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ORIGINAL PAPER

Variation in amylose content in three rice variants predominantly influences the properties of sushi rice

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Abstract

Sushi rice is a ready-to-eat traditional Japanese dish seasoned with vinegar, sugar and salt that has gained popularity worldwide. There are many rice cultivars grown in the world which vary in their cooking, sensory, and processing quality. The aim of this study was to analyse chemical, physical, and functional properties of three rice varieties (Vietnamese, Italian, and Australian) to determine their suitability for sushi rice production. Rice was cooked using industry norms and vinegar was then added; samples with no vinegar were prepared for comparison. The rice was stored during 5 days at 4 °C after cooking for texture profile analysis and samples were taken on day 1 and day 5. Flour composition as well as amylose content, gelatinisation properties using differential scanning calorimeter, pasting properties using Rapid Visco Analyser, water absorption capacity (WAC), oil absorption capacity (OAC) and swelling power of extracted starch were determined. Results showed that the amylose content (16.51 to 21.37%) had a large impact on the functional and quality characteristics of the rice variants including texture, pasting, gelatinisation and WAC properties. Australian starch showed the highest amylose content, setback viscosity, final viscosity, pasting temperature and lowest gelatinisation temperature. The lower amylose content and gelatinisation temperature contributed to a softer texture in the Vietnamese rice samples over life. The added vinegar aided in keeping the texture soft during the shelf-life of the rice. Since sushi rice is usually prepared with vinegar, Italian and Vietnamese rice are better candidates for sushi rice based on their lower hardness after 5 days of storage when compared to the Australian variety.

Keywords Amylose content · Texture · Vinegar · Starch structure · Sushi rice

Introduction

Rice (*Oryza sativa* L.) is a staple commodity in diets for more than half of the world's population across more than 100 countries, with approximately 510 million metric tons produced worldwide in 2022 [1]. Rice has played a large part within cultural history for decades. It has been known to link histories of Africans, Europeans, and the region of Asia [2]. There are many different species, with the most common *Oryza sativa* being divided into subcategories of long-grain indica, and short-grain japonica. Rice is used as a staple food and in food processing applications, such as sushi, and rice cakes. Koshihikari is a popular Japonica rice cultivated in Japan, Australia and United States and is widely used in sushi rice preparation. It has also been diversified into convenient products, such as frozen cooked rice and retort-pouch rice which have been increasingly available. A rice grain constitutes 75–80% starch, 12% water, and 7% protein with a unique composition of amino acids; eight of the essential amino acids are found in balanced proportions [2]. The two starches in rice are amylose and amylopectin, a higher ratio of amylopectin results in the desired stickier sushi rice [3].

Sushi is a traditional Japanese dish of cooked, cooled rice seasoned with vinegar, sugar, and salt, then rolled

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with fillings such as vegetables or raw fish, which has become a popular ready-to-eat convenience food sold by most UK retailers [4]. There are as many as 600 varieties of Japanese rice alone, of which the most abundant is Koshihikari [5]. An important factor in manufacturing sushi is its sensory properties. Good quality sushi rice is a short and rounded grain that has a sticky, chewy texture when cooked and a compact soft shape when cooled [4]. The addition of vinegar gives rice acidity, eliminates undesirable changes in texture, restores freshness and decreases hardness, which arises from aged rice and starch retrogradation [6]. Vinegar, a preservative due to its acetic acid content, when added to rice retards microbial growth thus enhancing the shelf-life of the sushi [7]. It is also used as a seasoning for the product [8]. Furthermore, in most restaurants, sushi rice is kept hot to prevent retrogradation and may be chilled for retail storage.

Starch plays a major factor in the eating properties of rice [9]. It consists of two glucose polymers: amylopectin (approx. 80%) and amylose (approx. 20%). The structure of amylopectin is highly branched with α-1,4-linked glucose molecules and α-1,6-linkages at the branch points, whereas amylose is a linear α-1,4-linked glucose molecule [10]. The short side chains of branched starch are stacked in the double helix structure to form the crystalline shape [11]. Amylose and amylopectin chain-length distributions (CLDs) have been shown to correlate with starch structural parameters such as pasting and retrogradation. A study by Li et al. [12] reported that the enthalpy and melting temperature of retrograded starches are positively connected with the quantity of amylopectin short chains and amylose long chains. Moreover, higher amounts of amylopectin medium to long chains provide higher peak viscosity, whereas comparatively longer amylose short to medium chains can result in higher trough and breakdown viscosities. Amylose content influences both cooking and texture characteristics of rice, with high levels ($> 25\%$) of amylose attributing to firm and dry rice, and lower levels ($< 25\%$) of amylose (higher level of amylopectin) attributing to softer and stickier rice. Waxy rice contains little to no amylose which gives it its sticky characteristics after cooking [13].

At roughly 65 °C and 87 °C during cooking, the starch granules absorb water, and the rice grain swells, causing amylose to leak out and lose its crystalline structure. This causes the viscosity to increase due to gelatinization. The characteristics, composition, morphology, molecular weight, and structure of starch granules also affect the extent of gelatinization [14]. After cooking, as the rice cools, the amylose chains lock up and form a gel and then crystallize. The crystallization phase during cooling is also known as retrogradation. Starch retrogradation is a process where gelatinized amylose and amylopectin change from an amorphous state to a different ordered structure [10]. The rate of starch retrogradation is affected by intrinsic factors such as the amylose content, chain length distribution and the degree of branching for amylopectin. It is also affected by extrinsic factors including water, storage temperature, salts, hydrocolloids, and lipids [10].

Even though there are many rice cultivars grown in the world, these vary in their cooking, sensory, and processing quality [15]. The cooking and eating requirements of different rice varieties are usually determined by amylose content, gelatinization temperature, viscosity, and the texture of cooked rice. During refrigerated storage, desired quality aspects of cooked rice can change. For example, there can be a loss of flavor/aroma and color, rice becomes hard, dry, crumbly, and unpalatable due to moisture migration. Sushi rice products have a 4-day shelf life; however, as they lose 1–2 days in transit to stores, their retailable life is just 2–3 days [16]. Several factors can influence starch retrogradation and texture of rice during storage, such as rice variety, degree of milling, amylose content, and water-to-rice ratio [17]. Li and Gilbert [18] conducted research to understand the underlying molecular factors affecting the textures of rice. The authors reported that understanding rice texture is important to ensure the industry, manufacturers and consumers can manage the cooking and quality of their home cooked rice.

Not using a suitable rice variety with an appropriate content of amylose and amylopectin may result in rice hardening during sushi rice storage and yield increased product complaints. This may lead to consumer's dissatisfaction and affect the relationship between retailer and manufacturer. Thus, studies are on-going to characterize different rice varieties that are suitable for sushi rice production [19–21]. A study by Hong et al. [20] aimed to identify the best rice varietals and selection index for sushi, with 13 expert chefs testing seven rice varieties. Hopum and Sindongjin were found to be more suitable for sushi shape and flavor, with exceptional pasting qualities similar to Koshihikari. The study found a strong positive association between pasting qualities and sushi suitability [20]. Although some literature studied the quality characteristics of cooked rice as affected by vinegar addition, studies that discuss the impact of both the variety of rice and the use of seasonings such as vinegar on sushi rice characteristics have not been reported. Thus, this paper aims at analyzing chemical, physical and functional properties of three rice varieties sourced from Vietnam, Italy, and Australia and their suitability for sushi rice production. This includes a shelf-life study of cooked sushi rice during 5 days of storage at 4 °C after cooking.

Materials and methods

Materials

The rice samples from three different regions (Vietnam, Italy, and Australia) used for this research were donated by a British food company. The rice bags (25 kg) were stored at ambient temperature, and this was monitored during storage within the company. The Australian variety is a medium grain, while Vietnamese and Italian are short grains. Other reagents used were of laboratory grade and were obtained from Sigma Aldrich, St. Louis, MO, USA.

Proximate composition of rice

The moisture, fat, and ash contents of rice samples were determined using the AOAC Method [22]. The protein content (N × 6.25) was determined by the Kjeldahl method, fat content by Soxhlet fat extraction method, ash by the gravimetric method using a muffle furnace, while total carbohydrate was calculated by difference [100 − (ash + fat + protein + moisture)].

Rice milling and starch extraction.

Two separate batches of rice samples (5 kg per batch) from the three varieties were milled into flour and sieved through a fine mesh (aperture size: 350 µm) to give 6 samples in total. For starch extraction, rice flour (1 kg) from each sample was suspended in 10 L of 0.3% (w/v) NaOH solution and kept overnight at 4 °C to solubilize proteins. The suspension was milled in a kitchen blender Multi Mill 1.6 L 450 W (Kenwood, London, UK) and sieved in successions using sieves of 350 µm, 250 µm and 90 µm. The filtrate was centrifuged using an Eppendorf centrifuge (5810R, Eppendorf, Hamburg, Germany) at 1600 *g* for 30 min after which the supernatant was discarded, and the sediment was resuspended in distilled water and re-centrifuged. This process was repeated several times to increase starch purity. After decantation, the settled starch was dried at 45 °C in a hot air oven (Binder GmbH Im Mittleren Tuttlngen/Germany) for 12 h and stored refrigerated at 4 °C until analysis.

Colour and amylose content

The colour of rice starch samples was measured using a Minolta Chromameter (illuminant D65; 8-mm-diameter aperture, 2 degrees standard observer; CR-400; Konica-Minolta Corp., Tokyo, Japan). The parameter recorded was L^* representing lightness (0 = dark black, 100 = brightest white). Samples were placed in transparent petri dishes and digital colour photos were taken in triplicate with the Chromameter.

The amylose content of the starch was determined using the iodine binding method [23]. Starch samples (20 mg) were weighed and dispersed in 10 mL 0.5 N KOH for 5 min. The dispersed samples were made up to 100 mL with deionized water. Ten mL of starch solution was mixed with 5 mL 0.1 N HCl and 0.5 mL iodine reagent and brought to 50 mL with deionized water. Iodine reagent was prepared by dissolving potassium iodide (20 g) and resublimed iodine (2 g) in 100 mL of water. The absorbance of the blue color was measured at 625 nm using a UV/Vis spectrophotometer (Bibby Scientific Limited, Stone, UK) after 5 min and amylose content was calculated using a standard calibration curve of pure amylose. For the standard calibration curve, a 50 mL centrifuge tube was filled with approximately 40 mg of potato amylose. Next, 1 mL of 9 N NaOH and 1 mL of 95% ethanol were added. With the help of a water bath, the resultant solution was heated to 100 °C for 10 min, cooled, and then poured into a 100 mL volumetric flask. After adding distilled water to the mixture until the flask reached the 100 mL mark, the mixture was well stirred and sealed with a plastic cork. Pipetted aliquots of the mixture (0.5 mL, 1.0 mL, 1.5 mL, 2.0 mL, and 2.5 mL) were placed into 50 mL centrifuge tubes, and 1 N acetic acid was added in increments of 0.1 mL, 0.2 mL, 0.3 mL, 0.4 mL, and 0.5 mL. In order to develop the colour of the iodine, 1 mL of a 0.2% iodine solution was pipetted into each tube. The solutions were then left in a dark area for 20 min, and absorbance (A) was measured at 625 nm using Spectrophotometer (Bibby Scientific Limited, Stone, UK) in comparison to a reagent blank.

Functional properties of starch

The functional properties of the starch samples including water absorption capacity (WAC), oil absorption capacity (OAC) and swelling power were determined as described by Oyeyinka et al. [24]. Briefly, for WAC, one (1 g) starch was mixed with 10 mL of distilled water. The mixture was allowed to stand at room temperature for 30 min and thereafter centrifuged at 3400 × *g* for 20 min at 25 °C. WAC was expressed as g of water bound/g of starch (Eq. 1). For the determination of OAC, the water (10 mL) used in the WAC test was replaced with sunflower oil (TESCO, Spalding, UK) and values expressed as g of oil bound/g of starch (Eq. 2).

The swelling power of the starch was measured as previously reported [24]. Briefly, starch samples (0.1 g starch in 10 mL of distilled water) were stirred and placed in a water bath for 30 min at temperatures ranging from 50 to 90 °C with constant stirring. The suspension was centrifuged at 3400 × *g* for 20 min and the supernatant discarded. Swelling power was obtained by weighing the swollen starch residue after centrifugation and dividing by original weight of starch on dry weight basis (Eq. 3).

$$WAC = \frac{\text{Mass of water absorbed } \times 100}{Original\, mass\, of\, starch} \tag{1}$$

$$OAC = \frac{\text{Mass of oil absorbed } \times 100}{Original\, mass\, of\, starch} \tag{2}$$

$$Swelling\, power = \frac{\text{Mass of swollen starch}}{Original\, mass\, of\, starch} \tag{3}$$

Pasting properties of starch

The viscosity of the sample during heating was measured by Rapid Visco Analyzer (RVA) which assesses the pasting behaviour of uncooked starch in the test material (Perten RVA 4500, PerkinElmer, Beaconsfield, Buckinghamshire, UK). Analysis of moisture content was carried out beforehand on the two batches from each variety. The test method required 2.5 g of starch and 25 g of water to perform the test based on a 14% moisture content of the sample. The method is a heating profile that heats the sample from 50 to 95 °C and then cools it back down to 50 °C. Peak, trough, breakdown, final, setback viscosities (cP) as well as pasting temperature (°C) and peak time (min) were determined.

Thermal properties of starch

The thermal properties including onset (T_o), peak (T_p), conclusion (T_c) gelatinization temperatures and gelatinization enthalpy (ΔH) of the extracted starch samples were determined using a differential scanning calorimeter from Mettler Toledo (Leicester, UK) as previously reported [25]. Briefly, the sample (3 mg) was weighed into an aluminium DSC pan and distilled water (12 µL) was added. Pans were hermetically sealed and equilibrated for 12 h at room temperature (25 ± 2 °C). Samples were heated from 20 to 120 °C at a rate of 10 °C/min with an empty pan used for calibration.

Rice cooking for texture profile analysis

Rice samples were cooked following a standard method for making sushi rice using a 1.8 L kitchen Breville ITP181 rice cooker and steamer (Sydney, Australia). Briefly, rice (360 g) was washed, placed in a pot containing water (about 1.5 times weight of rice) and vegetable oil was added (1.6 g). After cooking, vinegar (44 g) was added to the rice and mixed before placing the cooked samples in plastics for storage. For the experiment, rice samples were cooked and divided into two portions (600 g each), one without vinegar and another with vinegar and their hardness and stickiness were examined at day 0 and day 5. Stored samples were kept in the refrigerator at 4 °C for 5 days in a round bottom plastic containers (612 × 252 × 260 mm). The storage period was chosen to mimic the expected shelf-life of sushi rice. The texture analysis was performed at room temperature using a TA texture analyzer (TA-XTplus Texturometer; Stable Micro System, Vienna Court, UK) equipped with a 500 N load cell and coupled with a P35, 35 mm dimension cylinder probe. Texture profile analysis was performed with sample fracture, with compression to 50% of the original height. Two replications were performed in this experiment. The hardness (g) and stickiness (g) values were used for textural properties. These values were calculated using Exponent Stable Micro Systems software, version 6.1.13. 0 (Stable Micro Systems, UK), where the maximum force and area under the graph illustrated the hardness, and force needed to pull the probe off after compression illustrated the bonding power to a surface (adhesiveness or stickiness).

Statistical analysis

Except otherwise stated, samples were prepared in duplicates and analysis was performed in triplicate. All data was analyzed using SPSS statistical software (SPSS Inc., Chicago, IL, USA). Analysis of variance (ANOVA) and means with significant differences ($p < 0.05$) were determined using the Fisher least significant difference (LSD) test. Furthermore, selected data were subjected to Pearson correlation analysis to establish the relationship among rice composition and other physicochemical properties of starch.

Results and discussion

Proximate composition of rice flour

The proximate composition of the rice samples determined after milling the grains into flour is presented in Table 1. Except for moisture content which was very similar (average of 6.44%) across the rice types, other components were significantly different ($p < 0.05$). Carbohydrate (82.13–87.06%) was the major component in the rice grain, while protein (5.03–9.53%), fat (0.46–1.28%) and ash (0.48–0.97%) contents were generally low. Australian rice showed higher fat, protein and ash contents compared to Vietnamese and Italian varieties. The variation in the proximate composition data could be due to inherent genetic differences in the rice grains as well as growing conditions [26]. It is worth mentioning that the Italian and Vietnamese were short grain, unlike the Australian variety which was medium grain. Grains intended for use as sushi rice, even within the same variety and that have same length (e.g., medium grain), can show differences

Table 1 Grain composition (rice flour), amylose content, colour, water absorption capacity, pasting and gelatinisation properties (rice starch)

Parameters	Vietnamese	Italian	Australian
Colour, starch composition and functional properties			
Moisture (%)	6.74 ± 0.46^a	6.51 ± 0.33^a	6.07 ± 0.22^a
Ash (%)	0.48 ± 0.14^b	0.77 ± 0.19^{ab}	0.97 ± 0.12^a
Fat (%)	0.46 ± 0.16^b	0.64 ± 0.24^b	1.28 ± 0.37^a
Protein (%)	7.23 ± 0.88^b	5.03 ± 0.65^c	9.53 ± 0.53^a
Carbohydrate (%)	85.09 ± 1.02^b	87.06 ± 0.68^a	82.13 ± 0.20^c
Amylose content (%)	16.67 ± 2.72^b	16.92 ± 1.93^b	21.61 ± 1.06^a
L*	100.38 ± 0.29^a	100.58 ± 0.11^a	100.20 ± 0.09^a
Water absorption capacity (%)	97.28 ± 1.54^{ab}	95.24 ± 0.46^b	98.66 ± 0.99^a
Oil absorption capacity (%)	85.41 ± 2.20^a	90.21 ± 1.32^a	80.33 ± 8.62^a
Pasting properties			
Peak viscosity (cP)	1453.50 ± 68.50^a	1389.50 ± 62.50^a	1133.50 ± 1.50^b
Trough viscosity (cP)	740.50 ± 12.50^a	731.00 ± 19.00^a	666.50 ± 0.50^b
Breakdown viscosity (cP)	713.00 ± 56.00^a	658.50 ± 43.50^a	467.00 ± 1.00^b
Final viscosity (cP)	1374.50 ± 33.50^a	1592.00 ± 50.00^b	1670.00 ± 6.00^c
Setback viscosity (cP)	634.00 ± 21.00^c	861.00 ± 31.00^b	1003.50 ± 5.50^a
Pasting temperature (°C)	77.15 ± 1.25^c	78.78 ± 0.43^b	86.03 ± 0.38^a
Peak time (min)	5.47 ± 0.67^a	5.17 ± 0.03^b	5.50 ± 0.03^a
Thermal properties			
T_o (°C)	69.2 ± 0.30^a	68.9 ± 0.60^a	59.7 ± 0.20^b
T_p (°C)	75.2 ± 0.50^a	75.9 ± 0.70^a	65.4 ± 0.30^b
T_c (°C)	83.1 ± 0.60^b	85.5 ± 0.70^a	74.2 ± 0.30^c
ΔH (J/g)	14.3 ± 0.30^a	13.8 ± 0.60^a	$12.6^b \pm 0.30^b$

Values are reported as Mean ± standard deviation. Mean with different superscript letters along a row are significantly different ($p \leq 0.05$). T_o, T_p, Tc and ΔH represent onset gelatinisation temperature, peak gelatinisation temperature, conclusion gelatinisation temperature and gelatinisation enthalpy, respectively

between each other in chemical composition. The results of proximate composition in the present study agree with the study of Sandhu et al. [27] who reported that short grain Indica rice cultivar contained lower ash, protein, lipids, and minerals than long grain of same variety.

Amylose content and colour

The starch extract from the three rice varieties showed variable amylose content (Table 1). Starch from the Australian variety had a significantly ($p < 0.05$) higher amylose content (21.61%) than the Vietnamese (16.67%) and Italian variety (16.92%). The variation in amylose contents may be associated with the source of the grain as well as their inherent genetic differences. These values are within the range reported for starch extracted from Vietnamese rice (0.20–28.40%) [28], Italian rice (15.50–25.20%) [29] and Australian rice (26.90–31.80%) varieties [30]. Amylose content of starch can significantly ($p < 0.05$) influence the functional and physicochemical properties of starch and the impact of this starch component will be discussed in subsequent sections.

The lightness (L^*) values of the rice were generally high (approx. 100) and were not significantly ($p \geq 0.05$) different among the rice varieties, indicating that varietal difference did not influence the whiteness of the starch samples (Table 1). A high L^* value is generally associated with whiteness of starch and indicates that the extracted starches are pure [24].

Functional properties

WAC, OAC, and swelling power are the functional characteristics of the starch samples that were determined. The WAC of the starch samples was generally higher than the OAC. This behaviour of starch is mainly due to the presence of hydrophilic components in starch such as amylose and amylopectin which are capable of absorbing water. On the other hand, the mechanism of oil absorption in starch is thought to be due to physical entrapment within the starch granules rather than absorption since starch does not have hydrophobic or non-polar sites like those found in proteins which could bind to oil. This may explain the similarity and non-significant differences ($p > 0.05$) among the OAC of the starches (Table 1). The results showed a significantly ($p < 0.05$) higher WAC in Australian rice starch, only when compared to Italian rice starch, which can be due to the high level of amylose observed in this variety (Table 1). High WAC has been associated with a high level of amylose in various cereal starches including wheat and rice starches. For example, Li et al. [31] reported a significant ($p < 0.05$) increase in WAC of wheat from 0.8 to 1.2 g/g, when the amylose content increased from 32 to 71%. Falade and Christopher [32] similarly reported a higher WAC for Faro rice variety with a higher amylose content compared to varieties with low amylose.

The swelling ability of the starches generally increased with an increase in test temperature but were different across the rice varieties (Fig. 1). The increase in swelling power during heating was not very different between 50 and 60 °C for Vietnamese and Italian varieties but the Australian starch showed a very different swelling ability in this region. Above 60 °C, the three starches showed pronounced swelling, suggesting the gelatinization of the starch granules. During heating, the intramolecular bonds within starch granules are broken resulting into greater ability of starch to absorb water. Among the three rice varieties, Australian rice displayed a substantially higher swelling power compared to the Vietnamese and Italian varieties, which showed similar swelling abilities. Amylose is known to prevent swelling of starches by forming a barrier around the granules [33]. Thus, a high amylose starch would display a low swelling ability. However, the opposite was observed in this study since the Australian starch with the highest amylose content showed the highest swelling. Other components of starch as well as the molecular structure of amylose and amylopectin may also affect starch swelling [34]. Future studies are therefore needed to characterize the molecular structure of amylopectin in these starches of the present study to fully understand the reason for the variation in swelling behaviour.

Pasting properties of rice starch

The starch isolates displayed similar pasting curves (Fig. 2) typical of starches, but their pasting properties were significantly ($p < 0.05$) different (Table 1). Starch isolated from Australian rice showed significantly ($p < 0.05$) lower peak viscosity (PV), trough viscosity (TV) and breakdown viscosity (BV) compared to Vietnamese and Italian rice starches, which were similar (Table 1). The peak viscosity of starches may be influenced by starch composition, i.e., amylose and amylopectin ratio, starch structure, and the presence of other minor components of starch such as lipids [35]. In general, starches with high amylose contents would show low peak viscosity due to limited swelling of starch granules [34] and formation of a barrier around starch granules during pasting [33]. Thus, the lower PV of Australian starch compared to the other two varieties could be due to its higher amylose content (Table 1).

On the other hand, Australian starch showed significantly higher ($p < 0.05$) setback (1003.50 cP) and final (1670.00 cP) viscosities compared to the Italian (setback: 861.00 RVU; final: 1592.00 cP) and Vietnamese rice (setback: 634.00 cP; final: 1374.50 cP) starches (Table 1). Final viscosity is a measure of the actual viscosity of starch paste after cooking and cooling and could be used to determine the thickening ability of starch in food systems. The significant ($p < 0.05$) variation among these starches suggest they could have varied application, with the Australian starch showing better thickening ability, which could be the reason for the harder texture of Australian rice, as will be detailed later in section "Texture". In terms of setback viscosity values, the Australian starch shows greater tendency towards retrogradation since it has higher values than the other two starches.

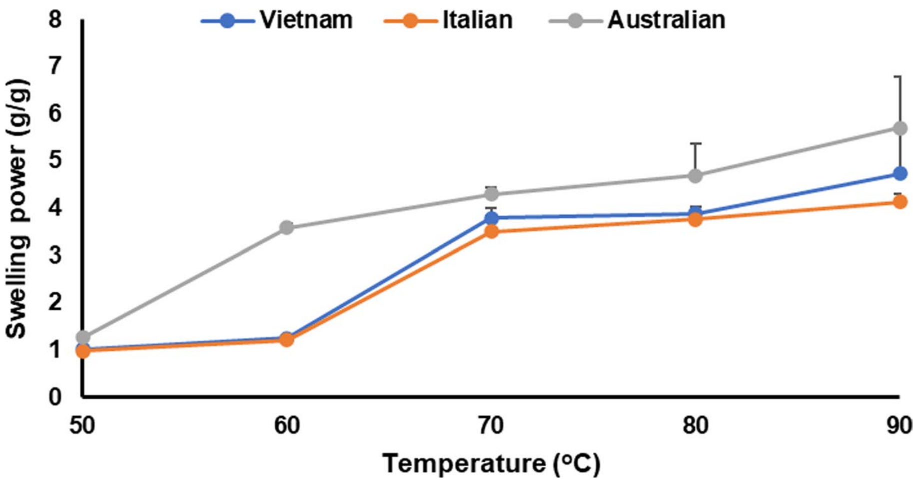

Fig. 1 Swelling power of starch extracted from three rice varieties (Vietnam, Italy and Australia).

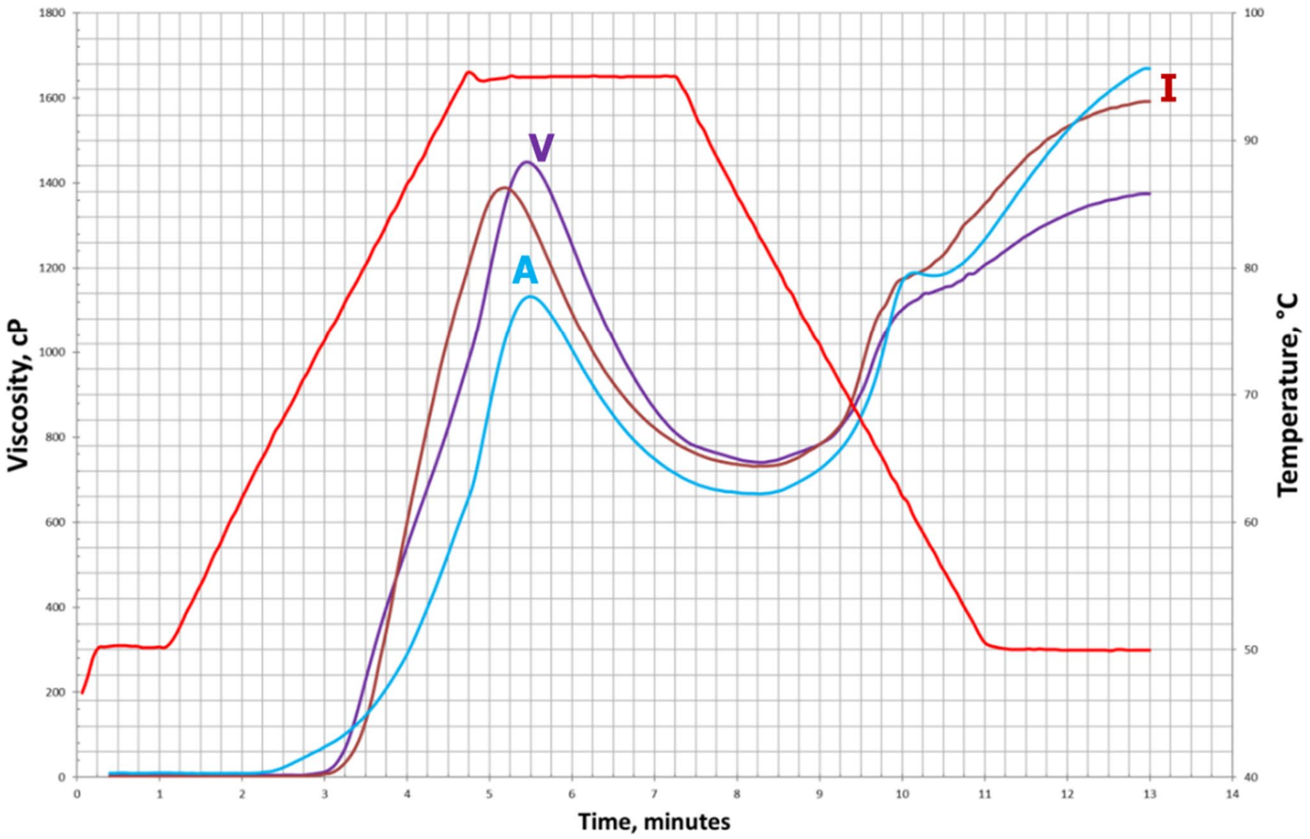

Fig. 2 Pasting curves of starch extracted from three rice varieties (Vietnam, Italy and Australia). V: Vietnamese; I: Italian; A: Australian. The red line is the pasting temperature profile curve.

Retrogradation of starch predominantly involves reorganization and reassociation of amylose and amylopectin during cooling. Although both amylose and amylopectin undergo reassociation during cooling of starch paste, amylose reportedly undergoes retrogradation at a faster rate than amylopectin [36]. According to Jacobson et al. [36], retrogradation is not only influenced by the ratio of these starch components but also by their molecular structures, starch concentration, botanical source of the starch, and presence and concentration of other minor starch components. Thus, the variation in setback viscosity values is closely related to the amylose contents of the rice starches (Table 1).

Similarly, the Australian rice starch showed the highest ($p < 0.05$) pasting temperature of 86.03 °C compared to Vietnamese (77.15 °C) and Italian (78.78 °C). These values are within the range (63.80–95.10 °C) reported in the literature for rice starches [37]. Earlier studies reported that amylose content is a key component that influences the pasting temperature of starch [38]. Starches with higher amylose content generally displays high pasting temperature [39], presumably due to its ability to confer rigidity and compactness to starch granules.

Thermal properties of rice starch

Starch extracted from Vietnamese and Italian rice showed very similar onset gelatinization temperature (T_c), peak gelatinization temperature (T_p), conclusion gelatinization temperature (T_c), and gelatinization enthalpy, which were significantly ($p < 0.05$) higher than those of Australian rice starch (Fig. 3, Table 1). The T_p of the rice starches varied between 65.4 and 75.9 °C, which agrees with previous reports on rice starch [37, 39]. Australian starch had 21.61% amylose content in this study, which was higher than those of Vietnamese and Italian rice samples (Table 1). Thus, it is plausible to associate the much lower T_p of the Australian rice starch to its higher amylose content. Naidoo et al. [34] associated low gelatinization temperatures in starch to their high amylose contents and suggested that the nature of interaction within the amorphous and crystalline region of starch may influence the gelatinization behaviour of various starches. Meanwhile, the structure of amylose and amylopectin, in terms of their chain length distribution, rather than their relative amounts has been established as the major factor that influences the gelatinization behaviour of starches

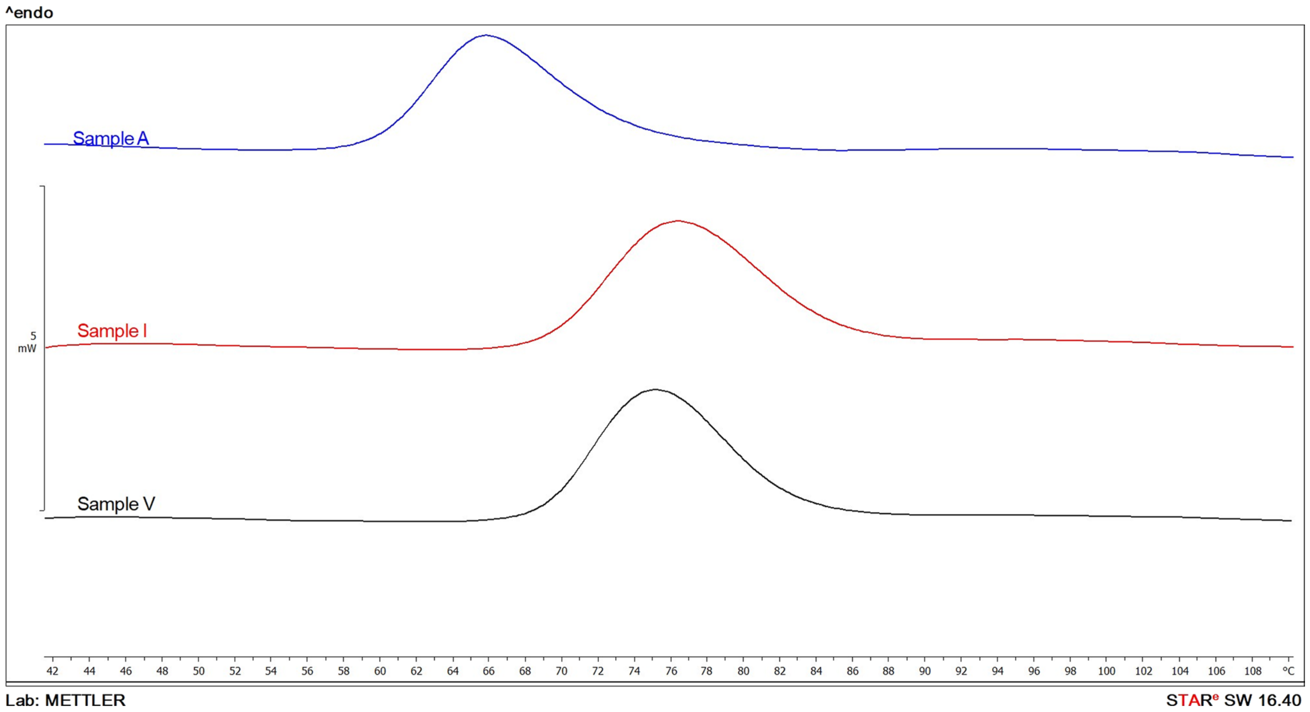

Fig. 3 Thermogram of starch extracted from three rice varieties (Vietnam, Italy and Australia). V: Vietnamese; I: Italian; A: Australian

[40, 41]. Sasaki et al. [42] reported that amylopectin plays a major role in starch granule crystalline structure and that the presence of amylose decreases the melting temperature and the energy needed to cause the onset of gelatinization. The higher the amylose content, the higher the amorphous regions and the lower the crystalline regions, which lowers the T_p and the endothermic enthalpy.

Texture

Hardness and stickiness were the two textural properties determined on cooked rice with added vinegar stored at 4 °C and their results are shown in Table 2. The rice samples behaved differently during storage and showed variation when vinegar was added. With or without vinegar addition, the Vietnamese rice sample showed the lowest ($p < 0.05$) hardness among the samples at day 0. Meanwhile, the Italian and Australian rice showed higher hardness values without vinegar. After storage for 5 days, while the hardness of Vietnamese rice without vinegar increased and that of Australian rice decreased, the hardness of Italian rice did not change significantly ($p < 0.05$) (Table 2).

Sushi rice is usually made with vinegar and thus the impact of vinegar addition was studied at day 0 and day 5 (Table 2). Day 5 was selected since sushi rice have a maximum shelf-life of 5 days depending on the storage

Table 2 Effect of storage (5 days) on hardness and stickiness of cooked rice with or without vinegar

Parameters	Additive	Days	Rice variety		
			Vietnamese	Italian	Australian
Hardness (g)	No vinegar	0	7930.48 ± 2785.65^{b}	$12{,}163.98 \pm 2244.44^{a}$	$11{,}716.45 \pm 804.91^{a}$
Hardness (g)	No vinegar	5	$11{,}821.41 \pm 2657.45^{a}$	$11{,}625.49 \pm 1834.30^{a}$	7791.70 ± 763.47^{b}
Hardness (g)	Vinegar	0	7957.47 ± 2448.54^{b}	$10{,}439.32 \pm 1138.96^{a}$	$11{,}483.61 \pm 1390.09^{a}$
Hardness (g)	Vinegar	5	7008.04 ± 1929.89^{b}	6851.54 ± 583.09^{b}	8863.96 ± 605.23^{a}
Stickiness (g)	No vinegar	0	-197.90 ± 117.49^{a}	-784.47 ± 328.48^{b}	-639.46 ± 249.38^{b}
Stickiness (g)	No vinegar	5	-137.10 ± 46.31^{ab}	-85.64 ± 41.19^{a}	-151.51 ± 47.61^{b}
Stickiness (g)	Vinegar	0	-1182.99 ± 110.13^{b}	-809.40 ± 198.59^{a}	-791.17 ± 222.84^{a}
Stickiness (g)	Vinegar	5	-171.74 ± 78.62^{a}	-240.64 ± 123.31^{a}	-216.09 ± 36.17^{a}

Values are reported as Mean ± standard deviation. Mean with different superscript letters along a row, for each parameter are significantly different ($p \leq 0.05$)

conditions. Vinegar addition did not significantly ($p \geq 0.05$) change the hardness of the rice samples at day 0, though there was a significant difference ($p < 0.05$) among the three rice samples. However, at day 5, the hardness of the rice samples all reduced. Italian rice showed a higher reduction (approx. 34%) in hardness compared with the Vietnamese (approx. 12%) and Australian variety (approx. 23%). The reduction in hardness with the addition of vinegar in all the rice samples indicates that the vinegar interfered with amylose and amylopectin re-alignment/reassociation and possibly slowed down the retrogradation process. Hardness of rice during storage is greatly influenced by starch composition (ratio of amylose and amylopectin) as well as their structure (chain length). Earlier studies found that amylose content was positively correlated with hardness [6, 43].

After storage for 5 days, the Australian variety with added vinegar had the highest hardness, and this may be explained by its higher amylose content and associated increased retrogradation rate (Table 1). Hardness of cooked rice relates to the retrogradation of the starch components. It is also plausible to associate hardness to moisture migration from the inside of the grain to the surface, during handling/storage. It has been suggested with evidence that amylopectin is the main cause of long term retrogradation while amylose is responsible for short-term changes. Flour composition may also influence the hardness of starchy foods. For example, previous studies indicated that protein promotes retrogradation in various starches [44–47]. Thus, the significantly ($p < 0.05$) high protein content and possibly the high fat content in Australian rice may explain its high hardness. The interactions between these components and interactions between dispersed and continuous phase of the starch gel with the vinegar could also have influenced the rice hardness. Difference in cooked rice texture has also been associated with the difference in the fine structure of its amylopectin component [48].

Stickiness is an important textural characteristic of rice but the preferences for it vary among consumers around the world. For instance, consumers from Laos, Thailand, Cambodia, Japan, and Korea, prefer sticky rice, whilst those from India, Madagascar and Nepal generally prefer rice with low stickiness [49]. The result of the present study shows that the Australian rice with higher amylose content showed a harder and less sticky cooked rice compared to the other varieties. This is in-line with what was reported in other studies. For instance, a study by Hiroshi [50] reported a lower stickiness and a harder texture for Hoshiyutaka rice variety with a high amylose content. However, Koshihikari was preferred in the same study because of its flavour and aroma, as well as its chewy, sticky texture and capacity to compact, which was related to low level of amylose [50]. Stickiness of the rice samples also showed significant ($p < 0.05$) variation with storage period and vinegar addition (Table 2). The addition of vinegar generally increased the stickiness of the rice samples, but the stickiness values reduced with storage period. The results from this study correlate with the findings of Ghasemi et al. [6] who stated that acetic acid promoted water absorption which enabled the starch structure to become more fluid, leading to a softer texture and stickiness. According to Odahara et al. [51], the presence of sugars (19.28% and 8.44% sugar content of black rice and citrus vinegar, respectively) in cooked rice seasoning resulted in higher superficial adhesiveness. The authors also reported an increase in the surface adhesion of the cooked grain in the presence of acetic acid.

Pearson correlation among functional pasting and textural properties

To understand the interplay between some of the studied factors, the Pearson correlation of selected rice properties (fat, protein, and carbohydrate), textural properties of cooked rice (hardness and stickiness), swelling power, amylose content, pasting properties and gelatinization properties of rice starch were evaluated (Table 3).

The fat content of the rice played a significant ($p < 0.05$) influence on the hardness of cooked rice as there was a significant ($p < 0.05$) negative correlation with rice hardness at day 5 ($r = -0.72$). The Australian rice showed the highest fat content of 1.28% and the lowest hardness (without vinegar) suggesting that the fat may have complexed with amylose in starch with single helical structures during the gelatinization process lowering water absorption capacity and gel-forming abilities and limiting or preventing the formation of junction zones responsible for the hardness of starch [52].

The same is true for proteins which also showed a significant ($p < 0.05$) negative correlation with the hardness of rice without vinegar at day 5 ($r = -0.67$). Depending on the type of bonds and interactions between starch and proteins, retrogradation may be enhanced or limited. For example, Scott and Awika [53] reported that covalent bonds formed between proteins may enhance starch retrogradation, while glycosidic bonds formed between protein and starch may limit starch retrogradation.

As stated in previous section, we associated most of the changes and observations in cooked rice properties to amylose content since this was the most probable reason based on the experiment and observation. However, the correlation result showed that amylose content of the starch only correlated negatively ($r = -0.66$, $p < 0.05$) with the hardness of the rice without vinegar at day 5, indicating that amylopectin played more role in long-term hardness of the cooked rice than amylose content. Interestingly, this was further confirmed by a negative but significant ($p < 0.05$) correlation of amylose content with T_o ($r = -0.84$, T_p ($r = -0.84$), T_c,

Table 3 Pearson Correlation matrix between raw rice composition, cooked rice textural properties, functional, thermal and pasting properties

	Fat	Pro	CHO	HN0	HV0	SN0	SV0	HN5	HV5	SN5	SV5	WAC	SP^{50}	SP^{60}	SP^{70}	SP^{80}	SP^{90}	Amylose	ΔH	T$_{o}$	T$_{p}$	T$_{c}$	PV	TV	BV	FV	SB	PT	Pt
Fat	1																												
Pro	.56*	1																											
CHO	-.67**	-.98**	1																										
HN0	.37	.00	-.06	1																									
HV0	.59**	.13	-.22	.53*	1																								
SN0	-.32	.11	-.05	-.37	-.37	1																							
SV0	.24	-.01	-.03	.57*	.40	-.48*	1																						
HN5	-.72**	-.67**	.73**	-.55*	-.32	.21	-.24	1																					
HV5	.53*	.49*	-.54*	-.09	.05	.07	.20	-.42	1																				
SN5	-.28	-.56*	.50*	-.17	-.10	-.27	.03	.35	.05	1																			
SV5	.07	.07	-.08	-.65**	-.31	-.01	-.33	.11	.32	.14	1																		
SP^{50}	.77**	.88**	-.92**	.17	.40	-.08	.29	-.69**	.63**	-.41	-.02	.73**	1																
SP^{60}	.82**	.84**	-.89**	.27	.48*	-.19	.37	-.72**	.63**	-.38	-.05	.69**	.98**	1															
SP^{70}	.73**	.85**	-.90**	.20	.31	-.18	.09	-.80**	.51*	-.30	-.00	.45	.87**	.85**	1														
SP^{80}	.70**	.52*	-.63**	.25	.42	-.20	.31	-.64**	.45	-.06	.01	.27	.73**	.72**	.75**	1													
SP^{90}	.52*	.74**	-.76**	.26	.35	-.17	.46	-.57*	.55*	-.27	-.07	.64**	.84**	.85**	.66**	.64**	1												
Amylose	.63**	.70**	-.80**	.30	.36	-.15	.33	-.66**	.53*	-.15	-.07	.44	.77**	.81**	.78**	.69**	.78**	1											
Enthalpy	-.79**	-.60**	.70**	-.35	-.54*	.43	-.41	.70**	-.61**	.00	.09	-.43	-.82**	-.86**	-.84**	-.81**	-.75**	-.80**	1										
To	-.81**	-.83**	.88**	-.30	-.49*	.23	-.39	.73**	-.63**	.34	.07	-.65**	-.97**	-.99**	-.86**	-.73**	-.87**	-.84**	.88**	1									
Tp	-.78**	-.87**	.91**	-.25	-.44	.16	-.35	.73**	-.62**	.38	.05	-.68**	-.98**	-.99**	-.88**	-.73**	-.88**	-.84**	.86**	.99**	1								
Tc	-.79**	-.90**	.94**	-.17	-.39	.07	-.25	.72**	-.61**	.47*	-.03	-.74**	-.98**	-.97**	-.85**	-.73**	-.86**	-.79**	.79**	.96**	.98**	1							
PV	-.71**	-.71**	.74**	-.38	-.51*	.28	-.55*	.63**	-.56*	.27	.23	-.52*	-.91**	-.93**	-.78**	-.64**	-.78**	-.73**	.83**	.93**	.92**	.85**	1						
TV	-.70**	-.75**	.78**	-.33	-.47*	.23	-.51*	.63**	-.58*	.29	.21	-.56*	-.92**	-.94**	-.80**	-.64**	-.80**	-.77**	.83**	.95**	.94**	.87**	.99**	1					
BV	-.71**	-.69**	.73**	-.39	-.51*	.30	-.56*	.62**	-.55*	.27	.24	-.51*	-.90**	-.93**	-.77**	-.64**	-.78**	-.71**	.83**	.93**	.91**	.84**	.99**	.99**	1				
FV	.75**	.23	-.34	.64**	.68**	-.66**	.65**	-.55*	.41	.01	-.17	.13	.54*	.67**	.48*	.57*	.60**	.57*	-.79**	-.69**	-.63**	-.55*	-.70**	-.65**	-.71**	1			
SB	.79**	.36	-.46	.61**	.68**	-.61**	.66**	-.61**	.47*	-.05	-.19	.24	.66**	.77**	.58*	.62**	.68**	.65**	-.85**	-.79**	-.74**	-.65**	-.81**	-.77**	-.82**	.98**	1		
PT	.29	.83**	-.78**	-.34	-.10	.46	-.24	-.35	.36	-.56*	.15	.74**	.69**	.57*	.59**	.34	.43	.36	-.25	-.53*	-.60**	-.68**	-.44	-.50*	-.42	-.21	-.06	1	
Pt	.81**	.73**	-.78**	.38	.55*	-.31	.50*	-.69**	.59**	-.31	-.16	.55*	.94**	.96**	.81**	.70**	.80**	.74**	-.86**	-.96**	-.95**	-.90**	-.98**	-.97**	-.98**	.75**	.85**	.44	1

Pro protein; *CHO* carbohydrate; *HN0* hardness at day 0-without vinegar; *HV0* hardness at day 0-with vinegar; *SN0* stickiness at day 0-without vinegar; *SV0* stickiness at day 0-with vinegar; *HN5* hardness at day 5-without vinegar; *HV5* hardness at day 5-with vinegar; *SN5* stickiness at day 5-without vinegar; *SV5* stickiness at day 5-with vinegar; *L** lightness; *WAC* water absorption capacity; T_o onset gelatinisation temperature; T_p peak gelatinisation temperature; T_c conclusion gelatinisation temperature; ΔH gelatinisation enthalpy; *PV* peak viscosity; *TV* trough viscosity; *BV* breakdown viscosity; *FV* final viscosity; *SB* setback viscosity; *PT* pasting temperature; *Pt* peal time; SP^{50} swelling power at 50 °C; SP^{60} swelling power at 60 °C; SP^{70} swelling power at 70 °C; SP^{80} swelling power at 80 °C; SP^{90} swelling power at 90 °C

n* = Significant correlations at 10% (0.01)

n** = Significant correlations at 5% (0.05) (r = – 0.79) and ΔH (r = – 0.80,). These results suggest that amylopectin is playing a dominant role in the hardness of the cooked rice after day 0. Starches with abundant proportions of short-chain amylopectin (DP 6 to 12) would exhibit low DSC parameters (T_o, T_p, T_c, and ΔHg). Long amylopectin chains (DP 19–30) are usually disrupted at higher temperatures while the short chains (DP 6–12) are disrupted at relatively lower temperatures [54]. Chung [55] found that Vietnamese rice contained lower amount of short A chains (DP 6–12), higher amount of B1 chains (DP 13–24), and higher amount of longer B3+ chains (DP ≥ 37). Thus, we suspect that Australian rice starch contains more short chains while Vietnamese and Italian rice contain greater proportion of long chain amylopectin.

Nevertheless, amylose content played significant ($p < 0.05$) role in the pasting properties of the extracted starch as seen in the correlation data for peak viscosity (r = – 0.73), trough viscosity (r = – 0.77), breakdown viscosity (r = – 0.71) and setback viscosity (r = 0.6) (Table 3). The positive correlation of setback viscosity with amylose suggests that aggregation of amylose molecules during cooling is mainly responsible for the setback viscosity of the rice starch.

Furthermore, the peak viscosity which represents the swelling peak showed a significant ($p < 0.05$) positive correlation with the gelatinization properties [T_o (r = 0.93), T_p (r = 0.92), T_c, (r = 0.85) and ΔH (r = 0.83)]. Similarly, trough and breakdown viscosities also showed a positive correlation with the gelatinization properties, but the final and setback viscosities showed a significant ($p < 0.05$) negative correlation. Furthermore, a negative but significant ($p < 0.05$) correlation was found between T_p (r = – 0.744) and setback viscosity indicating that rice starch with high gelatinization temperature would show tendency to retrograde. In terms of functional properties, amylose content showed a significant ($p < 0.05$) positive correlation with swelling power at 50 °C (r = 0.77), 60 °C (r = 0.81), 70 °C (r = 0.78), 80 °C (r = 0.69) and 90 °C (r = 0.78). This explains why Australian rice starch showed the highest swelling power despite having high amylose content. Again, since amylose is known to prevent swelling of starches by forming a barrier around the granules [33], it is impossible to overrule the role of amylopectin structure in the swelling behaviour of these starches. This suggest that future studies should characterize these starches for the chain length distribution of the amylopectin component.

Conclusions

The objective of the current study was to determine the functional and quality characteristics of three rice varieties. Raw rice samples were significantly ($p < 0.05$) different in fat, protein, and carbohydrate contents. Cooked rice on the other hand showed significant ($p < 0.05$) variation in their textural properties before and after storage. Starch from the Italian and Vietnamese rice showed similar peak, trough and breakdown viscosities which were significantly ($p < 0.05$) different from the Australian variety. The cooked Australian rice with added vinegar, displayed significantly ($p < 0.05$) higher hardness than Italian and Vietnamese, indicating that these two varieties are better candidates for sushi rice based on their lower hardness after 5 days of storage. The higher hardness of Australian rice variety may be explained by its higher amylose content which resulted in a starch with significantly ($p < 0.05$) higher swelling power, higher setback viscosity and lower gelatinization temperature. Although the results of this study are suggestive that Australian rice may not be suitable for Sushi rice, the extracted starch can form a more viscous gel due to its high final viscosity and could find application as a thickener in various food application such as in soups, gravies, and yoghurt. However, modification of the starch is vital prior to use due to high tendency to retrograde which may lead to separation in food systems. Future studies may be required to use food additives such as low molecular weight sugars to modify the rice during cooking to extend the keeping quality beyond the traditional 5 days. In addition, the molecular architecture of the amylopectin component of the starch may also require further investigation.

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Data availability Data will be made available on request.

Declarations

Conflict of interest The authors declare no conflict of interest.

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