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Review Paper

Comparative study of grain quality characteristics of some selected traditional and improved rice varieties in Sri Lanka: A review

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Abstract: Consumer acceptability and market demand in rice (*Oryza sativa* L.) are mainly determined by its grain quality. Therefore, the main aim of the present analytical review was to evaluate some selected traditional and improved rice varieties in Sri Lanka for their grain quality characteristics that include physical, physico-chemical, milling, cooking and eating and nutritional properties. Information from higher number of traditional varieties than that of improved varieties was used in the review as existing number of traditional varieties is about ten times higher than that of improved varieties in the country. Most of the traditional rice varieties are red with short to medium size grains having round and bold shape. Most of the improved rice varieties are white with long to medium-size grains having either round, bold, or internationally acceptable slender shapes. The total milling recoveries of both traditional and improved rice varieties are more or less similar and are in the range of 69-74%. Nutritional value of rice is influenced by genotype, soil and environmental condition under which the rice is grown as well as postharvest processing and storage condition and also degree of milling influences on the end-use nutritional quality. Both the cooking and eating quality and nutritional properties varied within traditional as well as within improved varieties. Total carbohydrate content of almost all of the improved rice varieties is higher except in the improved variety Bg 360 than that of the traditional varieties studied. Available data on grain protein, crude fat and crude fiber contents of traditional and improved rice varieties are significantly varying and inconsistent within and between traditional and improved rice varieties. The majority of the traditional and improved rice varieties belong to high amylose class, however, improved rice variety At 405 recorded the lowest amylose content and several traditional rice varieties recorded intermediate amylose content. Both traditional and improved rice varieties showed a similar swelling power. Though the swelling power of rice grains has shown a negative linear relationship with grain amylose content in general, a positive linear relationship between those two characteristics has been observed between improved and traditional rice varieties in Sri Lanka.

Keywords: Grain quality characteristics, improved and traditional varieties, rice, Sri Lanka

Introduction

Rice (*Oryza sativa* L.), the staple food in Sri Lanka, is grown all over the country over both wet (*Maha*) and dry (*Yala*) seasons under all agro climatic conditions. It remains as the major source of calories and protein for Sri Lankans (Mendis, 2006). The annual per capita consumption (114 kg) of rice plays a major role in providing energy, protein and fat for the whole Sri Lankan population (Prasantha *et al.*, 2014; Rebeira *et al.*, 2014). Although the rice contains comparatively less protein content than that of other cereals, rice comprises the highest digestible protein and has relatively a good balance of amino acids (Liyanaarachchi *et al.*, 2021).

Rice cultivation in Sri Lanka dates back to about 3000 years ago and about 600 traditional rice varieties had been cultivated by Sri Lankan farmers in the past. Traditional rice varieties have naturally evolved to a considerable level so that some of them fit better to different agro-ecological conditions such as drought, submergence, salinity and iron toxicity than newly improved rice varieties. In addition, traditional rice has more variability in grain nutrition, texture, appearance and the aroma in cooked rice (Rohman *et al.*, 2014) and this may be due to about 10 times bigger population size and long exposure to natural selection of traditional varieties compared to that of improved varieties. Grain yield of traditional varieties is very much lower than that of improved varieties because improved varieties have been bred purposely for high grain yields with acceptable grain quality. However, except yield differences both traditional and improved rice cultivars perform equally well in rice processing.

Though, some traditional rice varieties are believed to be good in health properties *viz.* low glycemic index, high antioxidant activity high fiber content (Abeysekera *et al.*, 2017a; 2017b; Prasantha, 2018), few studies have been conducted to prove the nutritional quality of traditional rice over-improved rice.

It is a well-known fact that red pigmented traditional rice varieties have received higher market demand due to retention of fully or some amount of pigmented bran layer on the grain even after milling. Rice millers purposely apply less degree of polishing for pigmented rice than white rice during milling to retain the pigment. Rice grains with intact bran contains comparatively higher nutrients, such as dietary fat, fiber, minerals and vitamins as well as health-promoting bioactive phytochemicals such as phenolics, flavonoids, γ-oryzanol, tocopherols, ferulic acid, phytic acid and tocotrienols (Reddy *et al.*, 2017) than full milled white rice. However, most of the improved rice varieties are white. Therefore, some interest in growing and consuming traditional rice over improved rice across the country could be observed over last 5 years (Ginigaddara and Disanayake, 2018; Priya *et al.*, 2019).

Improved rice varieties have been genetically improved with the objectives of increase in grain yield with resistance to pests and diseases and acceptable grain quality. They are also resistant to lodging as their plant height is short with erect leaves. In addition, improved rice varieties are highly responsive to added fertilizer (Wickramasekara, 1980; Ekanayake, 2009) and their milled rice yield is comparatively higher than traditional rice.

Consumer acceptability and market value of rice are dependent on various quality traits such as physical, milling, cooking, eating and nutritional qualities. The amount of grain amylose and amylopectin, physical and physico-chemical properties such as gelatinization temperature etc. and also nutritional composition which includes carbohydrate, protein, fat, crude fiber and ash contents vary among the traditional as well as improved rice varieties (Rebeira *et al.*, 2014). Grain whiteness, grain size, grain shape, grain hardness, head rice yield and gelatinization characteristics and cooking time significantly affect the consumer preference in the market (Hettiarachchi *et al.*, 2016; Nirmaan *et al.*, 2020). In addition, nutritional properties also cause significant influence on the consumer preference due to their effect on human health. Studies on grain quality attributes of traditional and improved rice varieties are required for further improvement in rice grain quality and to meet the increasing demand for rice with superior grain quality.

The main concern of the consumer is to have rice varieties with superior grain quality in terms of their cooking and eating quality attributes, which in turn largely depends on physico-chemical and cooking properties of milled rice (Bhattacharjee *et al.*, 2002). Therefore, the present review was made to evaluate the variability of rice grain quality characteristics within and between traditional and improved rice varieties grown in Sri Lanka in order to provide important information for future rice breeding programs, rice marketing agencies as well as for rice consumers.

Grain Quality Characteristics

<u>Color, size and shape</u>:
Pericarp color and grain size and shape of traditional and improved rice varieties in Sri Lanka are presented in Table 1. Rice varieties have been classified in the local market based on the color, size and shape of the rice grain. Anthocyanin and proanthocyanidine are the main pigments responsible for pericarp color in rice. Red color grains are produced by anthocyanin in the pericarp and white color grains are produced by proanthocyanidins in the pericarp (Somaratne *et al*., 2017). Preference for rice is mostly dependent on the color of the rice grain. Most of the traditional varieties have red pigment in the pericarp (rice bran) except few white pericarp rice varieties such as *Suwandel*, *Gonabaru*, *Suduru Samba*, *Iginimittiya*, *Rathal*, and *Dular* (Rebeira *et al*., 2014; Hettiarachchi *et al*., 2016; Abeysekera *et al*., 2017a; 2017b; Hafeel *et al*., 2020), but most of the improved rice varieties have white pericarp (Hettiarachchi *et al*., 2016; Hafeel *et al*., 2020). Traditional rice is generally but partially polished to retain the red pigment on the grain whereas white pericarp rice is purposely and completely polished for better appearance.

Grain size which is determined by the kernel length is an important parameter in classifying rice (Nirmaan *et al*., 2020). Previous studies have shown that the length of the rice kernel was in the range of 3.76-6.82 mm regardless of whether traditional or improved (Table 1) (Hafeel *et al*., 2008; Rebeira *et al*., 2014; Hettiarachchi *et al*., 2016; Thilakarathna *et al*., 2017; Prasantha *et al*., unpublished data). The highest and lowest kernel lengths were recorded by At 306 and Bw 272-6b in the improved varieties and by *Dik Wee* and *Rathal*, in the traditional varieties, respectively.

Based on the kernel length, rice is categorized into three groups namely short grain (5.5 mm), medium-grain (5.5-6.3 mm) and long-grain (6.4-7.4 mm) rice in the market (Hettiarachchi *et al*., 2016; Samaranayake *et al*., 2017). According to the grain size and shape, most of the traditional rice varieties can be categorized as medium or short bold while *Dik Wee* and *Iginimitiya* were the only traditional rice varieties that can be categorized as medium slender. Previous studies have also reported that in most of the traditional varieties grain length is smaller than that of improved varieties and grain size can be categorized either under short or medium whereas in improved varieties, grain size can be categorized under either short, medium or long (Hettiarachchi *et al*., 2016; Thilakarathna *et al*., 2017). Thus, mostly the red pericarp short or medium grain is a characteristic feature of local traditional rice. In the local market, small (short round) grains are named as "*Samba*" and medium bold grains are categorized as "*Nadu*" (Pathiraje *et al*., 2010).

The grain width of rice varieties is in the range of 1.61-2.87 mm but the highest and the lowest widths are observed in the traditional rice variety *Kahawanu* and improved rice variety At 405, respectively (Table 1). The grain thickness of different rice varieties though not shown in Table 1, is almost the same for both traditional and improved rice, but the traditional variety *Kahawanu* showed the highest thickness when compared to all the other recorded rice varieties (Thilakarathna *et al*., 2017). The Length: width ratio of the rice kernel is the indicator of the grain shape which can be categorized as round (<2.0), bold (2.0-3.0) and slender (>3.0) (Samaranayake *et al*., 2017). Several studies have revealed that most of the traditional rice varieties could be categorized into round and bold shape grains except varieties Iginimitiya and *Dik Wee* (length: width ratio >3 mm) but improved rice varieties could be categorized into all three shapes viz. round, bold and slender shape grains (Rebeira *et al*., 2014; Hettiarachchi *et al*., 2016; Thilakarathna *et al*., 2017; Abeysekera *et al*., 2017a). Improved rice varieties with Basmati type grains (At 306 and At 405) are long-slender in shape which is not found among traditional varieties (Hettiarachchi *et al*., 2016).

<u>Grain weight, volume and bulk density:</u>
Grain weight, volume and bulk density of traditional and improved rice varieties are presented in Table 2. The traditional rice variety *Herathbanda* showed the highest grain weight followed by *Sulai* and *Kahata Wee*. Among the improved rice varieties, Bg 94-1 showed the highest grain weight. However, among all recorded traditional and improved rice varieties, *Suduru Samba* showed the lowest grain weight (Hettiarachchi *et al*., 2016). Grain weight of rice depends on its volume and bulk density.

Table 1: Pericarp color and grain size and shape of traditional and improved rice varieties in Sri Lanka.

Rice Variety	Pericarp color	Length (mm)	Grain size	Width (mm)	Length/ width ratio	Grain shape
Traditional rice varieties						
Sudu Heenati	Red	5.7 ± 0.12*	Medium	2.31 ± 0.24*	2.47	Bold
Iginimitiya	White	5.78 ± 0.02	Medium	1.7 ± 0.10	3.4	Slender
Kahamaala	Red	5.64 ± 0.16	Medium	2.33 ± 0.11	2.42	Bold
Maa Wee	Red	5.64 ± 0.06	Medium	2.14 ± 0.02	2.64	Bold
Pokkali	Red	5.60 ± 0.05	Medium	2.22 ± 0.01	2.52	Bold
Kahata Wee	Red	5.47 ± 0.23	Medium	2.26 ± 0.11	2.42	Bold
Madathawalu	Red	5.25 ± 0.52	Medium	2.35 ± 0.12	2.23	Bold
Dik Wee	Red	5.60 ± 0.13	Medium	1.81 ± 0.10	3.10	Slender
Sudu Heenati	Red	5.62 ± 0.10	Medium	2.48 ± 0.10	2.27	Bold
Herathbanda	Red	5.47 ± 0.15	Short	2.34 ± 0.15	2.26	Bold
Deveraddiri	Red	5.45 ± 0.02	Short	2.58 ± 0.14	2.11	Bold
Dular	White	5.38 ± 0.05	Short	2.12 ± 0.02	2.54	Bold
Wannidahanala	Red	5.44 ± 0.05	Short	2.30 ± 0.13	2.28	Bold
Sulai	Red	5.46 ± 0.20	Short	2.48 ± 0.28	2.20	Bold
Pachchaperumal	Red	5.39 ± 0.24	Short	2.30 ± 0.06	2.34	Bold
Kalu Heenati	Red	5.38 ± 0.33	Short	2.28 ± 0.02	2.36	Bold
Kuruluthuda	Red	5.20 ± 0.04	Short	2.4 ± 0.01	2.17	Bold
Gonabaru	White	5.38 ± 0.31	Short	2.16 ± 0.25	2.49	Bold
Hondarawalu	Red	5.40 ± 0.48	Short	2.36 ± 0.09	2.29	Bold
Rathna Samba	Red	4.45 ± 0.11	Short	2.07 ± 0.14	2.15	Bold
Hangimuttan	Red	4.26 ± 0.16	Short	2.14 ± 0.13	1.99	Round
Kahawanu	Red	4.26 ± 0.16	Short	2.87 ± 0.09	1.48	Round
Unakola Samba	Red	4.21 ± 0.18	Short	2.16 ± 0.09	1.95	Round
Suwandel	White	4.02 ± 0.21	Short	2.10 ± 0.13	1.91	Round
Rath Suwandel	Red	5.32 ± 0.01	short	2.44 ± 0.01	2.18	Bold
Suduru Samba	White	3.85 ± 0.30	Short	1.65 ± 0.10	2.33	Bold
Masuran	Red	3.89 ± 0.1	Short	2.27 ± 0.15	2.13	Round
Rathal	White	3.76 ± 0.11	Short	1.93 ± 0.02	1.95	Round
Rathu Heenati	Red	4.44 ± 0.01	Short	2.46 ± 0.04	1.81	Round
Beheth Heenati	Red	4.44 ± 0.10	Short	2.26 ± 0.01	1.87	Round
Improved rice varieties						
At 306	White	6.82 ± 0.03	Long	1.63 ± 0.20	4.18	Slender
At 405	White	6.53 ± 0.05	Long	1.61 ± 0.01	4.05	Slender
Bg 94-1	White	6.19 ± 0.02	Long	1.90 ± 0.01	3.24	Slender
Bg 300	White	5.71 ± 0.25	Medium	2.54 ± 0.09	2.24	Bold
Bg 352	White	5.60 ± 0.11	Medium	2.63 ± 0.08	2.12	Bold
Bg 366	White	5.51 ± 0.20	Medium	2.44 ± 0.12	2.25	Bold
At 307	White	5.51 ± 0.19	Medium	2.57 ± 0.15	2.14	Bold
Bg 358	White	4.19 ± 0.14	Short	2.36 ± 0.15	1.77	Round
Bg 360	White	4.15 ± 0.19	Short	2.09 ± 0.09	1.98	Round
Bw 367	White	4.11 ± 0.13	Short	2.54 ± 0.12	1.61	Round
Bw 267-3	White	3.97 ± 0.01	Short	2.06 ± 0.01	1.92	Bold
Bw 272-6b	Red	3.95 ± 0.03	Short	2.06 ± 0.01	1.92	Bold

*Mean ± Standard deviation

Sources: Hafeel *et al*. (2008); Rebeira *et al*. (2014); Hettiarachchi *et al*. (2016); Thilakarathna *et al*. (2017); Abeysekera *et al*. (2017a); Hafeel *et al*. (2020).

Grain weight, volume and bulk density:

The traditional rice variety *Herathbanda* showed the highest grain weight followed by *Sulai* and *Kahata Wee* (Table 2). Among the improved rice varieties, Bg 94-1 showed the highest grain weight. However, among all recorded traditional and improved rice varieties, *Suduru Samba* showed the lowest grain weight (Hettiarachchi *et al.*, 2016). Grain weight of rice depends on its volume and bulk density.

Table 2: Grain volume, weight and bulk density and milling properties of traditional and improved rice varieties in Sri Lanka.

Rice variety	Physical and milling properties of rice (Mean ± SD*)					
	Grain Volume (mm^3)	100 grain weight (g)	Grain Bulk density (kg/m^3)	Brown Rice (%)	Husk (%)	Total milled Rice (%)
Traditional rice varieties						
Deveraddiri	20.54±0.4	2.37 ± 0.03	800	79.0 ± 1.0	21.0 ± 0.5	72.0 ± 1.2
Dik Wee	6.88 ± 0.2	1.58 ± 0.03	775	78.9 ± 1.2	21.1 ± 1.3	73.1 ± 1.4
Dular	7.92 ± 0.6	1.89 ± 0.01	794	77.8 ± 0.6	22.2 ± 0.8	72.0 ± 1.0
Gonabaru	-	-	-	77.8 ± 1.1	22.2 ± 0.5	71.4 ± 1.2
Hangimuttan	-	-	-	78.2 ± 1.0	23.0 ± 0.4	72.5 ± 0.7
Herathbanda	13.88 ±0.2	2.69 ± 0.03	823	79.7 ± 1.3	20.3 ± 0.7	74.1 ± 0.9
Hondarawalu	-	-	-	78.0 ± 0.6	22.0 ± 0.17	70.5 ± 1.1
Iginimitiya	7.00 ±0.1	1.48 ± 0.01	762	80.0 ± 1.2	20.0 ± 0.15	73.8 ± 0.6
Kahamaala	-	-	-	78.8 ± 0.8	22.83±0.15	71.9 ± 1.0
Kahata Wee	14.85±0.1	2.39 ± 0.01	800	79.0 ± 0.7	21.1 ± 0.8	72.2 ± 0.5
Kahawanu	-	-	-	76.0 ± 0.4	23.73 ± 0.1	70.0 ± 0.3
Kalu Heenati	11.50 ±0.8	1.75 ± 0.01	800	78.5 ± 0.8	21.5 ± 0.21	72.2 ± 0.4
Kuruluthuda	-	-	-	78.0 ± 1.2	22.0 ± 0.2	69.4 ± 1.1
Madathawalu	-	-	-	79.0 ± 0.7	21.0 ± 0.5	73.0 ± 1.0
Masuran	-	-	-	78.2 ± 1.1	20.8 ± 1.0	71.4 ± 0.2
Maa Wee	13.6 ± 0.2	2.20 ± 0.00	800	78.8 ± 0.5	21.2 ± 1.1	73.2 ± 1.0
Pachchaperumal	13.53±0.1	2.19 ± 0.01	813	79.8 ± 1.8	20.2 ± 0.6	73.5 ± 1.2
Pokkali	13.23±0.1	2.04 ± 0.03	798	79.1 ± 1.4	20.9 ± 1.2	73.0 ± 1.1
Rathal	-	-	-	77.3 ± 0.7	22.7 ± 0.4	72.7 ± 0.8
Rathna Samba	-	-	-	76.3 ± 0.2	22.62 ± 0.5	70.1 ± 0.2
Sudu Heenati	12.91 ± 0.1	2.21 ± 0.01	825	79.2 ± 1.6	20.8 ± 0.7	73.0 ± 0.8
Suduru Samba	4.08 ± 0.03	0.83 ± 0.02	781	77.1 ± 2.2	22.9 ± 0.5	72.1 ± 1.5
Sulai	12.83 ± 0.1	2.41 ± 0.01	814	80.0 ± 1.5	20.0 ± 0.3	72.7 ± 0.5
Suwandel	5.92 ± 0.1	1.03 ± 0.01	825	78.5 ± 0.7	21.5 ± 1.0	73.4 ± 0.7
Unakola Samba	-	-	-	76.1 ± 0.4	22.9 ± 0.1	69.9 ± 0.3
Wannidahanala	13.21 ± 0.1	2.11 ± 0.01	798	71.5 ± 1.6	21.2 ± 0.8	71.5 ± 0.8
Improved rice varieties						
At 306	6.86 ± 0.1	1.99 ± 0.01	794	-	-	-
At 405	8.28 ± 0.01	1.96 ± 0.01	780	79.4 ± 0.1	19.5 ± 1.1	72.5 ± 0.4
At 307	-	-	-	79.0 ±1.65	20.4 ± 1.2	72.7 ± 1.4
Bg 94-1	10.87 ± 0.1	2.25 ± 0.01	787	-	-	-
Bg 300	11.21 ± 0.3	2.17 ± 0.04	820	76.5 ± 0.3	22.7 ± 0.6	70.4 ± 0.5
Bg 352	13.50 ± 0.1	2.20 ± 0.02	810	78.4 ± 0.8	21.3 ± 0.8	72.0 ± 0.8
Bg 358	6.61 ± 0.2	1.33 ± 0.01	813	78.4 ± 0.1	22.7 ± 0.9	71.8 ± 0.3
Bg 360	5.37 ± 0.05	1.08 ± 0.03	814	76.8 ± 0.5	23.1 ± 1.1	70.1 ± 0.6
Bg 366	12.47 ± 0.2	2.02 ± 0.01	800	76.5 ± 0.7	23.2 ± 1.1	70.4 ± 0.9
Bw 267-3	10.2 ± 0.01	1.68 ± 0.01	814	-	-	-
Bw 272-6b	8.40 ± 0.1	1.31 ± 0.01	805	-	-	-
Bw 367	-	-	-	77.6 ± 0.1	21.6 ± 0.2	71.4 ± 0.1

*SD = Standard deviation;
Sources: Hafeel *et al*. (2008); Rebeira *et al*. (2014); Prasantha *et al*. (2014); Hettiarachchi *et al*. (2016); Thilakarathna *et al*. (2017);

The reported grain volume of traditional rice varieties has a wide range from 4.1 mm^3 to 20.54 mm^3. However, among the recorded traditional varieties *Deveraddiri* showed the highest grain volume and *Suduru Samba* showed the lowest grain volume. The grain volume of improved varieties was in the range of 5.37-13.50 mm^3, which is narrower than that of traditional varieties. The improved rice variety Bg 352 showed comparatively a higher grain volume and Bg 360 showed comparatively a lower grain volume. Due to the short grain size, the lowest grain volume and the lowest grain weight, *Suduru Samba* deserves the highest price in the local market. Hettiarachchi *et al*. (2016) have reported that the bulk density of some traditional and improved rice varieties was in the range of 754.2 - 833.9 kg/m^3. Comparatively, a higher bulk density was observed in the rice varieties namely Bg 300, Bg 360, Bg 358, Bw 267-3 and Bw 272-6b with the highest in *Sudu Heenati* and *Suwandel*. The slender-shape traditional rice varieties such as *Dik Wee* and *Inginimitiya*, and the improved rice varieties such as At 405, At 306, and Bg 94-1 showed the lowest bulk density values.

Milling Properties

Milling properties of traditional and improved rice varieties are presented in Table 2. Rice is commonly used as fully milled or partially milled rice, which is produced by removing the hull and bran layers of the rough rice through de-hulling and milling processes. Rice milling quality is determined by the percentage of head rice (= ¾ size of a whole kernel) and broken rice in the commercial rice bags. Total milled rice recovery is influenced by the genotype, plant ecosystem, agronomic practices, efficacy of the milling equipment, and the effect of hydrothermal treatments such as parboiling method (Puri *et al*., 2014). Furthermore, structural characteristics of rough rice grains also play an important role in milling properties.

Brown rice and hull content of Sri Lankan improved and traditional rice varieties have been studied by Rebeira *et al*. (2014) and Thilakarathna *et al*. (2017). Brown rice out turn of most of the traditional rice varieties is 76-80% except in few varieties and the brown rice out turn of improved rice varieties is in the range of 76-78% which is more or less similar to that of traditional rice. Rebeira *et al*. (2014) reported that the hull contents of both traditional and improved rice varieties were in the range of 20-23%. Both improved and the traditional rice varieties showed more or less similar total milled rice recoveries. However, during milling, some of the traditional rice varieties such as *Kuruluthuda*, *Kalu Heenati*, *Hondarawalu*, *Dular*, *Rathal*, *Gonabaru*, *Sudu Heenati*, *Sulai*, *Masuran*, and *Kahata Wee* have recorded the highest percentage of broken rice (28.3%) (Rebeira *et al*., 2014). This may be due to inherent varietal differences in milling performance.

<u>Amylose content:</u>
The amylose content is largely influenced by genetic factors, however, a negative correlation was found between temperature at maturity period and amylose content in starch (Gomez *et al*., 1979; Asaoka *et al*., 1985). Amylose content in the rice starch is affected by ambient temperature during the ripening stage of the rice crop. However, amylose content in rice can also vary within the same cultivar depending on the cultivated season and site (Aboubacar *et al*., 2006) due to variation in soil and environmental factors. Chen *et al*. (2008) showed that grain amylose content of rice is influenced by environment temperature.

Amylose content is the key determinant factor of the cooking, pasting, nutritional and eating qualities of rice (Gonzalez *et al*., 2004; Wickramasinghe and Noda, 2008; Darandakumbura *et al*., 2013a; Thilakarathna *et al*., 2017; Prasantha, 2018) and it is correlated with textural characteristics, for example, hardness and stickiness (Li *et al*., 2016). Low amylose rice cultivars are associated with cohesive, tender, and glossy texture when cooked. Compared to low amylose rice, high amylose rice absorbs more water and consequently expand comparatively more during cooking (Juliano, 1992). Rice can be categorized based on the average amylose content into waxy rice (0-5%), very low amylose rice (5-12 %), low amylose rice (12-20%), intermediate amylose rice (20-25%) and high amylose rice (25-33%) (Juliano, 1971; 1992; Abeysekera *et al.*, 2008). Rice with soft-medium gel consistency, intermediate amylose content and intermediate gelatinization temperature are mainly preferred by the consumers (Khatun *et al*., 2003).

Several studies have been carried out to assess the amylose content of traditional and improved rice varieties in Sri Lanka (Table 3). Reported data indicate that the amylose contents of the traditional and improved rice varieties were in the range between 21.5-29.5% and 16.3-30.8%, respectively. Most of the traditional and improved rice varieties belong to high amylose class except few varieties namely *Martin Samba*, *Maa Wee*, *Suduru Samba*, *Suwandel* and *Uvar Rellai* that belong to intermediate amylose class (20-25%) and At 405 that belongs to low amylose class (12-20%). Most of the improved rice varieties have been categorized as high amylose varieties except At 405 which has been categorized under low amylose group (Wickramasinghe and Noda, 2008; Fari *et al.*, 2011; Rebeira *et al.*, 2014). Darandakumbura *et al.* (2013a) has reported that the apparent amylose content did not significantly change between raw and parboiled rice and on the polishing rates.

Table 3: Amylose content and class, peak viscosity, swelling power, water absorption ratio and gelatinization temperature of traditional and improved rice varieties in Sri Lanka.

Rice Variety	Cooking properties of rice (Mean ± SD*)					
	Amylose content (%) (Mean±SD)	Amylose Class	Peak viscosity	Swelling power (g/g)	Water absorption ratio	Gelatinization Temperature class
Traditional variety						
Bandara Heththanawa	25.7 ± 0.8	High	332‡	12.6 ± 0.2	2.41 ± 0.51	Intermediate
Batapola Wee	26.3 ± 2.2	High	218‡	10.9 ± 0.1	2.66 ± 0.07	Intermediate
Beheth Heenati	26.5 ± 1.4	High	-	-	-	Intermediate
Deveraddiri	27.6 ± 4.2	High	262‡	13.4 ± 0.4	2.54 ± 0.03	Intermediate
Dik Wee	27.7± 3.2	High	348‡	16.1 ± 0.3	3.17 ± 0.33	Intermediate
Dular	26.3 ± 2.6	High	265‡	11.7 ± 0.2	2.13 ± 0.01	Low
Gonabaru	24.0 ± 3.4	Intermediate	-	-	-	Low
Heenati	25.6 ± 1.8	High	272‡	9.1 ± 0.30	2.47 ± 0.12	Low
Herathbanda	29.5 ± 3.4	High	270‡	11.7 ± 0.1	3.21 ± 0.03	Intermediate
Hondarawalu	26.1 ± 2.2	High	-	-	-	Intermediate
Iginimitiya	25.7 ± 2.3	High	-	-	2.82 ± 0.06	Low
Kahata Wee	27.3 ± 4.1	High			2.56 ± 0.12	Low
Kalu Heenati	29.1 ± 3.2	High	284‡	12.1 ± 0.2	2.77 ± 0.05	Intermediate
Kuruluthuda	25.7 ± 1.5	High	-	-	-	Intermediate
Madathawalu	27.2 ± 3.0	High	-	-	-	Intermediate
Martin Samba	22.5 ± 1.2	Intermediate	423‡	10.5 ± 0.5	2.64 ± 0.23	Intermediate
Maa Wee	20.2 ± 1.6	Intermediate		13.1 ± 0.8	3.0 ± 0.52	Low
Masuran	25.4 ± 2.5	High	-	-	-	Intermediate
Murungakayan	26.8 ± 3.6	High	-	-	-	Intermediate
Pachchaperumal	27.1 ± 2.4	High	-	-	2.75 ± 0.02	Intermediate
Pokkali	26.5 ± 1.3	High	-	-	3.20 ± 0.11	Intermediate
Rathal	28.1 ± 3.7	High	-	-	-	Intermediate
Rath Suwandel	28.3 ± 1.2	High	-	-	-	Intermediate
Sudu Heenati	25.6 ± 3.0	High	-	-	3.20 ± 0.02	Intermediate
Suduru Samba	21.5 ± 2.8	Intermediate	-	-	2.45 ± 0.02	Intermediate
Sulai	26.4 ± 2.4	High	-	-	2.74 ± 0.02	Intermediate
Suwandel	22.5 ± 3.3	Intermediate	-	-	2.44 ± 0.01	Intermediate
Uvar Rellai	23.5 ± 2.2	Intermediate	292‡	9.8 ± 0.1	-	Intermediate
Wannidahanala	26.5 ± 3.0	High	-	-	2.58 ± 0.01	Intermediate
Improved variety						
At 306	26.1 ± 1.2	High	321‡/813$	10.5 ± 0.2	2.25 ± 0.04	Intermediate
At 405	16.5 ± 1.7	Low	458‡/103	7.33 ± 0.1	2.26 ± 0.04	Low
At 362	27.1 ± 1.0	High	-	-	-	Low
Bg 300	29.5 ± 2.6	High	321‡/124	11.1 ± 0.3	2.54 ± 0.10	Low
Bg 352	30.0 ± 1.8	High	340‡/119	13.7 ± 0.4	3.40 ± 0.17	Intermediate
Bg 357	28.1 ± 2.5	High	322‡	11.4 ± 0.2	3.32 ± 0.03	Intermediate
Bg 358	27.1 ± 1.6	High	311‡	13.4 ± 0.4	3.02 ± 0.17	Intermediate
Bg 369	27.7± 0.8	High	-	-	-	Intermediate

Bg 379-2	30.1± 1.4	High	281‡	13.7 ± 0.2	-	Intermediate
Bg 450	28.5 ± 0.7	High	325‡	11.3 ± 0.2	-	Intermediate
Bg 94-1	30.8 ± 0.5	High	274‡/120	12.8 ± 0.2	3.09 ± 0.02	Intermediate
Bg 360	30.0 ± 1.7	High	302‡	6.3 0± 0.1	2.46 ± 0.05	Intermediate
Bw 267-3	28.7 ± 0.5	High	-	12.5 ± 0.3	3.30 ± 0.08	Intermediate
Bw 272-6b	27.0 ± 1.3	High	1177$	-	3.00 ± 0.06	Low
Bw 361	30.0± 0.7	High	-	-	-	Intermediate
Ld 356	27.2 ± 0.8	High	1133$	-	-	Intermediate
Ld 408	25.5± 1.4	High	-	-	-	Low

*SD = Standard deviation; ‡RVU = Rapid Visco Units; $BU = Brabender unit;
Sources: Abeysekera *et al*. (2008); Wickramasinghe and Noda (2008); Fari *et al*. (2011); Darandakumbura *et al*. (2013a and 2013b); Rebeira *et al*. (2014); Prasantha *et al*. (2014); Hettiarachchi *et al*. (2016); Abeysekera *et al*. (2017a; 2017c); Kemashalini *et al*. (2018); Gunaratne *et al*. (2020); Hafeel *et al*. (2020).

The ambient temperature, relative humidity and solar radiation pattern in Sri Lanka differ between *Maha* (wet) and *Yala* (dry) seasons. Although the maximum-minimum temperature varied between *Maha* (29.1 °C - 23.1 °C) and *Yala* (31.8 °C - 26.9 °C) seasons, Abeysekera *et al*. (2008; 2017c) did not find any significant variation of amylose content between *Maha* and *Yala* seasons among the 26 traditional rice varieties they tested (*Herathbanda*, *Batapolal Wee*, *Kahata Wee*, *Molligoda*, *Kottayar*, *Pachchaperumal*, *Hondarawala*, *Gonabaru*, *Murungakayan*, *Kalu Heenati*, *Rathu Heenati*, *Sudu Heenati*, *Goda Heenati*, *Deveraddiri*, *Wanni Dahanala*, *Dhahanala*, *Sulai*, *Rathal*, *Kalubala Wee*, *Kattamanjal*, *Masuran*, *Beheth Heenati*, *Rath Suwandel*, *Madathawalu* and *Dikwee*). Higher proportion of improved varieties showed stable amylose contents over seasons than that of traditional varieties and their amylose contents were approximately in the range of 23-30% irrespective of the season (Abeysekera *et al*., 2017c).

Out of 29 traditional varieties (Table 3), only 6 varieties could be classified as intermediate amylose rice (20%) whereas almost all the improved rice varieties could be classified as high amylose rice except At 405 with low amylose. Intermediate amylose rice is widely accepted in the world because cooked intermediate amylose rice is soft and flaky (Hossaina *et al*., 2009). This may be one of the reasons that some traditional rice is comparatively more popular among local consumers and they pay a premium price for them.

Swelling power:

Swelling power is inhibited by amylose content and lipid content but enhanced by the amylopectin content (Tester and Morrison, 1990; Lii *et al*., 1995; Bhattacharya *et al*., 1999). After harvesting, the swelling behaviour of rice is changed during storage with the aging of stored rough rice. At the initial stage of storage, the swelling power is comparatively high and subsequently, it declines with the increase in storage period (Patindol *et al*., 2005). Lii *et al*. (1996) found that swelling power increased with increasing storage temperature. Abeysundara *et al*. (2017) also found that swelling power was significantly higher during the early period of storage in three improved rice varieties namely Bg 300, Bg 352 and At 362. The swelling power ratios significantly varied among rice varieties.

Among the reported improved rice varieties, Bg 360 showed the lowest swelling power (6.3±0.1 g/g) and Bg 352 and Bg 379-2 showed the highest swelling power of 13.7±0.4 g/g. Wickramasinghe and Noda (2008) also reported that the traditional rice variety *Dik wee* has the highest swelling power (16.1 ± 0.3) and the improved rice variety Bg 360 has the lowest swelling power (6.3±0.1 g/g). Although the low amylose rice variety At 405 is containing comparatively higher amylopectin, it has comparatively low swelling power (7.33±0.1 g/g) and that may be due to longer branch lengths of amylopectin molecules. Chung *et al*. (2011) reported that a high amount of amylose content or comparatively longer branch lengths of amylopectin molecules of long-grain rice has comparatively lower swelling power.

No reports are available on the relationship between grain amylose content and swelling power established using Sri Lankan rice varieties. Therefore, we estimated a simple liner regression between amylose content and swelling power using a selected data set collected from local traditional and improved rice varieties (Figure 1). Very weak but statistically significant positive linear relationship (y = 0.224 x + 5.70; r^2 = 0.23 P<0.05) was observed between amylose content (%) and the swelling power (g/g) of traditional and improved rice varieties. This relationship showed that rice with comparatively higher amylose content has higher swelling power but the relationship would have been comparatively stronger if the major outlier Bg 360 is removed from the relationship. Although Bg 360 has high amylose content, it showed the lowest swelling power. Therefore, behaviour of Bg 360 in this respect is hard to be explained. However, this is in contrast with the previous reports which showed the negative relationship between grain amylose content and swelling power in cooked rice (Tester and Morrison, 1990; Lii *et al*., 1995; Bhattacharya *et al*., 1999; Chung *et al*., 2011; Kemashalini *et al*. 2018; Thilakarathna *et al*., 2017). Kemashalini *et al*. (2018) and Thilakarathna *et al*. (2017) reported that the swelling power of rice has a negative correlation with amylose content and showed a significantly higher positive correlation with water absorption capacity. This may relate to the structural differences between amylose and amylopectin molecules in the starch granules. During heating, starch granules gradually swell and solubilize. With further increase in temperature and application of shear forces, amylose leaks out and the outermost amylopectin layer is fragmented and then these fragments dispersed in the amylose phase (Zhou *et al*., 2002; Wickramasinghe and Noda, 2008; Kemashalini *et al*., 2018). However, swelling decreases in high amylose rice because of the long linear chain length of amylose. Amylose content is considered the single most important characteristic for predicting the cooking and processing characteristics of rice (Zhou *et al*., 2002).

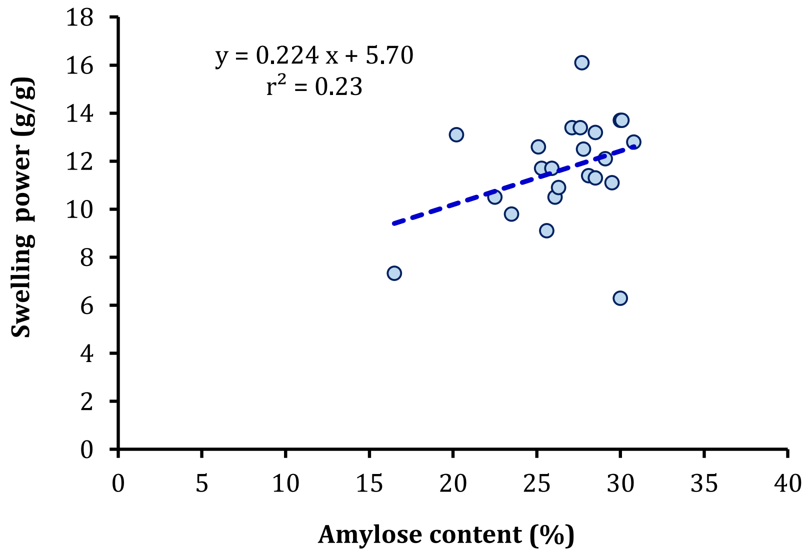

Figure 1: Linear relationship between grain amylose content and swelling power estimated using some selected Sri Lankan traditional and improved rice varieties.

<u>Water absorption capacity:</u>

Water absorption capacity directly influence the consistency and sensory properties of rice and high-water uptake indicates the best quality of rice (Shittu *et al*., 2012; Verma *et al*., 2013). Water absorption capacity is affected by soaking time, temperature and solute concentration (Sopade and Obekpa, 1990; Badau *et al*., 2005). Although the amylose content and water absorption capacity of rice have a negative correlation (Thilakarathna *et al*., 2017; Kemashalini *et al*., 2018), amylopectin content and water absorption capacity showed a moderate but positive correlation (Thilakarathna *et al*., 2017) because amylopectin helps to absorb and retain the water in the rice kernel.

The highest water absorption capacity (Table 3) was observed for improved variety Bg 352 and the lowest observed was for traditional rice variety *Dular* (Hettiarachchi *et al*., 2016). Although *Dular* has much lower amylose content than that of Bg 352, the molecular chain length of amylose and amylopectin may affect the water absorption of rice. It is a well-known fact that amylopectin plays a significant role in the process of starch gelatinization and retrogradation. The highest water absorption ratio was noted in *Herathbanda*, *Pokkali* and *Sudu Heenati* (≈ 3.2±0.03%). However, there is no considerable variation of the water absorption ratio between traditional and improved rice cultivars. Thilakarathna *et al*. (2017) observed high water absorption capacity for *Unakola Samba*, Bg 300, *Suduru Samba*, *Kahamaala* and *Suwandel* and low water absorption capacity for *Rathna Samba*, Bg 358 after four hours of hot soaking at 70 °C. Abeysundara *et al*. (2017) noted that water absorption and water-binding capacities increased during storage in Bg 352, Bg 300 and At 362. The varieties, Bg 352, Bg 300 and At 362 showed a constant amylose content during four months of storage; hence amylose may not be the single factor to determine swelling and hydration properties of rough rice during storage (Abeysundara *et al*., 2015).

Viscosity:

Starch properties of rice could be evaluated by the pasting behaviour of starch granules (Zhou *et al*., 2002). In general, rice with high eating quality and palatability has high viscosity. The pasting viscosities can reflect the status of starch gelatinization, disintegration, swelling and gelling. The highest viscosity or peak viscosity of rice flour is a significant parameter that indicates the gelatinization of rice starch during heating under-control conditions (Kemashalini *et al*., 2018). Viscosity varied similarly within traditional as well as within improved varieties. Wickramasinghe and Noda (2008) found the highest peak viscosity for traditional variety, *Martin Samba* and improved rice variety, At 405 (Kemashalini *et al*., 2018) but the lowest peak viscosity was observed in the traditional rice variety of *Batapola Wee*.

Wickramasinghe and Noda (2008) have also reported that the improved rice variety At 405 has the highest viscosity breakdown, lowest setback viscosity, least final viscosity, lowest pasting temperature despite its low amylose content. Among the traditional rice varieties, *Batapola Wee*, *Heenati* and *Deveraddiri* have the lowest peak viscosity compared to other varieties. The lowest peak viscosity was recorded in Bg 94-1 of which the amylose content is high. In general, most of the Sri Lankan red rice varieties recorded high amylose content and comparatively highest pasting temperature (Sompong *et al*., 2011; Somaratne *et al*., 2017).

Gelatinization:

Gelatinization describes the irreversible collapse (disruption) of molecular order within a starch granule when heated in excess water (Sivak and Preiss, 1998). Gelatinization temperature is also influenced by environmental conditions such as temperature during grain development and high ambient temperature during grain ripening, which will increase the gelatinization temperature (Faruq *et al*., 2004).

Juliano (1985) reported that the rice can be classified into three categories based on the gelatinization temperature, namely (1) high gelatinization temperature (74.5-80 °C), (2) intermediate gelatinization temperature (70-74 °C) and (3) low gelatinization temperature (<70 °C). Gelatinization temperature is basically measured by the alkaline spreading value proposed by Bhattacharya *et al*. (1982). According to the reported data, more than 65% of the traditional rice varieties belong to the intermediate gelatinization temperature class (Abeysekera *et al*., 2008) and rest of the varieties can be classified into low gelatinization temperature class (Prasantha *et al*., unpublished data). Similarly, Rebeira *et al*. (2014) reported that most of the traditional rice varieties fit into the intermediate gelatinization temperature class. It is notable that more than 70% of the improved rice varieties can also be categorized into intermediate gelatinization temperature class but rest can be categorized into low gelatinization temperature class (Table 3).

Gelatinization temperature has a direct relationship with the amylose content of rice. Low amylose rice such as At 405 has the ability to gelatinize rapidly compared to that of high amylose rice such as Bg 300. Irrespective of traditional or improved, high amylose rice gelatinized at a high-temperature range than low amylose rice. Hettiarachchi *et al*. (2016) reported the relationship between gelatinization temperature and cooking time of improved and traditional rice varieties. According to their study, minimum cooking time was observed for At 405 (15±0.01 min) and the maximum cooking time was observed for *Herathbanda* (31±0.24 min). The varieties At 306, Bg 352, *Maa Wee* and *Pokkali* had a high gelatinization temperature and short cooking time, but the traditional variety *Sulai* showed the lowest gelatinization temperature and longest cooking time.

Nutritional Properties

Nutritional value of rice is influenced by genotype, environmental condition under which the rice is grown, postharvest processing, storage and degree of milling. Therefore, if varieties are compered for grain nutrient contents, it is very important to make such comparisons under the similar climatic and other conditions to avoid miss-conceptions and experimental errors. The protein, fat and vitamins are concentrated in the germ and outer layer of the endosperm so that milling can reduce the nutrient contents, but milling improves the shelf-life and affects the appearance and palatability of rice (Zhou *et al*., 2002; Puri *et al*., 2014; Atungulu and Pan, 2014, Prasantha *et al*., 2014). The nutrition retention during milling is influenced by the parboiling process which leads to a positive impact on nutrition retention in the rice kernels (Paiva *et al*., 2016).

Carbohydrates**:**
The total available carbohydrate contents of selected rice varieties varied from 74.5±0.4% to 88.7±1.5% (Table 4). Among the traditional rice, red rice variety *Gonabaru* recorded the highest total available carbohydrate content (85.7±0.8%) while red rice variety *Kalu Heenati* recorded the lowest carbohydrate content (75.0±10.8) as reported by Abeysekera *et al*. (2017a) and Hafeel *et al*. (2020). Samaranayake *et al*. (2017) reported that the available carbohydrates in some traditional rice varieties namely *Suwandel*, *Heenati*, *Nilkanda*, *Kurulu Thuda* and *Maa Wee* were 80.8, 82.37, 82.74, 82.04 and 82.23%, respectively. Rice variety *Maa Wee* has recorded a high sugar content of 5.86% compared to other varieties of rice. Improved rice variety Bg 352 recorded the highest total available carbohydrate content (88.7±1.5%) and Bg 360 recorded the lowest carbohydrate content (75.6±3.8%) compared to the other tested improved rice varieties but 10% polished CIC-Red Fragrance, an improved red basmati type variety, reported to contain 74.5±0.4% of total available carbohydrate (Somaratne *et al*., 2017). Similarly, Samaranayake *et al*. (2018) reported that the total carbohydrate content of traditional rice varieties was in the ranges of 68.6-73.3% and of improved rice varieties was in the range of 70.4-76.3%. This is in agreement with the data presented in Table 4 where total carbohydrate content of almost all the improved rice varieties is higher except in the improved variety Bg 360 than that of all the traditional varieties although the values presented in Table 4 are comparatively higher. Carbohydrate content may also increase with the increasing rate of grain polishing during milling. In Sri Lanka, rice is reported to contribute 45% of the per capita dietary energy and available carbohydrate content is associated with the high glycemic index of rice (Darandakumbura *et al*., 2013b; Somaratne *et al*., 2017; Prasantha, 2018). The presence of high dietary fiber, amylose, protein, dietary fat, and antioxidant contents of less milled pigmented rice may inhibit the carbohydrate digestion enzymes, therefore, reduces the glycemic index of improved (Somaratne *et al*., 2017) and traditional red rice varieties (Prasantha, 2018).

Protein:
Protein is the second major constituent next to starch in the rice grain. The protein content of rice is one of the important factors in relation to the quality of rice (Gomez, 1979). The rice protein is rich in essential amino acids like lysine and is easily digestible (>90% digestibility) compared to the wheat protein. Rice varieties that contain more than 13% protein can be considered as high protein-containing varieties (Juliano, 1985). Data presented in Table 4 show that the crude protein content of traditional and improved rice varieties varied from 6.9-13.14% to 6.8-10.2%, respectively. The variety *Wannidahanala* showed the highest crude protein content (13.14±0.12%) among the traditional varieties whereas Ld 356 showed the highest crude protein content (10.18±1.41%) among the improved rice varieties (Fari *et al*. 2010; 2010; Abeysekera *et al*., 2017a). However, Industrial Technology Institute and Department of Agriculture (ITI and DOA, 2011) reported that the grain protein content of *Wannidahanala* significantly varied approximately from 13.1% to 7.1% when it was grown at Bombuwela in the Low Country Wet Zone and Batalagoda in the Low Country Intermediate Zone, respectively. This indicates that grain protein content of rice may significantly influenced by the agro-ecological factors. In the same study 25 traditional rice varieties had been used and all of them recorded a higher grain protein content at Bombuwela in the Low Country Wet Zone than that of at Batalagoda in the Low Country Intermediate Zone showing 15-45% increase in grain protein content in the Wet Zone compared to that in the Intermediate Zone.

Table 4: Proximate composition of traditional and improved rice varieties (% of dry weight) in Sri Lanka.

Rice variety	Proximate composition of rice (Mean ± SD*)				
	Crude protein (%)	Crude fat (%)	Crude ash (%)	Crude fiber (%)	Total carbohydrate (%)
Traditional varieties					
Madathawalu	8.43 ± 2.0	2.46 ± 0.55	1.48 ± 0.68	0.30 ± 0.20	81.66 ± 3.33
Pachchaperumal	10.00 ± 2.4	2.31 ± 0.70	1.44 ± 0.42	0.09 ± 0.00	76.35 ± 8.40
Sulai	9.22 ± 1.4	2.18 ± 0.32	1.62 ± 0.03	0.60 ± 0.21	81.12 ± 0.79
Suduru Samba	8.76 ±3.9	3.30 ± 1.17	1.20 ± 0.15	0.09 ± 0.01	81.42 ± 2.25
Kalubala Wee	12.5 ± 0.5	2.67 ± 0.10	1.79 ± 0.07	-	83.05 ± 0.60
Sudu Heenati	9.01 ± 1.71	2.37 ± 0.58	1.40 ± 0.41	0.20 ± 0.03	78.35 ± 8.13
Rathu Heenati	10.17 ± 1.10	3.08 ± 0.37	1.59 ± 0.03	-	84.38 ± 0.40
Hondarawalu	9.53 ± 2.60	2.49 ± 0.18	1.42 ± 0.09	-	84.75 ± 0.45
Wannidahanala	13.14 ± 0.12	2.45 ± 0.07	1.92 ± 0.05	-	82.48 ± 1.08
Rathal	11.09 ± 0.11	2.89 ± 0.17	1.61 ± 0.03	-	84.41 ± 2.23
Kottayar	12.20 ± 0.05	2.50 ± 0.08	1.63 ± 0.05	-	83.67 ± 2.05
Kalu Heenati	9.94 ± 1.35	2.46 ± 0.27	1.64 ± 0.41	0.51 ± 0.20	74.91 ± 10.8
Rath Suwandel	9.45 ± 3.14	2.60 ± 0.42	1.37 ± 0.42	0.09 ± 0.01	82.84 ± 0.57
Batapolal	10.5 ± 0.85	2.50 ± 0.06	1.48 ± 0.06	-	84.93 ± 1.06
Kattamanjal	10.86 ± 1.92	3.25 ± 0.09	1.69 ± 0.07	-	82.84 ± 0.51
Gonabaru	9.50 ± 1.92	2.21 ± 0.07	1.54 ± 0.16	-	85.66 ± 0.84
Goda Heenati	12.20 ± 0.02	2.18 ± 0.10	1.81 ± 0.04	-	83.81 ± 1.08
Wannidahanala	12.37 ± 0.24	2.61 ± 0.03	1.87 ± 0.05	-	83.16 ± 1.25
Kahata Wee	10.25 ± 1.10	2.23 ± 0.50	1.63 ± 0.03	0.30 ± 0.04	84.61 ± 0.29
Beheth Heenati	8.68 ± 2.54	2.29 ± 0.42	1.56 ± 0.34	0.36 ± 0.10	80.07 ± 0.24
Masuran	8.34 ± 0.63	2.30 ± 0.59	1.45 ± 0.08	0.11 ± 0.01	85.22 ± 0.73
Dik Wee	10.05 ± 2.33	2.39 ± 0.12	1.61 ± 0.18	-	84.30 ± 0.18
Herathbanda	9.51 ± 1.29	1.90 ± 0.57	1.17 ± 0.38	0.11 ± 0.01	82.36 ± 1.30
Murungakayan	7.0 ± 0.15	1.55 ± 0.31	0.92 ± 0.10	0.11 ± 0.02	-
Pokkali	8.02 ± 2.70	1.90 ± 0.81	1.19 ± 0.61	0.50 ± 0.28	77.26 ± 2.45
Rath Suwandel	6.86 ± 1.33	-	-	-	-
Suwanda Samba	7.27 ± 1.02	2.14 ± 0.34	1.03 ± 0.27	0.11 ± 0.05	80.5 ± 6.75
Suwandel	8.26 ± 0.11	2.85 ± 0.61	1.38 ± 0.20	0.10 ± 0.00	75.87 ± 2.24
Kuruluthuda	8.11 ± 0.46	2.86 ± 0.40	1.88 ± 0.62	0.90 ± 0.11	-
Maa Wee	11.00 ± 2.3	2.80 ± 0.82	-	-	82.23 ± 1.65
Kahawanu	11.8 ± 1.21	2.80 ± 0.74	1.7 ± 0.51	0.90 ± 0.24	-
Improved Varieties					
Bg 352	8.00 ± 0.33	1.83 ± 0.80	1.30 ± 0.41	0.10 ± 0.01	88.68 ±1.52
Bg 300	7.52 ± 1.10	1.67 ± 1.00	1.40 ± 0.70	0.20 ± 0.10	87.7 ± 0.41
Bg 403	7.34 ± 0.14	1.83 ± 0.94	-	-	88.25 ± 0.33
Bg 94-1	7.22 ± 1.50	1.50 ± 0.32	1.40 ± 0.70	0.09 ± 0.01	87.63 ± 0.50
Ld 356	10.18 ± 1.41	0.98 ± 0.33	-	-	86.27± 0.25
Ld 408	7.50 ± 1.22	2.00 ± 0.43	0.92 ±0.21	0.10 ± 0.00	-
Bw 272-6b	9.41 ± 0.50	1.77 ± 0.84	1.50 ± 0.50	0.09 ± 0.01	86.88 ± 0.28
At 405	8.00 ± 1.10	1.51 ± 0.54	1.81 ± 0.81	0.10 ± 0.02	86.5 ± 1.13
At 306	8.85 ± 2.47	1.60 ± 0.60	1.52 ± 0.74	0.11 ± 0.01	86.08 ± 1.30
At 362	6.83 ± 1.87	1.97 ± 0.82	1.40 ± 0.33	0.12 ± 0.03	-
Bg 358	7.56 ± 1.22	0.91 ±0.52	0.78 ± 0.11	0.11 ±0.01	-
Bg 369	7.52 ± 0.82	1.26 ± 0.73	0.81 ± 0.26	0.08 ± 0.00	-
Bg 360	7.92 ± 1.01	1.87 ± 0.22	0.93 ± 0.41	-	75.55 ± 3.78
CIC-Red basmati**	11.38 ± 0.20	1.40 ± 0.11	1.14 ± 0.01	0.80 ± 0.10	75.82 ± 0.50
CIC-White basmati**	9.77 ± 0.04	0.80 ± 0.03	1.12 ± 0.02	0.50 ± 0.01	77.51 ± 0.10
CIC-Red Fragrance**	11.24 ± 0.20	2.40 ± 0.10	1.44 ± 0.01	0.80 ± 0.08	74.48 ± 0.40

*SD = Standard deviation; **10% polished CIC basmati rice varieties

Sources: Fari *et al.* (2011; 2010); Gunaratne *et al.* (2013); Darandakumbura *et al.* (2013a; 2013b); Prasantha *et al.* (2014); Kariyawasam *et al.* (2016); Samaranayake *et al.* (2017); Abeysekera *et al.* (2017a); Kulasinghe *et al.* (2017); Hafeel *et al.* (2020); Somaratne *et al.* (2017); Gunaratne *et al.*, (2020); B.D.R. Prasantha (Unpublished data).

This shows the importance of comparing grain protein content of rice varieties grown under the same agro-ecological condition. Previous studies have shown that the grain protein content of traditional and improved rice varieties is more or less similar when they grow under the same agro-climatic conditions (ITI and DOA, 2011; Breckenridge, 1980). In addition, whether traditional or improved, no significant difference has been noted in grain protein content between red and white pericarp varieties. According to Breckenridge (1980), rice varieties with short maturity duration tended to have higher average grain protein content than that of varieties with comparatively longer maturity duration. These findings showed that though the protein content of rice is mainly under genetic control, it may also depend on the agronomic practices, cultivated agro-ecological region and other climatic conditions (Rajapakse *et al*., 2011; Liyanaarachchi *et al*., 2021).

The protein content of the milled rice may change with the milling and processing conditions of rice. Samaranayake *et al*. (2018) reported that the crude protein in rice increased with increasing rate of milling or degree of polishing. According to Bahmaniar and Ranjbar (2007) and Anjana *et al*. (2018), the crude protein content may significantly increase with the increasing rate of nitrogen or potassium fertilizer application at the time of heading. Significant impact of seasonal variation on total amino acid levels was observed in many rice varieties. Most of the rice varieties reported higher amino acid levels when cultivated during "*Maha*" season than in "*Yala*" season (Liyanaarachchi *et al*. 2021). According to Abeysekera *et al*. (2017a), red rice variety *Pachchaperumal* showed the highest protein content, but the lowest protein content was recorded in the variety *Gonabaru*. In general, red-pigmented rice has comparatively higher protein content than polished white rice varieties due to the presence of some amount of bran layer even after milling. Somaratne *et al*. (2017) reported that the grain protein content of 10% polished improved CIC Red Fragrant, a basmati type variety, was more than 11%. As reported by Priya *et al*. (2019), many Sri Lankan and Chinese rice varieties have a higher protein content than that of Indian varieties. In Sri Lanka, rice is reported to provide approximately 40% of the recommended daily protein requirement. According to Liyanaarachchi *et al*. (2021), *Beheth Heenati* and Bg 300 consist of five out of eight essential amino acids while *Suwandel* and At 306 comprised of four out of eight essential amino acids within the daily requirement. Therefore, consumption of high protein rice may be important to get a considerable amount of recommended daily allowance of dietary protein for healthy individuals (Abeysiriwardena and Gunasekara, 2020).

Fat:

Rice oil is a good source of linoleic acid and other essential fatty acids. The lipid fraction of rice is mainly confined to the outermost layer of the rice bran which is nearly 20% (dry basis) of the total bran content. The crude fat content of Sri Lankan traditional rice varieties was in the range from 1.55±0.3% to 3.3±1.2% (Table 4). Samaranayake *et al*. (2017) reported that the traditional rice variety *Suwandel* contains 3.3% of crude fat followed by *Kuruluthuda* (3.1%), *Heenati* (3.0%), *Nilakanda* (2.8%) and *Maa Wee* (2.8%). Abeysekera *et al*. (2017a) reported that *Suduru Samba*, *Kattamanjal* and *Rathu Heenati* contain high crude fat contents (>3%) than other varieties. The crude fat content of improved rice varieties was in the range of 0.9-2.4% and the highest amount of fat content was recorded in 10% polished CIC-Red Fragrance, a red basmati type rice.

In general crude fat content of most of the traditional varieties is higher than that of improved varieties (Table 4) assuming that all the varieties has been polished to the same level. In contrast to that, ITI and DOA (2011) reported more or less similar crude fat contents in traditional and improved rice varieties. They reported that the crude fat content of Sri Lankan traditional rice varieties was in the range of 2.2 – 4.1% and that of improved varieties was in the range of 2.2-4.3%. Kulasinghe *et al*. (2017) and Samaranayake *et al*. (2018) observed the comparatively similar crude fat content of both traditional and improved rice varieties. It is also important to note that some Sri Lankan traditional rice bran (*Suwandel*, *Heenati*, *Nilkanda*, *Kuruluthuda* and *Maa Wee*) contains more oleic acid and linoleic which are considered unsaturated fatty acids compared to palmitic (Samaranayake *et al*., 2017).

Mineral ash:

The mineral ash content (Table 4) can be considered as an indicator of the macro and micro mineral contents of rice. The most common minerals found in rice include potassium, magnesium, iron and zinc (Priya *et al*., 2019).

Kulasinghe *et al*. (2017) and Samaranayake *et al*. (2018) reported that the ash content varied within traditional as well as within improved rice varieties. Ash content of traditional varieties was in the range of 0.92-1.9% and that of improved rice varieties was in the range of 0.78-1.8%. Abeysekera *et al*. (2017a) have reported that the ash content of the traditional rice varieties was in the range of 1.3% (*Suduru Samba*) - 1.92% (*Wannidahanala*). In improved varieties, the highest ash content of over 1.5% has been reported in At 306 and in At 405. Red pigmented rice variety *Wannidahanala* contained the highest crude ash (1.92±0.05%) content while red pigmented rice variety *Murungakayan* showed the lowest (0.92±0.2%).

Potassium is the most abundant mineral found both in traditional as well as in improved rice varieties, and it ranged from 203±4.0 mg/100 g to 238±1.0 mg/100 g (Kulasinghe *et al*., 2017). Previous studies have reported the micro-nutrient contents of traditional rice varieties and *Kalubala Wee*, *Pachchaperumal*, *Dahanala*, *Rathu Heenati*, *Kattamanjal*, *Rathal*, *Suwandel*, *Kuruluthuda*, *Madathavalu*, *Pokkali* and *Sudu Heenati* contained high Iron (Fe) contents (1.9-3.7 Fe mg/100 g), while *Kalubala Wee*, *Wannidahanala*, *Rathu Heenati*, *Dahanala*, *Rathal*, *Kalu Heenati*, *Suwandel*, *Kuruluthuda*, *Madathavalu*, *Pachchaperumal*, *Pokkali* and *Sudu Heenati* contained a considerably high Zinc (Zn) content (2.5-3.8 Zn mg/100 g) than that of other tested varieties (Herath *et al*., 2011 and 2016; Kariyawasam *et al*., 2016; Kulasinghe *et al*., 2017).

It is important to note that lower Fe content has been reported among improved rice varieties (1.9-2.24 Fe mg/100 g) than that of some of the traditional rice varieties (Herath *et al*., 2016). Comparatively higher Zn content was reported in Bg 352 (3.3±0.3 Zn mg/100 g) than that of in most of the traditional varieties (Kulasinghe *et al*. 2017). The lowest Zn content of 2.28±0.9 mg/ 100 g was found in *Madathavalu* while the highest Zn content 3.44±0.3 mg/ 100 g was found in *Kalu Heenati* (Kulasinghe *et al*. 2017). However, Kariyawasam *et al*. (2016) have shown that *Sudumurunga* contained a higher amount of Zn (3.8±0.01 mg/100 g) than that of in *Kalu Heenati* (2.3±0.14 Zn mg/100g). According to Herath *et al*. (2011), Fe contents in the rice grown in the Low-Country region ranged from 2.0 to 3.7 mg/100 g and it varied significantly with the variety and the cropping season. They have also observed about 85% reduction of Fe content in polished rice.

Application of inorganic fertilizer strengthens the mineral contents (Ca, Mg, Mn, and Zn) of rice kernels and bran layer of improved rice varieties (Herath *et al*., 2019). A study conducted by Kariyawasam *et al*. (2016) has reported that the mineral content (Fe, Zn, Mn, K and Mg) of the traditional rice can also be increased more than 60% by rice parboiling. Priya *et al*. (2019) reported that the Zn and Fe contents of Indian red rice are two to three times higher than that of Indian white rice. In general, considerable amount of mineral ash associate with the rice bran layer so that the availability depends on the amount of bran layer remained after milling. It is a well-known fact that significant amount of Fe, Zn, and the other essential micro-nutrients are lost during rice polishing. Therefore, consumption of less milled red pigmented rice may help to acquire essential micro-nutrient into the body.

<u>Fiber</u>:

Arabinoxylans and β-d-glucan, are the major component of soluble dietary fiber in rice. In addition, rhamnose, xylose, mannose, galactose and glucose are also present in soluble dietary fiber fractions (Priya *et al*., 2019). Total crude fiber contents (%) of reported traditional and improved rice varieties are presented in Table 4. Rice bran contains approximately 10% of the weight of brown rice rich in dietary fiber.

The crude fiber content in traditional and improved varieties varied from 0.09 to 0.9% and from 0.08 to 0.80%, respectively, indicating that most of the traditional varieties are having little more crude fiber than that of improved varieties. However, all the varieties have been polished to the same degree is assumed as degree of polishing is one of the main factors that affect grain nutrient content of rice (Puri *et al*., 2014; Atungulu and Pan, 2014, Prasantha *et al*., 2014; Somaratne *et al*., 2017). Furthermore, the highest crude fiber content was observed in traditional varieties *Kuruluthuda* and *Kahawanu* while the lowest crude fiber content was observed in the improved variety Bg 369. In contrast, ITI and DOA (2011) reported more or less similar crude fiber contents in traditional and improved rice varieties. Moreover, the crude fiber content of Sri Lankan traditional rice varieties was in the range of 0.8 – 1.6% and that of improved varieties was in the range of 0.9 -1.9%. Abeysekera *et al*. (2017a) reported that the red rice varieties *Sudu Heenati* contained the highest total and insoluble dietary fiber contents of 7% and 4.8%, respectively, while *Beheth Heenati* contained the highest soluble dietary fiber content of 2.1%.

Conclusion

The grain size, brown rice percentage, hull percentage and milling recovery of both traditional and improved rice varieties showed almost the same within group variability. Most of the traditional rice varieties have red pigmented pericarp (rice bran) except few white pericarp varieties and vice versa in improved rice varieties. Both the cooking and eating quality and nutritional properties varied within traditional as well as within improved varieties and both the traditional and improved varieties recorded the highest and lowest values in different grain quality characteristics included in the present review. Data for the present review have been collected from different sources where the experiments may have been conducted under different conditions. Therefore, the comparison of grain quality characteristics between traditional and improved varieties is highly inconsistent.

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