Food Sci Biotechnol (2022) 31(6):681–690
https://doi.org/10.1007/s10068-022-01075-2

RESEARCH ARTICLE

High-amylose and Tongil type Korean rice varieties: physical properties, cooking behaviour and starch digestibility

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Received: 7 October 2021 / Revised: 21 March 2022 / Accepted: 23 March 2022 / Published online: 6 April 2022

Abstract The National Institute of Crop Science, Rural Development Administration (RDA) of Korea is presently developing new rice varieties suitable for producing Western rice-based foods, such as *risotto*, a well-known Italian-style product. The study considered different milled rice from five Tongil-type and six Japonica-type varieties. Besides the biometric properties, cooking behaviour, starch properties, and in vitro digestibility of Korean rice samples were compared with those of the 'Carnaroli' Italian variety. The physicochemical traits of the Korean varieties extended over a vast range; the amylose content stood out (from 13.0 to 41.7%), influencing the hardness and stickiness of cooked samples, and their starch digestibility. Although none of the Korean varieties seemed to guarantee cooking performances for *risotto* similar to the 'Carnaroli' one, 'Saemimyeon' and 'Shingil' cvs were judged the best for this purpose up-to-now.

Keywords Rice · Amylose · Physicochemical properties · Risotto · Starch digestibility

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Introduction

Rice (*Oryza sativa*) is part of the diet of many countries, thanks to its versatility. Although the most common way of eating rice is as cooked grain, its cooking can take place in different ways (e.g., boiled rice, pilaf, *risotto*, etc.) to obtain the desired texture according to consumer taste and dietary habits. Moreover, in recent decades rice has been increasingly sought after as an ingredient of various food formulations, including gluten-free pasta, baked products, and snacks (Bresciani et al., 2021a).

In Korea, the paradigm of rice consumption is rapidly shifting from cooked rice to processed foods due to changes in the population structure and eating habits, such as the increase in dual-income couples and the increase in single-person households derived from the recent advancement of women into society. However, it is difficult to find varieties suitable for various processed foods desired by consumers in the rice-based industrial field.

So far, varieties developed exclusively for processing purposes are limited to some processing fields such as rice noodles and are mainly limited to amylose content control (Cho et al., 2018, 2019; Lee et al., 2020). In rice, the gelatinization feature of starch is one of the fundamental characteristics in processing. Starch retrogradation is positively correlated with amylose content, and medium-high amylose rice varieties have a higher retrogradation rate than low amylose rice varieties (Kang et al., 2004). In addition, the amylose content of rice is one of the main factors determining the physical properties of rice, and it is known that the higher the amylose content, the higher the hardness and the lower the stickiness of the rice (Radhika Reddy et al., 1993). For this reason, many studies have been conducted on the physicochemical characteristics of rice varieties with different amylose contents, but studies on the change in processing aptitude due to retrogradation properties are still incomplete to highlight this relationship (Choi, 2010; Sim et al., 2017).

Recently, the interest in developing high-value-added products is growing as well as the need for available varieties that meet the consumer interest in healthy foods. Resistant starch (RS) is defined as various types of starch that are not digested and not absorbed in the small intestine (EURESTA, 1993), and it is reported that the content of RS varies greatly depending on the type of plant and processing (Hu et al., 2004; Walter et al., 2005; Xie et al., 2006; Shi & Gao 2011). In particular, starch classified as RS3 is stable to temperature, and for that reason, it is not affected by cooking (Haralampu, 2000), and many studies classified it as a functional dietary fibre (Zhao and Lin, 2009).

Meanwhile, in the recent rice processing and market sector, in addition to the traditional processed rice noodles in Southeast Asia, various dishes such as Italian *risotto* are becoming more and more popular by the influence of foreign food culture. In addition, there is a growing demand for cost-saving, high yielding varieties that can secure the price competitiveness of processed products in processing companies. Accordingly, in Korea, Tongil type varieties (grouped into *Indica* varieties) with high processing aptitude and high yielding are developed and distributed in farmer's fields. However, evaluation of processing aptitude for Tongil type and very high amylose content varieties is insufficient.

Therefore, in this study, various processing varieties cultivated in Korea, such as 'Dodamssal', a variety with high amylose together with high RS content and 'Saemimyeon', high yielding Tongil type *Indica* rice, were characterized for their physico-chemical properties to get some information on their processing suitability, especially for *risotto* dishes that require a long cooking time (about 15–18 min). For this reason, the Korean rice genotypes were compared with rice cv. 'Carnaroli', a valuable Italian variety for *risotto* preparation, to assess whether some of them can be considered suitable for this recipe.

Materials and methods

Rice varieties

The Department of Southern Area Crop Science, National Institute of Crop Science, RDA (Korea) provided milled rice from eleven rice varieties: five Tongil type Indica rice ('Geumgang1', 'Milyang354', 'Saegyejinmi', 'Saemimyeon', 'Shingil') and six Japonica type ('Dodamssal', 'Irumi', 'Milyang343', 'Milyang344', 'Saegoami', 'Yeongjin'). The samples were compared with a commercial sample of the Italian rice variety 'Carnaroli'.

Kernel characterisation

The kernels' length, width, and length to width ratio were measured according to the UNI EN ISO 11746:2018 method (UNI EN ISO, 2018). The test was carried out on 10 g of kernels. Crystallinity was assessed on 88 g of kernels using the standard UNI 11676:2017 method; (UNI, 2017). Amylose content was determined in duplicate according to the standard procedure (UNI EN ISO 6647-2:2020 method; UNI EN ISO, 2020).

Alkali test was modified as indicated by Bhattacharya and Sowbhagya (1972). Six whole milled rice kernels were immersed in 10 mL of 1.5% KOH solution in a Petri dish and arranged so that the grains did not touch each other.

The Petri dishes were then covered. After 23 h of incubation at room temperature, each grain was visually examined for its level of intactness and assigned a numerical score (ASV 23h) out of 7 by 3 trained human inspectors: "1" for not affected kernel; "2" for swollen kernel; "3" for the swollen kernel, with incomplete or narrow collar; "4" for the swollen kernel, with complete and wide collar; "5" for split or segmented kernel, with complete and wide collar; "6" for the dispersed kernel, with merging collar and "7" for completely dispersed and intermingled kernel (Bhattacharya and Sowbhagya, 1972).

Cooking behaviour

Gelatinization time measured the time necessary for 90% of the rice kernels to pass from the native to the gel state based on visual observation, i.e. by noting the time the opaque core disappeared during cooking when the grain was pressed between two glass slides (UNI EN ISO 14864:2004 method, UNI EN ISO 2004). Results are the average of five measurements.

Rice hardness was measured by an extrusion test using the UNI EN ISO 11747:2018 method (UNI EN ISO, 2018). Rice kernels (20 g) were cooked in water (38 ml) for 20 min. After that, the heat was turned off and the sample was maintained for 10 min, divided into portions of 17 g each and placed inside an Ottawa cell. Kernels were extruded with a square plunger (7.0 cm^2 cross-section) at 10 cm/min speed.

A compression test was carried out to evaluate stickiness, as reported by Lucisano et al. (2009). Briefly, rice (8 g) were cooked in water (12 ml) for 20 min. After 10 min resting, four portions of 2 g each were taken from the center of the rice, piled on a glass plate, and compressed at 5 mm/min speed with a plate covered with a glass slab. At a compression force of 6.4 N, the crosshead movement was stopped for 10 s and then moved upward at the same speed.

Rice texture was evaluated on two independent measurements.

Starch properties

Pasting properties

Rice kernels were grinded into flour (particle size < 250 mm) using a laboratory mill (IKA Universalmühle M20; IKA Laborteknic, Staufen, Germany). The pasting properties were measured using a micro-viscoamylograph (MVAG) (Brabender GmbH, Duisburg, Germany). An aliquot of 12 g of the sample was dispersed in 100 mL of distilled water, scaling both flour and water weight on a 14% flour moisture basis. The pasting properties were evaluated under stable conditions (speed: 250 rpm; sensitivity:300 cmgf) by using the following time-temperature profile: heating from 30 °C up to 95 °C; holding at 95 °C for 20 min; cooling from 95 °C to 30 °C; holding at 30 °C for 1 min. The heating and cooling phases were carried out with a temperature gradient of 3 °C/min. One representative curve for each sample was reported.

Thermal properties

Differential scanning calorimetry (DSC) measurements were carried out through a Perkin-Elmer DSC6 calorimeter (Waltham, Massachusetts, USA) working with stainless steel sealed pans to evaluate starch gelatinization properties. Flour samples were prepared at 70% moisture, and a heating/cooling cycle followed by a second heating run was applied in the 20–120 °C range at a scanning rate of 2.0 °C/min. Indium (melting temperature = 157 °C; melting enthalpy = 28.45 J/g) was used for calibration, whereas an empty pan was used as a reference.

Raw calorimetric data were worked out through the dedicated software IFESTOS as Marengo et al. (2017) reported. In brief, the output signal in mW units was normalized by the dry mass of each sample, and the excess heat capacity $C_P^{exc}(T)$/J K^{-1} $g^{-1}{}_{dry}$, i.e. the difference between the apparent heat capacity $C_P(T)$ of the sample and the heat capacity of the pre-gelatinization state, was recorded across the scanned temperature range, allowing the evaluation of the enthalpy drop ΔH by a straightforward integration of the corresponding trace. Gelatinization onset, T_{onset}, was obtained as the peak flex point tangent interception with the temperature axis. Errors were evaluated based on at least three replicas.

In vitro starch digestibility

The method of Englyst (Englyst et al., 2000) was used to assess *in vitro* carbohydrate digestibility on cooked rice grains by means of the estimation of rapidly (RDS) and slowly (SDS) digestible starch fractions. Each sample was cooked in boiling water (rice:water ratio = 1:10) at the gelatinization time reported in Table 2. Cooked samples were minced (0.9 cm particle size) to simulate mastication and aliquots containing 500–600 mg of carbohydrates were treated with pepsin (P7000, from gastric mucosa). After that, samples were incubated with a mixture of hydrolytic enzymes (P7545, pancreatin from porcine pancreas; A7095, amyloglucosidase from Aspergillus niger, from Sigma Chemical Co., St Louis, MO, USA), in presence of glass balls of 0.5 cm diameter. RDS and SDS fractions were calculated from the glucose released at 20 min and between 20 and 120 min of incubation with the mixture of

Table 1 Biometric indices, crystallinity, and amylose content of rice kernels

	Length (mm)	Width (mm)	Length to width ratio	Crystallinity (%)	Amylose content (%)
Dodamssal	4.80 ± 0.02[a]	2.91 ± 0.01[g]	1.65 ± 0.01[b]	0	41.7 ± 0.26[k]
Geumgang1	5.51 ± 0.01[de]	2.53 ± 0.01[ab]	2.18 ± 0.01[gh]	60	14.0 ± 0.13[bc]
Irumi	5.09 ± 0.01[b]	2.92 ± 0.01[g]	1.74 ± 0.01[c]	88	14.4 ± 0.07[cd]
Milyang343	4.75 ± 0.06[a]	3.00 ± 0.0[h1]	1.59 ± 0.02[a]	0	17.0 ± 0.39[f]
Milyang344	5.41 ± 0.01[cd]	2.52 ± 0.01[a]	2.15 ± 0.01[fg]	89	16.0 ± 0.26[e]
Milyang354	5.65 ± 0.05[f]	2.58 ± 0.01[c]	2.19 ± 0.03[gh]	84	13.3 ± 0.26[ab]
Saegoami	5.05 ± 0.01[b]	2.80 ± 0.01[e]	1.81 ± 0.01[d]	92	20.1 ± 0.06[g]
Saegyejinmi	5.56 ± 0.05[ed]	2.52 ± 0.01[a]	2.21 ± 0.01[h]	85	13.0 ± 0.01[a]
Saemimyeon	5.65 ± 0.02[f]	2.67 ± 0.01[d]	2.11 ± 0.02[ef]	0	27.1 ± 0.01[j]
Shingil	5.33 ± 0.01[c]	2.56 ± 0.01[bc]	2.08 ± 0.01[e]	0	25.7 ± 0.13[i]
Yeongjin	4.74 ± 0.04[a]	2.86 ± 0.02[f]	1.66 ± 0.01[b]	94	15.0 ± 0.26[d]
Carnaroli	*6.79 ± 0.03*[g]	*3.07 ± 0.01*[i]	*2.21 ± 0.02*[h]	*0*	*23.6 ± 0.4*[h]

In italics the Italian variety

Value in the same columns with different letters are significantly different (one-way ANOVA, Tukey test HSD, $p < 0.05$)

hydrolytic enzymes. Glucose was measured by High Performance Liquid Chromatography (HPLC) (Series 200, Perkin Elmer, USA) equipped with 4 × 250 mm CarboPac™ PA1 column (Dionex, USA) and PAD detector (ED50, Dionex, USA). Sample (20 µL) was injected to column at room temperature using NaOH (160 mM) as the mobile phase at a flow rate of 1 mL/min.

Statistical analysis

Analysis of variance (one-way ANOVA) was assessed by Statgraphics Plus 5.1 (StatPoint Inc., Warrenton, USA) using the samples as factors. The significant differences ($p < 0.05$) were determined by using Tukey HSD test. Data were processed by Principal Component Analysis (PCA) by using Statgraphic Plus for Windows v. 5.1. (StatPoint Inc., Warrenton, USA).

Results

Rice kernel characterization

Based on the dimensions, rice varieties can be classified into the round grain (grain length ≤ 5.2 mm; length/width ratio < 2), medium grain (5.2 < length ≤ 6.0 mm; length/width < 3), long grain type A (length > 6.0 mm; 2 < length/width < 3), and long grain type B (length > 6.0 mm; length/width ≥ 3) (Reg. EU n.1308/2013). According to this classification, apart from the rice cv. 'Carnaroli' (which is a long A rice cv), the Korean varieties belonged to the category of medium ('Milyang344', 'Milyang354', 'Geumgang1', 'Saegyejinmi', 'Saemimyeon', 'Shingil') or round ('Dodamssal', 'Irumi', 'Milyang343', 'Saegoami', 'Yeongjin') grains (Table 1).

Kernel crystallinity varied in a wide-range five varieties (including rice cv. 'Carnaroli') did not show crystallinity; 'Geumgang1' presented 60% crystallinity, four varieties ('Irumi'; 'Milyang 344'; 'Milyang354'; 'Saegyejinmi') showed a degree of crystallinity between 60 and 90% and two samples ('Yeongjin', 'Saegoami') more than 90% (Table 1). The amylose content ranged from 13 to 42% for 'Saegyejinmi' and 'Dodamssal', respectively (Table 1). Most of the varieties can be classified as low amylose content (10–20%; Juliano et al., 1992), whereas 'Shingil', 'Saemimyeon', and 'Dodamssal' have high amylose content (> 25%). Rice cv. 'Shingil' was the most similar to 'Carnaroli' variety for the amylose content (25.7 and 23.6%, respectively).

The time required to fully gelatinized 90% of the kernels (referred to as Gelatinization Time) varied from 13 to 27.5 min for 'Shingil' and 'Dodamssal', respectively (Table 2). 'Milyang344', 'Milyang354', 'Yeongjin', 'Saegyejinmi', and 'Saegoami' showed a gelatinization time similar to that of 'Carnaroli'(17 min). Also, the Alkali score of Korean cvs ranged in a wide range: from 1 (kernels not affected by alkali) to 7 (kernels completely dispersed and intermingled), for 'Milyang344' and 'Saegoami', respectively. The latter showed a degree of degradation similar to 'Carnaroli'. However, most of the varieties showed an alkali score of about 4.7 (i.e., median value).

Regarding the hardness of the samples determined by the extrusion test, 'Dodamssal' showed the highest

Table 2 Gelatinization time, alkali score, hardness, and stickiness of rice kernels

	Gelatinization time (min)	Alkali score	Hardness (kg/cm^2)	Stickiness ($g \times cm$)
Dodamssal	28	4.7	1.39 ± 0.03^{f}	0.54 ± 0.07^{a}
Geumgang1	16	4.7	0.61 ± 0.01^{a}	9.94 ± 0.82^{de}
Irumi	19	5.0	0.68 ± 0.01^{ab}	12.66 ± 1.14^{f}
Milyang343	15	3.3	0.62 ± 0.01^{a}	11.52 ± 0.18^{ef}
Milyang344	17	1.0	0.65 ± 0.01^{ab}	6.99 ± 0.09^{b}
Milyang354	17	1.6	0.67 ± 0.01^{ab}	8.06 ± 0.01^{bcd}
Saegoami	18	7.0	0.97 ± 0.01^{d}	1.28 ± 0.06^{a}
Saegyejinmi	17	2.8	0.63 ± 0.01^{a}	7.43 ± 0.8^{bc}
Saemimyeon	20	1.0	1.10 ± 0.04^{e}	0.93 ± 0.07^{a}
Shingil	13	5.5	0.81 ± 0.02^{c}	1.82 ± 0.33^{a}
Yeongjin	18	5.9	0.71 ± 0.01^{b}	9.58 ± 1.32^{cde}
Carnaroli	*18*	*6.8*	0.98 ± 0.01^{a}	0.98 ± 0.02^{a}

In italics the Italian variety

Value in the same columns with different letters are significantly different (one-way ANOVA, Tukey test HSD, $p < 0.05$)

maximum force, whereas the lowest firmness was observed for 'Geumgangl' (Table 2). As for gelatinisation time and Alkali score, kernels from 'Saegoami' and 'Carnaroli' exhibited a similar hardness.

For stickiness, Korean varieties (except 'Dodamssal' and 'Saemimyeon') appeared highly sticky due to elevated values of the negative area of the graph (Table 2). In particular, the stickiness of Korean varieties was almost 7–13 times higher than that of 'Carnaroli', with 'Irumi' showing the highest value.

Starch properties

Pasting properties

Significant variations were evidenced in the pasting properties of the rice cultivars investigated (Fig. 1). Specifically, pasting temperatures ranged from 64.7 to 80 °C (for 'Yeongjin' and 'Dodamssal', respectively); maximum viscosities from 139 to 1097 mPa × s (for 'Dodamssal' and 'Saemimyeon', respectively); maximum temperatures from 88 °C ('Milyang343') to 95 °C ('Dodamssal' and 'Shingil'); breakdowns from 0 (for both 'Dodamssal' and 'Shingil') to 574 mPa × s (for 'Geumgang1'); final viscosities from 400 to 1329 mPa × s (for 'Dodamssal' and 'Saemimyeon', respectively); and setbacks from 220 to 714 mPa × s (for 'Dodamssal' and 'Saemimyeon', respectively). Among all, 'Dodamsaal' and 'Shingil' samples stand out for their low values for maximum and final viscosities and their low breakdown (that was absent) and setback values. Among the samples, 'Milyang344' and 'Carnaroli' showed a similar pasting profile during the heating phase (i.e., pasting temperature, maximum viscosity, and breakdown), whereas 'Saegoami' behaviour was similar to that of 'Carnaroli' during the cooling phase (i.e., final viscosity and setback).

Thermal properties

Figure 2 reports the DSC gelatinization profiles obtained for 'Carnaroli' and three selected Korean varieties, namely 'Dodamssal', 'Geumgang1' and 'Irumi'. All thermal profiles highlight three main endothermic contributions/regions corresponding to the different steps of the starch gelatinization process. The first and the second contributions are generally indicated as first and second gelatinization peaks. The onset temperature of gelatinization is distinctive of the specific rice variety, and it is only dependent on the native starch composition and structure (Fessas & Schiraldi, 2000). Although the first gelatinization step extension depends on the immediately available water molecules of the whole sample: the higher the water content, the higher the percentage of gelatinized starch at the end of the first endothermic event. The residual starch granules undergo gelatinization at higher temperatures when the increased mobility of water and its release from other matrix constituents make water molecules available again for the completion of the gelatinization. Instead, the third region of the calorimetric profiles is ascribable to the dissociation process of the amylose-lipid complexes (Fessas & Schiraldi, 2000).

'Geumgang1', 'Irumi' and 'Carnaroli' showed almost similar calorimetric profiles as evinced by Fig. 2, whereas 'Dodamssal' exhibited a different thermal behaviour.

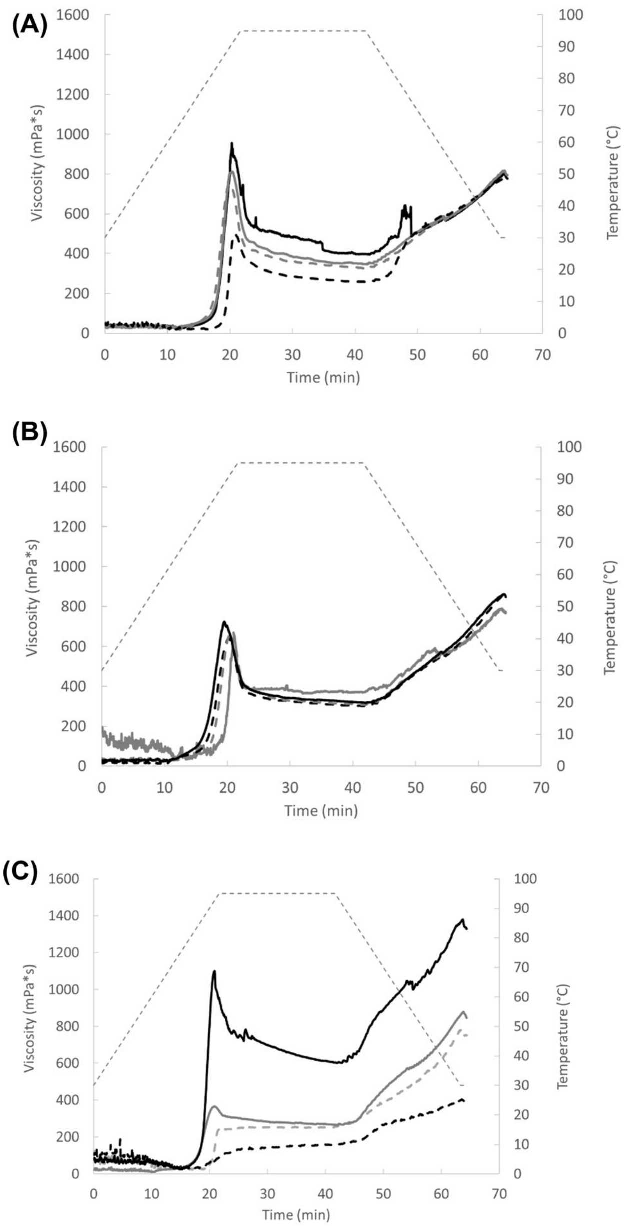

Fig. 1 Pasting profiles of Korean rice genotypes and Carnaroli. Panel (**A**): Carnaroli (dashed black line), Geumgang1 (solid black line), Milyang354 (dashed grey line), Saegyejinmi (solid grey line). Panel (**B**): Irumi (dotted black line), Milyang343 (solid black line), Milyang344 (solid grey line), Yeongjin (dashed black line). Panel (**C**): Dodamssal (dashed black line), Saegoami (solid grey line), Saemimyeon (solid black line), Shingil (dashed grey line)

Specifically, it was characterized by a much higher onset temperature (T_{onset} of about 71 ± 1 °C, 59 ± 1 °C, 59 ± 1 °C and 57 ± 1 °C, for 'Dodamssal', 'Geumgang1', 'Irumi' and 'Carnaroli', respectively) and a lower enthalpy of gelatinization (ΔH of 14 ± 1 J $g^{-1}{}_{dry}$, 18 ± 1 J $g^{-1}{}_{dry}$, 17 ± 1 J $g^{-1}{}_{dry}$, and 19 ± 1 J $g^{-1}{}_{dry}$, for 'Dodamssal', 'Geumgang1', 'Irumi', and 'Carnaroli', respectively). On the other hand, excluding the

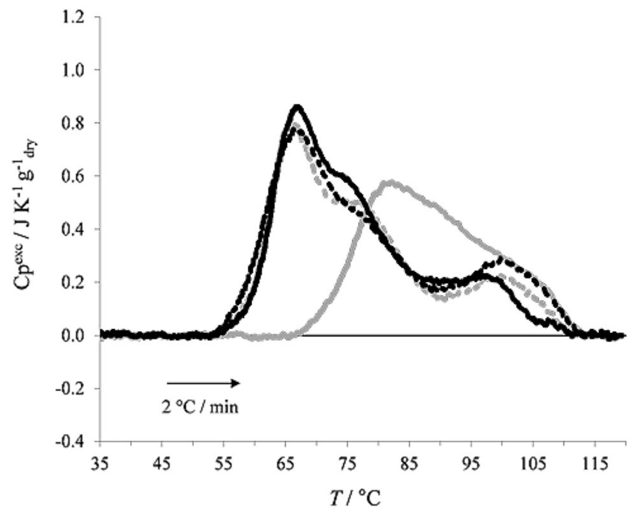

Fig. 2 DSC thermograms for the various rice flours (70% moisture, scan rate 2 °C/min). Carnaroli (dashed black line), Geumgang1 (solid black line), Irumi (dashed grey line), Dodamssal (solid grey line)

'Dodamssal' because of the overlapped contributions to the signal, the comparison of 'Geumgang1' and 'Irumi' with the Italian variety showed a slightly greater presence of amylose-lipid complex in 'Carnaroli' compared to the others.

In vitro starch digestibility

RDS and SDS fractions were assessed on selected varieties, i.e. 'Dodamssal', 'Geumgangl', 'Irumi', and 'Saemimyeon', which were different in amylose content (Table 1) and pasting profiles (Fig. 1). Also, starch digestibility parameters were compared with those of 'Carnaroli' (Table 3). The SDS fraction followed the order Dodamssal' (41.1%) > 'Saemimyeon' (36.5%) > 'Carnaroli' (24.6%) > 'Irumi' (21.3%) > 'Geumgang1' (8.3%). Accessibility to amylase hydrolysis is used to estimate the potential glycemic response of foods (EFSA, 2011). Glycemic responses appear to be directly related to RDS, whereas insulin demand was shown to be inversely correlated to SDS (Garsetti et al., 2005).

Discussion

Many of Eastern consumers are highly attracted by foods typical from Western countries. When talking about rice, although being mainly consumed in Italy, *risotto* is becoming more and more appreciated all over the world thanks to its peculiar texture: creamy outside and firm inside (Bresciani et al., 2021a). Among Italian varieties, 'Carnaroli' is considered one of the most suited for *risotto*

Table 3 *In vitro* starch digestibility

	RDS (g/100 g available starch)	SDS (g/100 g available starch)
Dodamsaal	58.9 ± 3.6[a]	41.1 ± 3.6[d]
Geumgang1	91.7 ± 0.8[d]	8.3 ± 0.8[a]
Irumi	78.7 ± 1.8[c]	21.3 ± 1.8[b]
Saemimyeon	63.5 ± 1.7[b]	36.5 ± 1.7[c]
Carnaroli	*75.4 ± 1.7c*	*24.6 ± 1.7b*

In italics the Italian variety

Value in the same columns with different letters are significantly different (one-way ANOVA, Tukey test HSD, $p < 0.05$)

RDS Rapidly digestible starch, *SDS* Slowly digestible starch

preparation, thanks to a combination of qualitative traits including kernel size, medium-high amylose content (Table 1) and high gelatinization time that assure partial leaching of starchy material and, therefore, the valued/required texture (Table 2).

With the attempt to expand the end-uses of local cultivars, eleven rice varieties of Korean origin were characterized to verify whether some of them have similar quality traits as 'Carnaroli' and thus can be used for *risotto* preparation.

Several factors contribute to the quality of rice and thus to its end-uses. Besides the biometric indices (length, width and their ratio) that allow classifying all the Korean rice samples inside the medium-grain or round classes, according to the EU Regulation n.1308/2013 and the Italian Law 131/2017, rice characterization usually begins with the quantification of amylose. Indeed, this parameter strongly influences the cooking behaviour of rice. Specifically, the higher the amylose content, the higher the hardness ($r = 0.94$; $p < 0.0001$) and the lower the stickiness ($r = -0,76$; $p < 0.005$). The amylose content of the Korean rice genotypes varied in a wide range, with the highest values measured in 'Dodamssal' (about 42%). Despite the great interest in using such varieties because of the well-known relation between amylose and resistant starch content (Toutounji et al., 2019), it can be anticipated that 'Dodamssal' is unsuitable for *risotto* preparation: it had an extremely high gelatinization time and hardness (Table 2). Alongside traditional consumption, rice has been increasingly sought after in recent decades as an ingredient of various food formulations, including extruded snacks and gluten-free pasta (Bresciani et al., 2021a). Previous findings on high amylose corn (Alfieri et al., 2020; Bresciani et al., 2021b, 2021c) – as well as the characterization reported in the present study for rice – suggest that 'Dodamssal' would be more suitable for co-extruded snack production rather than gluten-free pasta (if used alone), due to the fact that the high-amylose starch requires very high temperature (95 °C) for starch gelatinization (Fig. 1) and assure high firmness. The high onset gelatinization temperature likely reflects the presence of stable starch crystals that need high energy for the thermal transition to begin, in agreement with its longer gelatinization time (Table 2) that resulted in 10 min higher than the time exhibited by rice cv. 'Carnaroli'. Consequently, the 'Dodamssal' kernels could require a longer cooking time for *risotto* preparation than the optimal one (normally 15–16 min). The high amylose content of this variety is also responsible for its high hardness, which is not suitable for the risotto preparation.

Regarding rice kernels, various approaches can be used to gather information about gelatinization behaviour; from a macroscopic to a molecular level: the time required to fully gelatinized rice grains during cooking (i.e., gelatinization time), degree of kernel degradation in KOH (i.e., alkali score), changes in viscosity during the heating and stirring of rice flour-water mixture (i.e., pasting temperature) and the loss of crystalline order (i.e., onset gelatinization temperature and enthalpy).

Gelatinization time is an important property of rice and grains in general because it strongly correlates with the cooking time and the texture of the cooked product. In this study, gelatinization time was correlated to pasting temperature ($r = 0.73$; $p < 0.01$) and both of them correlated with hardness (gelatinization time: $r = 0.78$; $p < 0.001$) and seem to be influenced by the amylose content (gelatinization time: $r = 0.69$; $p < 0.05$; pasting temperature: $r = 0.74$; $p < 0.001$).

Exploratory multivariate analysis via PCA was used to explore the data further and provide additional discriminatory power. The Principal Components Analysis (PCA) in Fig. 3 A shows the distribution of the Korean rice genotypes ('Dodamssal' was excluded from the data set due to the considerations above) according to all the indices described above. The first two principal components provided a good summary of the data, accounting for about 62% of the total variance (PC 1 = 37%; PC 2 = 25%). Moreover, the loading plot (Fig. 3B) distinguishes the variables affecting sample distributions, which are those more distant from the origin of the plot.

In quadrants I and IV, samples were characterized by kernels with high length and low width values (resulting in a high length to width ratio). Moreover, those genotypes were characterized by high maximum viscosity and high breakdown values. Changes in viscosity of a starch-water slurry subjected to heating and cooling under controlled conditions are the macroscopic effect of structural changes of starch granules during starch gelatinization and retrogradation. Precisely, maximum viscosity reflects starch gelatinization intensity, whereas breakdown its tolerance to heating and shear stress. Genotypes in quadrants I and II

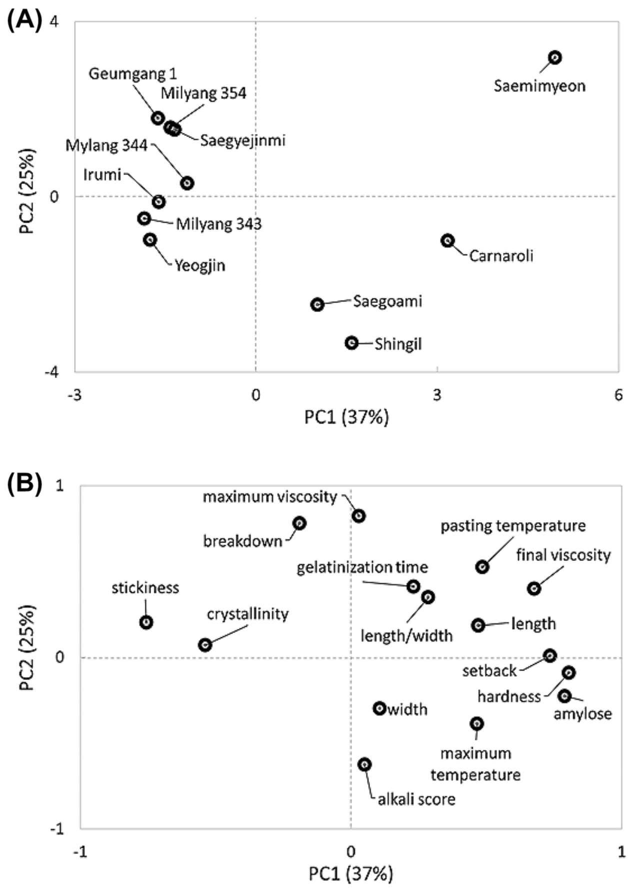

Fig. 3 Principal component (PC) analysis on data collected for Korean rice genotypes and Carnaroli: score plot (**A**) and loading plot (**B**)

(i.e., 'Saemimyeon', 'Saegoami', 'Shingil' and 'Carnaroli') were separated from all the other samples for their high amylose content and high hardness, low stickiness, and low crystallinity.

To further investigate the starch characteristics of Korean rice genotype compared to 'Carnaroli, 'Irumi' (quadrant III) and 'Geumgang1' (quadrant IV), as well as 'Dodamssal', were selected for differential scanning calorimetry and in vitro starch digestibility studies.

Regarding the 'Dodamssal', the DSC results (Fig. 2) confirm the peculiar properties that emerged from the other techniques. In particular, the gelatinization onset temperature resulted in being rather high (T_{onset} of about 71 °C, i.e. about 14 °C higher than 'Carnaroli'), justifying its cooking behaviour as well as its pasting properties. As concerns 'Irumi', 'Geumgang1' and 'Carnaroli', the gelatinization onset temperature, the calorimetric profiles, and the overall gelatinization enthalpy were very similar, with only slight differences in the amylose-lipid dissociation region. Specifically, the contribution deriving from the dissociation of amylose-lipid complexes seems to be increasingly lower when moving from 'Carnaroli' to 'Irumi' and 'Geumgang1'. Such a trend of contributions is comparable with the increasingly lower amylose content reported in Table 1.

Hence, we may argue that the differences in physical properties and behaviour are due to the starch gelatinization properties and could depend on other parameters (including amylose content, the size distribution of starch granules, other matrix components, etc.) that deserve further investigation.

Regarding starch digestibility, the SDS fraction in boiled rice ranged from 8.3 to 41.1%, increasing with increasing amylose content. In 2011, the European Food Safety Authority (EFSA) approved a health claim regarding the role of SDS in the control of post-prandial blood glucose. A high SDS fraction is potentially related to a low post-prandial glycemic response and, therefore, a better health impact. Starch digestibility is affected by an interplay between intrinsic food characteristics and extrinsic food processing factors (Toutounji et al., 2019). Considering that all the samples were processed in the same way, differences in starch digestibility can be related to the intrinsic factors, including molecular composition (e.g. size and amount of amylose and amylopectin) and supramolecular structures (e.g. crystallinity, growth rings, packing in cell) (Toutounji et al., 2019). The amylose content is negatively correlated with RDS, whereas positively correlated with SDS (Chung et al., 2010, 2011; Morita et al., 2007). For example, in the study of Chung et al. (2011), the SDS of selected type of rice followed the order long-grain rice (60.1%) > 'Arborio' (i.e., Italian short-grain rice; 51.5%) > 'Calrose' (japonica medium-grain rice; 47.8%) > glutinous rice (28.6%), which is similar to the order of amylose content (27%, 19%, 15%, and 4%, for long-grain rice, 'Arborio', 'Calrose' and glutinous rice, respectively). However, differences in starch digestibility might also be due to differences in amylose and amylopectin organization within the starch granules, aspects that deserve further investigation.

Finally, we assessed whether some Korean varieties might be suitable for *risotto* preparation (data not shown). Specific varieties were compared to rice cv. 'Carnaroli': 'Saemimyeon' (quadrant I; Fig. 3A), 'Shingil' (quadrant II; Fig. 3A), and 'Milyang344' (quadrant IV; Fig. 3A). All the Korean varieties required less preparation time (< 10 min) compared to rice cv. 'Carnaroli' (16 min). Among the tested varieties, 'Saemimyeon' and 'Shingil' were the most suitable for *risotto* preparation, giving a product similar in appearance to 'Carnaroli' but different in texture ('Saemimyeon') or amylose leaching ('Shingil') (Table 2). Although this preliminary investigation provides helpful information about the suitability of selected Korean varieties to make *risotto*, the sensory profile of the products needs to be assessed by a trained panel.

In conclusions, the physicochemical properties of Korean rice varieties here tested varied in a wide range. This significant variability will identify the most suitable variety for each processing (bread-making, pasta making, etc.). Indeed, Korean cvs characterized by a medium-high amylose content (about 20%, such as ‘Saegoami’) appear to be of great interest for gluten-free pasta/noodle production. Samples characterized by an even higher amylose content (i.e., ‘Dodamssal’ and ‘Saemimyeon’) are of interest for their high amount of SDS, although this characteristic needs to be confirmed by in vivo studies. ‘Saemimyeon’ and ‘Shingil’ seem to be the most suitable varieties for preparation. However, their thermal properties remain to be addressed. Further breeding programs would focus on decreasing the differences now present among the Korean and Western varieties. The large size of the latter seems to influence the starch swelling and its leaching during the preparation of *risotto*, favoring both the creaminess and high consistency of the final product.

Acknowledgements The authors would like to thank Mr. Giovanni Fiorillo (Università degli Studi di Milano) for technical assistance for starch digestibility analysis and Dr. Marco Signorelli (Università degli Studi di Milano) for DSC measurements. The support of Dr. Gaetano Cardone (Università degli Studi di Milano) in risotto cooking trials is also aknowledged.

Funding This work was supported by the Rural Development Administration (Project title: Introduction of rice germplasms and technology related to rice processing for HMR (home meal replacement), Project No.: PJ 0138882020), Republic of Korea.

Declarations

Conflict of interest The authors declare that they have no conflict of interests.

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