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Morphological and Rheological Properties of Starches Separated from Cultivars of Rice (*Oryza sativa* L.) from North East India

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Abstract

Starch granules isolated from different accessions of rice from North East India showed a typical polygonal morphology with size ranging from 3.4 ± 0.8 µm to 6.4 ± 1.2 µm. The apparent amylose content (AAC) of the granules varied from 1.9% to 28.33%. Our results identify starch from IC-583088 as "waxy" and IC-583085, IC-583038, DPRR-168 as "very low" amylo-. The coefficient of resistance to flow (n) for starch pastes from the varieties of rice studied in the present investigation recorded a value of <1.0. The observed "n" value deviates from the Newtonian flow indicating the pseudoplastic nature of starches isolated from these varieties. While starch pastes from the accession IC-583088 recorded the highest "n" value of 0.6, that from the accession IC-545197 showed the lowest value of 0.03. The variations in coefficient of resistance to flow clearly revealed a higher "n" value for starch pastes from the "waxy" and "low" amylo-cultivars than the "intermediate" or "high" amylo-cultivars. Our results clearly established characteristic rheological properties for starches from the accessions SKY-AK-1608, IC-583035, YS-RC-219, IC-564939 and IC-332963, which exhibited greater resistance to thinning and shearing than other varieties.

Keywords

Rice, Starch, Apparent Amylose Content, Rheology

1. Introduction

Starch, an insoluble polymer that occurs in plant cells in the form of a complex granular mixture of amylose and amylopectin, is one of the major dietary sources of carbohydrates and the most abundant storage polysaccharide in plants. Starch is synthesized in amyloplasts in the form of granules with a partially crystalline texture. De-

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pending on the number of starch granules initiated in each amyloplast, they have been classified as simple, compound and semi-compound [1]. Compound starch granules are composed of several sub-granules, each of which is synthesized simultaneously within a single amyloplast. Depending upon the species and the tissue, the granules vary in size from 1 to 100 µm and in shape from round to polygonal [2]. Starch granules of wheat, barley, rye and triticale have been reported to show bimodal size distribution in the endosperm tissues and have been classified into two types *viz.*, "A" type which is lenticular in shape with diameter ranging between 10 and 20 µm and "B" type which is spherical in shape with a diameter of <10 µm [3]-[7]. Starches of rice and oat tend to exist in clusters of individual granules designated as compound granules [8]-[11]. "C" type starches are considered to be a mixture of A- and B-type polymorphs. While the "A" and "C" type starches are characteristic of cereals and legumes, respectively, the "B" type structures are characteristics of starches from roots and tuber tissues [12]-[14].

The functional properties of starches from different sources vary considerably and are therefore unique for each type. These differences arise from variations in amylose to amylopectin ratio [15] [16], presence of lipids [17] and in morphology [18]. According to Tester and Morrison [19] while starch swelling is a property associated with amylopectin, amylose in starch restricts it [15] [16]. Thus, while low amylose flour is good for preparation of oriental noodles as well as for extended shelf life of bread, flour with high amylose content is good for fried foods [20] [21].

As the primary dietary source of carbohydrates for human nutrition, rice plays an important role in meeting energy requirements and nutrient intake [22]. Juliano [8] has highlighted the unique characteristics of rice starch and has emphasized that it can be a better substitute for many other different types of starches including that from corn. North East India, being at the confluence of Indo-Malayan and Indo-Chinese biogeographic realms, covering an area of 2.55×10^5 km^2 from 21˚57' to 29˚28'N latitude and from 89˚40' to 97˚25'E longitude, represents one of the "biodiversity hotspots" of the world. Even though the region houses a large diversity of both upland and lowland cultivars of rice which show large variations in some of the key quality attributes including kernel length, aroma and cooking quality [23], there is no information on the quality characteristics of starches from cultivars of rice from this region. The paper reports the physico-chemical and rheological properties of starch from cultivars of rice from North East India differing in their amylose-amylopectin ratio.

2. Materials and Methods

2.1. Plant Material

Grains of different accessions of rice (*Oryza sativa* L.) from North East India, representing cultivars with varying apparent amylose content (AAC) of starch, were procured from the rice germplasm bank of North Eastern Regional Station of National Bureau of Plant Genetic Resources, India. The collection comprised of 24 upland and 20lowland accessions from the region. The collection was maintained *ex situ* in the experimental field of the University. Grains of each accession were raised to seedling stage in 6 cm deep plastic trays filled with 50:50 mixture of soil and compost which was irrigated with water to cover the soil surface. The seedlings were subsequently transferred to 2 meter × 2 meter low level beds raised for the purpose in the experimental fields of the University and maintained *ex situ* under irrigation till maturity at an average day temperature ranging between 19˚C to 22˚C. Transplanting of seedlings was done at a spacing of 20 × 15 cm with the soil submerged in 1 to 2 cm of water up to 10 days after transplanting. The seedlings were dipped in chloropyriphos: water (1:1000) solution before transplanting for preventing insect attack. Fertilizers were applied @ 80:60:40 kg NPK/ha in split dozes with P, K and 50 % of N applied as the basal dose, 25% N at maximum tillering and rest 25% N at panicle initiation stage. Grains were harvested at maturity from plants of each accession maintained in the experimental field.

2.2. Isolation of Starch Granules

Starch granules were isolated from mature grains of rice according to Takaoka *et al*. [24]. The granules were homogenized to fine powder under liquid nitrogen in a chilled pestle and mortar. The powder was subsequently suspended in deionised water and the suspension maintained at 4˚C for 4 hours with occasional stirring. The suspension was filtered through a single layer of muslin and the filtrate centrifuged at 10,000 ×g at 4˚C for 10 min. The pellet was resuspended in appropriate volume of SDS sample buffer containing 60 mM Tris-HCl (pH

6.8), 10% (w/v) sodium dodecylsulfate (SDS), 3% (v/v) *β*-mercaptoethanol and 10% (v/v) glycerol and then pelleted by centrifugation at 30,000 g at 4˚C for 10 min. The resultant pellet was resuspended again in SDS sample buffer, pelleted by centrifugation at 30,000 ×g at 4˚C for 10 min and finally washed twice with deionised water followed by three washes with chilled acetone. The washed pellet comprising of purified starch granules was dried at room-temperature and stored at −20˚C.

2.3. Scanning Electron Microscopy of Isolated Starch Granules

Surface morphology of the starch granules was determined under a scanning electron microscope after spraying a thin layer of purified starch granules on 'brass stubs' and coating with a thin layer of gold vapour (300 Å) as per David *et al*. [25]. The starch granules were subsequently observed in a JOEL-1850 SEM at magnification ranging between 7500× and 10000× operated at 20 kV.

2.4. Determination of Apparent Amylose Content

The apparent amylose content of starch was determined by the method described by Juliano [26]. A suitable mass of starch was suspended in an appropriate volume of 95% ethanol: 1N NaOH (1:9). The suspension was mixed thoroughly and heated at 100˚C for 10 min. in a dry bath. A suitable aliquot of the suspension was mixed with 1N acetic acid and I_2-KI solution and allowed to stand for 20 min. in dark at room temperature. Absorbance of the solution was recorded at 620 nm in Lambda650 UV/Vis Spectrophotometer (Perkin Elmer, U.S.A.) against a reagent blank with potato amylose (Sigma) as the reference standard. Starch isolated from grains of *var.* NDR97, a traditional variety of indigenous "Bororice" which is known to have low (4%) AAC [27], was used as a reference for purposes of comparison.

2.5. Determination of Rheological Properties

The rheologicalproperties of starches suspended in distilled water were determined by Rotational rheometer (C-DG26.7/QC, RheolabQC) according to Li *et al.* [28]. An 8% (w/v) suspension of native rice starch was prepared by dispersing a suitable mass of dried starch granules in appropriate volume of MilliQ deionized water with constant stirring. After loading the starch suspension between the cone and plate, it was equilibrated to 50˚C for 1 min at 200 s^{-1} followed by increase in the temperature to 95˚C at the rate of 12˚C·min.$^{-1}$. The sample was held at 95˚C for 2 min. and 30 seconds after which the temperature was decreased to 50˚C at the rate of 12˚C·min.$^{-1}$. The sample was finally held at 50˚C for 1 min. The shear rate was maintained at 200 s^{-1} throughout the experiment. The pasting properties including onset temperature, peak temperature, peak viscosity, trough viscosity, final viscosity, breakdown viscosity and setback viscosity of each sample were inferred from acquired data.

2.6. Statistical Analysis

All the observations were recorded with 3 technical and 3 biological replicates. Statistical analysis of the data was carried out with SPSS package to obtain the values for standard deviation from the mean as well as least significant difference between accessions for grain size, AAC, and pasting properties of starch at 5% probability level.

3. Results and Discussion

The accessions showed an average plant height of 110 - 152 cm. While the upland accessions showed an average maturity time of 105 days, the lowland accessions showed an average maturity time of 123 days from the date of transplanting. Grains of different accessions of rice (*Oryza sativa* L.), representing both upland and lowland varieties from North East India, varied in length from 7.75 mm to 3.5 mm and in width from 2.05 mm to 3.1 mm (**Table 1** and **Table 2**). While the grains of accession IC-583088 showed the highest length to width ratio (L/W) of 3.6, those from IC-540182 and SKY-AK-1608 showed the lowest L/W of 1.2. Cruz and Khush [29] have classified rice grains into different size and shape categories on the basis of their morphology. While grains with a length of >7.5 mm were classified as very long, those with average length between 6.61 and 7.5 mm and between 5.51 and 6.6mm were respectively classified as long and intermediate type. Grains with a length of < or =

Table 1. Morphological features of grains of different upland accessions of rice from Northeast region of India.

Rice variety	Mean grain length† (mm)	Mean grain width† (mm)	Grain length/width ratio*†	Grain type[a]	Mean grain weight† (g)	Grain colour
IC-583088	7.75 ± 0.57(*a*)	2.15 ± 0.12(*e*)	3.6 ± 0.28(*g*)	LS	0.022 ± 0.005(*i*)	White
IC-583085	6.6 ± 0.42(*b*)	2.05 ± 0.09(*e*)	3.2 ± 0.3(*g*)	MS	0.018 ± 0.002(*i*)	Light cream
DPRR-168	5.5 ± 0.46(c)	3.1 ± 0.09(*f*)	1.8 ± 0.15(*h*)	SB	0.020 ± 0.003(*i*)	Light green
IC-583038	4.5 ± 0.30(*c*)	3.1 ± 0.18(*f*)	1.5 ± 0.1(*h*)	SB	0.024 ± 0.004(*i*)	Light green
SKY-AK-1608	3.87 ± 0.48(*d*)	3.1 ± 0.2(*f*)	1.2 ± 0.09(*h*)	SB	0.018 ± 0.002(*i*)	Off white
IC-583035	4.12 ± 0.57(*c*)	3.1 ± 0.2(*f*)	1.3 ± 0.09(*h*)	SB	0.026 ± 0.004(*i*)	Light green
YS-RC-219	5.5 ± 0.40(*c*)	3.1 ± 0.16(*f*)	1.8 ± 0.09(*h*)	SB	0.020 ± 0.003(*i*)	Light brown
VP-28	5.0 ± 0.62(*c*)	3.1 ± 0.2(*f*)	1.6 ± 0.087(*h*)	SB	0.017 ± 0.003(*i*)	Brown
SKY-AK-1569	6.65 ± 0.58(*b*)	2.15 ± 0.14(*e*)	3.0 ± 0.18(*g*)	MM	0.026 ± 0.005(*i*)	Off white
IC-540276	3.87 ± 0.82(*d*)	2.15 ± 0.16(*e*)	1.8 ± 0.17(*h*)	SB	0.017 ± 0.005(*i*)	Light brown
YS-RC-27	5.5 ± 0.81(*c*)	3.1 ± 0.21(*f*)	1.8 ± 0.15(*h*)	SB	0.024 ± 0.004(*i*)	Off white
IC-526602	6.0 ± 0.79(*c*)	3.1 ± 0.21(*f*)	1.9 ± 0.155(*h*)	MB	0.020 ± 0.003(*i*)	Brown
IC-398030	6.25 ± 0.89(*c*)	3.1 ± 0.19(*f*)	2.0 ± 0.16(*h*)	MB	0.031 ± 0.005(*i*)	Brown
IC-583129	6.7 ± 0.91(*c*)	2.6 ± 0.20(*e*)	2.6 ± 0.18(*g*)	LM	0.020 ± 0.005(*i*)	Off white
IC-583032	5.7 ± 0.77(*c*)	2.15 ± 0.16(*e*)	2.6 ± 0.18(*g*)	MM	0.016 ± 0.*005*(*i*)	Light green
IC-540182	3.75 ± 0.61(*d*)	3.1 ± 0.22(*f*)	1.2 ± 0.11(*h*)	SB	0.015 ± 0.005(*i*)	Light green
VP-15	4.87 ± 0.65(*c*)	3.1 ± 0.22(*f*)	1.6 ± 0.14(*h*)	SB	0.017 ± 0.006(*i*)	Brown
SKY-AK-1556	5.0 ± 0.61(*c*)	2.15 ± 0.19(*e*)	2.3 ± 0.20(*g*)	SM	0.026 ± 0.005(*i*)	Light green
SKY-AK-1549	6.75 ± 0.71(*c*)	3.1 ± 0.20(*f*)	2.2 ± 0.20(*g*)	LM	0.022 ± 0.007(*i*)	Off white
IC-583029	6.12 ± 0.70(*c*)	2.15 ± 0.15(*e*)	2.8 ± 0.25(*g*)	MM	0.022 ± 0.007(*i*)	Brown
YS-RC-105	5.0 ± 0.78(*c*)	2.15 ± 0.15(*e*)	2.3 ± 0.2(*g*)	SM	0.021 ± 0.007(*i*)	Brown
IC-583113	6.0 ± 0.88(*c*)	3.1 ± 0.21(*f*)	1.7 ± 0.1(*h*)	MB	0.018 ± 0.006(*i*)	Off white
VP-44	7.2 ± 0.71(*c*)	3.34 ± 0.18(*f*)	3.3 ± 0.12(*g*)	LS	0.026 ± 0.008(*i*)	Brown
IC-540270	7.5 ± 0.77(*c*)	2.15 ± 0.13(*e*)	3.48 ± 0.27(*g*)	LS	0.026 ± 0.008(*i*)	Off white

*[a]SB (short-bold), LM (long-medium), LS (long-slender), MS (medium-slender), MM (medium-medium), SM (short-medium), MB (medium-bold) (as per Dela Cruz and Khush [29]); †Same letters in parenthesis against data for each parameter indicates statistically insignificant difference ($p < 0.05$).

Table 2. Morphological features of grains of different lowland accessions of rice from Northeast region of India.

Rice variety	Mean grain length† (mm)	Mean grain width† (mm)	Grain length/width ratio*†	Grain Type[a]	Mean grain weight† (g)	Grain colour
IC-564948	7.0 ± 0.11(*a*)	2.15 ± 0.04(*e*)	3.2 ± 0.13(*g*)	LS	0.022 ± 0.002(*i*)	Reddish brown
IC-564953	6.6 ± 0.32(*b*)	2.15 ± 0.04(*e*)	3.0 ± 0.14(*g*)	MM	0.021 ± 0.002(*i*)	Light green
IC-564950	5.0 ± 0.21(*b*)	2.15 ± 0.04(*e*)	2.3 ± 0.10(*g*)	SM	0.018 ± 0.001(*i*)	Light green
IC-321204	6.25 ± 0.25(*c*)	2.15 ± 0.03(*e*)	2.9 ± 0.10(*g*)	MM	0.021 ± 0.002(*i*)	Reddish brown
IC-558321	5.0 ± 0.12(*b*)	3.1 ± 0.06(*f*)	1.6 ± 0.12(*h*)	SB	0.021 ± 0.002(*i*)	Light yellow
IC-321201	6.75 ± 0.42(*c*)	2.15 ± 0.03(*e*)	3.1 ± 0.15(*g*)	LS	0.022 ± 0.003(*i*)	Light yellow
IC-564939	6.5 ± 0.34(*c*)	3.1 ± 0.05(*f*)	2.0 ± 0.08(*h*)	MB	0.020 ± 0.003(*i*)	Light yellow
IC-332963	6.0 ± 0.43(*c*)	2.15 ± 0.04(*e*)	2.7 ± 0.17(*g*)	MM	0.022 ± 0.002(*i*)	Reddish brown
IC-324133	6.37 ± 0.24(*c*)	2.15 ± 0.04(*e*)	2.9 ± 0.20(*g*)	MM	0.022 ± 0.002(*i*)	Reddish brown
IC-321195	5.0 ± 0.17(*b*)	2.15 ± 0.05(*e*)	2.3 ± 0.11(*g*)	SM	0.019 ± 0.005(*i*)	Reddish brown
IC-558311	5.75 ± 0.17(*b*)	2.15 ± 0.04(*e*)	2.6 ± 0.11(*g*)	MM	0.025 ± 0.005(*i*)	Light yellow
IC-545288	3.5 ± 0.08(*d*)	2.15 ± 0.04(*e*)	1.6 ± 0.11(*h*)	SB	0.019 ± 0.002(*i*)	Light green
IC-564949	5.75 ± 0.09(*b*)	2.15 ± 0.05(*e*)	2.6 ± 0.16(*g*)	MM	0.016 ± 0.002(*i*)	Light green
IC-321206	3.87 ± 0.09(*d*)	2.15 ± 0.04(*e*)	1.8 ± 0.09(*h*)	SB	0.019 ± 0.002(*i*)	Reddish brown
IC-564952	5.0 ± 0.10(*b*)	3.1 ± 0.06(*f*)	1.6 ± 0.10(*h*)	SB	0.020 ± 0.003(*i*)	Greenish yellow
IC-321193	6.12 ± 0.19(*c*)	2.15 ± 0.04(*e*)	2.8 ± 0.14(*g*)	MM	0.023 ± 0.005(*i*)	Reddish brown
IC-564940	5.37 ± 0.17(*b*)	2.15 ± 0.05(*e*)	2.4 ± 0.13(*g*)	SM	0.023 ± 0.005(*i*)	Light yellow
IC-545274	4.25 ± 0.19(*d*)	3.1 ± 0.07(*f*)	1.3 ± 0.06(*h*)	SB	0.020 ± 0.004(*i*)	Greenish yellow
IC-558315	7.0 ± 0.25(*a*)	2.15 ± 0.05(*e*)	3.2 ± 0.12(*g*)	LS	0.020 ± 0.004(*i*)	Greenish yellow
IC-545197	6.75 ± 0.30(*a*)	2.15 ± 0.05(*e*)	3.1 ± 0.11(*g*)	LS	0.022 ± 0.005(*i*)	Reddish brown

*[a]SB (short-bold), LM (long-medium), LS (long-slender), MS (medium-slender), MM (medium-medium), SM (short-medium), MB (medium-bold) (as per Dela Cruz and Khush [29]); †Same letters in parenthesis against data for each parameter indicates statistically insignificant difference ($p < 0.05$).

5.5 mm were classified as short type. Further, Cruz and Khush [29] classified grains with L/W of >3.0, 2.1 to 3.0 and <2.0 as slender, medium and bold respectively. In conformity with this classification, rice grains from accessions studied in the present investigation can be classified into seven categories *viz*., long-slender (LS), long-medium (LM), medium-slender (MS), medium-medium (MM), medium-bold (MB), short-medium (SM) and short-bold (SB). The accessions also showed marked variations in the colour of pericarp (**Table 1** and **Table 2**).

Starch granules isolated from different accessions, representing both upland and lowland cultivars of rice from North East India, showed a typical polygonal morphology (**Figure 1** and **Figure 2**) with a mono-modal distribution and size ranging from a minimum of 3.4 ± 0.8 μm in IC-564948 to a maximum of 6.7 ± 1.2 μm in IC-540270 (**Table 3**). A distinct feature of starch granules isolated from accessions YS-RC-105, IC-321201 and IC-332963 was the presence of pores on the surface of the granules. No such pores were visible on the surface of

Table 3. Size and apparent amylose content of starch granules isolated from endosperm tissues of grains of upland and lowland accessions of rice from North East India. †Same letters in parenthesis against data for each parameter indicates statistically insignificant difference ($p < 0.05$).

Accessions	Granule size† (μm)	AAC† (%)	Type	Accessions	Granule size† (μm)	AAC† (%)	Type
Upland				Lowland			
IC-583088	3.7 ± 0.8(*a*)	1.90 ± 0.08(*b*)	Waxy	IC-564948	3.4 ± 0.8(*a*)	13.78 ± 0.57(*f*)	Low amylo
IC-583085	3.6 ± 1.1(*a*)	4.15 ± 0.25(*c*)	Very low amylo	IC-564953	3.5 ± 0.5(*a*)	14.10 ± 0.72(*f*)	Low amylo
DPRR-168	3.9 ± 1.0(*a*)	10.27 ± 0.52(*d*)	Very low amylo	IC-558321	4.1 ± 0.7(*a*)	14.94 ± 0.70(*f*)	Low amylo
IC-583038	4.1 ± 0.8(*a*)	11.80 ± 0.48(*e*)	Very low amylo	IC-564939	4.2 ± 0.8(*a*)	15.14 ± 0.69(*f*)	Low amylo
IC-540276	4.5 ± 0.8(*a*)	15.74 ± 0.78(f)	Low amylo	IC-558311	4.7 ± 0.6(*a*)	18.73 ± 1.30(*h*)	Low amylo
IC-564950	3.9 ± 1.0(*a*)	14.3 ± 1.26(*f*)	Low amylo	IC-321204	4.0 ± 1.1(*a*)	14.72 ± 1.6(*f*)	Low amylo
SKY-AK-1608	4.0 ± 0.9(*a*)	14.0 ± 1.38(*f*)	Low amylo	IC-545288	4.9 ± 0.5(*a*)	19.63 ± 1.73(*h*)	Low amylo
YS-RC-219	4.2 ± 0.6(*a*)	14.21 ± 1.38(*f*)	Low amylo	IC-321201	4.2 ± 1.2(*a*)	15.11 ± 1.86(*f*)	Low amylo
IC-583035	4.2 ± 0.6(*a*)	14.12 ± 1.58(*f*)	Low amylo	IC-332963	4.3 ± 1.9(*a*)	15.25 ± 1.16(*f*)	Low amylo
VP-28	4.2 ± 1.3(*a*)	14.35 ± 1.57(*f*)	Low amylo	IC-324133	4.4 ± 1.5(*a*)	16.24 ± 1.89(*f*)	Low amylo
SKY-AK-1569	4.3 ± 0.7(*a*)	14.82 ± 1.28(*f*)	Low amylo	IC-321195	4.6 ± 0.4(*a*)	17.52 ± 1.23(*f*)	Low amylo
YS-RC-27	4.5 ± 1.1(*a*)	16.59 ± 0.95(*g*)	Low amylo	IC-321206	4.8 ± 1.7(*a*)	21.8 ± 0.0(*h*)	Intermediate amylo
IC-398030	4.8 ± 1.0(*a*)	19.61 ± 1.03(*h*)	Low amylo	IC-564949	4.9 ± 1.1(*a*)	21.62 ± 0.0(*h*)	Intermediate amylo
IC-526602	4.4 ± 1.6(*a*)	19.5 ± 1.85(*h*)	Low amylo	IC-545274	5.3 ± 0.7(*a*)	25.52 ± 1.51(*k*)	High amylo
IC-583129	4.8 ± 0.6(*a*)	20.08 ± 0.91(*h*)	Low amylo	IC-558315	5.7 ± 0.8(*a*)	26.65 ± 1.53(*k*)	High amylo
IC-583032	4.7 ± 1.1(*a*)	21.62 ± 1.02(*h*)	Intermediate amylo	IC-545197	5.8 ± 1.2(*a*)	27.85 ± 1.76(*k*)	High amylo
IC-540182	4.9 ± 0.5(*a*)	21.80 ± 0.99(*h*)	Intermediate amylo	IC-564952	5.0 ± 0.1(*a*)	25.22 ± 1.23(*k*)	High amylo
VP-15	4.9 ± 0.7(*a*)	21.90 ± 1.11(*h*)	Intermediate amylo	IC-321193	5.1 ± 0.4(*a*)	25.40 ± 1.35(*k*)	High amylo
SKY-AK-1556	4.9 ± 1.9(*a*)	21.90 ± 0.93(*h*)	Intermediate amylo	IC-564940	5.1 ± 1.1(*a*)	25.41 ± 1.31(*k*)	High amylo
SKY-AK-1549	5.0 ± 0.1(*a*)	21.90 ± 1.31(*h*)	Intermediate amylo				
YS-RC-105	5.3 ± 0.8(*a*)	23.72 ± 1.52(*j*)	Intermediate amylo				
IC-583029	5.2 ± 0.6(*a*)	26.32 ± 1.58(*k*)	High amylo				
IC-583113	5.2 ± 1.9(*a*)	26.7 ± 1.88(*k*)	High amylo				
VP-44	5.5 ± 0.2(*a*)	28.33 ± 1.88(*k*)	High amylo				
IC-540270	6.4 ± 1.2(*a*)	28.33 ± 1.97(*k*)	High amylo				

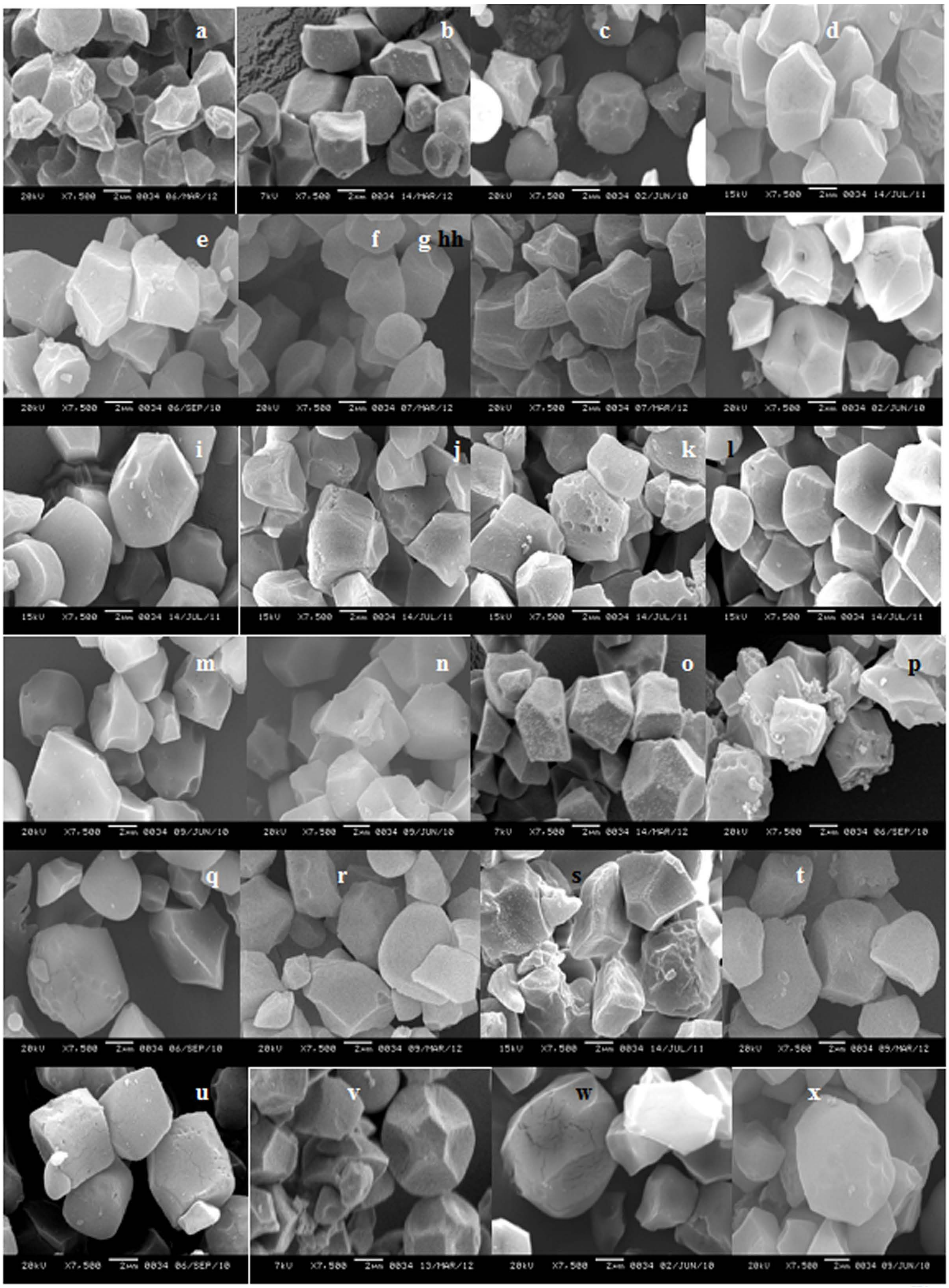

Figure 1. (a) Scanning electron micrographs of starch granules isolated from upland varieties of rice from Northeast India. (a) IC-583088; (b) IC-583085; (c) DPRR-168; (d) IC-583038; (e) SKY-AK-1608; (f) IC-583035; (g) YS-RC-219; (h) VP-28; (i) SKY-AK-1569; (j) IC-540276; (k) YS-RC-27; (l) IC-526602; (m) IC-398030; (n) IC-583129; (o) IC-583032; (p) IC-540182, (q) VP-15; (r) SKY-AK-1556; (s) SKY-AK-1549; (t) IC-583029; (u) YS-RC-105; (v) IC-583113; (w) VP-44; (x) IC-540270.

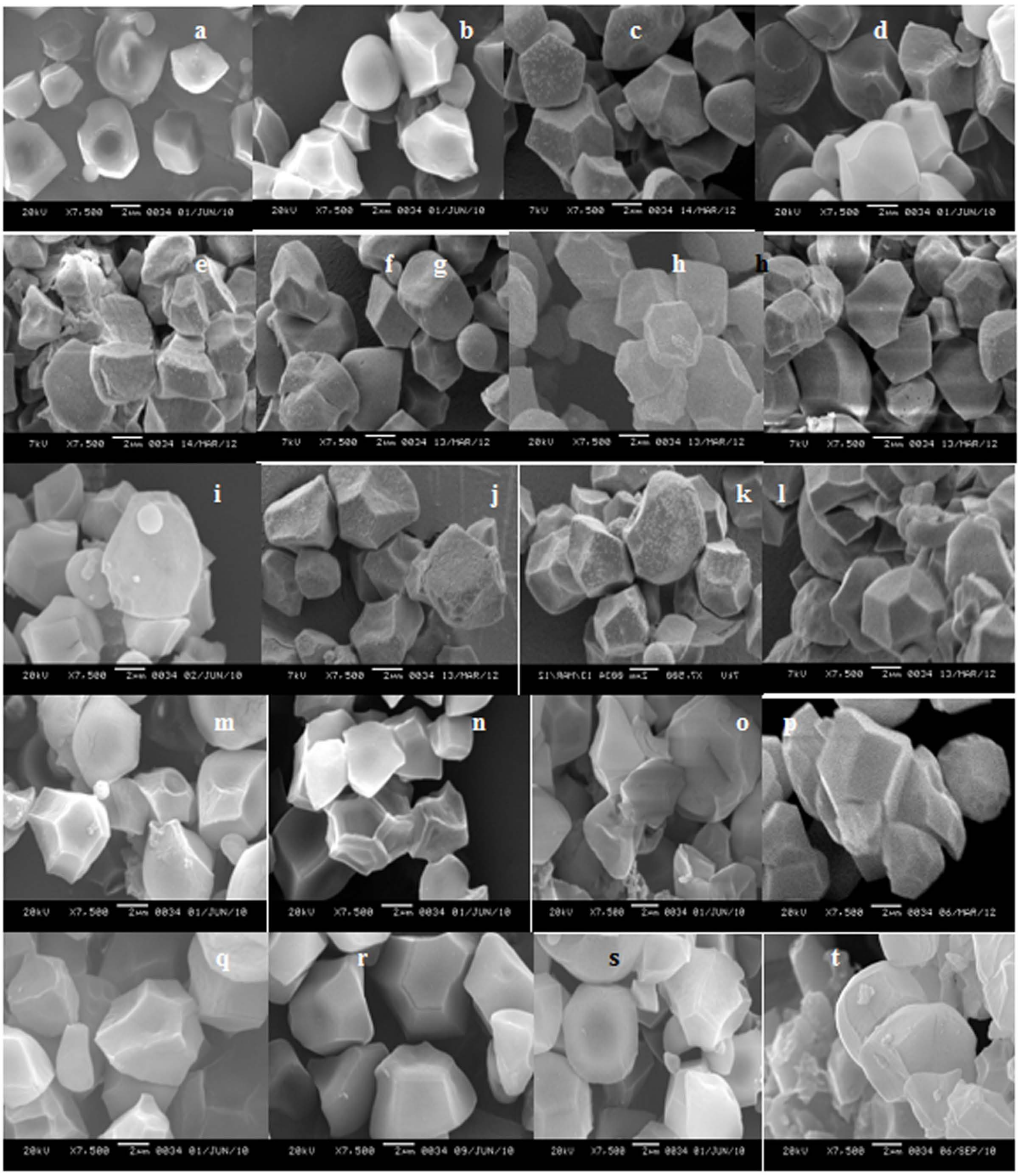

Figure 2. Scanning electron micrographs of starch granules isolated from lowland varieties of rice from Northeast India (a) IC-564948; (b) IC-564953; (c) IC-564950; (d) IC-321204; (e) IC-558321; (f) IC-321201; (g) IC-564939; (h) IC-332963; (i) IC-324133; (j) IC-321195, (k) IC-558311; (l) IC-545288; (m) IC-564949; (n) IC-321206; (o) IC-564952; (p) IC-321193; (q) IC-964940; (r) IC-545274; (s) IC-558315; (t) IC-545197.

starch granules from other accessions. On the basis of their size, Lindeboom *et al*. [7] have classified starch granules as large (>25.0 µm), medium (10.0 to 25.0 µm), small (5.0 to 10.0 µm) and very small (<5.0 µm). In conformity with this classification, starch granules isolated the accessions of rice investigated in the present study fall under the "small" to "very small" size category. Juliano [8], Yeh and Li [30] and Li and Yeh [31] have also reported the presence of small starch granules in rice with size ranging between 2.0 µm and 10.0 µm. Starch granule size has been described as an important parameter which has strong correlation with its pasting behaviour [32]-[34].

The apparent amylose content (AAC) of starch from different accessions of rice studied in the present investigation ranged from a low of 1.9% in IC-583088 to a high of 28.33% in IC-540270 and VP-44 (**Table 3**). Even though typical levels of amylose in starches range from 15% to 25% [34], the amylose content is known to vary with source of the starch and is affected by the climatic conditions as well as the nutrient status of soil during grain development. Our results on AAC of starch in different accessions of rice are in agreement with Wang *et al*. [36] who have reported 18.1% to 31.6% AAC in starches of different non-glutinous cultivars and 0.1% to 3.25% AAC in starches of different glutinous cultivars of rice. While Dobo *et al*. [37] have classified non-glutinous starches into high (>25%), intermediate (21% - 24%) and low (15% - 20%) AAC types, Jiminez *et al*. [38] have suggested categorization of non-glutinous starches into high (>25%), intermediate (20% - 25%) and low (<20%) AAC types. Considering the broad range of amylose content in the low AAC category, starches with <20% AAC have been further categorized into "waxy" (0% - 2%), "very low" amylo- (5% - 12%) and "low" amylo- (12% - 20%) types [39]-[41]. In conformity with this classification, the starch of IC-583088 can be classified as "waxy" and that of IC-583085, IC-583038 and DPRR-168 as "very low" amylo-types. While the starches from IC-540276, YS-RC-27, IC-398030, IC-583129, IC-564948, IC-564953, IC-558321, IC-564939 and IC-558311 can be classified as "low" amylo-, that from IC-583032, IC-540182, VP-15, SKY-AK-1556, SKY-AK-1549, YS-RC-105 and from IC-564952, IC-321193, IC-564940, IC-545274, IC-583029, IC-558315, IC-545197, VP-44 and IC-540270 can be respectively grouped under the "intermediate" and "high" amylo-types. Jayamani *et al*. [42] have made similar classifications for a collection of International germplasm maintained in Portugese rice germplasm bank.

Marked differences were observed in the rheological properties of starches isolated from different accessions of rice studied in the present investigation. While the values for shear stress recorded a steady increase with increase in shear rate, the magnitude of increase varied from accession to accession. Thus, starch from the accession IC-583088 showed the lowest of 3.6 fold increase in shear stress and that from VP-44 showed the highest of 119 fold increase in shear stress with increase in shear rate from 0.054 to 100 s^{-1} (**Table 4** and **Table 5**). The

Table 4. Relationship between shear stress and shear rates of 4% (w/v) aqueous pastes of starches from upland varieties of rice from Northeast India.

Accession	Shear rate (1/s)																					η	R^2
	0.054	0.072	0.107	0.156	0.229	0.335	0.714	0.789	1.05	1.53	2.24	3.27	4.78	6.99	10.2	15	21.9	32	46.8	68.4	100		
	Shear stress (Pa)																						
IC583088	2,1	2,14	3,2	3,39	3,43	3.76	3.8	4.28	4.33	4.6	4.73	5.6	5.74	5.98	6.09	6.26	6.36	6.46	6.53	6.77	7.56	0.6	0.9
IC583085	2.08	1.98	2.26	2.33	2.52	2.63	2.65	2.76	2.77	2.82	3.01	3.31	3.62	3.63	3.77	4.26	4.29	4.8	5.01	5,24	5.44	0.44	0.9
DPRR-168	0.943	1.95	1.43	1.59	1.71	1.93	2.27	2.33	2.67	2.89	2.96	3.08	3.32	3.36	3.41	3.78	4.12	4.38	4.47	4.48	5.04	0.48	0.9
IC583038	0.765	1.38	1.21	1.46	1.51	1.92	2.09	2.29	2.37	2.77	2.91	3.07	3.14	3.18	3.23	3.58	3.62	3.68	3.78	4.41	4.58	0.48	0.9
SKY-AK-1608	0.454	0.616	0.823	1.29	1.36	1.56	1.96	2.16	2.36	2.45	2.48	2.58	3.11	3.16	3.19	3.26	3.32	3.36	3.46	3.53	3.6	0.41	0.9
IC583035	0.454	0.616	0.769	1.12	1.27	1.55	1.63	2.15	2.16	2.17	2.04	2.35	2.47	2.57	2.62	3.25	3.31	3.32	3.44	3.53	3.6	0.37	0.9
YS-RC-219	0.259	0.476	0.744	1.01	1.21	1.27	1.61	1.69	1.84	1.88	1.95	2.2	2.26	2.46	2.54	2.78	2.92	2.98	3.02	3.08	3.13	0.37	0.9
VP-28	0.233	0.367	0.546	0.97	1.08	1.22	1.35	1.58	1.62	1.79	1.86	2.1	2.22	2.29	2.34	2.73	2.79	2.82	3.01	3.04	3.11	0.36	0.9
SKY-AK-1569	0.198	0.35	0.546	0.945	0.989	0.998	1.28	1.36	1.51	1.55	1.62	2.01	2.04	2.12	2.26	2.68	2.75	2.8	2.98	3.01	3.08	0.25	0.9
IC540276	0.196	0.335	0.465	0.867	0.907	0.919	0.994	1.01	1.07	1.18	1.05	2.01	2.06	2.09	2.18	2.45	2.49	2.52	2.64	2.76	2.98	0.27	0.9
YS-RC-27	0.184	0.323	0.453	0.769	0.771	0.786	0.962	0.981	0.982	0.999	1.01	1.09	1.41	1.56	1.68	1.72	1.78	1.87	2.04	2.12	2.93	0.23	0.9
IC398030	0.173	0.313	0.431	0.643	0.656	0.689	0.692	0.804	0.815	0.932	0.967	1.01	1.23	1.31	1.42	1.47	1.52	1.68	1.8	1.88	2.29	0.22	0.9
IC583129	0.166	0.291	0.413	0.578	0.607	0.628	0.636	0.761	0.769	0.931	0.958	0.98	1.13	1.16	1.26	1.45	1.5	1.62	1.75	1.79	2.27	0.19	0.9
IC583032	0.155	0.29	0.408	0.575	0.596	0.619	0.649	0.724	0.734	0.894	0.897	0.961	1.11	1.15	1.26	1.44	1.49	1.53	1.6	1.73	2.26	0.19	0.9
IC540182	0.154	0.286	0.401	0.552	0.573	0.605	0.636	0.695	0.701	0.868	0.890	0.893	1.08	1.11	1.18	1.34	1.38	1.45	1.52	1.56	1.98	0.19	0.9
VP-15	0.333	0.253	0.382	0.515	0.536	0.568	0.571	0.689	0.698	0.807	0.826	0.829	1.05	1.08	1.16	1.31	1.36	1.42	1.51	1.57	1.95	0.19	0.9
SKY-AK-1556	0.121	0.242	0.371	0.48	0.506	0.539	0.540	0.615	0.622	0.787	0.798	0.812	0.961	1.05	1.12	1.2	1.28	1.38	1.45	1.48	1.66	0.18	0.9
SKY-AK-1549	0.110	0.218	0.343	0.478	0.501	0.533	0.542	0.568	0.592	0.693	0.708	0.728	0.983	0.99	1.11	1.18	1.25	1.27	1.29	1.32	1.56	0.17	0.9
IC583029	0.032	0.058	0.336	0.443	0.469	0.510	0.522	0.556	0.577	0.585	0.607	0.641	0.731	0.75	1.08	1.16	1.22	1.25	1.28	1.31	1.55	0.17	0.9
YS-RC-105	0.032	0.034	0.323	0.38	0.401	0.509	0.516	0.526	0.564	0.578	0.595	0.601	0.642	0.66	1.01	1.14	1.2	1.24	1.27	1.29	1.35	0.15	0.9
IC583113	0.025	0.032	0.101	0.152	0.159	0.447	0.467	0.482	0.512	0.524	0.568	0.582	0.622	0.64	0.96	1.12	1.18	1.2	1.24	1.27	1.33	0.15	0.9
VP-44	0.011	0.034	0.069	0.064	0.086	0.095	0.118	0.196	0.212	0.295	0.312	0.326	0.409	0.42	0.66	0.78	0.80	0.83	0.87	0.90	1.31	0.14	0.9
IC540270	0.02	0.036	0.056	0.079	0.089	0.098	0.118	0.198	0.201	0.298	0.301	0.320	0.404	0.42	0.66	0.78	0.90	0.82	0.87	0.90	1.30	0.14	0.9

Table 5. Relationship between shear stress and shear rates of 4% (w/v) aqueous pastes of starches from lowland varieties of rice from Northeast India.

Accession	Shear rate (1/s)																					η	R^2
	0.054	0.072	0.107	0.156	0.229	0.335	0.714	0.789	1.05	1.53	2.24	3.27	4.78	6.99	10.2	15	21.9	32	46.8	68.4	100		
	Shear stress (Pa)																						
IC564948	0.172	0.367	0.567	0.867	1.35	1.68	2.16	2.56	2.84	2.96	3.08	3.14	3.18	3.23	3.26	3.31	3.36	3.44	3.53	3.6	3.65	0.45	0.9
IC564953	0.154	0.343	0.453	0.945	1.27	1.66	2.26	2.39	2.74	2.95	3.01	3.07	3.11	3.16	3.19	3.25	3.32	3.38	3.46	3.53	3.6	0.45	0.9
IC564950	0.133	0.335	0.453	0.857	1.12	1.58	2.06	2.32	2.46	2.52	2.78	3.01	3.09	3.15	3.19	3.21	3.26	3.36	3.42	3.44	3.45	0.45	0.9
IC321204	0.124	0.323	0.449	0.846	1.10	1.56	2.06	2.31	2.39	2.57	2.82	2.92	3.01	3.16	3.21	3.23	3.27	3.34	3.41	3.43	3.45	0.45	0.9
IC558321	0.118	0.301	0.317	0.713	0.86	0.99	1.01	1.11	1.31	1.45	1.48	1.52	1.54	1.57	1.82	1.92	2.22	2.48	2.67	3.16	3.27	0.36	0.9
IC321201	0.11	0.256	0.305	0.665	0.83	0.88	0.91	1.13	1.17	1.33	1.31	1.39	1.41	1.66	1.69	1.88	2.14	2.34	2.56	2.85	3.16	0.34	0.9
IC564939	0.11	0.238	0.299	0.64	0.68	0.87	0.92	0.99	1.05	1.19	1.22	1.31	1.34	1.56	1.66	1.74	2.06	2.33	2.44	2.67	3.12	0.33	0.9
IC332963	0.10	0.232	0.276	0.515	0.536	0.63	0.66	0.79	0.90	1.03	1.11	1.21	1.32	1.40	1.60	1.68	1.94	2.22	2.42	2.46	2.85	0.33	0.9
IC324133	0.09	0.23	0.256	0.497	0.518	0.568	0.64	0.724	0.804	0.894	0.95	1.10	1.23	1.34	1.50	1.62	1.72	1.87	2.19	2.32	2.46	0.29	0.9
IC321195	0.078	0.218	0.228	0.415	0.501	0.539	0.61	0.66	0.730	0.868	0.943	0.996	1.08	1.19	1.45	1.50	1.64	1.89	2.12	2.25	2.29	0.28	0.9
IC558311	0.06	0.216	0.225	0.41	0.51	0.533	0.612	0.656	0.734	0.858	0.943	1.09	1.10	1.20	1.40	1.40	1.62	1.84	2.04	2.28	2.29	0.28	0.9
IC564949	0.018	0.172	0.191	0.368	0.480	0.498	0.571	0.615	0.727	0.832	0.935	0.98	1.05	1.08	1.12	1.14	1.18	1.25	1.28	1.31	1.32	0.17	0.9
IC545288	0.018	0.172	0.191	0.368	0.470	0.475	0.57	0.598	0.686	0.811	0.910	0.978	1.01	1.07	1.1	1.15	1.16	1.27	1.28	1.31	1.32	0.17	0.9
IC321206	0.015	0.166	0.199	0.366	0.454	0.501	0.561	0.588	0.616	0.764	0.897	0.961	0.983	1.05	1.08	1.09	1.25	1.27	1.29	1.31	1.34	0.17	0.9
IC564952	0.011	0.111	0.175	0.299	0.406	0.447	0.467	0.505	0.563	0.578	0.585	0.605	0.642	0.661	0.66	0.684	0.705	0.744	0.77	0.785	0.846	0.09	0.9
IC321193	0.011	0.10	0.166	0.252	0.305	0.325	0.347	0.360	0.404	0.414	0.433	0.455	0.473	0.510	0.52	0.527	0.543	0.567	0.586	0.743	0.797	0.07	0.9
IC564940	0.011	0.058	0.128	0.152	0.219	0.228	0.234	0.262	0.281	0.295	0.343	0.364	0.404	0.417	0.43	0.441	0.451	0.469	0.490	0.542	0.665	0.06	0.9
IC545274	0.009	0.092	0.116	0.121	0.159	0.195	0.196	0.212	0.259	0.289	0.31	0.327	0.341	0.343	0.35	0.375	0.413	0.457	0.473	0.561	0.574	0.06	0.9
IC558315	0.009	0.055	0.099	0.116	0.153	0.19	0.196	0.201	0.235	0.286	0.31	0.327	0.339	0.337	0.34	0.373	0.41	0.456	0.473	0.523	0.573	0.06	0.9
IC545197	0.006	0.034	0.066	0.079	0.086	0.088	0.091	0.099	0.105	0.119	0.122	0.139	0.141	0.166	0.17	0.21	0.213	0.222	0.242	0.246	0.312	0.03	0.9

coefficient of resistance to flow (n) for the starch pastes recorded a value of <1.0, with starch paste from IC-583088 showing the highest value of 0.6 and that from IC-545197 showing the lowest value of 0.03. The observed "n" value deviates from the Newtonian flow, for which n = 1, thereby indicating the pseudoplastic nature of the starches isolated from these varieties. The non-Newtonian behaviour of starch pastes has also been reported by Rao *et al*. [43] and Nurul *et al*. [44]. Our results on the variations in coefficient of resistance to flow (n) of starch pastes from different accessions of rice clearly revealed a higher "n" value for starch pastes from the "waxy" and "low amylo"-cultivars than the "intermediate" or ‘‘high" amylo-cultivars, thereby indicating a positive relationship between amylose/amylopectin ratio of starch and its flow behaviour. Starch pastes from all the accessions of rice studied in the present investigation showed the shear-thinning phenomenon. This is evident from a decrease in apparent viscosity of the starch pastes with increase in shear rate, thereby increasing its fluidity. Our results on the variations in shear stresses clearly revealed that starch pastes from the "waxy" and ‘‘low" amylo-cultivars exhibited higher shear stress than the "intermediate" or ‘‘high" amylo-cultivars at the same shear rate. This indicates a clear relationship between the amylose/amylopectin ratio of starch grains and their rheological properties. Since higher values for shear stress indicate higher structural stability of the starch granules [45], it can be assumed that "waxy" and "low" amylo-starches have a more stable structure than those with intermediate or high AAC.

Marked variations were observed in the pasting properties of the starches from accessions of rice studied in the present investigation. While the pasting onset temperatures of the "waxy" and "very low" amylo-cultivars were within the range of 61.6˚C - 62.9˚C, those for the "low" and "intermediate" amylo-cultivars were in the range of 63.47˚C - 66.36˚C and 67.26˚C - 73.52˚C, respectively (**Table 6** and **Table 7**). Our results on the past-

Table 6. Pasting properties of starch isolated from upland varieties of rice from Northeast India. ± represents standard deviation, †Same letters in parenthesis against data for each parameter indicates statistically insignificant difference ($p < 0.05$).

Rice variety	Onset Temp† (˚C)	Peak Temp† (˚C)	Peak Visco† (Pa.s)	Trough Visco† (Pa.s)	Final Visco† (Pa.s)	Breakdown Visco † (Pa.s)	Setback viscosity†
IC-583088	61.6 ± 0.0(a)	69.70 ± .0.0(a)	0.87 ± 0.0(j)	0.52 ± 0.0(i)	0.44 ± 0.0(b)	0.345 ± 0.0(a)	0.25 ± 0.0(a)
IC-583085	62.45 ± 0.0(f)	69.71 ± 0.0(a)	0.83 ± 0.0(ij)	0.435 ± 0.0(h)	0.30 ± 0.0(a)	0.39 ± 0.0(a)	0.27 ± 0.0(j)
DPRR-168	62.9 ± 0.0(c)	70.03 ± 0.0(a)	0.82 ± 0.0(i)	0.43 ± 0.0(gh)	0.32 ± 0.0(a)	0.405 ± 0.0(ab)	0.27 ± 0.0(k)
1C-583038	62.6 ± 0.1(b)	70.11 ± 0.0(a)	0.81 ± 0.0(i)	0.44 ± 0.0(h)	0.56 ± 0.0(d)	0.41 ± 0.0(b)	0.28 ± 0.0(k)
SKY-AK-1608	63.47 ± 0.0(d)	71.92 ± 0.0(b)	0.65 ± 0.0(h)	0.43 ± 0.0(g)	0.82 ± 0.0(ij)	0.27 ± 0.0(c)	0.51 ± 0.0(h)
IC-583035	64.44 ± 0.2(f)	82.26 ± 0.0(c)	0.66 ± 0.0(h)	0.42 ± 0.0(fg)	0.835 ± 0.0(j)	0.25 ± 0.0(de)	0.51 ± 0.0(h)
YS-RC-219	65.52 ± 0.0(g)	84.34 ± 0.0(d)	0.62 ± 0.0(g)	0.435 ± 0.0(h)	0.835 ± 0.0(j)	0.24 ± 0.0(e)	0.52 ± 0.0(hi)
VP-28	64.49 ± 0.0(f)	83.53 ± 0.0(d)	0.61 ± 0.0(g)	0.415 ± 0.0(e)	0.62 ± 0.0(e)	0.30 ± 0.0(f)	0.31 ± 0.0(cd)
SKY-AK-1569	65.59 ± 0.0(g)	86.19 ± 0.2(e)	0.61 ± 0.0(g)	0.41 ± 0.0(efg)	0.64 ± 0.0(ef)	0.265 ± 0.0(cd)	0.28 ± 0.0(b)
IC-540276	63.91 ± 0.0(e)	87.24 ± 0.2(f)	0.60 ± 0.0(g)	0.39 ± 0.0(def)	0.63 ± 0.0(ef)	0.20 ± 0.0(g)	0.28 ± 0.0(b)
YS-RC-27	63.49 ± 0.0(d)	87.10 ± 0.0(f)	0.58 ± 0.0(g)	0.36 ± 0.0(def)	0.52 ± 0.0(c)	0.18 ± 0.0(h)	0.28 ± 0.0(b)
IC-526602	66.20 ± 0.0(h)	88.47 ± 0.3(g)	0.48 ± 0.0(f)	0.365 ± 0.0(def)	0.67 ± 0.0(gh)	0.14 ± 0.0(i)	0.30 ± 0.0(cd)
IC-398030	65.83 ± 0.0(i)	89.89 ± 0.0(ij)	0.43 ± 0.0(e)	0.37 ± 0.0(fg)	0.68 ± 0.0(h)	0.09 ± 0.0(j)	0.30 ± 0.0(c)
IC-583129	66.36 ± 0.0(h)	88.34 ± 0.0(g)	.042 ± 0.0(e)	0.37 ± 0.0(de)	0.79 ± 0.0(i)	0.16 ± 0.0(k)	0.30 ± 0.0(c)
IC-583032	67.26 ± 0.0(j)	88.88 ± 0.0(gh)	0.39 ± 0.0(cd)	0.36 ± 0.0(cde)	0.875 ± 0.0(kl)	0.145 ± 0.0(k)	0.30 ± 0.0(cd)
IC-540182	71.16 ± 0.1(k)	89.53 ± 0.0(hi)	0.38 ± 0.0©	0.36 ± 0.0(cde)	0.865 ± 0.0(k)	0.135 ± 0.0(i)	0.44 ± 0.0(e)
VP-15	73.25 ± 0.0(n)	90.33 ± 0.0(ij)	0.36 ± 0.0(bc)	0.34 ± 0.0(cd)	0.835 ± 0.0(j)	0.11 ± 0.0(m)	0.43 ± 0.0(e)
SKY-AK-1556	72.81 ± 0.0(m)	90.56 ± 0.2(jk)	0.37 ± 0.0(bc)	0.30 ± 0.0(bc)	0.82 ± 0.0(ij)	0.105 ± 0.0(m)	0.46 ± 0.0(g)
SKY-AK-1549	73.5 ± 0.0(n)	91.29 ± 0.3(kl)	0.37 ± 0.0(bc)	0.24 ± 0.0(b)	0.895 ± 0.0(m)	0.105 ± 0.0(m)	0.45 ± 0.0(fg)
IC-583029	73.52 ± 0.0(n)	91.5 ± 0.4(l)	0.36 ± 0.0(c)	0.26 ± 0.0(b)	0.885 ± 0.0(l)	0.105 ± 0.0(m)	0.43 ± 0.0(e)
YS-RC-105	72.05 ± 0.0(l)	92.6 ± 0.0(1m)	0.33 ± 0.0(b)	0.27 ± 0.0(b)	0.90 ± 0.0(m)	0.05 ± 0.0(n)	0.51 ± 0.0(h)
IC-583113	74.33 ± 0.0(o)	92.5 ± 0.0(m)	0.21 ± 0.0(a)	0.17 ± 0.0(a)	0.91 ± 0,0(m)	0.03 ± 0.0(f)	0.545 ± 0.0(j)
VP-44	75.58 ± 0.0(p)	92.12 ± 0.0(lm)	0.21 ± 0.0(a)	0.18 ± 0.0(a)	0.965 ± 0.0(n)	0.027 ± 0.0(c)	0.52 ± 0.0(i)
IC-540270	75.82 ± 0.0(p)	92.78 ± 0.0(m)	0.22 ± 0.0(a)	0.18 ± 0.0(a)	0.98 ± 0.0(n)	0.027 ± 0.0(c)	0.52 ± 0.0(hi)

Table 7. Pasting properties of starch isolated from lowland varieties of rice from Northeast India. ± represents standard deviation, †Same letters in parenthesis against data for each parameter indicates statistically insignificant difference ($p < 0.05$).

Rice variety	Onset Temp† (˚C)	Peak Temp† (˚C)	Peak Visco† (Pa.s)	Trough Visco† (Pa.s)	Final Visco† (Pa.s)	Breakdown Visco† (Pa.s)	Setback viscosity†
IC-564948	64.2 ± 0.0(a)	82.8 ± 0.3(a)	0.65 ± 0.0(lm)	0.39 ± 0.0(fgh)	0.21 ± 0.0(a)	0.40 ± 0.0(j)	0.28 ± 0.0(a)
IC-564953	64.5 ± 0.0(a)	83.7 ± 0.1(b)	0.62 ± 0.0(k)	0.38 ± 0.0(efg)	0.25 ± 0.0(b)	0.26 ± 0.0(ef)	0.28 ± 0.0(a)
IC-564950	65.94 ± 0.0(bc)	90.5 ± 0.1(c)	0.66 ± 0.0(mn)	0.36 ± 0.0(def)	0.28 ± 0.0(d)	0.30 ± 0.0(gh)	0.29 ± 0.0(ab)
IC-321204	65.6 ± 0.0(b)	90.3 ± 0.0(c)	0.677 ± 0.0(o)	0.40 ± 0.0(gh)	0.265 ± 0.0(c)	0.26 ± 0.0(ef)	0.30 ± 0.0(bc)
IC-558321	66.47 ± 0.0(cd)	91.35 ± 0.0(d)	0.67 ± 0.0(no)	0.36 ± 0.0(def)	0.52 ± 0.0(e)	0.31 ± 0.0(hi)	0.30 ± 0.0(bc)
IC-321201	66.62 ± 0.0(d)	91.5 ± 0.0(d)	0.69 ± 0.0(p)	0.37 ± 0.0(def)	0.54 ± 0.0(f)	0.30 ± 0.0(i)	0.29 ± 0.0(ab)
IC-564939	66.0 ± 0.6(cd)	91.3 ± 0.0(d)	0.64 ± 0.0(l)	0.40 ± 0.0(gh)	0.82 ± 0.0(j)	0.20 ± 0.0(d)	0.52 ± 0.0(fg)
IC-332963	68.9 ± 0.0(e)	90.5 ± 0.1(c)	0.65 ± 0.0(m)	0.49 ± 0.0(i)	1.00 ± 0.0(p)	0.14 ± 0.0(b)	0.54 ± 0.0(g)
IC-324133	70.3 ± 0.0(f)	90.5 ± 0.1(c)	0.62 ± 0.0(k)	0.51 ± 0.0(i)	0.56 ± 0.0(g)	0.12 ± 0.0(a)	0.30 ± 0.0(bc)
IC-321195	71.0 ± 0.1(g)	90.3 ± 0.1(c)	0.62 ± 0.0(k)	0.51 ± 0.0(i)	0.60 ± 0.0(h)	0.29 ± 0.0(g)	0.31 ± 0.0(c)
IC-558311	72.8 ± 0.0(h)	91.1 ± 0.0(d)	0.57 ± 0.0(i)	0.34 ± 0.0(cd)	0.67 ± 0.0(i)	0.17 ± 0.0(c)	0.30 ± 0.0(bc)
IC-545288	73.2 ± 0.0(h)	92.3 ± 0.0(e)	0.53 ± 0.0(h)	0.39 ± 0.0(fgh)	0.68 ± 0.0(i)	0.21 ± 0.0(d)	0.31 ± 0.0(c)
IC-564949	74.3 ± 0.0(i)	92.3 ± 0.0(f)	0.43 ± 0.0(g)	0.38 ± 0.0(efg)	0.87 ± 0.0(m)	0.25 ± 0.0(e)	0.36 ± 0.0(d)
IC-321206	74.5 ± 0.0(j)	92.5 ± 0.0(g)	0.41 ± 0.0(f)	0.25 ± 0.0(a)	0.90 ± 0.0(o)	0.17 ± 0.0(c)	0.37 ± 0.0(d)
IC-564952	75.5 ± 0.5(jk)	92.5 ± 0.0(e)	0.40 ± 0.0(ef)	0.39 ± 0.0(fgh)	0.88 ± 0.0(n)	0.18 ± 0.0(c)	0.46 ± 0.0(e)
IC-321193	75.53 ± 0.5(k)	93.3 ± 0.0(g)	0.39 ± 0.0(de)	0.30 ± 0.0(b)	0.855 ± 0.0(kl)	0.13 ± 0.0(a)	0.47 ± 0.0(e)
IC-564940	75.0 ± 0.0(k)	94.5 ± 0.0(h)	0.38 ± 0.0(d)	0.31 ± 0.0(c)	0.86k ± 0.0(lm)	0.029 ± 0.0(g)	0.53 ± 0.0(fg)
IC-545274	76.1 ± 0.1(l)	93.3 ± 0.1(g)	0.36 ± 0.0(c)	0.35 ± 0.0(de)	0.89 ± 0.0(no)	0.030 ± 0.0(gh)	0.52 ± 0.0(f)
IC-558315	78 ± 0.0(m)	95.3 ± 0.0(i)	0.27 ± 0.0(b)	0.31 ± 0.0(bc)	0.87 ± 0.0(jk)	0.031 ± 0.0(i)	0.53 ± 0.0(g)
IC-545197	78.78 ± 0.1(n)	94.7 ± 0.0(j)	0.25 ± 0.0(a)	0.35 ± 0.0(de)	0.87 ± 0.0(jk)	0.027 ± 0.0(f)	0.56 ± 0.0(h)

ing peak temperatures of starches from different cultivars of rice are in conformity with the temperature and viscosity pasting data reported for rice starches by Park *et al*. [15] and Li *et al*. [28]. The highest peak viscosity and lowest setback viscosity shown by starch pastes from the accession IC-583088, which is a waxy cultivar, are consistent with the fact that waxy starch comprises mainly of amylopectin which allows the granules to swell easily. Similar observations have been made by Tester and Morrison [19] and Morrison [46] for other waxy starches. Since setback viscosity reflects gel network formation after starch pasting [28], the near absence of amylose in "waxy" starch will result in fewer interactions among close-packed granules, resulting in low gel network formation. Thus, because of their greater resistance to thinning and shearing, starches from SKY-AK-1608, IC-583035, YS-RC-219, IC-564939 and IC-332963 can be of importance to industry for various applications.

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