Properties of South-Indian rice cultivars: physicochemical, functional, thermal and cooking characterisation

Modupalli Nikitha¹ · Venkatachalapathy Natarajan¹

Revised: 1 April 2020 / Accepted: 8 April 2020 / Published online: 21 April 2020
© Association of Food Scientists & Technologists (India) 2020

Abstract Physicochemical, functional, thermal, pasting and cooking properties of five Indian rice cultivars, ADT 36, 43, 39, IW PONNI and CR1009 were investigated. The starch, protein and fat contents varied from 1.321 to 2.489 mg/ml, 11.16–13.32% and 1.19–1.77% respectively, showing significant difference amongst the cultivars. ADT46 showed the highest amylose-amylopectin ratio. Water (103.55–132.48%) and oil (112.89–137.30%) absorption capacities also varied significantly. CR1009 showed highest swelling power at 60 °C, whereas IW PONNI exhibited the highest solubility (10.165%). The gel consistency of rice flours extended from 1.32 to 4.12 cm. The thermal properties of rice cultivars were found to be profoundly affected by amylopectin and showed correlation with amylose-amylopectin ratio. The pasting properties of rice flours also varied significantly, with peak viscosity and breakdown viscosity ranging between 2068.5–839 Cp and 1609.5–764.15 Cp respectively. The cooking time of the rice grains was found to be consistent with their shape and size. ADT43 and ADT46 showed the highest and least water uptake % on cooking. ADT46 showed the least cooking loss %, owing to the highest pasting viscosity. This study delivers the knowledge of the Indian rice cultivars, to be used for utilization of rice varieties for different products with relevance to the

properties and enhance the post-harvest value chain improvement.

Keywords Rice cultivars · Physicochemical · Functional · Thermal · Cooking · Properties

Introduction

Rice is one of the leading food crops in the world, being a staple diet for more than half of the world's population (Monks et al. 2013), especially in the densely populated South-East Asian countries (Tumpanuvatr et al. 2018). According to the Food and Agricultural Organization (FAO) of the United Nations, the world paddy production in 2017 summed up to 759.6 million tonnes, with 503.9 million tonnes on a milled basis. India stands second in production of paddy with an annual output of 166.5 million tonnes, after China. India is also a major exporter of rice, with about 12.5 million tonnes of rice being shipped from India (FAOSTAT, 2017)

In recent years, the use of rice as a substitute for wheat and corn in product-making has gained huge significance. The reason for this transition can be the unique physicochemical and functional properties of rice as well as its hypo-allergenicity (Helm and Burks, 1996). Rice, especially in the form of flour is being used in several preparations like baked goods, gluten-free products, noodles and pasta (Kolawole and Christopher, 2015). Such novel and substituted foods require the usage of raw materials with suitable and known physicochemical and functional properties, to ensure effective design and development of equipment (Kadan et al. 2008) and to establish a suitable culinary use. The functional, thermal and pasting properties decide the fate and behaviour of the constituents

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s13197-020-04440-3>) contains supplementary material, which is available to authorized users.

✉ Venkatachalapathy Natarajan
venkat@iifpt.edu.in

¹ Department of Food Engineering, Indian Institute of Food Processing Technology, Thanjavur, Tamilnadu 613005, India

of the rice during various stages and processing levels, storage, interactions with other raw materials of the product and shelf-stability (Falade et al. 2014).

The composition of the rice varieties is responsible for its different properties and influences its suitability for a specific food product development. The rice starch which is the most important constituent of rice is comprised of two fractions called amylose and amylopectin, which exert a fervent effect on the various properties of the rice cultivar, along with the minor influence of ageing, crop season, soil characteristics and genetic selection (Zhu et al. 2018). It has been reported in several studies that rice varieties with high-amylose content and low-gelatinisation temperature gives the best structure and good palatability to rice noodles (Bhattacharya, 2011). Previous researches have also reported that the rice cultivar has greatly affected the rheological and flow characteristics of the extracted rice milk (Lee et al. 2019).

Therefore, the objective of this study is to establish the compositional difference in the major south Asian/Indian rice varieties and determination of their physical, functional, thermal, pasting and cooking properties with help in the processing of different food products. This research helps in the establishment of different properties of major Indian home-grown rice varieties. This can be useful in the raw material selection for new and innovative food product development, thus gaining attention for these indigenous cultivars in the global markets for their specific properties.

Materials and methods

Paddy varieties ADT46, 43, 39, IW PONNI and CR1009 harvested in the month of January 2018, were procured from Soil and Water Management Research Institute, Kattuthottam, Thanjavur, Tamilnadu, India. The paddy was cleaned to remove the extraneous matter and stored in polypropylene bags at ambient temperature. The stored paddy was de-husked using Satake Rubber roll sheller (Model: 1012260, Make: Satake Corporation, Japan), at 190 rpm. The de-husked raw rice i.e. brown rice was packed, sealed and stored at room temperature, and utilized for various experiments in February month of the same year.

Chemical properties of rice cultivars

Determination of protein, fat, starch, ash and moisture of rice cultivars

Milled brown rice was ground into flour with a laboratory-scale pulveriser with 0.2 mm mesh and sieved with 0.3 mm mesh screen. The moisture content was determined

at 130 °C using Infra-red moisture meter (Mettler Toledo, Model: HE53/01). The crude fat, crude protein and ash contents were estimated using the solvent extraction method, Kjeldahl method and muffle furnace method respectively (AACC, 2000). Starch content was determined using the Anthrone reagent colorimetric method given by Sadasivam (1996).

Determination of apparent amylose (AAC) and amylopectin contents

The AAC of the rice samples was determined by using Iodine complex colourimetric method (AACC, 2000), in which the spectrophotometer reads the blue colouration of rice sample caused by the iodine complex by deposition on the helicase strands of amylose. Since there is no direct protocol for estimation of amylopectin, it was obtained by the difference between total starch content and amylose.

Physical properties

Physical characteristics of rice kernels

Length (L) and width (W) of randomly selected head grains of each rice sample were calibrated using Vernier calliper with an accuracy of 0.01 mm. The average length-by-width ratio (L/W) was calculated. Aspect ratio (AR) (Falade and Christopher, 2015) and the total volume of each rice kernel (V_i) (Oikonomopoulou et al., 2011) were calculated using the Eqs. (1) and (2) respectively.

$$AR = W/L \quad (1)$$

$$V_i = \pi d^2(h - d)/4 + 4/3\pi(d/2)^3 \quad (2)$$

where d and h are the diameter and height of the kernel respectively.

Determination of colour parameters of rice flours

The colour parameters of the rice flour were measured using a Hunter colour lab by assessing L* (lightness)-black to white (0 to 100), a*- red (+ 100) to green (− 100) and b*- yellow (+ 100) to blue (− 100) (Falade and Christopher, 2015). The instrument was calibrated using standard black and white tile. Colour intensity (ΔE) and chroma (ΔC) were calculated using the Eqs. (3) and (4) from the obtained values.

$$\Delta C = \sqrt{(\Delta a)^2 + (\Delta b)^2} \quad (3)$$

$$\Delta E = \sqrt{(\Delta a)^2 + (\Delta b)^2 + (\Delta L)^2} \quad (4)$$

Determination of bulk and packed densities

The bulk density of paddy, brown rice and flour were obtained by filling a measuring cylinder (100 ml) with the sample and weighing it on a digital weighing scale. The packed density was obtained with additional tapping of 50 times at the edge of the workbench before weighing (Falade et al. 2014). The densities were obtained as the ratio of weight (g) to volume (ml).

Functional properties of rice flours

Determination of water absorption (WAC) and oil absorption capacities (OAC)

Water absorption and oil absorption capacities of samples were determined by using the method described by Sosulski (1962). The sample of 1 g. was precisely weighed and dispersed in 10 ml of water for WAC and refined sunflower oil for OAC. The suspensions were vortexed thrice with a 10 min interval for uniform distribution and were centrifuged for 30 min at 2000 rpm. The supernatant was separated and the tubes with pellet were air-dried. The water and oil absorbed were calculated from the increase in weight of the sample and are expressed as a percentage of water/oil adsorbed by 1 g. of the sample.

Determination of gel consistency of rice flours

The gel consistency of the rice flours was determined by the method given by Cagampang et al. (1973). The rice flour of 0.1 g was taken in test tubes of 150 mm diameter. 0.2 ml of 95% ethanol with 0.025% thymol blue indicator and 0.2 N potassium hydroxide was added and samples were heated in a hot water bath for 10 min and consequently cooled in an ice bath for 20 min. The test tubes were then kept horizontally on a graph paper for 30 min. Gel consistency of samples was determined by the length of gel spreading in test tubes.

Determination of alkaline spreading value

Alkaline spreading values of the rice kernels were determined by using the procedure elaborated by Bhattacharya et al. (1972). Four to six brown rice kernels were placed in petri-dishes containing 1.7% potassium hydroxide solution, enough to cover the grains, and kept at ambient temperature overnight. Scores were given using a 7-point scale based on the degradation of the grain kernel. The highest score was given to grains with greater degradation and vice versa.

Thermal properties of rice cultivars

The thermal properties of rice flours were measured using Differential Scanning Calorimeter DSC 214 Polyma (Netzsch, Germany). About 8 mg of rice flour was taken in DSC aluminium pans and 8 µl of distilled water was added to make a starch–water slurry. The pans were sealed and equilibrated at room temperature for 1 h for moisture equilibration, after which they were heated from 20 to 200 °C at a rate of 10 °C/min, under nitrogen gas with an empty aluminium pan as reference. The obtained DSC endotherms were used to determine peak temperature (T_p), onset temperature (T_o), conclusion temperature (T_c) and gelatinization enthalpy (ΔH_G), using which temperature range ($T_c - T_o$) and peak height index (PHI) were also calculated (Falade and Christopher, 2015) using Eq. (5)

$$(PHI = \Delta H_G / (T_P - T_O)) \quad (5)$$

Pasting properties of rice cultivars

The determination of pasting properties of rice cultivars was done using Rheometer (MCR 52, Anton Paar Co. Ltd.) as described by AACC (2000). A 12% (w.b) flour–water slurry was stirred in the sample canister at a rotational speed of 960 rpm for an initial 10 s and 160 rpm for the rest of the procedure. The temperature–time protocol was started at 50 °C for 1 min after which a linear ramp-up of temperature till 95 °C in 3 min 42 s and held at that temperature for 2 min 30 s. After the holding time, the temperature was ramped-down to 50 °C in 3 min 48 s by the cooling system. The precise heat-hold-cool cycle causes changes in the starch granules in samples, leading to viscosity changes. The changes in viscosity due to simultaneous heating and stirring were plotted on a curve, give the peak viscosity, final viscosity, pasting temperature and time.

Cooking properties of rice cultivars

The cooking properties of the four rice cultivars were investigated using the protocols given by Chen et al. (2012).

Determination of the optimum cooking time

The optimum cooking time of the sample rice kernels was estimated by boiling 2 g of rice in 20 ml distilled water in a test tube on a water bath. The cooking time was determined by taking out a few grains at an interval of 1 min each and checking by pressing between glass plates until there is no white core present.

Change of dimensions of kernels on cooking

The change of dimensions of rice kernels before and after cooking was determined by the ratio of length to breadth of 10 grains.

Water uptake ratio

The water uptake ratio of rice grains was given by the amount of weight gain by the rice kernels after cooking. The increase in weight of the grains on cooking was determined as the water uptake ratio in percentage.

Gruel loss during cooking

The gruel loss is given by the quantity of solid leached out of the grains during cooking. The gruel and washings of the cooked grain were transferred into pre-weighed petri-dishes and evaporated at 110 °C to dry out the liquid contents. The gruel loss in percentage was found using the increase in weight of the petri-dishes.

Statistical analysis

The experimental data were analysed using the statistical software package of SPSS version 20. The significant difference in parameters between the varieties was determined at $p \leq 0.05$ using Duncan's multiple range tests and represented.

Results and discussion

Chemical analysis of rice flours

Protein, fat, starch, ash and moisture contents of rice cultivars

The protein content of ADT39 was found to be highest with 13.63% followed by ADT46 with 13%. ADT43 had the least protein content (Table 1). The occurrence of a greater amount of protein causes an increase in the paste rigidity (Xie et al. 2008). The fat content of the samples was not prominently varied. However, CR1009 variety of rice contained 1.74% to the highest and the least fat content of 1.20% was present in ADT39. The fat fraction directly affects the swelling properties of the starch granules (Rao, 2014). ADT 30 had the highest amount of ash content followed by CR1009. The average ash content of the cultivars is found to be 1.45%, slightly higher than the values given in previous studies (Heinemann et al. 2005).

Table 1 Proximate composition of brown rice flour of Indian rice cultivars

Cultivar	Moisture (wb%)	Ash (%)	Fat (%)	Protein (%)	Starch (mg/ml)	Amylose content (mg/ml)	Amylopectin content (mg/ml)	Amylose: amylopectin
CR1009	10.47 ± 0.036 ^c	1.53 ± 0.035 ^{bc}	1.77 ± 0.026 ^c	11.74 ± 0.170 ^a	1.321 ± 0.015 ^a	0.096 ± 0.004 ^a	1.225 ± 0.018 ^a	0.0786:1
ADT43	10.38 ± 0.006 ^d	1.33 ± 0.055 ^a	1.41 ± 0.026 ^b	11.16 ± 0.123 ^a	2.253 ± 0.036 ^b	0.104 ± 0.005 ^b	2.149 ± 0.037 ^b	0.0482:1
ADT46	10.31 ± 0.040 ^c	1.31 ± 0.035 ^a	1.40 ± 0.030 ^b	13.07 ± 0.059 ^b	2.440 ± 0.008 ^c	0.094 ± 0.002 ^a	2.346 ± 0.010 ^c	0.0400:1
ADT39	9.76 ± 0.031 ^a	1.58 ± 0.038 ^c	1.19 ± 0.100 ^a	13.32 ± 0.671 ^b	2.230 ± 0.009 ^b	0.095 ± 0.002 ^a	2.135 ± 0.008 ^b	0.0446:1
IW PONNI	10.11 ± 0.040 ^b	1.50 ± 0.010 ^b	1.21 ± 0.021 ^a	11.84 ± 0.563 ^a	2.489 ± 0.011 ^d	0.096 ± 0.002 ^a	2.384 ± 0.014 ^d	0.0400:1

*Results are means of three determinations ± standard deviations. Means in a column with the same letter are not significantly different ($p > 0.05$)

Apparent amylose (AAC) and amylopectin contents of rice cultivars

Amylose and amylopectin decide the properties of rice since amylose directly affects the water absorption by the starch granules and expanding in their volume without collapsing. This is due to the tendency of amylose to form hydrogen bonds with water molecules. After absorption of the water, the crystalline nature of the rice starch granules gets destroyed and forms into a viscous paste. The amylopectin content increases as the rice ages making the rice starch more crystalline in nature. The AAC is positively correlated with swelling and solubility, WAC, pasting and gelatinization properties of rice starches, whereas amylopectin affects the thermal properties (Bhattacharya, 2011).

The AAC of rice flours ranged from 0.109 to 0.093 mg/ml, which is a very slight difference (Table 1). Similarly, the amylopectin content extended from 2.387 to 1.220 mg/ml. ADT43 showed the highest AAC with CR1009, IW PONNI, ADT46 and ADT39 followed in a decreasing manner. The amylopectin content was found to be highest in IW PONNI, followed by ADT46, ADT43, ADT39 and CR1009. The amylose-amylopectin ratio was also found to be greater in CR1009 than other cultivars slightly. The amylose and amylopectin contents in rice also play a very crucial role in eating quality. The rice with higher amylopectin content produces moist and sticky rice on cooking (Gayin et al. 2017).

Physical properties

Physical characteristics of rice cultivars

The shape and size of rice grain have a critical impact on consumer preferences and sensory acceptance. The cultivars showed the grain length ranging between 0.67 and 0.50 cm, width between 0.37 and 0.21 cm, thus the L/W ratio ranging from 3.28 to 1.86 (Table 2). The cultivar ADT46 was found to be having the longest grain length of 0.67 cm. However, CR1009 showed highest grain width of 0.37 cm and with 0.21 cm, IW PONNI showed the least width. The L/W ratio was used to categorize the grains using classification given by Juliano (1985). CR1009 had the highest L/W ratio, owing to its greater width and shorter length, making it a short-bold variety. Similarly, IW PONNI was categorized as medium-round, while ADT43 and ADT39 were reported to be medium-slender cultivars. The ADT46 cultivar stands to be in the extra-long to slender category. The aspect ratio also followed the similar trend of the L/W ratio, with CR1009 having highest aspect ratio and ADT46 having the least. The total volume of the grain was indirectly proportional to L/W ratio, having

Table 2 Physical properties of brown rice of Indian rice cultivars

Cultivar	L (cm.)	W (cm.)	L/W	Aspect Ratio	Total volume (cm ³)	Grain type	ΔE	ΔC
CR1009	0.50 ± 0.001 ^a	0.37 ± 0.001 ^c	1.36 ± 0.002 ^a	0.73 ± 0.001 ^e	0.013 ± 5.21X10 ⁻⁵ ^a	Short, round	17.41 ± 0.415 ^b	178.91 ± 2.201 ^c
ADT43	0.55 ± 0.001 ^b	0.30 ± 0.01 ^b	1.83 ± 0.003 ^b	0.55 ± 0.001 ^d	0.017 ± 6.81X10 ⁻⁵ ^{bc}	Medium, round	20.53 ± 0.587 ^c	172.40 ± 1.297 ^a
ADT46	0.71 ± 0.01 ^c	0.22 ± 0.006 ^a	3.28 ± 0.100 ^d	0.31 ± 0.009 ^a	0.018 ± 8.24X10 ⁻⁴ ^d	Extra-long, slender	20.62 ± 1.151 ^c	168.91 ± 1.310 ^b
ADT39	0.55 ± 0.001 ^b	0.30 ± 0.001 ^b	1.86 ± 0.002 ^b	0.54 ± 0.001 ^c	0.017 ± 6.59X10 ⁻⁵ ^{cd}	Medium, round	19.66 ± 0.750 ^c	171.71 ± 0.405 ^b
IW PONNI	0.67 ± 0.006 ^d	0.21 ± 0.001 ^a	3.12 ± 0.032 ^c	0.32 ± 0.003 ^b	0.016 ± 1.81X10 ⁻⁴ ^b	Medium, slender	15.68 ± 0.228 ^a	180.62 ± 0.562 ^c
Cultivar	Bulk density (g/ml)			Tapped density (g/ml)				
	Paddy	Brown rice	Flour	Paddy	Brown rice	Flour		
CR1009	0.58 ± 0.003 ^b	0.88 ± 0.006 ^c	0.68 ± 0.009 ^{cd}	0.66 ± 0.003 ^d	0.98 ± 0.012 ^a		0.84 ± 0.009 ^b	
ADT43	0.55 ± 0.016 ^a	0.87 ± 0.012 ^c	0.66 ± 0.015 ^{bc}	0.60 ± 0.008 ^c	0.90 ± 0.014 ^a		0.78 ± 0.012 ^c	
ADT46	0.55 ± 0.015 ^a	0.77 ± 0.020 ^a	0.61 ± 0.008 ^a	0.56 ± 0.004 ^a	0.88 ± 0.005 ^a		0.70 ± 0.010 ^a	
ADT39	0.58 ± 0.012 ^b	0.83 ± 0.016 ^b	0.70 ± 0.012 ^d	0.58 ± 0.011 ^b	0.94 ± 0.013 ^a		0.76 ± 0.016 ^b	
IW PONNI	0.55 ± 0.007 ^a	0.89 ± 0.015 ^c	0.65 ± 0.011 ^b	0.56 ± 0.014 ^a	1.08 ± 0.112 ^b		0.87 ± 0.0031 ^e	

*Results are means of three determinations ± standard deviations. Means in a column with the same letter are not significantly different ($p > 0.05$)

ADT46 with highest grain volume and CR1009 had the least grain volume. The length, width and L/W ratio of the cultivars reported similar values for the Asian cultivars given by Gayin et al. (2017) and the African cultivars were given by Falade and Christopher (2015).

Colour parameters of rice cultivars

The colour parameters of rice indicating whiteness (L^*) ranged from 86.14 to 78.06 with IW PONNI being the whitest cultivar and ADT 46 having least L^* value. Similarly, the a^* value indicating redness(+) to greenness(–), showed all positive values ranging from 1.59 to 1.39 and b^* value showing yellowness(+) to blueness(–) also showed a positive range from 14.49 to 14.04. The possible reason for the difference in lightness and colouredness of the rice cultivars is that it may be due to the presence of bran content and other coloured pigments in the flour. ΔE value represents the perception of colour difference and ranged from 20.62 of ADT 49 to 15.68 of IW PONNI. Chroma value or ΔC describes the saturation level of the colour and describes the intensity of colour. ΔC ranges from 168.91 to 180.62, with highest colour intensity for IW PONNI and least for ADT 49. On a concluding note about colour of rice cultivars, the cultivar IW PONNI has the highest lightness and least red and yellow hues along with maximum colour intensity. There was no significant difference between ΔE values of ADT varieties of rice but they showed a significant difference from IW PONNI and CR 1009 cultivars. Also, for chroma values, ADT 43 showed a significant difference from ADT 46 and ADT 39, which in turn are different from IW PONNI and CR 1009. The differences between different cultivars are very small. The reason for differences might be due to leaching of bran pigments into the kernels (Falade and Christopher, 2015), level of polishing and chemical composition of the cultivars.

Bulk and tapped densities of paddy, brown rice and flour

The tapped density represents the maximum density that can be attained by the product on compaction. The densities of paddy, flour and brown rice followed an increasing trend in the same order, on par with the previous studies by Falade and Christopher (2015). The bulk densities of paddy, flour and brown rice ranged from 0.55 to 0.58 g/ml, 0.61–0.70 g/ml and 0.77–0.89 g/ml respectively, whereas the tapped density ranged from 0.56–0.66 g/ml, 0.70–0.87 g/ml and 0.88–1.08 g/ml (Table 2). The density is an important parameter to be considered to design equipment and to determine the packaging requirements of the products (Meera et al. 2019) and was found to be affected by the varietal differences, degree of milling and

moisture content of the rice cultivars (Bhattacharya et al. 1972). Products like weaning foods and geriatric foods require to be of lower bulk density for easy gut movements and digestion, whereas in case of speciality foods for obesity, higher bulk density is desirable to provide satiety to the consumer.

Functional properties of rice cultivars

Water absorption (WAC) and oil absorption capacities (OAC) of rice flours

The WAC is an important functional property as it directly affects the texture, freshness, and mouthfeel of the finished products (Falade and Christopher, 2015). It is the moisture-binding capacity of the rice, which helps in avoiding loss of moisture from the products on processing and storage, especially for products like baked foods and viscous foods like soups, where water retention capacity is highly desired. The WAC of the rice flours ranged from 103.55 to 132.48% when determined at room temperature (Table 3). The major constituents of rice that enhance WAC in rice flours are starch and proteins, owing to their hydrophilic nature (Lawal and Adebawale, 2004). The WAC of ADT46 was highest with 132.48%, with IW PONNI at a similar value of 130.01%, and followed by CR1009, ADT43 and ADT39 in decreasing order, which is on par with the starch content and amylose of the rice flours (Table 1). The difference in WAC of the rice flours might be due to the difference in protein and starch structures of the cultivar, which may cause variations in internal binding forces and degree of formation of covalent bonds, in a very minor way, between the constituents of rice flour and water molecules at the available hydrophilic sites (Falade and Christopher, 2015).

The oil absorption capacity (OAC) of rice flours is a measure of their emulsifying capability, and is important functional character since oil act as a flavouring agent and imparts desirable texture and mouthfeel to food products (Falade et al. 2014). The OAC of ADT43 was reported to be the highest with 137.30%, followed by ADT46, IW PONNI, ADT39 and CR1009 in decreasing order. The OAC of rice flours is essentially due to the proteins because of the presence of hydrophobic ends in the non-polar amino acid ends of polypeptide chains, that can form an interaction with the hydrocarbon groups of lipid chains (Jitngarmkusol et al. 2008). Rice flours with good OAC can be used for the preparation of products like gluten-free cake batters, whereas the ones with low OAC can be used in fried foods since the absorption of oil will be relatively lesser than the traditional wheat flour or pulse flour batters.

Table 3 Functional properties of brown rice flour of Indian rice cultivars

Cultivar	WAC (%)	OAC (%)	Alkaline digestion score	Gel consistency (mm.)
CR1009	109.18 ± 1.78 ^b	112.89 ± 1.35 ^a	2.00 ± 0.441 ^{bc}	3.20 ± 0.11 ^d
ADT43	108.07 ± 1.62 ^b	137.30 ± 1.44 ^d	1.33 ± 0.500 ^a	4.12 ± 0.12 ^e
ADT46	132.48 ± 0.95 ^c	127.68 ± 1.45 ^c	2.22 ± 0.441 ^c	1.32 ± 0.10 ^b
ADT39	103.55 ± 1.75 ^a	121.61 ± 0.84 ^b	1.44 ± 0.527 ^a	2.82 ± 0.06 ^c
IW PONNI	130.01 ± 1.64 ^c	127.45 ± 1.52 ^c	1.56 ± 0.527 ^{ab}	1.38 ± 0.08 ^a

*Results are means of three determinations ± standard deviations. Means in a column with the same letter are not significantly different ($p > 0.05$)

Gel consistency and alkaline spreading value of rice cultivars

The gel consistency can be described as the strength of the gels formed from rice flours. It is an important characteristic for determining the process parameters during product formation and can be used as an indicator for testing the eating quality of rice (Cagampang et al. 1973). The gel consistency of rice flours extended from 4.12 to 1.32 cm, which can be positively correlated to the amylose content of flours and slightly on par with the setback viscosities (Table 3). The alkali degradation score is used to evaluate the gelatinization properties of the raw grain. The gelatinization temperature influences the hydration and cooking properties of rice kernels. The alkali degradation score is the measure of the resistance offered by the whole rice kernel against hydration, which depends on the amylose chain nature as it absorbs water and swells causing the grain kernel to disintegrate. The scores of rice kernels varied from 2.22 to 1.33, with ADT46 having greater disintegration than other cultivars.

Thermal properties of rice flours

Gelatinisation is the disruption of the ordered molecular structures present in the starch granules to change irreversibly to create granular swelling, loss of birefringence, solubilization of starch and melting of the crystalline constituents of native starch. Glass transition is the rearrangement of the molecules from solid to amorphous matrix that involves breaking the existing bonds and creating new bonds (Falade and Christopher, 2015).

The heat capacity (C_p), which is the amount of heat required for increasing the temperature of a unit mass of a sample by 1 °C, will also be changing with glass transition due to varying physical properties of amorphous and glassy states. The graphs obtained from DSC were endothermic. The onset temperature varied vividly from 41.6 to 100.2 °C and the peak temperatures ranged from 82.6 to 92.8 °C. Highest onset temperature (T_o) was shown by CR1009

which also showed the highest peak temperature (T_p) (Table 4). But the lowest T_o was shown by IW PONNI, whereas ADT46 showed the lowest T_p . The specific heat difference (ΔC_p) was found by sensing the rate of increase of the temperature of the sample against an empty pierced sample pan for the provided specific amount of heat. The ΔC_p of the samples varied from 0.948 to 5.168 J/(g °K), following the T_p trend.

The values of T_p are not consistent with the previous values given by Singh et al. (2006), for which the reason might be the chemical composition of the selected rice varieties. One of the reasons might also be that the DSC was performed to the composite flour, unlike the rice starches, due to which the interaction between various constituents like protein and minerals could elevate the T_o and T_p values. The presence of an initial small peak in the graph indicates the influence of other constituents present in the flour.

The results of DSC can be correlated with the amylose-amylopectin ratio since gelatinization properties of rice flours have found to be controlled by amylopectin content predominantly (Tikapunya et al. 2017). ADT46 had the highest amylose: amylopectin ratio among all the samples, which caused lower T_p . Though ADT43, ADT39 and CR1009 had a similar amylose-amylopectin ratio, only ADT39 and ADT43 showed similar T_p . CR1009 showed a drastic increase in T_p up to 100.2 °C. The results of DSC followed mixed trends when compared with the trends of protein, ash content and water absorption of the samples indicating that there is not much effect of the individual constituent. However, the cumulative effect of all the constituents might affect the melting properties.

Pasting properties of rice flours

The pasting properties of composite flours showed varied trends in peak, trough, breakdown, final, setback viscosities and pasting time and temperature. The composite flours of different cultivars showed characteristic pasting curves with an increase of viscosity till attainment of peak after

Table 4 Thermal properties of brown rice flour of Indian rice cultivars

Cultivar	T _o (°C)	T _m (°C)	T _i (°C)	T _c (°C)	T _p (°C)	T _f (°C)	ΔC _p (J/ (g °K)	PHI	ΔT _G (°C)
CR1009	100.2	129.2	99.8	150.6	92.8	28.0	5.168	-0.69	50.4
ADT43	79.0	67.6	81.1	79.7	86.0	35.2	0.948	0.13	0.70
ADT46	53.7	96.4	175.4	133.4	82.6	119.6	4.508	0.15	79.7
ADT39	46.4	60.4	65.6	69.2	86.6	33.7	2.279	0.05	22.8
IW PONNI	41.6	59.3	61.9	72.6	87.6	32.1	3.824	0.08	31.0

*Results are means of three determinations ± standard deviations. Means in a column with the same letter are not significantly different ($p > 0.05$)

which it diminishes down during the holding period. The viscosity rises further after setback to reach final viscosity forming sharp peaks. The pasting behaviour of various starches is known to alter due to interactions between starch and non-starch components, type of proteins and minerals present in samples, structures and orientation of starch granules, amylose-amylopectin ratio, degree of milling, presence of impurities, pH and cultivars (Mahasukhonthachai et al. 2010). However, researches have mentioned that the amount of starch content present in the cultivar does not contribute much to alter the pasting and gelatinization properties (Waramboi et al. 2011).

The peak viscosities varied from 2068.5 to 839 cP, whereas the final viscosities ranged from 4154 to 6133 cP (Table 5). It has been reported that the higher final viscosity of the rice flours indicates greater retrogradation tendency due to the crystallization of amylose molecules that are leached from the swollen starches (Wu et al. 2011). The higher final viscosity of ADT43 could be correlated to its greater amylose content than rest cultivars. This might be due to the amylose molecules that provide stability to starch granules against swelling and greater susceptibility for retrogradation (Singh et al. 2006). ADT46 showed the

least final viscosity of 4154 cP, followed by IW PONNI with 4990 cP. The varieties CR1009 and IW PONNI showed greater peak viscosities that can be showing that these two varieties hold higher resistance against the shear stress creating due to the rotation of spindle without attaining breakdown point (Falade and Christopher, 2015).

The greater pasting temperature was shown by ADT46, depicting the higher energy and time required for cooking, correlating with higher amylose content. The pasting temperatures of different cultivars ranged from 67.9 to 73.1 °C. Though there was no significant difference between the pasting temperature and time for different cultivars, the peak, breakdown and setback viscosities exhibited significant differences among them. The breakdown viscosity which depicts the rate of disintegration of cooked starches is indirectly proportional to the ability of the processed sample to withstand heat and shear during cooking (Adebawale et al. 2005). The greater breakdown viscosity of CR1009 followed by IW PONNI depicted that the cultivar has a low ability to withstand shear stress and heat. Similarly, greater trough viscosity shows the ability of formed pastes to retain viscosity without breaking during the cooling period.

Table 5 Pasting properties of brown rice flour of Indian rice cultivars

Cultivar	Peak viscosity (cp)	Trough viscosity (cp)	Breakdown viscosity (cp)	Final viscosity (cp)	Setback viscosity (cp)	Pasting temperature (°C)	Pasting time (min.)
ADT39	1441 ± 166.8 ^{ab}	5039.5 ± 456.1 ^a	1140.5 ± 150.6 ^{ab}	5340 ± 472.3 ^a	3899 ± 305.4 ^{ab}	72.28 ± 1.15 ^a	4.5935 ± 0.19 ^a
ADT46	1491 ± 135.2 ^b	5810 ± 957.4 ^a	1168 ± 111.5 ^b	4154 ± 981.46 ^a	4631 ± 846.4 ^{ab}	73.11 ± 3.23 ^a	4.7265 ± 0.53 ^a
ADT43	839 ± 272.9 ^{ab}	4079 ± 141.4 ^a	764.15 ± 222.0 ^{ab}	6133 ± 192.3 ^a	3314.5 ± 65.0 ^a	69.9 ± 0.41 ^a	4.1925 ± 0.06 ^a
CR1009	2068.5 ± 7.8 ^a	4606.5 ± 40.3 ^a	1609.5 ± 3.5 ^a	5065.5 ± 51.6 ^a	2997.5 ± 44.5 ^b	70.76 ± 1.75 ^a	4.3295 ± 0.29 ^a
IW PONNI	1588.5 ± 294.8 ^{ab}	4730 ± 308.3 ^a	1328.5 ± 228.4 ^{ab}	4990 ± 374.7 ^a	3401.5 ± 79.9 ^{ab}	67.985 ± 2.02 ^a	3.874 ± 0.32 ^a

*Results are means of three determinations ± standard deviations. Means in a column with the same letter are not significantly different ($p > 0.05$)

Table 6 Cooking properties of brown rice flour of Indian rice cultivars

Cultivar	Cooking time (min.)	Weight gain on cooking (%)	Water uptake ratio	Gruel loss (%)	Length after cooking (cm.)	Width after cooking (cm.)	Elongation ratio
CR1009	30.7 ± 0.577 ^d	274.95 ± 3.78 ^c	0.260 ± 0.007 ^a	6.38 ± 0.151 ^c	0.64 ± 0.005 ^b	0.21 ± 0.003 ^a	1.28 ± 0.009 ^c
ADT43	30.0 ± 1.000 ^d	288.03 ± 4.71 ^d	0.259 ± 0.002 ^a	3.52 ± 0.092 ^c	0.63 ± 0.006 ^b	0.22 ± 0.006 ^{ab}	1.15 ± 0.009 ^b
ADT46	22.7 ± 0.577 ^a	180.42 ± 4.52 ^a	0.384 ± 0.023 ^b	2.83 ± 0.114 ^a	0.81 ± 0.042 ^c	0.23 ± 0.008 ^b	1.14 ± 0.086 ^b
ADT 3;9	24.3 ± 1.155 ^b	193.95 ± 1.44 ^b	0.382 ± 0.036 ^b	3.15 ± 0.063 ^b	0.63 ± 0.005 ^b	0.24 ± 0.007 ^{bc}	1.14 ± 0.007 ^b
IW PONNI	28.3 ± 0.577 ^c	279.21 ± 1.01 ^c	0.275 ± 0.028 ^a	3.89 ± 0.140 ^d	0.54 ± 0.006 ^a	0.22 ± 0.006 ^a	0.81 ± 0.011 ^a

*Results are means of three determinations ± standard deviations. Means in a column with the same letter are not significantly different ($p > 0.05$)

Cooking properties of rice cultivars

The optimum cooking time of rice kernels

The cooking time of the rice kernels varied significantly with the cultivar and other properties like the degree of milling, size and shape of grain and chemical composition. The cooking times of the rice cultivars extended from 22.7 to 30.7 min. CR1009 showed highest cooking time due to its roundness. The least cooking time was shown by ADT46, which can be attributed to its slender shape, on par with the previous researches by Sandhu et al. (2018) on Indian rice cultivars PUSA1121 and PR113. The average cooking time was shown to be 27.2 min, which was greater than the cooking time for the *indica* variety of rice cultivars. The reason for this might be the presence of cellulosic fibres in the bran, that increase the time taken to cook the kernels completely (Monks et al. 2013).

Change of dimensions of kernels on cooking

ADT46 showed the most increase in the length of the kernel after cooking, followed by CR1009, ADT43, ADT39 and IW PONNI in decreasing manner. However, the increase in width of the kernel was greater in ADT39, followed by ADT43, ADT46, IW PONNI and CR1009 in reducing order. The difference in the increase in length and width of rice kernels can be attributed to the kernel shape and size, along with the water absorption capacity. The increase in the dimensions of the kernels on cooking has been reported due to swelling of starch due to water uptake and temperature rise (Juliano, 1978). The elongation ratio of the grain kernels followed a different trend with CR1009 showing highest elongation ratio, showing the significant difference with ADT 36, ADT43 and ADT46 with least elongation ratio. However, the effect of bran content on the kernel can affect the elongation (Sandhu et al. 2018).

Water uptake ratio, weight gain and gruel loss during cooking

The weight gain and water uptake ratio depend on the amylose content and structure as amylose binds the water molecules. The weight gain % on cooking was reported to be higher in ADT43, tailed by IW PONNI, CR1009, ADT39 and ADT46, with a significant difference. Also, water uptake ratio was found to be highest in ADT46 and ADT39, with no significant difference. The other cultivars followed a decreasing trend of ADT46, IW PONNI and CR1009, with no significant difference. The gruel loss and water uptake by the rice kernels were profoundly affected by starch and its fractions. Previous studies have reported a direct correlation between amylopectin content on rice ageing (Bhattacharya et al. 1972). It has been reported by previous researchers that the fresh rice had greater water-uptake capacity than pre-treated or pre-dried rice because it can cause partial gelatinization of starch granules (Tumpanuvatr et al. 2018). Partially gelatinized starch loses its property to absorb and bind the water. The gruel loss or cooking loss is the amount of solid leaching out of the grain kernels during cooking. It has been observed that CR1009 has highest cooking loss% and ADT46 has the least solid loss%, showing a significant difference among the cultivars.

Conclusion

Physical, chemical, functional and cooking properties of rice showed variations with cultivar and among paddy, brown rice and flour. The cultivar ADT46 was categorized as extra-long slender grain, whereas CR1009 was in the short-round category. The other cultivars were medium-sized. The bulk and tapped densities of brown rice were found to be greater than paddy and flour. The functional properties like swelling power, WAC, OAC and gel

consistency were found to be significantly different among the rice cultivars, can be correlated with the amylose-amylopectin ratio. CR1009 showed a good gel consistency, and therefore the extracted starch can be used as a thickening agent in food preparations. Similar findings were observed in pasting and thermal properties of rice varieties. Final viscosities of all rice cultivars increased upon cooling, with a significant increase in ADT43. ADT43 also showed the least breakdown viscosity, having more stability to withstand heat and shear during processing, thus favouring traditional consumption as table rice. However, the effect of other constituents of rice like proteins and lipids affected the thermal properties and pasting time by forming the bonds with amylose and amylopectin strands of starches. The cooking properties of rice cultivars also directly depended on the composition of the grain. ADT46 showed the least cooking time and highest water-uptake ratio. Also, CR1009 revealed highest elongation ratio and gruel loss %.

This study signifies the properties of different indigenous Indian rice cultivars, which helps to effectively establish the culinary use and suitable processing technique for producing value-added final products to meet the consumer demands and to address market swings. Utilization of rice as an alternative for wheat and other allergic and high-calorie cereals has started the trend of developing new products. This study establishes the different properties of rice cultivars as well as the correlation between the properties and ageing of rice, thus helping to simplify the choosing of raw material used for specific products depending on the end-user requirement (Table 6).

Acknowledgement This work was supported by Hangrow Foods Pvt. Ltd, Erode, Tamilnadu, India. The authors sincerely thank Soil and Water Research Institute, Thanjavur, Tamilnadu, India for providing necessary rice samples.

References

- Chemists, AACC (2000) Approved methods of the AACC
- Adebowale KO, Olu-Owolabi BI, Kehinde Olawumi E, Lawal OS (2005) Functional properties of native, physically and chemically modified breadfruit (*Artocarpus arilis*) starch. *Ind Crops Prod* 21(3):343–351
- Bhattacharya KR, Sowbhagya CM, Swamy YI (1972) Some physical properties of paddy and rice and their interrelations. *J Sci Food Agric* 23(2):171–186
- Bhattacharya KR (2011) Rice quality: a guide to rice properties and analysis. Elsevier, Amsterdam
- Cagampang GB, Perez CM, Juliano BO (1973) A gel consistency test for eating quality of rice. *J Sci Food Agric* 24(12):1589–1594
- Chen HH, Chen YK, Chang HC (2012) Evaluation of physicochemical properties of plasma-treated brown rice. *Food Chem* 135(1):74–79
- Falade KO, Christopher AS (2015) Physical, functional, pasting and thermal properties of flours and starches of six Nigerian rice cultivars. *Food Hydrocolloids* 44:478–490
- Falade KO, Semon M, Fadairo OS, Oladunjoye AO, Orou KK (2014) Functional and physico-chemical properties of flours and starches of African rice cultivars. *Food Hydrocolloids* 39:41–50
- FAOSTAT (Producer) (2017) Retrieved from <https://www.fao.org/economic/est/publications/rice-publications/rice-market-monitor-rmm/en/>
- Gayin J, Abdel-Aal ESM, Manful J, Bertoft E, Marcone M, Ragaei S (2017) Physical, cooking and thermal properties of African rice (*Oryza glaberrima*) and its starch digestibility in vitro. *LWT* 75:481–487
- Heinemann RJB, Fagundes PDL, Pinto EA, Penteado MDVC, Lanfer-Marquez UM (2005) Comparative study of nutrient composition of commercial brown, parboiled and milled rice from Brazil. *J Food Compos Anal* 18(4):287–296
- Helm RM, Burks AW (1996) Hypoallergenicity of rice protein. *Cereal foods world* 41(11):839–843
- Jitngarmkusol S, Hongsuwankul J, Tananuwong K (2008) Chemical compositions, functional properties, and microstructure of defatted macadamia flours. *Food Chem* 110(1):23–30
- Juliano BO (1978) Amylose analysis in rice—a review. In *Proceedings of the workshop on chemical aspects of rice grain quality*. Los Banos, Philippines, International Rice Research Institute, 1979
- Juliano BO (1985) Rice: chemistry and technology, 2nd edn. American association of cereal chemists, St. Paul (Minn.)
- Kadan RS, Bryant RJ, Miller JA (2008) Effects of milling on functional properties of rice flour. *J Food Sci* 73(4):E151–E154
- Lawal OS, Adebowale KO (2004) Effect of acetylation and succinylation on solubility profile, water absorption capacity, oil absorption capacity and emulsifying properties of mucuna bean (*Mucuna pruriens*) protein concentrate. *Food/Nahrung* 48(2):129–136
- Le Y, Dias-Morse PN, Meullenet JF (2019) Effect of rice variety and milling fraction on the starch gelatinization and rheological properties of rice milk. *Food Sci Technol (AHEAD)*
- Li JY, Yeh AI (2001) Relationships between thermal, rheological characteristics and swelling power for various starches. *J Food Eng* 50(3):141–148
- Mahasukhonthachai K, Sopade PA, Gidley MJ (2010) Kinetics of starch digestion and functional properties of twin-screw extruded sorghum. *J Cereal Sci* 51(3):392–401
- Meera K, Smita M, Haripriya S (2019) Varietal distinctness in physical and engineering properties of paddy and brown rice from southern India. *J Food Sci Technol* 56(3):1473–1483
- Monks JLF, Vanier NL, Casaril J et al (2013) Effects of milling on proximate composition, folic acid, fatty acids and technological properties of rice. *J Food Compos Anal* 30(2):73–79
- Oikonomopoulou VP, Krokida MK, Karathanos VT (2011) Structural properties of freeze-dried rice. *J Food Eng* 107(3–4):326–333
- Osundahunsi OF, Fagbemi TN, Kesselman E, Shimon E (2003) Comparison of the physicochemical properties and pasting characteristics of flour and starch from red and white sweet potato cultivars. *J Agricultural Food Chem* 51(8):2232–2236
- Rao MA (2014) Flow and functional models for rheological properties of fluid foods. *Rheology of fluid, semisolid, and solid foods*. pp 27–61. Springer, Boston
- Sadasivam S. (1996) *Biochemical methods*. New age international.
- Sandhu RS, Singh N, Kaler RSS, Kaur A, Shevkani K (2018) Effect of degree of milling on physicochemical, structural, pasting and cooking properties of short and long grain Indica rice cultivars. *Food Chem* 260:231–238
- Singh N, Kaur L, Sandhu KS, Kaur J, Nishinari K (2006) Relationships between physicochemical, morphological, thermal,

- rheological properties of rice starches. *Food Hydrocolloids* 20(4):532–542
- Sosulski FW (1962) The centrifuge method for determining flour absorption in hard red spring wheats. *Cereal Chem* 39:344–350
- Tikapunya T, Zou W, Yu W, Powell PO, Fox GP, Furtado A, Henry RJ, Gilbert RG (2017) Molecular structures and properties of starches of Australian wild rice. *Carbohydr Polym* 172:213–222
- Tumpanuvatr T, Jittanit W, Surojanametakul V (2018) Effects of drying conditions in hybrid dryer on the GABA rice properties. *J Stored Prod Res* 77:177–188
- Wani IA, Sogi DS, Wani AA, Gill BS, Shivhare US (2010) Physicochemical properties of starches from Indian kidney bean (*Phaseolus vulgaris*) cultivars. *Int J Food Sci Technol* 45(10):2176–2185
- Waramboi JG, Dennien S, Gidley MJ, Sopade PA (2011) Characterisation of sweetpotato from Papua New Guinea and Australia: physicochemical, pasting and gelatinisation properties. *Food Chem* 126(4):1759–1770
- Wu WS, Chang YH, Sun Pan B, Huang TC (2011) Effects of phosphates on the pasting properties of rice flour from waxy and non-waxy varieties. *J Texture Stud* 42(1):31–41
- Xie M, Huff H, Hsieh F, Mustapha A (2008) Puffing of okara/rice blends using a rice cake machine. *J Food Sci* 73(8):E341–E348
- Zhu L, Sun J, Wu G, Wang Y, Zhang H, Wang L, Qian H, Qi X (2018) Identification of rice varieties and determination of their geographical origin in China using Raman spectroscopy. *J Cereal Sci* 82:175–182

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.