice grain before and after cooking. It is closely related to physical properties of l/b ratio. The translucent grains showed greater l/b ratio and elongation ration than their chalky rice counterparts after cooking (Singh et al., 2003). The glutinous rice is considered as chalky rice since the amylose content is low and its disordered granular structure. Moreover, elongation of rice can be influenced by both the l/b ratio and the amylose content (Singh et al., 2005: Danbana et al., 2011). A positive correlation was also recorded by both amylose content and l/b ratio in relation to elongation of rice. The highest elongation, 1.77 was observed in Basmati rice (Husain, 1984; Thomas et al., 2013). While, based on the past result Table 2.17 below, the other type of rice elongation ration ranges from 1.37- 1.68 and imported glutinous rice recorded 1.41 of elongation ratio.

Table 2.17: Elongation ratio of different glutinous rice cultivar

Rice samples	Elongation ratio
Glutinous (Imported)	1.41±0.1
Glutinous (Imported)	*1.49

Source:
(Thomas, Wan-Nadiah & Bhat, 2013)
*(Danbana et al., 2011)

2.8.4 Cooked l/b

Rice is the only cereal crop cooked and consumed mainly as whole grains and quality considerations are much more important than for any other food crop (Hossain et al., 2009). Length to breadth (l/b) ratio is to determine the shape of rice itself. Thus, it is important to determine after cooked of length to breadth ratio for grain quality assessment and importantly for consumer preference (Rita & Sarawgi, 2008). According to Thomas et al. (2013), the cooked l/b of brown rice is the lowest, 2.25 and the highest is basmati rice type which is 4.18. Based on the past result Table 2.18 below for imported glutinous rice highlighted to be 3.17 of cooked length to breadth ratio. L/b for cooked rice is common in cooking properties of rice since it measures the elongation of rice effect after the soaking period (Juliano, 1999).

Low solid content in the cooking gruel can be attributed to the fact that the surface area in contact with water is smaller, resulting in a lower l/b ratio. These observation is comparable to the report from Hirannaiah et al., (2001) who have also observed gruel solid loss of basmati rice. Rice variety with higher amylose content high tendency to leach out into the cooking water as starch grains expand during cooking (Juliano, 2001). Cooked l/b ratio has positive correlation with gruel solid loss.

Table 2.18: Cooked l/b ratio of glutinous rice

Rice samples	Cooked l/b
Glutinous (Imported)	3.17±0.4
Glutinous (Imported)	*3.45±0.5

Source: (Thomas, Wan-Nadiah & Bhat, 2013)
*(Danbana et al., 2011)

2.9 Soaking Time

Soaking rice speeds up the cooking by kick-starting the absorption of water before the rice even enters the pot. By letting the rice soak for several hours able to reduce the cooking time of the most rice varieties about 20%. The ideal soaking time for sticky rice between 30 minutes to 6 hours depending on the amount of rice (Schmidt, 2019). This is due to the average length and volume of the glutinous rice corresponding to the particular soaking period. Soaked rice grains cook faster and the hardness of cooked grain decreases (Han & Lim, 2009). It is generally performed at a temperature below the temperature of gelatinization. The importance of soaking can effect the flavour of the finished dish (Joachim & Schlosss,n.d.). The effect of soaked rice impart more flavour, more even, tender texture and much better by appearance. Table 2.19 below shows the unsoaking and soaking treatment by using white rice sample. For controlled cooking parameter, when soaked the rice, the cooking time is shorten compared to unsoaked treatment.

Table 2.19: Comparison on cooking time after soaking treatment

Treatment	Total water (g)	Cooking time (min)
Unsoaked rice		
Normal cooking	800	24
Controlled cooking	732	32
Soaked rice		
Normal cooking	800	24
Controlled cooking	730	26

Source: (Chakkaravarthi et al., 2008)

2.10 Texture Properties

Textural profile of a food are that group of physical characteristics that arise from the structural element of the food, are sense primarily by the feeling of touch, related to the deformation, disintegration, and flow of the food under a force. Rice is one of the food crops that can describe its texture profile when the rice is cooked. From the texture profile, it can executes the rice hardness, adhesiveness, cohesiveness, chewiness, and gumminess across the running time. The figure below shows the predicted result from texture profile analyzer (TPA).

Figure 2.6 below shows the pattern of TPA graph cycle and its parameter measured. Hardness is the highest peak form during the run cycle. Then, cohesiveness is the degree to which the sample deforms before rupturing when it is bitten with molars. By formula, it is the ratio of area under graph of second cycle to the area under graph of the first cycle. Adhesiveness is the force required to remove the material that adheres to a specific surface. The adhesiveness value is measured from the area under the graph of negative region. Springiness is the distance travel of cycle 2 to the distance travel of cycle 1. Next, chewiness is the number of chews at 1 chew per second needed to masticate the sample to a consistency that is suitable for swallowing. Chewiness also known as product of springiness and gumminess. Lastly, the gumminess is an energy required to disintegrate a semi-solid food to a state ready for swallowing. It is also known as product of hardness and cohesiveness. All of the texture parameters is executed according to the TPA graph shown in Figure 2.6 below and Table 2.20 as the reference for the graph.

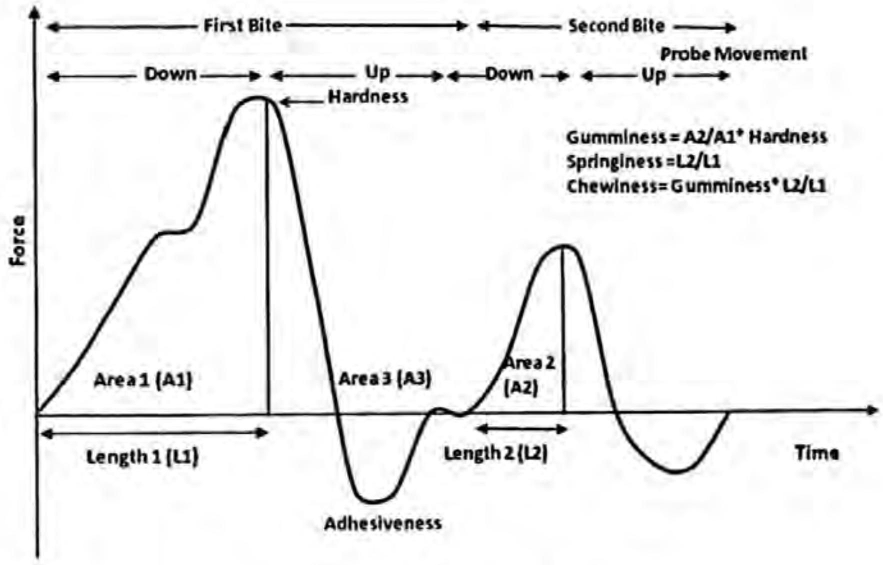


Figure 2.6: TPA graph

Table 2.20: Summary of texture analysis measurement

Parameters	Unit	How to measure
Hardness	N	Highest peak
Adhesiveness	N.s	Area 3 (A3)
Gumminess	N	$\frac{A2}{A1} \times$ Hardness
Springiness	-	$\frac{L2}{L1}$
Cohesiveness	-	$\frac{A2}{A1}$
Chewiness	N	Guminess $\times \frac{L2}{L1}$

Source: (Bourne, 2002)

CHAPTER 3

METHODOLOGY

3.1 Overall flow diagram

Figure 3.3 shows the overall flow diagram of glutinous rice with two different variety of *Siding,* and *Susu.* While, variety of *Susu Thai* will act as benckmark in this study. There are some test methods applied which in complement to the objectives mentioned in Section 1.4. Two samples of glutinous rice which are *Siding* and *Susu* were obtained from Lembaga Pengurusan Peladang (LPP), Langkawi, Kedah Darul Aman. While, the *Susu Thai* cultivar were bought from the local market located in Kelantan.

Figure 3.1: Pulut Siding in Kg. Baru/Teluk, Langkawi

Figure 3.2:Pulut Susu in Kg. Baru/Teluk, Langkawi

Figure 3.1 and 3.2 shows two different cultivars of glutinous rice planted in Langkawi. For the first objective is to determine the physicochemical properties of the glutinous rice such their physical properties are length to breadth (l/b) ratio, bulk density, true density, colour, angle of repose, aspect ratio, length, width, surface area, thickness, sphericity, porosity, volume, and thousand weight kernel (TWK) rice. Then, morphological properties for rice kernel is determined to observe granular structure of rice. All of these properties will be further elaborated in Section 3.3 onwards. Determination of chemical and thermal properties needed in the form of rice powder. The chemical properties are divided into amylose content analysis (%), and proximate composition (%). Their proximate composition (%) can be analysed such as moisture content, carbohydrate, protein, fat, fiber, and ash. Then, for the second objective, the rice were cooked at different soaking period to analyse its cooking and texture properties.

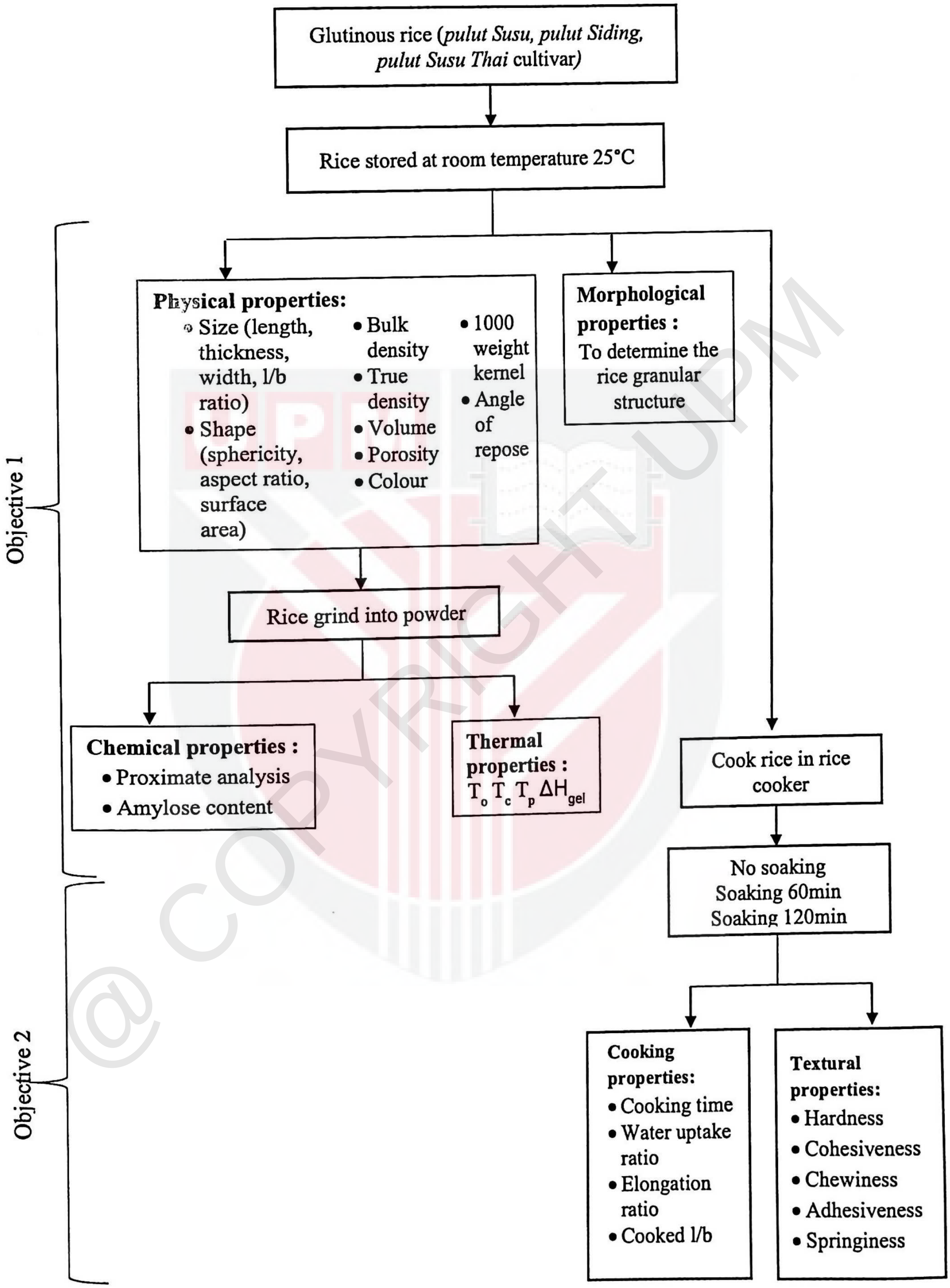


Figure 3.3: Overall flow diagram of analysis of two local glutinous rice cultivar and commercial Thai cultivar

3.2 Sample preparation

Originally, the seed of local and imported *Susu* cultivar both were coming from Thailand. But the samples were planted in different area which *Susu* Thai cultivar cultivated in Thailand while local *Susu* cultivar cultivated in Langkawi. Another one sample is *Siding* cultivar were cultivated in Kuala Kedah, Kedah. Then, for the local *Susu*, the rice is milled in the laboratory while *Siding* cultivar were already milled by Padiberas National Berhad (BERNAS) meanwhile *Susu* Thai were bought from market in Kelantan.

Sample of glutinous rice were prepared according to three different conditions which are in the form of rice kernel, rice powder, and cooked rice. The glutinous rice grain were ground into powder by using flour grinder (Laboratory Mill 120, Perten, Sweden) and sieve until 20 U.S mesh size or 841 micron size (Singh et al., 2003) For the cooked rice condition, the rice is being cooked by using automatic rice cooker (PSN-SRE10, Panasonic, Malaysia).

Figure 3.4: Milled local *Susu* cultivar sample

Figure 3.5: Milled *Siding* cultivar sample

3.3 Physical properties of glutinous rice

3.3.1 Grain dimension and shape

There are three principle dimensions: length (l), width (w), and thickness (t) are required to determine. These measurements are measured by using vernier calliper to an accuracy of 0.05mm. 20 grains from each sample were collected at random and the dimensions were measured to obtain the average length (l) in millimetre (mm), width (w) in mm, and thickness (t) in mm of milled rice. Figure 3.4 shows the measurement of grain dimension of rice.

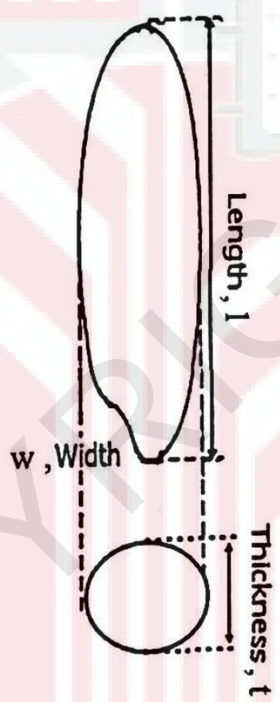


Figure 3.6: Dimension of rice grain

Width of the shape is similar as breadth of the shape. Based on the length (l) to breadth (b) ratio (l/b), where l and b as describe in section 2.3.1, the shape of the milled rice was determined (IRRI, 2004). l/b ratio is calculated as follows:

$$b=\sqrt{wt} \tag{3.1}$$

$$l/b = \frac{\text{average length of rice in mm}}{\text{average breadth of rice in mm}} \tag{3.2}$$

Where l= length of grain (mm);

w= width of grain (mm);

b= breadth of grain (mm);

t= thickness of grain (mm)

3.3.2 Thousand weight kernel

The thousand weight kernel of each sample were counted randomly in triplicate and weighed separately to determine thousand kernel weight by weighing them onto the analytical balance (Singh et al., 2003).

3.3.3 Surface area, aspect ratio, and sphericity

The surface area ($\dot{S}$), aspect ratio (R_a), and sphericity ($\emptyset$) of rice was determined by the measurement of the grain dimension. All of properties are calculated as follows (Jain & Bal, 1997):

$$S = \frac{\pi b l^2}{(2l-b)} \quad (3.3)$$

Where $b=\sqrt{wt}$

$$R_a = \frac{w}{l} \quad (3.4)$$

$$\emptyset = \frac{(lwt)^{1/3}}{l} \quad (3.5)$$

Where S= surface area (mm^2)

w= width of grain (mm)

b= breadth of grain (mm)

l= length of grain (mm)

t= thickness of grain (mm)

$\emptyset$= sphericity of grain (%)

3.3.4 Bulk density, true density, and porosity

Grain volume (V) were calculated by using formula (Jain & Bal,1997) below:

$$V = 0.25[\left(\frac{\pi}{6}\right) l(w + t)^2] \quad (3.6)$$

Where w= width of grain (mm)

l= length of grain (mm)

t= thickness of grain (mm)

V= grain volume (mm^3)

The bulk density (ρ_b) was calculated according to equation mentioned by (Fraser et al., 2008) when 100ml beaker was filled with rice up to 100ml sign and then mass of rice grains was weighed. The weight of the rice was divided with the volume of the beaker (100ml). The procedure was repeated five times:

$$\rho_b = \frac{M_g}{V_b} \quad (3.7)$$

Where ρ_b = bulk density (kg/m^3)

M_g = mass of rice grain (kg)

V_b = volume of beaker (m^3)

The true density (ρ_t) was calculated by filling the 100ml beaker with 50ml of distilled water and then placing there 3g sample of rice. The displaced water (volume of the grains) is recorded. The measurement is repeated five times (Shittu et al., 2012):

$$\rho_t = \frac{M_{gt}}{V_{dw}} \quad (3.8)$$

Where ρ_t = true density (kg/m^3)

M_{gt} = mass of rice grain (kg)

V_{dw} = volume of displaced water (m^3)

Porosity determination is based on the bulk density and true density of the rice grain. The porosity (ε) of rice grain is calculated by using formula (Jain & Bal, 1997):

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (3.9)$$

Where ε = porosity (%)

ρ_b = bulk density (kg/m^3)

ρ_t = true density (kg/m^3)

3.3.5 Angle of repose

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using the apparatus consisting of a plywood box of 140 x 160 x 35mm and two plates: fixed and adjustable. The box was filled with the sample, and then the adjustable plate was inclined gradually allowing the seeds to follow and assume a natural slope, this was measured as emptying angle of repose (Tabatabaeefar, 2003).

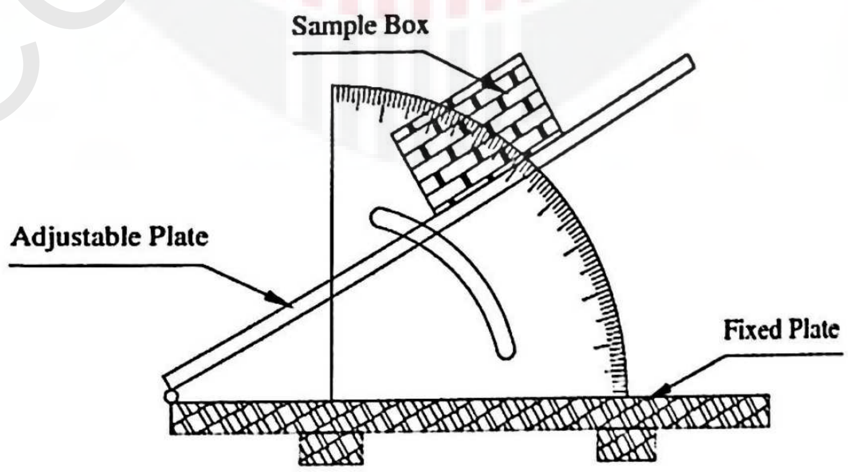


Figure 3.7: Apparatus measuring angle of repose

3.3.6 Colour

The colour of rice samples was determined by a colorimeter (ZE 400 Nippon Denshoku, Japan). Measurement based was based on the HunterLab system for the extent of lightness (L*), redness-greenness (a*), and yellowness-blueness (b*). The L* value change from 0 (black) to 100 (white). The a* value changes from –a* (greenness) to +a* (redness) while b* value is from –b* (blueness) to +b* (yellowness). The L*, a*, and b* values were then used to calculate the parameters of colour appearance: chroma (C), hue angle (h) and colour difference (ΔE). All analysis was conducted at room temperature and three replications were carried out for the each determination on colour of the rice (Gavahian et al., 2019).

$$\text{Chroma, C}=\sqrt{a^{*2}+b^{*2}} \quad (3.10)$$

$$\text{Hue angle, h}=\tan^{-1}\frac{b^{*}}{a^{*}} \quad (3.11)$$

$$\text{Colour difference, }\Delta\text{E}=\sqrt{\Delta L^{*2}+\Delta a^{*2}+\Delta b^{*2}} \quad (3.12)$$

3.4 Chemical properties of glutinous rice

3.4.1 Determination of amylose content

Amylose content in rice samples were determined based on the Iodine-binding procedure as described by (Juliano, 2000). 20mg of ground rice, 10ml of 0.5N NaOH solution were added in a volumetric flask (100 ml) and diluted to 100ml using distilled water followed by thorough mixing. Further, samples were heated on a boiling water bath (Thermo 286, Memmert , Germany) (100°C) for 10 mins to gelatinize the starch and later on cooled to room temperature. Iodine reagent was prepared by adding 20mg potassium iodide and were diluted with 100ml of distilled water. Amylose standard were prepared by mixing 0.04g amylose and 10ml of NaOH solution. Then, the mixture were diluted with 100ml of distilled water. 5 amylose standard were prepared at different concentration by taking out 1ml, 2ml, 3ml, 4ml, and 5ml of diluted solution respectively. Each were added with 5ml of 0.1N HCl solution and 0.5ml of iodine reagent. 10 ml of sample solution mixed with 5ml of 0.1N HCl and 0.5ml of iodine reagent, with the volume adjusted to 50 mL with distilled water were prepared. All the contents from the amylose standard solution and sample solutions were thoroughly vortex mixed and allowed to stand for 20 min. The absorbance was measured at 620 nm using a UV-Spectrophotometer (Model AA-6650, Shimadzu Co. Japan). The amylose content in samples was determined based on the standard curve prepared (Thomas et al., 2013).

3.5 Proximate Analysis for ground glutinous rice

3.5.1 Determination of moisture content

The crucible changed into very well washed and dried in an oven (OF-G22W, Jeio Tech, Korea) at 100°C for 30 minutes and allowed to chill inside the desiccators. They have been weighed by using a weighing balance after cooling and their diverse weights were recorded as (W1). Then, 3.0 g of the finely-ground samples had been placed into the crucibles and weighed to determine W2. Thereafter, the crucibles that were filled with samples had been put inside the oven (OF-G22W, Jeio Tech, Korea). The samples were dried for 4 hours at 100°C and then cooled. After that, they were weighted until constant weights were obtained to determine W3 at the constant temperature for 30 minutes. The percentage of moisture content of the samples was calculated as below (Association of Official Analytical Chemists, 1990):

$$\frac{\text{(Initial weight of filled crucible)} - \text{(Final weight of filled crucible)}}{\text{(Initial weight of filled crucible)} - \text{(Initial weight of empty crucible)}} \times 100 \quad (3.13)$$

3.5.2 Determination of crude protein

Kjeldahl method of (Association of Official Analytical Chemists, 1990) was used to determine the crude protein content of the samples, which involved protein digestion and distillation. About 2.0 g of the sample was weighed and 2 tablets of Kjeldahl Catalyst were added into a Kjeldahl flask for the protein digestion. Next, 25 ml of concentrated sulphuric acid was poured into the Kjedahl flask. The entire solution became subjected to heat in the fume cabinet. The heating changed into accomplished gently at the beginning and extended with occasional shaking till the solution received an inexperienced shade (green colour). The digester was remained at the temperature above 420 °C for approximately 30 minutes. After that, the solution was cooled and the neck of the flask was washed with distilled water if the black particles found on it. The solution was re-heated lightly at beginning until the inexperienced coloration (green colour) disappeared. It was allowed to cool.

In protein distillation preparation, 15 minutes were taken to steam the Kjeltec distillation apparatus (KjeltecTM 2300, Foss Analytical; Denmark). After that, 5 ml of the boric acid / indicator was added into a 100 ml conical flask and placed under the condenser as the condenser tip was under the liquid. A small funnel aperture is used to pipette 5.0 ml of the digest into the apparatus. The 50 ml of 60% NaOH solution was added after the digest was washed with distilled water. The ammonium sulphate was collected sufficiently. Next, the steaming process of the digest inside the condenser takes place about 1 until 5 minutes. The condensed water become removed, and then the receiving flask was removed and the top of the condenser was washed down into the flask. The 0.01 M hydrochloric acid was used to treat the solution in the receiving flask. Additionally, a blank was run via together with the sample (James, 1995). The nitrogen content was calculated in percentage by using equation (3.2) after titration.

$$\% \text{ Nitrogen} = (V1 - V2) \times (M) \times 0.01410 \times (W) \times 100\% \qquad (3.14)$$

Where;

V1: Volume of the acid used in the titration (ml)

V2: Corresponding amount of acid for the blank titration (ml)

W: Weight of the sample (g) and M: Molarity of acid (M)

Commonly, 16% of nitrogen consisted in all biological proteins. Therefore, the percentage of nitrogen must be multiplied by 6.25 (6.25 is the reciprocal of 0.16) in order to estimate the protein content. Thus, nitrogen in feed samples was not differentiated by the crude protein, which coming from either true crude protein or other non-protein nitrogen (NPN) compounds. It also does not differentiate between available and unavailable protein.

$$\%N \times 6.25 = \% CP \qquad (3.15)$$

Where;

N: Nitrogen

CP: Crude Protein

3.5.3 Determination of fat

According to the Soxhlet extraction method, Soxtec Extraction (SoxtecTM 2050, Foss Analytical, Denmark) was used to determine the total fat in the sample. Firstly, a 250 ml clean aluminium cup was dried at 105°C in an oven for 30 minutes and then it was cooled in a desiccator. About 1 gram of the sample was weighed and put into labelled thimbles. Next, the aluminium cup was weighed before filled with solution. The 80 ml of petroleum ether which is boiling point from 40°C until 60°C was poured into an aluminium cup. The cotton wool was put into the extraction thimbles as they have been plugged tightly. The assembled of Soctex apparatus was allowed to reflux for 75 minutes. After the thimble was removed, the collected petroleum ether from the top container was drained into another container for reuse. When the flask become almost free of the petroleum ether, it was dried at 105°C for 1 hour. It turned into cooled in a desiccator and weighed after drying. The fat percentage of the sample was calculated as below (Association of Official Analytical Chemists, 1990):

$$\text{(Weight of fat) / (weight of sample)} \times 100\% = \%\ \text{fat} \qquad (3.16)$$

3.5.4 Determination of ash

The total ash content of the samples was determined by using furnace incineration based on the vaporization of water and volatiles with burning organic substances in the presence of oxygen in the air to carbon dioxide at 550°C. A porcelain crucible was filled with 1 gram of the finely-ground dried sample and it was incinerated in an ashing muffle furnace (KSL-1700X, MTI Corporation, USA) for 6 hours at 525°C until ash was acquired. After that, the ash becomes cooled in a desiccator and weighed.

The calculation for the percentage of ash content in the samples was shown as below (Association of Official Analytical Chemists, 1990):

$$(\text{Weight of ash}) / (\text{weight of the original}) \times 100\% = \%\ \text{ash} \quad (3.17)$$

3.5.5 Determination of crude fiber

According to Association of Official Analytical Chemist (2000), this method was used to determine the crude fiber. The petroleum ether (initial boiling temperature, 35-38°C; dry-flask end point, 52-60°C; ≥95% distilling <54°C and ≤60% distilling <40°C; specific gravity at 60°F, 0.630-0.660; evaporation residue ≤0.002% by weight) was used to extract the 2 g of ground test portion. If the fat is ≤1%, the extraction can be neglected. In order to avoid fiber contamination, the 600ml reflux beaker was transferred from paper or brush. About 0.25-0.5g of the bumping granules and 200ml near-boiling 1.25% H_2SO_4 solution were added in small stream directly to sample to aid in complete wetting of the sample. In every 24 samples, the two blanks were run. The beakers were placed on digestion apparatus at 5 minutes intervals and 30 minutes for boiling, then the beakers were rotated periodically to keep solids from adhering to sides.

California Buchner was placed at near end of refluxing, previously fitted with No. 9 rubber stopper to provide vacuum seal, into filtration apparatus (Model AS-2000, Analytical Bio-Chemistry Laboratories, Columbia) and vacuum was adjusted to ca 25 mm Hg (735 mm pressure). The near-boiling H_2O was flow through funnel to warm it; then the liquid was decanted trough funnel, washing solids into funnel with minimum of near-boiling H_2O. After that the filtration was done by using 25 mm vacuum and residue was washed with four 40-50 ml portions near-boiling H_2O, then each washing was filtered. Do not add wash to funnel under vacuum; the funnel was lifted from apparatus when adding wash. The residue from funnel into reflux beaker was washed with near-boiling 1.25% NaOH solution. The beakers were placed on reflux apparatus at 5 minutes intervals and reflux 30 minutes. Near end of refluxing, the filtration apparatus was turned on, the crucible was placed and vacuum was adjusted to ca 25 mm. Near-boiling H_2O was flow through crucible to warm it. At end of refluxing, the liquid was decanted trough crucible and solids were washed into crucible with minimum of near-boiling H_2O. The vacuum was needed to increase to maintain filtration rate.

Next, the residue was washed once with 25-30 ml near-boiling 1.25% H_2SO_4 solution, and then with two 25-30 ml portions near-boiling H_2O, each washing was filtered. The crucible with residue was dried for 2 hours at 130 ±2 ^{0}C or overnight at 110^{0}C, and then it was cooled in desiccator and weighted (W_2). After that, it was done for ash at 550 ±10^{0}C for 2 hours. It was then cooled in desiccator before weighted (W_3). Do not remove crucibles from furnace until temperature is ≤250^{0}C, as fritted disk may be damaged if cooled too rapidly.

$$\text{Crude fiber (\%)} = [(W_2 - W_3) - (B_2 - B_3)] / W_1 \times 100 \tag{3.18}$$

Crude fiber on desired moisture basis, % (w/w) =

$$C \times \frac{100 - \%\ \text{moisture basis desired}}{100 - \%\ \text{moisture in test sample}} \tag{3.19}$$

$$\text{Or } C \times \frac{\%\ \text{dry matter basis desired}}{\%\ \text{dry matter in test sample}} \tag{3.20}$$

Where B_2 and B_3 are average weights of all blanks after oven drying and ashing, respectively (Association of Official Analytical Chemists, 2000).

3.5.6 Determination of carbohydrate

The method used to determine total percentage of carbohydrate content in the samples involves adding the total values of moisture, crude protein, fat, ash and crude fiber constituents of the sample and subtracting it from 100. The determination of carbohydrate was calculated as below:

$$\% \text{ Carbohydrate} = 100\% - (\% \text{ moisture} + \% \text{ crude protein} + \% \text{ fat} + \% \text{ ash} + \% \text{ crude fiber}) \quad (3.21)$$

3.6 Determination of thermal properties

Rice flour (3.5 mg, dwb) was weighed into a 40 ml capacity aluminium pan (Mettler, ME-27331) and distilled water was added with the help of a Hamilton microsyringe to achieve a flour–water suspension containing 70% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in the DSC. Sample pans were heated at a rate of 10°C/min from 20 to 100°C. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) were calculated automatically. Because the peaks were symmetrical, the gelatinization range (R) was computed as ($T_c - T_o$) (Singh et al., 2003).

3.7 Determination of morphological properties

Rice grains were fractured in the mid-region using a razor blade by applying slight pressure to the top of the grain. The fractured rice grains were mounted on a circular aluminium specimen stub and gold coated in a vacuum using sputter coater. The rice granular structures in the centre part of the grain were examined using an environmental scanning electron microscope (S-570, Hirachi, Japan) operating at 10 kV (Kang et al., 2010).

3.8 Determination of cooking properties

Initially, the rice was rinsed with water for three times. For unsoaked rice treatment was proceed to cook the rice in an automatic rice cooker (PSN-SRE10, Panasonic, Malaysia). For soaking treatment, the rice was let soaked in a container containing water twice amount from the rice for 60minutes and 120 minutes (Sareepuang et al., 2008). Then, the water is drained and the rice were cooked following in the next step as describe in section 3.8.1.

3.8.1 Cooking time

Then, rice was mixed with water in weight of ratio of 1:1.2 and put in an automatic rice cooker (ERC1066T, Elba, Malaysia) and cooked until the thermostat trips the shut-off switch which indicate the rice is done (Sundelin, 2011).

3.8.2 Water uptake ratio

The water uptake ratio is determined based on the mass of raw rice and mass of cooked rice. Water uptake ratio is calculated by using the formula below (Thomas et al., 2013) :

$$\text{Water uptake ratio} = \frac{\text{mass of cooked rice (g)}}{\text{mass of raw rice (g)}} \quad (3.22)$$

3.8.3 Cooked l/b

These measurements are measured by using vernier calliper to an accuracy of 0.05mm. 20 grains from each sample were collected at random and the dimensions were measured to obtain the average length (l) in millimetre (mm), width (w) in mm, and thickness (t) in mm of cooked rice grain. Measurement similar as shown in Section 3.3.1. Based on the length to breadth ratio (l/b), the shape of the cooked rice was determined (IRRI, 2004). L/b ratio is calculated as follows:

$$b=\sqrt{wt} \quad (3.23)$$

$$l/b = \frac{\text{average length of rice in mm}}{\text{average breadth of rice in mm}} \quad (3.24)$$

Where l= length of grain (mm);

w= width of grain (mm);

b= breadth of grain (mm);

t= thickness of grain (mm)

3.8.4 Elongation ratio

The elongation ratio is determined by measuring the length (l) and breadth (b) of the raw rice and cooked rice. 20 grains from each sample were measured by using Vernier calliper to an accuracy of 0.05mm. The elongation is calculated by using formula below (Sareepuang et al., 2008):

$$\text{Elongation ratio} = \frac{\text{l/b of cooked rice}}{\text{l/b of raw rice}} \quad (3.25)$$

3.9 Analysis of texture properties

Textural analysis of cooked rice was tested by a texture analyser (TA-XT plus, Stable Micro Systems Ltd, United Kingdom) according cooked rice (after cooled at room temperature for 2 hours) were arrayed on the platform and tested. This analysis used a two-cycle compression program (TPA) and the parameters as follow: 70%strain, the pre-test speed, test speed and post-test speed were set 1.0, 0.5, and 1.0 m/s respectively. 10g of cooked rice were weighed and shaped into circle. Then, the samples were put at the centre of the platform. Cylindrical probe P/36 was used. Each samples repeated for 3 times.

3.10 Statistical Analysis

Paired-T statistic was used to analysis of variance is applied in determination of statistically significant differences between the means of triplicate raw data of samples. Significance is accepted at $P < 0.05$ using Minitab Software Version 17. Pearson correlation was obtained using Minitab Software version 17.

CHAPTER 4

DISCUSSION

4.1 Physical properties

4.1.1 Grain dimension and shape

Table 4.1 shows a summary of the physical properties of local rice cultivar, *Susu* and *Siding*. The *Susu* Thai cultivar is act as a reference. Length (mm), width (mm), and thickness (mm), of rice grain determine its dimension. Based on Table 4.1, the average value of length, width, and thickness for local *Susu* cultivar were found to be 6.63mm, 1.88mm, and 1.50mm respectively while 6.24mm, 1.98mm, and 1.48mm were obtained for *Siding* cultivar. In comparison, *Susu* Thai results 6.57mm, 1.98mm, and 1.47mm respectively for its length, width, and thickness. *Susu* Thai and *Siding* cultivars were wider compared to local *Susu*. However, local *Susu* cultivar was thicker than *Susu* Thai and *Siding* cultivars. Length of *Susu* Thai and local *Susu* did not show significant difference ($P>0.05$) between them but, significantly longer than *Siding* cultivar. The result for width and thickness of *Susu* Thai and *Siding* cultivar did not differ significantly ($P>0.05$). However, it shows significant differences ($P<0.05$) to local *Susu* cultivar. Length of local *Susu* cultivar similar to the length of *Pulut* Malaysia I cultivar which was 6.63mm reported by Husain (1984) in the past literature.

The mean value of length-breadth (L/B) for *Susu* Thai, local *Susu*, and *Siding* were 3.58, 3.82, 3.17 respectively as shown in Table 4.1. The L/B ratio for three of the glutinous rice cultivars shows no significant difference (P>0.05). In addition, L/B ratio has positive correlation with cooked L/B when the rice has cooked. This is because during cooking, the water is absorbed and volume expanded as well with the length. As the result for those three cultivar were above 3, it is considered as slender (IRRI,1980). For the local cultivars, both of the seeds can be considered as slender. However, local *Susu* has the highest L/B ratio which yield very significant slender shape compared to *Susu* Thai and *Siding* cultivars. L/B ratio shows the dimension of rice grain. This proves that the dimension for different cultivar is similar since they were same of rice type of glutinous rice.

4.1.2 Surface area, volume and sphericity

Based on the result from Table 4.1, the surface area for *Susu* Thai, local *Susu*, and *Siding* were 22.02 mm^2, 20.22 mm^2 and 19.45mm^2 respectively. *Susu* Thai cultivar recorded the highest surface area value followed by local *Susu* then *Siding* cultivars. For these three cultivars they showed significant difference (P<0.05) of surface area values.

The grain volume showed significant differences between both *Susu* cultivar and *Siding* cultivar. From Table 4.1, the average volume values for *Susu* Thai, local *Susu* and *Siding* were 9.76 mm^3, 9.89 mm^3 and 9.95 mm^3, respectively. *Susu* Thai recorded the lowest volume of rice grain compared to local *Susu* and *Siding*. *Susu* Thai and local *Susu* cultivars did not showed significant difference (P>0.05) however they are significantly different (P<0.05) with *Siding* cultivar. Surface area of the grain has positive correlation with the volume of the grain. Heat transfer surface importantly influence the rate or speed of heat transfer during cooking or drying process. Higher rate of heat transfer occur when the material has smaller volume per unit surface contact (Varnamkhasti et al., 2008). From this study, *Susu* Thai has the highest rate of heat transfer hence might short in drying or cooking time.

From Table 4.1, the result for surface area for *Susu* Thai, local *Susu*, and *Siding* were 0.41, 0.40 and 0.42 respectively. Sphericity for these three cultivars showed no significant difference (P>0.05). Sphericity of *Siding* is the highest may due to the rounded ends, which decreases the length of grains. The sphericity ranges from 0.40% - 0.42%. For many agricultural materials, raw rough rice fall within ranges from 0.32 to 1% for the sphericity values (Mohsenin, 1986). Thus, result from these three cultivars obeyed with the statement.

4.1.3 Bulk density, true density and porosity

Table 4.1 shows that the bulk density mean values for local *Susu* and *Siding* were 800.54 kg/m^3 and 767.22 kg/m^3 respectively. Compare to *Susu* Thai cultivar, the mean value bulk density was 722.73 kg/m^3. Bulk density values show no significant difference (P>0.05) between three cultivars regardless of local or commercial cultivars. This study recorded slightly lower to the past result of imported glutinous rice cultivar reported by Thomas (2013) which is 830 kg/m^3. In an existing grain of a combine hopper, the design needs to ascertain the volume. So, various approaches are applied in this agricultural industry. Information about bulk density is useful in controlling the load of product in the hopper. Also, bulk density is useful in this application for outlining storage bins and silos desgn (Nalladulai et al., 2002). Due to the bulk density value for *Siding* was smaller than *Susu* cultivar, *Siding* cultivars will need a bigger silo in comparison to *Susu* cultivar in relation with same load of rice kernels. In addition, bulk density was found to be positively correlated with thousand weight kernel (TWK) and water uptake ratio. Density is proportional to the mass of grain, so that bulk density increase resulted in increase in TWK. Water uptake ratio is an important parameter while cooking rice. If the bulk density is higher, then correspondingly water uptake will also be high. Similar findings has been reported by Harper et al. (2005).

Then, the true density of *Siding* showed significant differences between *Susu* Thai and local *Susu* cultivars. From Table 4.1, the mean value of true density for *Susu* Thai, local *Susu* and *Siding* were found to be 1234.70 kg/m^3, 1502.36 kg/m^3 and 1206.2 kg/m^3, respectively. The true density showed no significant difference ($P>0.05$) between *Susu* Thai and local *Susu* but differ significantly ($P<0.05$) with *Siding* cultivar. *Siding* recorded in the same range to Sorkheh cultivar from India which was 1210 kg/m^3 (Varnamkhasti et al., 2008). True density has strong correlation with porosity parameters (Chen, 2010). Local *Susu* recorded the highest true density value since its porosity is the lowest due to its void spaces inside the grain.

From Table 4.1, the mean value of porosity for *Susu* Thai, local *Susu* and *Siding* were found to be 37.67%, 35.92% and 41.76%, respectively. The porosity values for three difference cultivars showed significant difference ($P<0.05$) between them. The highest porosity value possessed by *Siding* cultivar due to its large void spaces. *Susu* cultivar recorded within the same range to *Ozgon* cultivar from Kyrgyzstan which is 36.54% (Martina et al., 2018). When the porosity of the material is large, it will effects in lower TWK of rice grain due to many void spaces (Danbana, 2011).

4.1.4 Thousand weight kernel

Based on Table 4.1, an average of TWK for *Susu* Thai, local *Susu*, and *Siding* cultivars were 18.79g, 19.02g and 17.05g, respectively. The TWK result showed no significant difference (P>0.05) between *Susu* Thai and local Susu but differ significantly (P<0.05) with Siding cultivar. Local *Susu* has the heaviest weight compared to *Susu* Thai and *Siding* cultivar because it has the highest value in density; proportional to the mass of the grain. Also, the weight for both *Susu* cultivars were affected with the small porosity in the grain. Thus, the result was in agreement with Thomas et al. (2013) which he said that TWK has strong correlation with density and porosity of rice grain. Weight kernel is reliable to measure the correlative amount of foreign substance in a designated bulk of raw rice and the number of shrink or unripe kernels, normally it based on the index of milling outturn. So, thousand grain weight of rice is important in this matter (Luh, 1980).

4.1.5 Angle of repose

Based on Table 4.1, the mean value angle of repose for *Susu* Thai, local *Susu* and *Siding* cultivars were 40.08°, 39.45° and 38.85° respectively. These three cultivars showed no significant difference (P>0.05) between each other. Grains with high value of angle may be due to the large size of grains and their relatively rough surface which reduced flow of grains (Akintunde,2007). Also, this angle of repose is important for the design of processing, storage, and conveying systems of particulate materials. Materials with low angle of repose are highly flowable and can be transported using gravitational force or a small energy (Teferra, 2019).

Table 4.1: Average value of physical properties of different glutinous rice cultivars

Properties	Grain/Rice cultivar		
	Susu Thai (reference)	Local *Susu*	*Siding*
Length (mm)	6.57 ± 0.28^a	6.63 ± 0.24^a	6.24 ± 0.42^b
Width (mm)	1.98 ± 0.09^b	1.88 ± 0.10^a	1.98 ± 0.08^b
Thickness (mm)	1.47 ± 0.09^a	1.50 ± 0.07^c	1.48 ± 0.10^a
L/B ratio	3.58 ± 0.34^a	3.82 ± 0.06^a	3.17 ± 0.06^a
Aspect ratio	0.30 ± 0.02^a	0.28 ± 0.02^a	0.32 ± 0.03^a
Surface area (mm^2)	22.02 ± 1.36^c	20.22 ± 1.31^a	19.45 ± 1.73^b
Sphericity (%)	0.41 ± 0.01^a	0.40 ± 0.01^a	0.42 ± 0.02^a
Volume (mm^3)	9.76 ± 0.90^a	9.89 ± 0.91^a	9.95 ± 0.68^b
Bulk density (kg/m^3)	772.73 ± 1.28^a	800.54 ± 1.20^a	767.22 ± 1.77^a
True density (kg/m^3)	1234.7 ± 1.81^a	1502.36 ± 2.30^a	1206.2 ± 2.80^b
Porosity (%)	37.67 ± 0.33^a	35.92 ± 0.44^c	41.76 ± 0.76^b
10000 weight kernel (g)	18.79 ± 0.10^a	19.02 ± 0.02^a	17.05 ± 0.04^b
Angle of repose (deg.)	$40.08^{\circ}\pm1.05^a$	$39.45^{\circ}\pm1.03^a$	$38.85^{\circ}\pm0.95^a$

Mean (±SD) with same letter in the same row do not differ significantly (P>0.05)

4.1.6 Colour appearance

Table 4.2 represents the colour parameters; L*,a*, b* and whiteness for three different cultivar of glutinous rice. Based on the result Table 4.2, *Siding* has the highest L* which is 73.75 followed by local *Susu* cultivar and *Susu* Thai cultivar which are 69.98 and 67.35 respectively. For the L*, a* and whiteness parameters showed no significant difference (P<0.05) between these three cultivars. Lightness, L* and whiteness has nothing much difference between them. Moreover, these two parameters has a positive effect on consumer acceptance. Customer acceptability is usually based on luster and whiter appearance of the particular rice. Whiteness of rice is proportional to the lightness of rice. The whiteness of the rice measures the opaqueness of the rice. From Table 4.2, *Siding* cultivars recorded highest whiteness 72.43 followed by local *Susu* and *Susu* Thai cultivars which were 69.10 and 66.20 respectively.

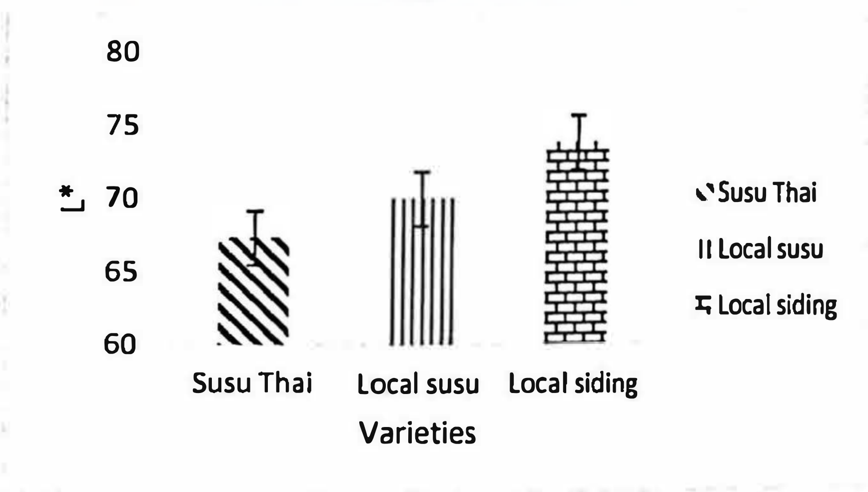
For a* value, *Susu* Thai recorded -0.58 while local *Susu* and *Siding* cultivars both recorded -1.02. The minus sign showed that all cultivars tendency on the greenness region. The value of a* showed the highest for *Susu* Thai cultivar compared to local cultivars. For b* value, *Susu* Thai, local *Susu,* and *Siding* cultivar recorded 8.66, 7.24, 8.35 respectively. The highest b* value recorded by *Susu* Thai cultivar followed by *Siding* then local *Susu* cultivar. However, the b* value showed significant difference (P<0.05) between *Susu* Thai and local *Susu* but they showed no significant difference (P>0.05) when compared with *Siding* cultivar.

Table 4.2:Colour parameters of different glutinous rice cultivars

Sample	Colour parameters			
	L*	a*	b*	Whiteness
Susu Thai	67.35±2.40[a]	-0.58±0.34[a]	8.66±0.79[a]	66.20±2.27[a]
Local *Susu*	69.98±1.27[a]	-1.02±0.17[a]	7.24±0.89[b]	69.10±1.44[a]
Siding	73.75±1.41[a]	-1.02±0.22[a]	8.35±0.24[ab]	72.43±1.37[a]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

The positive sign showed that all cultivars tendency on the yellowness region. The lightness of local glutinous rice is slightly higher than lightness of Korean glutinous rice cultivar reported by (Hapsari et al, 2016) which recorded at 65.50. The trend for L*, a*, b* value can be seen through figure 4.1 below.



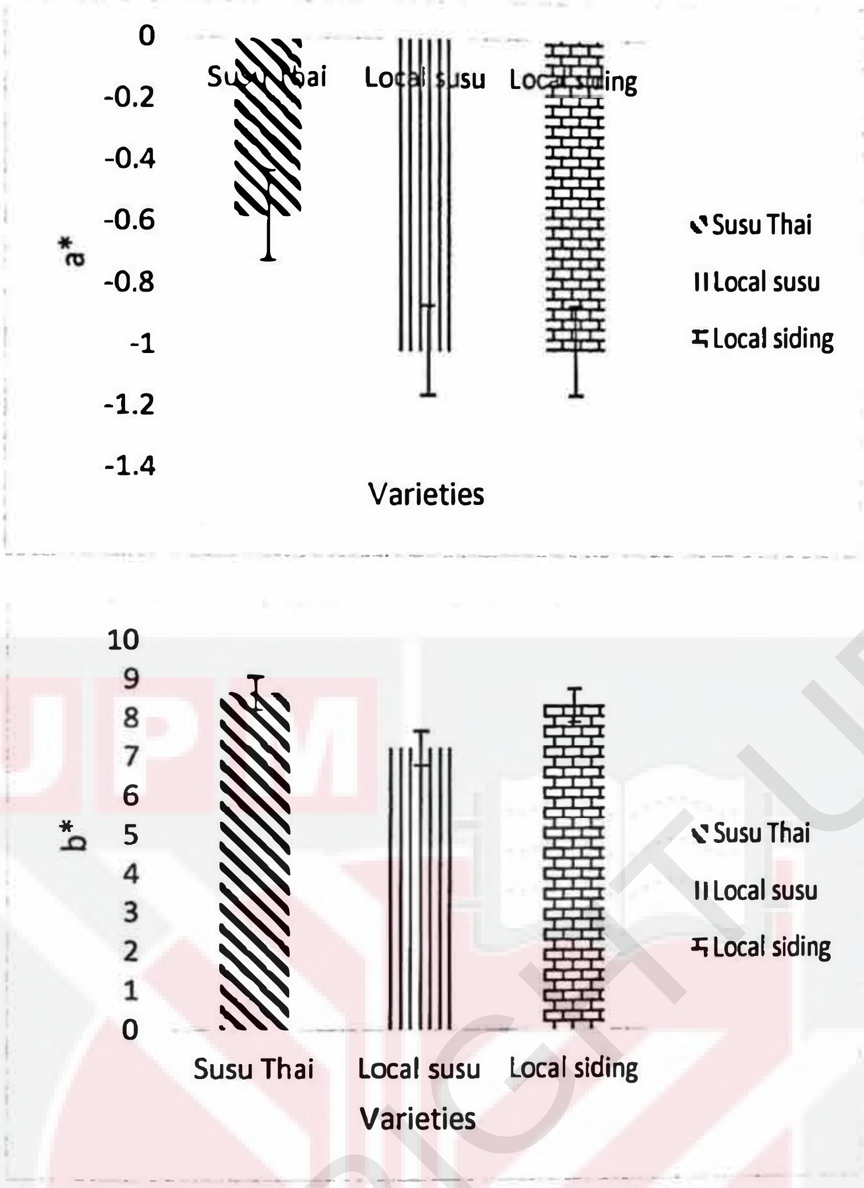


Figure 4.1: L, a*, b* value for glutinous rice with different cultivars*

4.2 Chemical properties

4.2.1 Amylose content

Amylose content is one of the important parameter that can be measured in rice. Starch is the major composition of rice and the amylose content of rice is different among the varieties. Based on Table 4.3, S*usu* Thai recorded the highest, 1.33% of amylose content followed by local *Susu* and *Siding* rice cultivar which are 1.25% and 1.18% respectively. The amylose content for these three cultivars showed significant different ($P<0.05$) to each other. Amylose content parameter has positive correlation to cooking time for the rice to fully cook. According to Kang (2015), as amylose content decreases, the rice takes longer time to fully cook. This is because during cooking, mainly the amylopectin, not the amylose will leached out (Hongyan et al., 2017). Hence, low amylose content correspondingly has high in amylopectin which takes longer to leach out during cooking. However, these results slightly higher with the observation made by Singh et al. (2005) where he observed the value of amylose for imported glutinous rice at 1.03% which was lower than this study. However, according to Husain (1984), *pulut Siding* and *pulut Malaysia I* cultivar recorded amylose content of 1.4% and 1.1% respectively. The result were in ranged with these three cultivars. All of the glutinous rice cultivars has relatively small amount of amylose content since their amylopectin is higher. Amylopectin gives high eating quality to the rice. Eating quality can be measured from textural parameter of rice after being cooked such as the hardness, adhesiveness, cohesiveness, and chewiness.

Table 4.3: Amylose content of different glutinous rice cultivars

Rice cultivar	Amylose content (%)
Susu Thai	1.33±0.00[a]
Local *Susu*	1.25±0.01[b]
Siding	1.18±0.00[c]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.3 Proximate analysis

These three cultivars from different origin were analysed the proximate analysis for the following parameters which are moisture content, protein content, ash content, fiber content, fat content, and carbohydrate content.

4.3.1 Moisture content

Table 4.4 below shows the result for moisture content in two particular ways which are wet basis and dry basis for three different cultivars. Wet basis is a measure of the water in a solid, while dry basis expressed as the ratio of the amount of moisture From the result in Table 4.4, the value of moisture content for local *Susu* cultivar found out to be the lowest at 8.96% followed by *Siding* and *Susu* Thai cultivar which are 10.63% and 11.10% on their wet basis respectively. In term of their dry basis moisture content, local *Susu* contains 9.85% of moisture followed by *Siding* and *Susu* Thai which are 11.89% and 12.49% respectively. The moisture content for three different cultivar showed no significant difference (P>0.05) regardless of the wet basis and dry basis.

Among these three cultivars, local *Susu* is the most dry cultivar compared to *Siding* and *Susu* Thai. This is because the cultivation of local *Susu* was located at Langkawi island where according to "Malaysia Climate" (2016), it is located off the west coast of the mainland receives approximately 100millimeters or less of rainfall from November to March; dry season in Langkawi. During this time, the local *Susu* cultivar is scheduled to be harvested. Furthermore, moisture content plays important role in determining the shelf life (Webb, 1985) was recorded to vary from 9.85-12.49% between three different cultivars. The acceptable level for storage grain moisture is below 14%. The recorded result almost within the acceptable limit (12%-13%) to literature reports (Adair et al., 1973) for long term storage of rice.

Table 4.4: Percentage composition of moisture content

Rice cultivar	**Moisture content (%)**	
	Wet basis	**Dry basis**
Susu Thai	11.10±0.01[a]	12.49±0.01[a]
Local *Susu*	8.96±0.01[a]	9.85±0.01[a]
Siding	10.63±0.00[a]	11.89±0.00[a]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.3.2 Protein content

Table 4.5 below shows the result for percentage of protein content for three different glutinous rice cultivar. The percentage of protein content in between of 6.35% and 7.60% for these three cultivars. *Susu* Thai cultivar results 6.35% of protein content while local *Susu* and *Siding* results 7.15% and 7.60% respectively. *Siding* has the highest protein content compared to *Susu* Thai and local *Susu*. The results for *Susu* Thai and *Siding* shows significant (P<0.05) while comparison between local *Susu* with *Susu* Thai and *Siding* cultivar shows no significant different (P>0.05).

The recorded result for *Siding* is within acceptable value of protein content which reported by Husain (1984) which ranges from 6.9% to 7.60%. Also, according to the past result that was presented by Thomas et al. (2013) recorded protein content ranges from 7.60% to 8.0%. According to Pan and Khir (2019), protein content in rice contain lysine that is considered hypoallergenic and is therefore give favourable touch for human consumption. High percentage value recorded for *Siding* cultivar considered as high in lysine that give more favourable taste to the rice itself. On the other hand, higher value of protein will let the consumer grow faster as proteins were used in the construction of body tissues such as muscles, nerves, cartilage, skin, and other parts of human body (Jacquie, 2018).

Table 4.5: Percentage composition of protein content

Rice cultivar	**Protein content (%)**
Susu Thai	6.35±0.07[a]
Local *Susu*	7.15±0.64[ab]
Siding	7.60±0.00[b]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.3.3 Fat content

Fat is called as lipid mainly present in food including grain crop such as rice. Based on Table 4.6, the fat content between local *Susu* and *Susu* Thai cultivar showed no significant different (P>0.05) same goes between local *Susu* and *Siding* cultivar. However, commercial *Susu* Thai and *Siding* showed significant difference (P<0.05) between them. *Siding* resulted with the highest value which is 0.35% of fat content followed by local *Susu* and *Susu* Thai cultivar which are 0.33% and 0.23% respectively.

The recorded result for *Siding* is within acceptable value of fat content which reported by Husain (1984) which recorded at 0.34% . However, the commercial *Susu* Thai cultivar is slightly lower of fat content compared to imported glutinous rice that was presented by Thomas et al. (2013) which is 1.21%. The addition of oils and fats to such food will make these food more palatable and enable the consumer to meet energy requirements more effectively. Fats must be present in the diet to absorb the fat-soluble vitamins A,D, E and K.

Table 4.6: Percentage composition of fat content

Rice cultivar	Fat content (%)
Susu Thai	0.23±0.24[a]
Local *Susu*	0.33±0.21[ab]
Siding	0.35±0.22[b]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.3.4 Ash content

Table 4.7 shows the fat content of *Susu* Thai, local *Susu*, and *Siding* cultivar. From Table 4.7, the result recorded for ash content are 0.42%, 0.45%, and 0.50% for *Susu* Thai, local *Susu*, and *Siding* cultivar, respectively. *Siding* has the highest ash content compared to *Susu* cultivar from local and commercial sample.

However, the ash content of *Susu* Thai and *Siding* cultivar showed significant difference (P<0.05). But, comparison between local *Susu* and *Susu* Thai and *Siding* cultivar shows no significant difference (P>0.05). The high value of ash content in the grain could be to *Siding* cultivar has major composition of mineral content since ash analysis is important in determining essential mineral for the food product such as magnesium, potassium, calcium, iron and zinc (Bhat & Sridhar, 2008).

Table 4.7: Percentage composition of ash content

Rice cultivar	Ash content (%)
Susu Thai	0.42±0.24[a]
Local *Susu*	0.45±0.21[ab]
Siding	0.50±0.22[b]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.3.5 Fiber content

Table 4.8 shows the fiber content for three different glutinous rice cultivars. The fiber content of *Susu* Thai, local *Susu*, and *Siding* cultivar were 0.30%, 0.32%, and 0.39% respectively. Based on the value, *Susu* Thai cultivar has the lowest fiber content compared to local *Susu* and *Siding* cultivars. The result of fiber content of *Susu* Thai and *Siding* cultivar showed significant difference (P<0.05). While, comparison between local *Susu* with *Susu* Thai and *Siding* cultivar showed no significant difference (P>0.05).

However, *Siding* cultivar recorded similar amount of fiber content with *Pulut Siding* which reported by Husain (1984) which is at 0.39%. Although, fiber helps to reduce disease of heart attack and stroke, rice is one of the source of soluble fiber that human can consume within the accepatable range of below than 0.50% (Anonymous, 2019)

Table 4.8: Percentage composition of fiber content

Rice cultivar	Fiber content (%)
Susu Thai	0.30±0.24[a]
Local *Susu*	0.32±0.21[ab]
Siding	0.39±0.22[b]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.3.6 Carbohydrate content

Table 4.9 shows the percentage composition of carbohydrate content for three different glutinous rice cultivars. The carbohydrate content for *Susu* Thai, local *Susu*, and *Siding* cultivars were 80.21%, 81.90%, and 79.27% respectively. Carbohydrate content is the major constituent in the proximate analysis. It was observed that local *Susu* cultivar has the highest carbohydrate content which is 81.90% compared to *Susu* Thai and *Siding* cultivars. Carbohydrate content of local *Susu* and commercial *Susu* Thai does not differ much. This is may due it is from the same cultivar however planted at different region, Thailand and Malaysia. The value of carbohydrate content was quite similar to the study by Thomas et al. (2013) which ranges from 78.21%-82.23%. Also, glutinous rice exhibited fairly higher amount of carbohydrate and somewhat similar and near about the desired range 80% that recorded by Juliano (2000).

Carbohydrate is the major source of energy needed by human because rice is considered as good source of carbohydrate in food pyramid despite in any type of rice variety. Most important nutritional property of total carbohydrate is their easy digestibility in the small intestine (Devindra & Longvah, 2011).

Table 4.9: Percentage composition of carbohydrate content

Rice cultivar	Carbohydrate content (%)
Susu Thai	80.21
Local *Susu*	81.90
Siding	79.27

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.4 Thermal properties

Table 4.10 shows the result of Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c), enthalpy (ΔH) and gelatinization range (R) of three different glutinous rice cultivar. T_p is considered as the gelatinization temperature where the starch starts to swell (Hongyan et al., 2017). From Table 4.10, *Susu* Thai, local *Susu* and *Siding* cultivar shows the value of ΔH at 8.20 J/g , 1.02 J/g, and 1.22 J/g respectively. The highest value of ΔH recorded by *Susu* Thai cultivar then followed by *Siding* and local *Susu*.

According to Bert (2003), high enthalpy makes the rice cooks faster which means the starch gelatinized within the short time. The lower value of ΔH reflected loss of double helical structure at lower temperature in the former type. The highest transition temperatures possessed by *Susu* Thai then followed by *Siding* and local *Susu* cultivar. This may be attributed to the presence of lower amylose and higher amylopectin contents (Singh et al., 2003). Because amylopectin has been reported to play a major role in starch crystallinity, the amylose lowers the melting point of crystalline regions and the energy for starting gelatinization (Flipse et al., 1996).

Therefore *Susu* Thai with high amylose contents might have less amorphous region and more crystalline region, decrease in gelatinization temperature and endothermic enthalpy (Sasaki, Yasui & Matsuki, 2000). Moreover, similar result have been reported for rice by (Nakazawa, 1994). The value of T_o, T_p, and T_c showed the lowest for *Susu* Thai cultivar. This is because it has high amylose content as well as the small and compact nature of starch granules (Sodhi &Singh, 2003).

Table 4.10: Thermal properties of different glutinous rice cultivar

Rice cultivar	T_o (°C)	T_p(°C)	T_c(°C)	ΔH_{gel} (J/g)	T_{gel} (°C)	R
Susu Thai	45.54	59.51	65.26	8.20	61	19.72
Local *Susu*	64.17	71.10	78.56	1.02	72	14.39
Siding	63.72	72.01	80.81	1.22	73.5	17.09

To=onset temperature, Tp=peak temperature, R=gelatinization range (Tc–To); ΔH_{gel}=enthalpy of gelatinization

4.5 Morphological properties

Figure 4.2 below shows two different magnification which are 1000x on the left side and 5000x on the right side. On the left side, it shows the distribution and size of the granules. Also, on the right side, the pores of the granules can be seen clearly. When viewed under the scanning electron microscope, the endosperms of rice samples have relatively same morphology. This is due rice amyloplast produces compound granules consist several polyhedral and irregular-shaped granules (Yun & Kawagoe, 2010). From the proximate composition, glutinous rice is a type of rice that rich in protein content. Hence, the microstructure of protein bodies of glutinous rice kernel was disengaged from the starch particles leave very small dimples. Similar findings have also been reported by Kakar et al. (2019). Amyloplasts were round with different sizes but starch granules were spherical and gathered without airgaps which lead the way for normal accumulation structure (Tran et al., 2019).

Based on Figure 4.2, protein bodies were located around and on the surface of the amyloplasts. The amylose and amylopectin content influenced morphology of rice granule size and shape of the samples (Svegmark & Hermansson, 2001). For *Susu* Thai and *Siding* cultivar, shapes of the amyloplasts were clearly round and polyhedral. However, amyloplasts shape for local *Susu* were not very significant might due to its nature of cross-section. High amylose content were observed in *Susu*

Thai cultivar thus it gives large size of granules compared to *Siding* cultivar which low in amylose content gives small size of granules. Large granules observed in *Susu* Thai created closely packed in arrangement of granules could resulted in fast cooking time due to their high in amylose content and enthalpy of gelatinization. On the other hand, the pores observed on the 5000x magnification lens (right side) has positive correlation to the porosity. *Siding* has larger pores hence it resulted high in porosity rice grains.

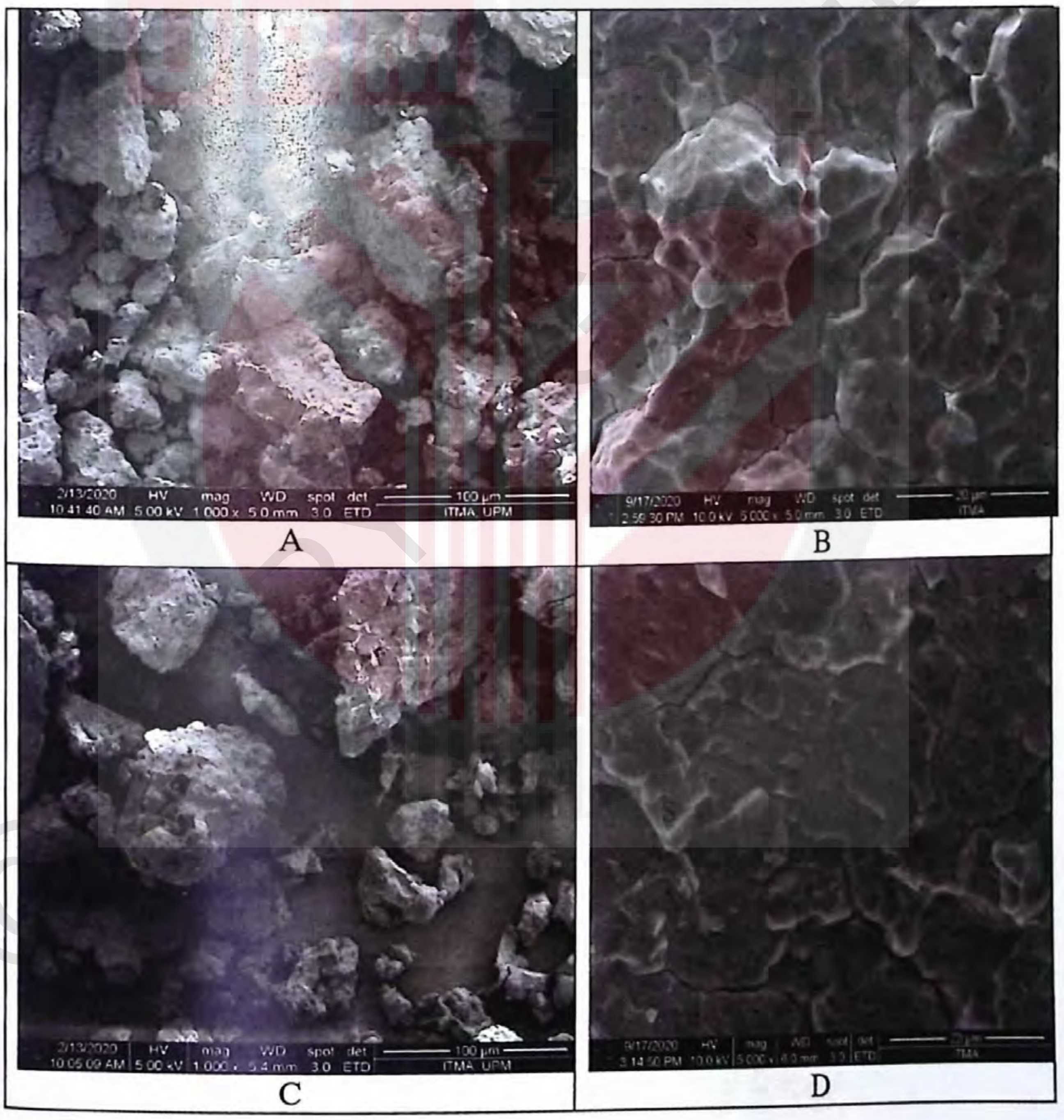


Figure 4.2: Scanning electron micrograms of different glutinous rice cultivars (A= Susu Thai , C= local Susu, E=Siding; 1000x magnification, B=Susu Thai, D=local Susu, F=Siding; 5000x magnification);A: amyloplast; S: Starch granules

4.6 Cooking properties

These three cultivars from different origin were analysed the cooking properties for the following parameters which are cooking time, water uptake ratio, cooked length to breadth (l/b), and elongation ratio.

4.6.1 Cooking time

The effect of different soaking time on cooking quality in terms of cooking time is shown in Table 4.11. Each samples were soaked at different soaking time of 0, 60, and 120 minutes. From Table 4.11, *Susu* Thai cultivar recorded the shortest cooking time ranging from 10.05 to 11.05 minutes then followed by local *Susu* cooking time ranging from 11.15 to 12.30 minutes and lastly *Siding* which are ranging from 11.20 to 12.45 minutes. However, cooking time showed significant different after soaking at 120 minutes of soaking ($P<0.05$). The reported result of *Siding* is within acceptable limit which is 13.0 minutes to literature reports (Husain, 1984). The cooking time was significantly decreased with increasing soaking time for three different cultivars. When the rice has been soaked it absorbs water, swelling and increasing in volume. The cracked granule formed disorganised cellular structure offers opportunity for fast diffusion of water and causes a decrease in cooking time (Lisle et al., 2000 ; Herath, et al., 2016). In addition, this result agreed with the the chemical properties where cooking time has strong correlation with amylose content; low amylose content (*Siding*) has longer cooking time. However, the cooking time for these three different cultivars shows no remarkable difference with each other within the same period of soaking time.

Table 4.11: Cooking time of different glutinous rice cultivar

Cultivar	Cooking time (min)		
	No soaking	60min soaking	120min soaking
Susu Thai	11.05±0.20[a]	10.20±0.15[a]	10.05±0.10[b]
Local *Susu*	12.30±0.15[a]	11.40±0.16[a]	11.15±0.10[b]
Siding	12.45±0.20[a]	11.40±0.18[a]	11.20±0.15[b]

Mean (±SD) with same letter in the same row do not differ significantly (P>0.05)

4.6.2 Water uptake ratio

Water uptake ratio is an important parameter while cooking rice. The weight of rice increases after cooking is due to water absorption by it during cooking process. The effect of water uptake ratio with different soaking period is shown in Table 4.12. Each samples were soaked at different soaking time of 0, 60, and 120 minutes. Local *Susu* recorded the highest water uptake ratio which both ranging from 1.83 to 2.18 then followed by *Susu* Thai ranging from 1.82 to 2.18 and lastly *Siding* cultivar which ranging from1.80 to 2.17. For three different glutinous rice cultivar, the water uptake ratio significantly decreases once the rice is being soaked. However, water uptake showed significant different once the rice has been soaked (P<0.05) for either local or imported cultivars. Factors affecting water absorption include the surface area, amylose and bulk density (Bett-Garber et al., 2007). These factors only gives medium to high correlation with each other. When bulk density and surface area of the rice grain is larger, it occupies more water for absorption thus increase in water uptake. On the other hand, water uptake ratio of local and imported *Susu* cultivars are in range to the glutinous rice reported by (Thomas et al., 2013) which is 2.20. While, the recorded result for *Siding* is within acceptable value of water uptake which reported by (Husain, 1984) which is 2.05.

Table 4.12: Water uptake of different glutinous rice cultivar

Cultivar	Water uptake ratio		
	No soaking	60min soaking	120min soaking
Susu Thai	1.82±0.00^{a}	2.18±0.01^{b}	2.15±0.01^{b}
Local *Susu*	1.83±0.01^{a}	2.18±0.02^{b}	2.16±0.00^{b}
Siding	1.80±0.01^{a}	2.17±0.00^{b}	2.10±0.00^{b}

Mean (±SD) with same letter in the same row do not differ significancly (P>0.05)

4.6.3 Cooked l/b

The effect of different of soaking time towards the cooked l/b is shown in Table 4.13. From Table 4.13, local *Susu* was observed has the highest l/b ratio of cooked rice ranging from 5.35 to 5.05. Then, followed by *Susu* Thai cultivar ranging from 4.83 to 4.61 and *Siding* ranging from 4.28 to 4.01. Cooked l/b has positive correlation with l/b ratio of raw rice grain and elongation ratio of cooked rice. This is because during cooking, the water is absorbed and volume expanded as well with the length. Thus, increase also in term of the elongation ratio because it correlated between raw and cooked rice length. The cooked l/b was significantly increase as soaking period increases for three different cultivars. Cooked l/b for no soaking parameter showed significant difference (P<0.05) between three different cultivar of glutinous rice. While, at 120 minutes of soaking period, it showed significant difference (P<0.05) in cooked l/b for both *Siding* and *Susu* cultivars. Cooked l/b of *Siding* cultivar has similar value reported by Thomas et al. (2013) of imported glutinous rice. Increase in either length or breadth can occur depending on the increase in volume during cooking and when water is absorbed (Danbana, 2011).

Table 4.13: Cooked l/b ratio of different glutinous rice cultivar

Cultivar	Cooked l/b		
	No soaking	60min soaking	120min soaking
Susu Thai	4.61±0.35[a]	4.74±0.21[a]	4.83±0.56[b]
Local *Susu*	5.03±0.24[a]	5.28±0.21[a]	5.35±0.59[b]
Siding	4.01±0.16[a]	4.18±0.34[a]	4.28±0.21[b]

Mean (±SD) with same letter in the same row do not differ significantly (P>0.05)

4.6.4 Elongation ratio

Based on Table 4.14, local *Susu* was observed has the highest l/b ratio of cooked rice ranging from 1.40 to 1.32. Then, followed by *Susu* Thai cultivar ranging from 1.35 to 1.30 and *Siding* ranging from 1.35 to 1.26. In addition, a positive correlation was also recorded by l/b ratio and cooked l/b in relation to elongation ratio of rice (Singh et al., 2005; Danbana et al., 2011). Elongation of rice significantly increases as soaking period increases for three different glutinous rice cultivars. From the result below, *Susu* and *Siding* cultivar showed significant different (P<0.05) after soaking at 120 minutes period. The longer soaking period, more significant difference resulted to the cooked rice. The recorded result for *Susu* Thai and local *Susu* is within acceptable range from 1.40 to 1.30 of elongation which reported by Danbana et al. (2011). Elongation ratio of rice is proportional to the cooked l/b which elongation ratio increases, cooked l/b increases.

Table 4.14: Elongation ratio of different glutinous rice cultivar

Cultivar	Elongation ratio		
	No soaking	60min soaking	120min soaking
Susu Thai	1.30±0.26[a]	1.32±0.33[a]	1.35±0.51[b]
Local *Susu*	1.32±0.08[a]	1.38±0.06[a]	1.40±0.13[b]
Siding	1.26±0.07[a]	1.32±0.15[a]	1.35±0.05[b]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.7 Correlation coefficient

Pearson correlation coefficients for relationships among three different glutinous rice cultivars have been shown in Table 4.15. Amylose content was negatively correlated with cooking time (r= -0.963, p<0.01). When the amylose content is lower, then correspondingly cooking time will be longer. Bulk density was found to be positively correlated with TWK (r= 0.86, p<0.05) and water uptake ratio (r= 0.82, p<0.01). Density is proportional to the mass of grain, so that bulk density increase resulted in increase in TWK. Water uptake ratio is an important parameter while cooking rice. If the bulk density is higher, then correspondingly water uptake will also be high. This has been attributed to the compact structure of a rice variety (Horigane et al., 2000). Another strong correlation was observed for volume with TWK (r= 0.74, p<0.05) and surface area (r= -0.79, p<0.05). Similar findings have also been reported by Varnamkhasti et al. (2008) . She said that higher rate of heat transfer highly attributed when material has small ratio of volume to surface area contact.

Next, L/B ratio was positively correlated with cooked L/B (r= 0.96, p<0.01). Increase in either length or breadth can occur depending on the increase in volume during cooking when water is absorbed. Elongation ratio has negatively strong correlation with cooking time (r= -0.77, p<0.01). This has been reported by Yadav et al. (2007) which he said that the cooking time influenced the increment volume and length of rice during cooking. On the other hand, another physicochemical parameters also showed small correlation but some had no correlation with cooking properties.

Table 4.15: Correlation coefficient for the relationship between physicochemical and cooking properties of three different cultivars of glutinous rice

	Amylose content	Bulk density	TWK	Surface area	Volume	L/B ratio	Cooked L/B	Elongation ratio	Cooking time	Water uptake ratio
Amylose content	1.00									
Bulk density	-0.209	1.00								
TWK	-0.251	**0.86***	1.00							
Surface area	-0.125	-0.219	0.426	1.00						
Volume	-0.155	0.328	**0.74***	**-0.79***	1.00					
L/B ratio	0.261	-0.171	-0.109	0.114	0.481	1.00				
Cooked L/B	0.098	-0.519	-0.542*	0.147	0.647	**0.96****	1.00			
Elongation ratio	0.441	0.414	-0.297**	0.015	0.066	0.58	0.603	1.00		
Cooking time	**-0.96****	-0.309	0.03	-0.56	-0.42	-0.495	-0.073	**-0.77****	1.00	
Water uptake ratio	0.654	**0.82****	0.52	0.653	-0.2	0.51	0.31	-0.219	0.27*	1.00

Bold letters indicate stronger Pearson correlation coefficients between the respective paramaters
*p<0.05 ; **p<0.01

4.8 Textural properties

4.8.1 Hardness

The effect of different soaking time on texture properties in terms of hardness is shown in Table 4.16. Each samples were soaked at different soaking time of 0, 60, and 120 minutes. Hardness is related to the strength of solid structure under compression and is the peak force during first cycle of compression (Chandra & Shamasundar, 2014). Based on Table 4.16, the hardness for *Susu* Thai is the highest ranging from 1154.7 to 1611.2 N followed by local *Susu* and *Siding* ranging from 1065.7 to 1248.4 N and 989.9 to 1289.5 N respectively. The hardness for each sample significantly decreases as soaking time increases. This is because during soaking, the amylose will leached out and causes granules swells and disintegrates. However, the hardness for each cultivars of glutinous rice showed significant different when soaking at different soaking period of time (P<0.05). As soaking time increases, the cooked rice produced much less firmer than that of the unsoaked rice. These result are in agreement with reported from Sareepuang et al. (2008). In addition, the highest of hardness in *Susu* Thai cultivar may be attributed to the high amylose content in the rice grain. This relationship similar as reported by Singh et al., (2003). He said that high amylose and long chain amylopectin can lead to hard texture, while low amylose can have a softer texture on cooking.

Table 4.16: Hardness of cooked glutinous rice cultivars at different soaking time

Cultivar	Hardness (N)		
	No soaking	60min soaking	120min soaking
Susu Thai	1611.2±4.80^{a}	1327.8±3.51^{b}	1154.7±3.50^{c}
Local *Susu*	1387.2±4.17^{a}	1248.4±3.20^{b}	1065.7±3.90^{c}
Siding	1289.5±4.90^{a}	1186.8±2.80^{b}	989.9±3.28^{c}

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.8.2 Adhesiveness

Adhesiveness is the property of sticking together or the joining of surfaces of different composition known as stickiness (Kasapis, 2009). The adhesiveness parameter in texture analysis for different glutinous rice cultivar is represented on Table 4.17. From Table 4.17, the maximum adhesiveness is observed from *Siding* cultivar which ranging from -1147.2 to -706.3 N.s followed by local *Susu* which its adhesiveness value ranging from -996.9 to -686.3 N.s. While, *Susu* Thai resulted in the minimum adhesiveness which ranging from -776.9 to-628.1 N.s. As soaking period increase, the adhesiveness for three different glutinous rice cultivars decreases. The adhesiveness for all of the glutinous rice cultivars showed remarkable differences ($P<0.05$) at different period of soaking time. Adhesiveness or stickiness is related to the amount of starch and starch gelatinization. Soaking produces a more compact arrangement of starch in the kernel and greater cohesion (Kato et al., 1993; Hapsari et al., 2016). Hence, adhesiveness has positive correlation to the cohesiveness. Soaking treatment is suggested to reduce the stickiness of rice after cooked. As soaking time increases, the cooked rice produced much less stickier than that of the unsoaked rice.

Table 4.17: Adhesiveness parameter of different glutinous rice cultivar

Cultivar	Adhesiveness (N.s)		
	No soaking	60min soaking	120min soaking
Susu Thai	-776.9±3.70[a]	-697.5±3.15[b]	-628.1±3.11[c]
Local *Susu*	-996.9±3.33[a]	-878.4±4.20[b]	-686.3±2.92[c]
Siding	-1147.2±4.10[a]	-765.9±3.92[b]	-706.3±3.01[c]

Mean (±SD) with same letter in the same column do not differ significantly ($P>0.05$)

4.8.3 Cohesiveness

Cohesiveness or consistency indicates the strength of internal bonds making up the body of food which here means the cooked rice and the degree to which the cooked rice grains can be deformed before it ruptures (Kasapis, 2009). The cohesiveness parameter in texture analysis for different glutinous rice cultivar is represented on Table 4.18. From Table 4.18, the highest value of cohesiveness is the highest for *Siding* cultivar ranging from 0.354 to 0.292 followed by local *Susu* ranging from 0.353 to 0.285. While, the lowest value of cohesiveness resulted by *Susu* Thai which ranging from 0.298 to 0.275.Based on the results, the cohesiveness of each samples significantly decreases as soaking time increases. However, it showed significant different (P<0.05) for these three cultivars at different period of soaking. In addition, cohesiveness has positive correlation with adhesiveness which they are highly relatable with sticking or pasting properties. Based on the result, the soaked rice produced much less cohesive and less sticky than unsoaked rice. This is due to the unsoaked rice retained the stronger kernel structure prevented loss of solid during cooking, resulting in higher cohesiveness of cooked rice. These results are on par with the observation made earlier by Hapsari et al. (2016).

Table 4.18: Cohesiveness parameter of different glutinous rice cultivar

Cultivar	Cohesiveness		
	No soaking	60min soaking	120min soaking
Susu Thai	0.298±0.02[a]	0.280±0.04[b]	0.275±0.06[c]
Local *Susu*	0.353±0.06[a]	0.336±0.01[b]	0.285±0.01[c]
Siding	0.354±0.03[a]	0.331±0.03[b]	0.292±0.04[c]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.8.4 Springiness

Table 4.19 shows texture quality of cooked rice in terms of springiness towards three different glutinous rice cultivar. Springiness could describe the initial compression that could destroy the gel structure (Tian et al., 2014). Based on Table 4.19, *Susu* Thai has the highest value of springiness ranging from 0.493 to 0.418 followed by local *Susu* and *Siding* cultivars which are ranging from 0.447 to 0.351 and 0.430 to 0.288 respectively. The springiness of the rice decreases as soaking time increases. From the results, it showed no significant different (P>0.05) for these three cultivar for no soaking and 60 minutes of soaking period. However, it showed significant different (P<0.05) during 120 minutes of soaking period. This may attributed from the physical changes of *Siding* after a long period of soaking since *Siding* has the shortest grain compared to *Susu* Thai and local *Susu* cultivar. Also, during soaking, the starch has swelled and started to leach out from the grain. High springiness generally shows a gel structure is broken into few big pieces during the first compression, whereas low springiness breaking into many small pieces (Huang et al., 2007). Moreover, high springiness requires more mastication or chewing energy in the mouth (Rahman, 2009). From the result, it shows that local *Susu* and *Siding* cultivars broke into small pieces in the mouth compared to *Susu* Thai cultivar.

Table 4.19: Springiness parameter of different glutinous rice cultivar

Cultivar	Springiness		
	No soaking	60min soaking	120min soaking
Susu Thai	0.493±0.09[a]	0.470±0.03[a]	0.418±0.02[b]
Local *Susu*	0.447±0.05[a]	0.389±0.12[a]	0.351±0.05[b]
Siding	0.430±0.04[a]	0.365±0.08[a]	0.288±0.03[b]

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

4.8.5 Chewiness

Chewiness is a measure of energy required to masticate or chewing the food and is normally reported for solid foods. Chewiness is defined as the product of hardness, cohesiveness, and springiness (Chandra & Shamasundar, 2014). The chewiness parameter in texture analysis for different glutinous rice cultivar is represented on Table 4.20. From Table 4.20, *Susu* Thai resulted the highest of chewiness value which is ranging from 234.5 to 127.5 N followed by local *Susu* and *Siding* ranging from 211.9 to 114.9 N and 168.7 to 116.2 N respectively. From the results, the chewiness value for each cultivar decreases as soaking period increases. The longer soaking period resulted less chewy of cooked rice. However, it showed significant different (P<0.05) for these three cultivars once the rice had been soaked. This results is corresponded with the springiness, cohesiveness, and hardness since they are in relationship with these three parameters. In addition, chewiness is another important texture parameter of cooked rice to measure the acceptability for people preference of cooked glutinous rice. Thus, *Susu* Thai required high mastication energy to chew the rice compared to local *Susu* and *Siding* cultivars.

Table 4.20: Chewiness parameter of different glutinous rice cultivar

Cultivar	Chewiness (N)		
	No soaking	60min soaking	120min soaking
Susu Thai	234.5±1.21^{a}	153.3±1.28^{b}	127.5±1.03^{b}
Local *Susu*	211.9±1.20^{a}	134.1±1.70^{b}	114.9±1.16^{b}
Siding	168.7±1.61^{a}	139.1±1.47^{b}	116.2±1.18^{b}

Mean (±SD) with same letter in the same column do not differ significantly (P>0.05)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Different cultivar of glutinous rice have different composition and properties in term of its physical, thermal, morphological, and also cooking properties. Hence, it gives different in texture properties result which it is important to validate consumer acceptance towards the cooked rice.

The first objective has been achieved which from its physical appearance, the local *Susu* cultivar is superior as imported glutinous rice cultivar. But for different type of cultivar, *Siding* cultivar has significantly shorter in length compared to *Susu cultivar*. *Susu* Thai resulted the highest in amylose content and enthalpy thus have a short in cooking time. In term of its proximate analysis, these three cultivars did not showed much significant difference since they are from the same group of rice type. This proved that local glutinous rice cultivar is on par with imported glutinous rice cultivar.

Next, customer acceptance on convenience food of short cooking time has been attributed to *Susu* Thai but it resulted in firmer texture and less stickier due to its high in amylose content. Due to soaking treatment, the glutinous rice becomes fluffy as the hardness of cooked rice is decreases as soaking time increases. But, soaking and no soaking treatment showed not much different in cooking time. Thus, it is suggested to soak the rice before cook to short the cooking time and experience much fluffy and soft texture of glutinous rice.

5.2 Recommendations

As recommendations or suggestions for future studies, the analysis for essential mineral content such as Na, K, Zn, Ca can be determined to acknowledge more benefits from the glutinous rice. Further research on free amino acid content is also recommended to analyse the good amino acid in the glutinous rice since protein constituted second highest amount in the proximate analysis.

Furthermore, some extensive research on value added such as study on the behaviour of cooked glutinous rice when adding coconut milk since this is the malay cuisines normal practice. Also, it is recommended to explore on black glutinous rice as it is one of the popular variety that consume by majority people in Malaysia.

Besides, varying on the treatment for the cooking method of glutinous rice could help such as steaming method. This is because steaming gives more fluffy rice rather than cooking method and also sensory test helps to determine kinetic studies of cooking glutinous rice and at the same time acceptability of consumers regarding to the method of cooking glutinous rice.

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APPENDICES

Appendix 1 Dimension of rice grain

Sample	***Susu* Thai**				**Local *Susu***				***Siding***			
Grain No.	Length (mm)	Width (mm)	Thickness (mm)	Breadth (mm)	Length (mm)	Width (mm)	Thicknes s (mm)	Breadth (mm)	Length (mm)	Width (mm)	Thicknes s (mm)	Breadth (mm)
1	7	1.9	1.5	1.688	7	1.9	1.6	1.7436	6.8	2	1.6	1.789
2	6.2	2	1.3	1.613	6.6	2	1.5	1.7321	6.7	2	1.5	1.732
3	6.9	2	1.5	1.732	6.8	1.8	1.5	1.6432	6.5	2	1.5	1.732
4	6.5	1.9	1.5	1.688	6.6	1.9	1.5	1.6882	5.4	1.9	1.3	1.572
5	6.6	1.9	1.4	1.631	6.7	1.9	1.6	1.7436	6.7	1.8	1.7	1.749
6	6.6	2	1.5	1.732	6.3	1.7	1.5	1.5969	6.3	2	1.5	1.732
7	6.5	2	1.5	1.732	6.5	1.8	1.3	1.5297	5.8	2.1	1.5	1.775
8	6.5	2.1	1.3	1.652	6.5	1.9	1.5	1.6882	6.2	2	1.5	1.732
9	7	1.9	1.6	1.744	7	1.9	1.5	1.6882	6.5	1.9	1.6	1.744
10	6.1	2	1.4	1.673	6.5	1.9	1.5	1.6882	6.2	2.1	1.4	1.715
11	6.7	2	1.6	1.789	6.1	1.9	1.4	1.6310	6.5	2	1.5	1.732
12	6.4	1.9	1.4	1.631	6.9	1.8	1.5	1.6432	6.4	2	1.5	1.732
13	6	2.1	1.4	1.715	6.6	1.7	1.5	1.5969	6.3	2	1.4	1.673
14	7	2.2	1.6	1.876	6.6	1.8	1.5	1.6432	5.4	2	1.4	1.673
15	6.4	2	1.5	1.732	6.4	1.9	1.4	1.6310	6.5	2	1.5	1.732
16	6.6	2	1.5	1.732	6.7	1.8	1.5	1.6432	5.5	2	1.3	1.613
17	6.5	1.9	1.5	1.688	6.6	1.9	1.6	1.7436	6.5	2.1	1.6	1.833
18	6.6	2	1.5	1.732	6.7	2.1	1.5	1.7748	6	2	1.4	1.673
19	6.6	1.8	1.5	1.643	6.4	1.9	1.5	1.6882	6.1	1.8	1.5	1.643
20	6.6	2	1.4	1.673	7	2	1.5	1.7321	6.4	1.9	1.4	1.631
Average	**6.565**	**1.98**	**1.47**	**1.7048**	**6.625**	**1.875**	**1.495**	**1.6734**	**6.235**	**1.98**	**1.48**	**1.7103**

Appendix 2 Physical parameters of glutinous rice cultivars

Sample	***Susu* Thai**				**Local *Susu***				***Siding***			
Grain No.	L/B ratio	Surface area (mm^2)	Aspect ratio	Sphericity (%)	L/B ratio	Surface area (mm^2)	Aspect ratio	Sphericity (%)	L/B ratio	Surface area (mm^2)	Aspect ratio	Sphericity (%)
1	4.146	21.111	0.27	0.387	4.014	21.902	0.27	0.396	3.801	22.004	0.29	0.411
2	3.845	18.053	0.32	0.407	3.810	20.671	0.30	0.410	3.868	20.937	0.29	0.406
3	3.984	21.470	0.29	0.398	4.138	19.966	0.26	0.388	3.753	20.406	0.30	0.414
4	2.369	19.812	0.29	0.407	3.909	1.448	0.28	0.403	3.436	15.603	0.35	0.439
5	3.066	19.295	0.28	0.394	3.842	21.097	0.28	0.408	3.830	21.177	0.26	0.409
6	3.464	20.671	0.30	0.410	3.945	18.098	0.27	0.401	3.637	19.875	0.31	0.423
7	4.042	20.406	0.30	0.414	4.249	17.704	0.27	0.381	3.268	19.093	0.36	0.454
8	4.842	19.329	0.32	0.401	3.850	19.812	0.29	0.407	3.580	19.610	0.32	0.427
9	3.162	21.902	0.27	0.396	4.146	21.111	0.27	0.387	3.728	20.562	0.29	0.416
10	2.976	18.585	0.32	0.422	3.850	19.812	0.29	0.407	3.616	19.381	0.33	0.424
11	4.149	21.730	0.29	0.415	3.740	18.041	0.31	0.415	3.753	20.406	0.30	0.414
12	3.358	18.793	0.29	0.402	4.199	20.219	0.26	0.384	3.695	20.140	0.31	0.418
13	3.582	18.857	0.35	0.434	4.133	18.831	0.25	0.388	3.765	19.098	0.31	0.413
14	3.462	23.825	0.31	0.416	4.017	19.459	0.27	0.396	3.227	16.798	0.37	0.458
15	4.660	20.140	0.31	0.418	3.924	18.792	0.29	0.402	3.753	20.406	0.30	0.414
16	3.238	20.671	0.30	0.410	4.077	19.712	0.26	0.392	3.411	16.326	0.36	0.441
17	4.070	19.812	0.29	0.407	3.785	20.829	0.28	0.412	3.546	21.791	0.32	0.430
18	3.392	20.671	0.30	0.410	3.775	21.533	0.31	0.412	3.586	18.329	0.33	0.427
19	3.563	19.460	0.27	0.396	3.791	19.552	0.29	0.411	3.712	18.198	0.29	0.417
20	3.952	19.869	0.30	0.401	4.041	21.736	0.28	0.394	3.924	18.793	0.29	0.402
Average	**3.583**	**22.0230**	**0.302**	**0.407**	**3.820**	**20.216**	**0.283**	**0.400**	**3.165**	**19.4465**	**0.319**	**0.423**

	Bulk density (kg/m^3)		
Reading	***Susu* Thai**	**Local *Susu***	***Siding***
1	771.92	799.42	768.77
2	774.55	799.07	765.15
3	771.17	801.6	767.28
4	773.10	801.15	769.15
5	772.91	801.47	765.75
Average	**772.73**	**800.542**	**767.22**

	True density (kg/m^3)		
Reading	***Susu* Thai**	**Local *Susu***	***Siding***
1	1232.6	1503.5	1209.4
2	1234.4	1497.6	1208.3
3	1233.7	1498.6	1202.8
4	1237.4	1502.2	1207.3
5	1235.2	1503.9	1206.7
Average	**1234.733**	**1500.36**	**1206.21**

Sample	***Susu* Thai**			**Local *Susu***			***Siding***		
Reading	L*	a*	b*	L*	a*	b*	L*	a*	b*
1	69.96	-0.72	9.16	68.78	-1.18	7.95	72.97	-0.91	8.15
2	65.23	-0.83	9.06	69.86	-1.03	7.52	75.38	-0.87	8.29
3	66.86	-0.2	7.75	71.31	-0.84	6.24	72.9	-1.27	8.62
Average	67.35	-0.5833	8.6567	69.983	-1.0167	7.23667	73.75	-1.0167	8.353

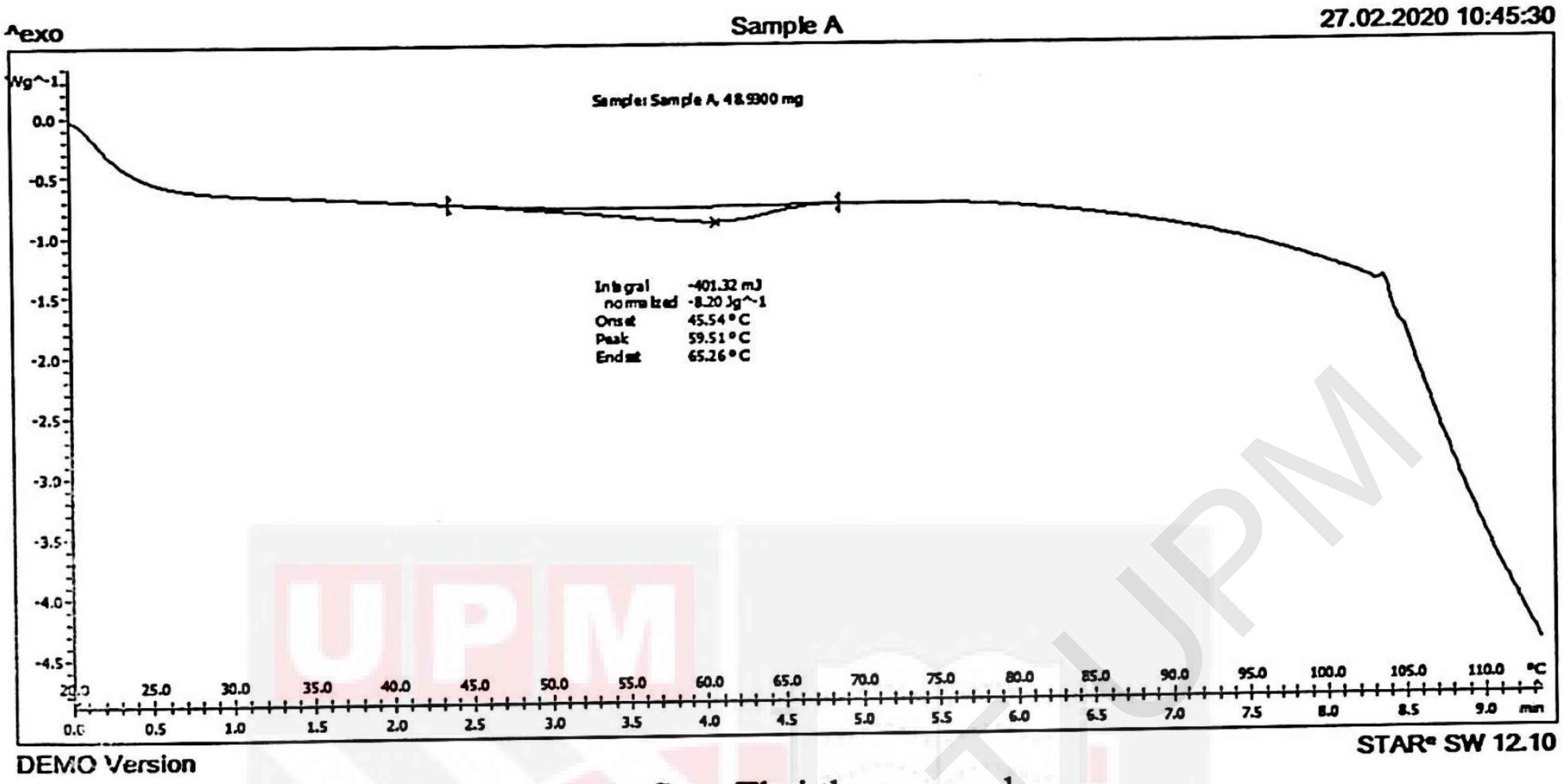
Appendix 3 Moisture analysis of glutinous rice cultivars

Sample	***Susu* Thai**			
	A1	A2	A3	Avg
Weight empty crucible	60.643	65.836	64.672	
Weight sample initial	3.014	3.003	3.005	
Weight final	63.2977	68.5237	67.3503	
Weight sample final	2.6547	2.6877	2.6783	
Moisture wet basis (%)	0.119210352	0.104995005	0.108718802	**11.09747**
Moisture dry basis (%)	0.13534486	0.1173122	0.121980361	**12.48791**

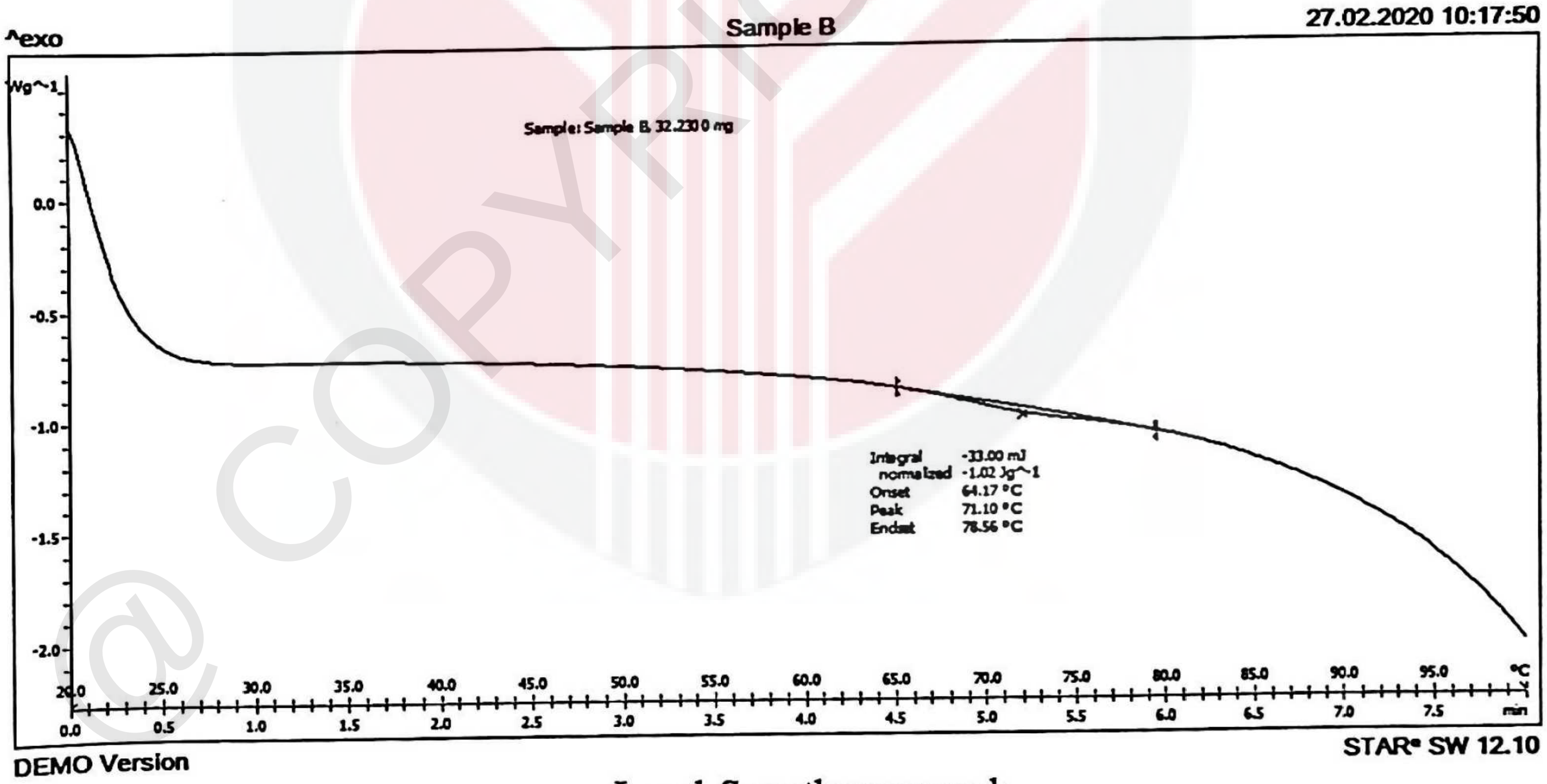
Sample	**Local *Susu***			
	B1	B2	B3	Avg
Weight empty crucible	56.74	62.6	58.06	
Weight sample initial	3.007	3.006	3.008	
Weight final	59.5063	65.3223	60.784	
Weight sample final	2.7663	2.7223	2.724	
Moisture wet basis (%)	0.080046558	0.094377911	0.094414894	**8.961312**
Moisture dry basis (%)	0.087011532	0.104213349	0.104258443	**9.849444**

Sample	***Siding***			
	C1	C2	C3	Avg
Weight empty crucible	60.403	67.843	60.217	
Weight sample initial	3.004	3.008	3.005	
Weight final	63.0927	70.523	62.906	
Weight sample final	2.6897	2.68	2.689	
Moisture wet basis (%)	0.104627164	0.109042553	0.10515807	**10.62759**
Moisture dry basis (%)	0.116853181	0.12238806	0.117515805	**11.8919**

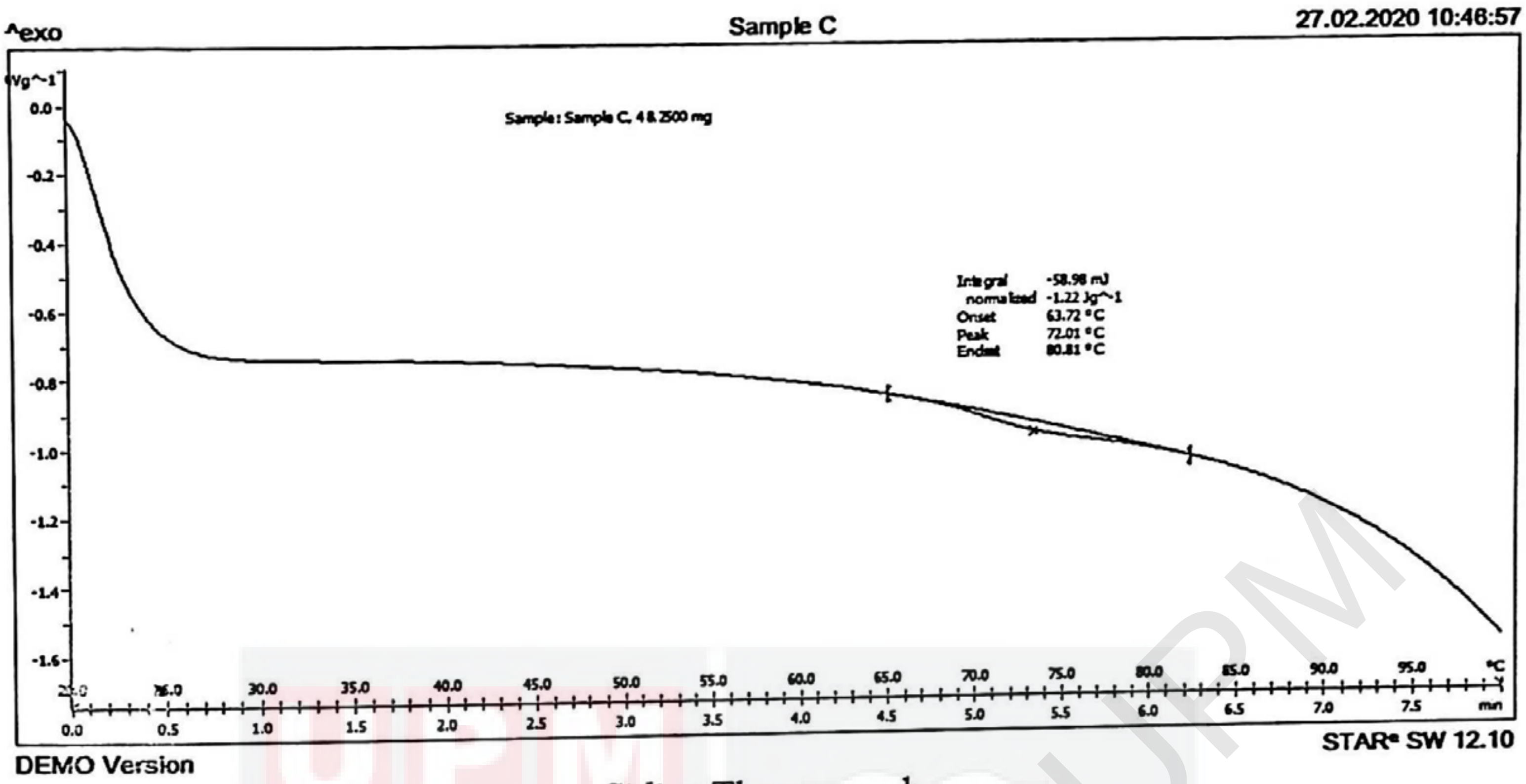
Appendix 4 Thermographs of glutinous rice cultivars



Susu Thai thermograph



Local *Susu* thermograph



Siding Thermograph

Appendix 5 Textural properties of cooked rice

***Susu* Thai**				
		No soaking	60 min soaking	120 min soaking
Hardness	1st	1615.685	1325.984	1153.899
	2nd	1606.658	1328.082	1157.144
	3rd	1611.338	1329.371	1152.944
	Average	**1611.185**	**1327.817**	**1154.662**
	Std deviation	**4.789**	**3.509**	**3.501**
Adhesiveness	1st	-774.703	-699.398	-629.147
	2nd	-779.820	-693.770	-624.41
	3rd	-773.958	-694.741	-628.137
	Average	**-776.940**	**-697.471**	**-628.108**
	Std deviation	**3.701**	**3.151**	**3.109**
Springiness	1st	0.398	0.437	0.412
	2nd	0.514	0.491	0.445
	3rd	0.568	0.483	0.398
	Average	**0.493**	**0.470**	**0.418**
	Std deviation	**0.0868**	**0.0291**	**0.0242**
Cohesiveness	1st	0.282	0.326	0.35
	2nd	0.274	0.282	0.219
	3rd	0.279	0.295	0.279
	Average	**0.298**	**0.280**	**0.275**
	Std deviation	**0.023**	**0.040**	**0.060**
Chewiness	1st	233.66	155.05	127.77
	2nd	235.90	154.99	125.97
	3rd	233.85	152.61	128.01
	Average	**234.47**	**153.32**	**127.52**
	Std deviation	**1.211**	**1.283**	**1.028**

Local *Susu*				
		No soaking	60 min soaking	120min soaking
Hardness	1st	1390.286	1249.937	1063.410
	2nd	1389.269	1249.818	1068.265
	3rd	1383.067	1245.391	1064.209
	Average	**1387.807**	**1248.382**	**1065.710**
	Std deviation	**4.780**	**3.209**	**3.899**
Adhesiveness	1st	-998.363	-892.402	-685.610
	2nd	-996.34	-881.258	-686.211
	3rd	-993.28	-874.675	-689.761
	Average	**-996.997**	**-878.445**	**-686.310**
	Std deviation	**3.326**	**4.201**	**2.921**
Springiness	1st	0.498	0.368	0.311
	2nd	0.392	0.301	0.335
	3rd	0.395	0.321	0.408
	Average	**0.447**	**0.389**	**0.351**
	Std deviation	**0.051**	**0.021**	**0.050**
Cohesiveness	1st	0.266	0.351	0.278
	2nd	0.275	0.329	0.281
	3rd	0.334	0.329	0.309
	Average	**0.353**	**0.3363**	**0.2853**
	Std deviation	**0.034**	**0.0127**	**0.014**
Chewiness	1st	213.014	133.775	113.927
	2nd	210.098	135.421	115.061
	3rd	212.675	132.094	114.925
	Average	**211.928**	**134.097**	**114.971**
	Std deviation	**1.203**	**1.692**	**1.158**

Siding				
		No soaking	60 min soaking	120min soaking
Hardness	1st	1289.311	1185.201	981.766
	2nd	1289.944	1188.012	987.115
	3rd	1269.198	1184.121	999.311
	Average	**1289.484**	**1186.801**	**989.321**
	Std deviation	**4.918**	**2.7890**	**3.2801**
Adhesiveness	1st	-1145.165	-762.091	-703.211
	2nd	-1151.457	-768.213	-709.432
	3rd	-1143.785	-763.019	-704.101
	Average	**-1147.190**	**-765.906**	**-706.331**
	Std deviation	**4.109**	**3.919**	**3.011**
Springiness	1st	0.389	0.442	0.310
	2nd	0.471	0.289	0.259
	3rd	0.421	0.375	0.315
	Average	**0.430**	**0.365**	**0.288**
	Std deviation	**0.041**	**0.079**	**0.030**
Cohesiveness	1st	0.32	0.307	0.287
	2nd	0.382	0.322	0.314
	3rd	0.36	0.362	0.261
	Average	**0.354**	**0.331**	**0.292**
	Std deviation	**0.031**	**0.028**	**0.041**
Chewiness	1st	167.060	139.616	115.611
	2nd	170.211	135.579	117.37
	3rd	169.871	140.012	115.615
	Average	**168.673**	**139.069**	**116.198**
	Std deviation	**1.6098**	**1.474**	**1.180**