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Effect of tempering on the milling quality, pasting properties and sensory attributes of two Uruguayan long-grain rice varieties☆

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ABSTRACT

After harvesting, rice must be dried to a moisture content (MC) of around 13 % for safe storage. Drying may affect rice quality due to the formation of fissures that lead to the breakage of the kernels during milling, reducing the head rice yield (HRY). Tempering holds the kernels at the drying temperature between drying passes, reducing fissures formation. However, the exposure of rice to the drying temperature for longer periods (compared to continuous drying), may affect the sensory attributes. The aim of the present research was to study the impact of drying on the milling quality, pasting properties and sensory attributes of two Uruguayan long-grain rice varieties (Merin and Guri). To this purpose, samples were dried using different drying temperatures and tempering periods. Samples dried under very mild conditions (20 °C) were used as control. The results showed that when sufficient temperings were applied (one-hour tempering every 2 % MC reduction), it was possible to dry both varieties without reducing the HRY, using air at 55 °C and 13 % relative humidity. However, this treatment increased all the measured pasting properties of Merin and the setback of Guri, which was reflected in some sensory attributes. Reducing the amount of temperings reduced the HRY, with Merin being more affected than Guri. In conclusion, Merin was more sensitive to the drying conditions than Guri, confirming the need of specific drying programs for each variety. This would allow defining the drying conditions depending on the variety and the milling quality and sensory attributes sought.

1. Introduction

Rice is a staple food all around the world. Water is one of its main components and the percentage of water in the kernels is known as the moisture content (MC). Rice is usually harvested with a MC of around 20 % or higher and should be dried to 13 % or less for safe storage. During the harvest season, large amounts of rough rice arrive at the industrial drying plants and must be dried in a short period of time to avoid spoilage.

Traditionally, the main quality parameter used to evaluate rice drying has been the head rice yield (HRY), which is defined as the mass percentage of rough rice that remains as head rice (kernels that are at least three-fourth of its original length) after milling (Aquerreta et al., 2007). During drying, water evaporates at the surface of the kernel, while the interior remains more humid. This generates a MC gradient, leading to tensions that could cause fissures. Fissured kernels are more prone to breaking during milling (Cnossen et al., 2003). Therefore, severe drying conditions increase the drying rate but, in contrast, may reduce the HRY.

Tempering is a common practice in industrial drying that helps reduce the MC gradient formed inside the kernels (Kumar et al., 2014). It consists of holding the rice at the drying temperature for a certain period between drying passes. This procedure, on the one hand prevents fissuring, increasing the HRY, but on the other hand, increases the duration of the rice drying process. Additionally, it implies keeping the rough rice at the drying temperature for longer periods (compared to continuous drying), which may affect the cooking characteristics (Dillahunty et al., 2001).

The cooking properties of rice, which include a broad group of sensory attributes of cooked rice related to texture, appearance and mouthfeel, represent an important aspect of rice quality. Certain markets demand specific cooking properties and are willing to pay more for

☆ ***Glossary***: MC: Moisture Content; HRY: Head Rice Yield; T: Temperature; RH: Relative Humidity; DOM: Degree of Milling

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rice that meets them (Unnevehr et al., 1992). Some cooking properties could be related to the pasting properties of rice, which refer to the viscosity response of rice starch when mixed with water and subject to a heating program.

Several authors studied the impact of the drying conditions and methods on the viscosity profile of rice (pasting properties) and the related cooking properties. Ondier et al. (2013) found that increasing the drying temperature increased the peak and final viscosities of three rice cultivars dried in a fluidized bed drier at pilot scale. This was related to an increase in cooked rice cohesiveness. On the contrary, Wiset et al. (2005) found that increasing the drying temperature decreased the peak viscosity and breakdown. These seemingly contradictory results could be due to differences in the drying temperatures and rice varieties used, among others. The exposure duration to the drying temperature could also impact the results. Dillahunty et al. (2001) found that increasing the exposure duration to high drying air temperatures (70–92 °C) reduced the peak viscosity, breakdown and final viscosity.

Color could also be affected by the drying conditions. Inprasit and Noomhorm (2001) observed that increasing the drying temperature (over 60 °C) and the exposure duration affected rice color of a long grain fragrant rice. Similar results were found by other authors using different varieties of rice (Wiset et al., 2005; Dillahunty et al., 2001), probably due to Maillard and caramelization reactions, both associated with elevated temperatures.

Although the literature shows a trend in the quality parameters and physicochemical properties of rice depending on the drying conditions, these results are dependent on the rice variety, the drying method, the exposure duration and the interaction between these factors. Therefore, further research is needed to better understand the variables involved in the drying process and their impact on rice quality. This would allow the design of specific drying programs for each rice variety and drying method, optimizing the process based on maximizing the HRY while meeting buyer's expectations.

Considering the above, the aim of the present research work was to study the impact of drying processing parameters (drying air temperature, relative humidity and tempering periods) on the milling quality, pasting properties, raw rice appearance and cooked sensory quality of two long-grain rice varieties. To this purpose, the HRY, color and viscosity profile were determined in samples dried using different drying conditions and tempering periods. The results were analyzed for each variety and both varieties were compared. Additionally, sensory analysis was performed on some selected samples.

2. Materials and methods

2.1. Rice samples

Two long-grain Uruguayan rice varieties, Merin (M) and Guri (G), were harvested during the 2022/2023 season, from a single producer, in the south-east region. These varieties were chosen because they are the two most widely planted in the country.

The average harvest moisture contents (wet basis) were 18 % and 19 %, respectively. Rice samples were homogenized and stored in a refrigerated container (Multicontainer, Uruguay) at 4 °C until use, to prevent deterioration. Samples were stored between 2 and 5 months, removing them from the chamber as it was needed to perform the experiments. Before each experiment, the samples were left in sealed bags at room temperature for at least two hours.

2.2. Characterization of rice

The MC was determined with a near infrared (NIR) spectrophotometer (IM 9500, Perten, United States). The ether extract was determined using the Randall extraction method, according to the ISO standard 11,085:2015 (ISO, 2015). The protein content was determined using the Kjeldahl method, based on the ISO standard 20,483:2013 (ISO, 2013). Both analyses were performed in duplicate on brown rice.

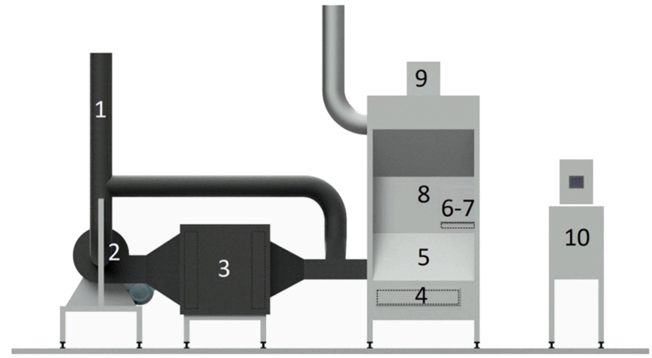

Fig. 1. Schematic of the drying equipment.
1-air entrance; 2-blower; 3- water condenser; 4-resistors; 5-vapor injector; 6-velocity sensor; 7-air temperature and relative humidity sensor; 8-drying chamber; 9-load cell; 10-PLC.

Length, width, and thickness of the individual kernels of brown and white rice were determined using an image analyzer (Image S, Selgron, Brazil). The amylose content of white rice of both varieties (Merin and Guri) was determined based on the ISO standard 6647–1:2020 (ISO, 2020).

The protein and fat content of white rice samples were measured using a NIR spectrophotometer (IM 9500, Perten, United States). A different lot of Merin and Guri were used for these analyses, since there was not enough sample of the original lots.

2.3. Drying

2.3.1. Equipment

Rice was dried in a laboratory drying equipment specially designed and built for this purpose (Urumáquinas, Uruguay). Fig. 1 shows a schematic of the drying system used. The ambient air entered the system with the aid of a blower, which controlled the air velocity. A condenser and a vapor injector regulated the air humidity and resistors regulated the air temperature. A temperature (T) and relative humidity (RH) sensor together with an air velocity sensor were installed just before the drying chamber. Air conditions were set and controlled with the aid of a programmable logic controller (Secoin, Uruguay). It allowed controlling the air T, RH, and velocity, with a precision of ± 0.6 °C, ± 2.6 % and ± 0.02 m/s, respectively. The equipment also monitored the grain temperature of the sample using a thermocouple.

The drying chamber had a basket in which the paddy rice was spread in a thin layer of 1 centimeter high (approximately 500 g). The hot air passed through the rice, and every 3 mins the fixed bed of rice was weighed with the aid of a load cell integrated to the system. The moisture content at each time was calculated using the initial MC and the weight difference between the initial paddy rice weight and the weight at that time. The dryer was configured to stop at 13±0.5 % MC.

Temperings were performed by putting the paddy rice in sealed plastic bags inside the drying basket. This way, the rice did not lose temperature but also did not dry.

Preliminary experiments showed that 1-hour tempering was the minimum time needed to minimize kernel's breakage after drying (data not shown). The rice was dried for 4 to 35 mins (depending on the experiment), before each 1-hour tempering.

2.3.2. Preliminary experiments

For all the experiments, the drying air velocity remained constant at 0.40 m/s, while the RH and T varied. Three different combinations of RH and T were chosen to study the effect of the drying air conditions on rice quality. Temperatures were chosen considering the temperature range used in the industry. Due to limitations of the drying equipment, the air

Table 1
Drying conditions for the preliminary experiments.

Condition	T (°C)	HR (%)
P1	38	30
P2	44	22
P3	55	13

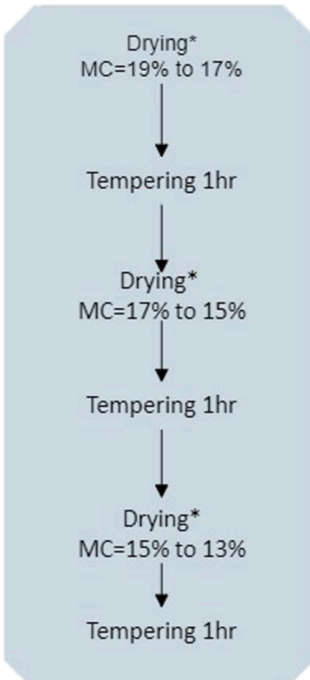

Fig. 2. Preliminary experiments: Drying program.
* Drying air conditions: P1: T1=38 °C, RH1=30 %; P2: T2=44 °C, RH2=22 %; P3: T3=55 °C, RH3=13 %. MC: grain moisture content.

humidity could not reach values under 0.012 kg water/kg dry air. The industrial dryers use air with very low water content, so this value of 0.012 kg water/kg dry air was used to determine the RH at each air T, with the aid of a psychrometric chart. Table 1 summarizes the three drying conditions set for the experiments: P1 (T1=38 °C, RH1=30 %), P2 (T2=44 °C, RH2=22 %) and P3 (T3=55 °C, RH3=13 %).

A one-hour tempering was set every 2 percentual points of MC reduction, as shown in Fig. 2. The intermittent drying, combining tempering and drying cycles, continued until the samples reached a final MC of 13 ± 0.5 %.

Control samples (C0) were dried using very mild drying conditions in a chamber (Alfa-Laval Gruppe, Germany) at 20.5 °C and 60 % RH until a final MC of 13 ± 0.5 %. This drying air condition produces minimum fissuring and thus, minimal HRY reduction (Schluterman & Siebenmorgen, 2007; Fan et al., 2000). These samples aimed to provide a reference (minimal impact of the drying process on the batches under study) for subsequent comparison of results. All experiments were performed in duplicate.

2.3.3. *Effect of tempering*

The preliminary experiments results showed the relevance of tempering during drying. Therefore, a new experimental design was developed varying the tempering frequency, to better understand the effect of tempering in rice drying. The new operational conditions were: C1 -samples dried with a single tempering period at the end of drying, C2 - samples dried with two tempering periods (at 15 % MC and at the end of drying), and C3 - samples dried with three tempering periods (at 17 % MC, 15 %MC, and at the end of drying). Fig. 3 summarizes these conditions.

Temperature, relative humidity and air velocity were kept constant (55 °C, 13 % and 0,40m/s, respectively). Control samples (C0), dried as described in the previous section, were used to compare the drying treatments. All experiments were performed in duplicate.

2.4. *Milling*

2.4.1. *One step milling: head rice yield*

After drying, samples were kept at room temperature for at least 72 h. Then, the head rice yield (HRY) was determined. Before milling, each sample was cleaned with a grain cleaner (Grainman, USA). Then, 100*g*

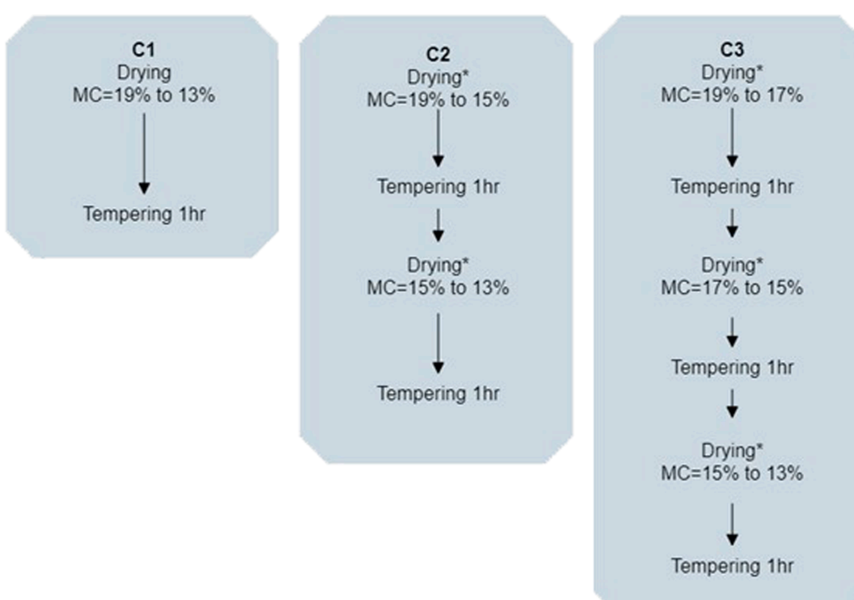

Fig. 3. Effect of tempering: Drying program.
* Drying air conditions: T = 55 °C, RH=13 %. MC: grain moisture content.

of clean paddy rice were hulled using a paddy husker (THU35B, Satake, Japan). The dehulled rice samples were milled with a laboratory rice polisher (TM05C, Satake, Japan) to a degree of milling (DOM) of 100 ± 2, measured with a milling meter (MM1D, Satake, Japan). After milling, the broken kernels were quantified using an Image Analyzer (Image 5, Selgron, Brazil). The results were expressed as grams of head rice obtained from 100*g* of rough rice.

2.4.2. Two-steps milling

The procedure aims to resemble the industrial milling process used to obtain commercial rice. Pasting viscosity profiles and sensory analyses were performed using rice obtained with this milling procedure.

A sample of 200*g* of clean rice with MC=13,0 ± 0.5 % was hulled using a paddy husker (THU35B, Satake, Thailand). Then, it was classified using a trieur (TWL05C(3)-T, Satake, Japan) with a 1,6 mm cylindric screen for 5 mins. Thereafter, the sample was subdued to a double polishing process: abrasion (TM05C, Satake, Thailand) until reaching a DOM of 55 ± 3 and friction (60–220–50-DT, McGill, USA) until reaching a DOM of 90 ± 3, both measured with a colorimeter (MM1D, Satake, Japan). Broken kernels were separated using a trieur (TWL05C(3)-T, Satake, Thailand) with a special sieve and an inclination of the trieur container of 15° counterclockwise. Afterwards, the white rice entered an image analyzer (MV15, MachVision, Argentina) to determine the percentage of defective grains (chalky, green, peck, broken). Finally, the defective kernels were separated by manual sorting.

2.5. Color and color difference

Color was determined in the Hunter Lab color scale, using a colorimeter (LabScan XE, Hunterlab, USA). It uses filters to decompose the reflected color in a tridimensional scale: L*, a, b,* where L corresponds to lightness, a is the red/green coordinate and b the yellow/blue coordinate. The rice samples were analyzed using a clean glass sample cup with a capacity of 70*g*.

The color difference (ΔE) was used to assess whether differences in color between samples were perceptible to the human eye, considering that an unexperienced standard observer notices a color difference when ΔE between samples is higher than 2 (Mokrzycki & Tatol, 2011). The following equation was used:

$$\Delta E = \sqrt{\left((\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right)} \quad (1)$$

where ΔL is the difference in brightness between two samples and Δa and Δb are the differences in the color coordinates a and b, respectively.

2.6. Pasting viscosity profiles

The pasting viscosity profiles were determined using a Rapid Visco Analyzer (RVA 4500, Perten, USA). To this end, the MC of the samples was measured based on the International Standard Method 44–15.02 (AACC, 1999a). Briefly, 20*g* of rice was ground in an ultracentrifugal mill (ZM 200, Retsch, Germany) using a 0.5 mm sieve. Then, 3 g of sample were dried in a forced-air circulation oven (UN30, Memmert, Germany). The water content was calculated gravimetrically and was expressed as % MC (g of water/100 g of sample). The amount of sample and the volume of water used for each analysis were calculated based on the International Standard Method 61–02.01 (AACC, 1999b). This method describes the procedure to obtain the pasting viscosity profile for a rice flour – water mixture using an RVA. The process has five stages: (1) hold at 50 °C for 1 min; (2) heat to 95 °C in 3.75 min.; (3) hold at 95 °C for 2.5 min; (4) cool down to 50 °C in 3.85 min.; (5) hold for 1.4 min. The viscosity profiles were recorded in centipoise (1 RVA unit = 12 cP), and the following viscosity values were extracted: *peak viscosity* (maximum viscosity developed short after finalizing the heat cycle); *breakdown* (difference between maximum viscosity and minimum viscosity); *setback* (difference between final viscosity and maximum viscosity) (Likitwattanasade & Hongsprabhas, 2010). Analyses were performed in duplicate.

Table 2
Sensory attributes used to characterize rice-cooked samples.

Attribute	Definition	Scale (anchor words, from left to right)
Visual appearance		
Integrity	Overall condition of the grains	Split ends - Intact
Glossiness	Degree to which sample is shiny	Dull - Shiny
Surface roughness	Degree of roughness on the surface of the grains	Smooth - Rough
Visual stickiness	Degree to which kernels stick together	Not sticky - Sticky
Texture to the touch		
Stickiness	Force required to separate the fingers after compressing the sample between the thumb and index fingers	Low (little force) - High (a lot of force)
Elasticity	Degree to which the grain returns to its original shape after partial compression between the fingers	Nule or little elastic - Very elastic
Texture in the mouth		
Hardness	Force required to compress the sample in the first mastication	Soft - Hard
Roughness	Irregularities on the surface of the product before chewing	Smooth - Rough

2.7. Descriptive sensory analysis

Sensory characterization of cooked rice samples was conducted through a descriptive sensory analysis by semi-trained panellists. Analysis was conducted at Latitud LATU Foundation (Montevideo, Uruguay), with nine semi-trained panellists, each with over 300 h of experience evaluating rice varieties. Each rice sample (300 g) was cooked in an electronic rice cooker (SR-W18AG, Panasonic, India) with a 1:1.5 rice: water mass ratio. Immediately after cooking, 30 gr of each sample was placed in a glass cup and covered with a plastic lid. Samples were held in an oven, at 60±2 °C until sensory analysis. Each of the four cooked rice samples was randomly presented to the panellists, one after another. To describe the rice samples, eight sensory attributes were selected: four visual, two tactile, and two related to mouthfeel. These attributes were chosen based on Rodriguez-Arzuaga et al. (2015) and on previous analyses on samples of same type (long-grain rice variety). Table 2 shows the attributes, their definitions and rating scales. Intensities of attributes were evaluated on 10-point numerical scales.

2.8. Data analysis

All experiments were performed in duplicate. The data were analyzed using Student's *t*-test with a significance level (α) of 0.05 when two varieties or drying conditions were implied. When more than two conditions were compared, analysis of variance (ANOVA) with a significance level (α) of 0,05 was applied. Tukey test with a significance level (α) of 0.05 was used to identify samples with significant differences. The data were subjected to a data reduction procedure using principal component analysis (PCA). To determine the relationship between sensory attributes and rice samples, a PCA was also carried out. Statistical software JMP15 (SAS Institute Inc., USA) was used for all the analyses.

3. Results and discussion

3.1. Characterization of the rice varieties

Table 3 describes the physical dimensions (length, width and thickness), shape (length/width ratio and sphericity) and chemical composition of brown and white rice samples of Merin and Guri varieties. The

Table 3
Characterization parameters of the lots of Merin and Guri varieties used.

		Length (mm)	Width (mm)	Thickness (mm)	Length/Width	Protein (%)	Fat (%)	Amilose (%)
Brown	**Merin**	7.24±0.03 [a]	2.15±0.01 [a]	1.82±0.01 [a]	3.38±0.03 [a]	8.6 ± 0.1 [a]	2.11±0.11 [a]	–
	Guri	7.46±0.02 [b]	2.11±0.01 [b]	1.81±0.00 [a]	3.54±0.02 [b]	8.8 ± 0.1 [a]	1.91±0.05 [a]	–
White	**Merin**	6.66±0.08 [a]	2.11±0.01 [a]	1.75±0.01 [a]	3.17±0.01 [a]	8.5 ± 1.19*	0.41±0.13*	23.9 ± 1.6 [a]
	Guri	6.87±0.02 [b]	2.07±0.00 [b]	1.73±0.01 [b]	3.32±0.02 [b]	8.0 ± 1.24*	0.45±0.17*	24.5 ± 0.03 [a]

Each value is the average of two repetitions ± 2 std.dev., except for Length/Width, where the propagation error was calculated using the error of each parameter. Different characters in a column indicate significant differences between varieties. *The lots used to determine protein and fat of white rice (both varieties) were different from those used for the rest of the analyses.

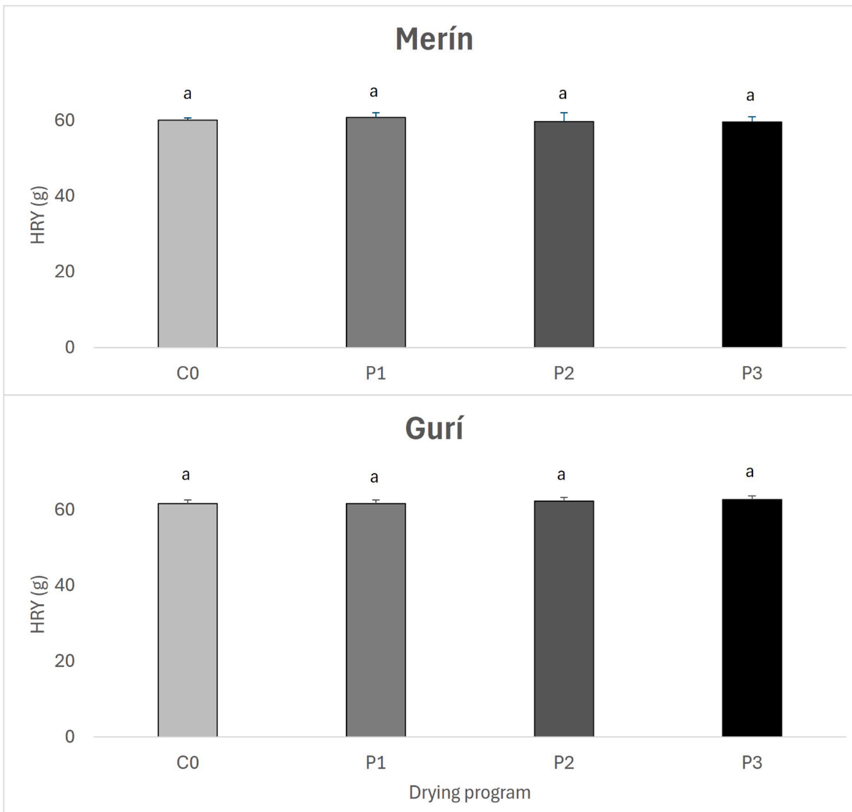

Fig. 4. Head Rice Yield (HRY) (g/100*g* paddy) of samples dried under different drying air conditions.
* Each bar represents the average of two repetitions and the error bar represents ± 2 std.dev. The same characters indicate no significant differences among samples. C0: mild drying at drying air $T = 20.5$ °C and RH= 60 %, P1: T1=38 °C, RH1=30 %; P2: T2=44 °C, RH2=22 %; P3: T3=55 °C, RH3=13 %.

comparison between both varieties showed significant differences in the length, width and length/width ratio. Although both are long-grain varieties, Merin is shorter and wider than Guri. Therefore, Merin's length/width ratio is smaller. Regarding the chemical composition, there are no significant differences in the proteins, fat and amylose content between them.

3.2. Preliminary experiments

Preliminary experiments were carried out to evaluate the impact of the drying air conditions on rice HRY. Fig. 4 presents the results obtained. ANOVA showed that neither of the two varieties had significant differences among samples, regardless of the drying air conditions. This was probably due to the tempering periods, which allowed the MC gradient formed during drying to subside. Schluterman and Siebenmorgen (2007) reduced Wells rice MC up to 6 percentage points using air at 60 °C and 17 % RH without reducing the HRY, given sufficient tempering. Under the same conditions, when no tempering was applied, the HRY reduction was >10 %. Cnossen et al. (2001) found similar results using Bengal rice. In the present study, it was possible to completely dry rice, from 19 % to 13 % MC, at 55 °C and 13 % RH without reducing the HRY, provided that sufficient temperings were applied. This was an important finding, since the latter drying condition applied (55 °C, 13 % RH) was quite severe considering that the rice reached the air temperature shortly after the drying started.

In view of these results, the drying condition of 55 °C and 13 % RH was chosen to evaluate the effect of tempering on the quality of the two long-grain rice varieties under study. This condition was chosen because higher air temperatures are related to shorter drying times. The drying duration is crucial during the harvest season, when all the rice harvested must be dried to a secure MC in a short period of time to avoid spoilage. Tempering increases drying duration, so reducing the number of tempering periods during drying, without reducing the HRY, is of interest to increase the drying rate. Therefore, the effect of tempering was studied in more detail, with the aim of reducing the number of tempering stages during the entire drying process without decreasing the HRY. In addition, the effect of tempering on the pasting properties and sensory attributes of rice were also studied.

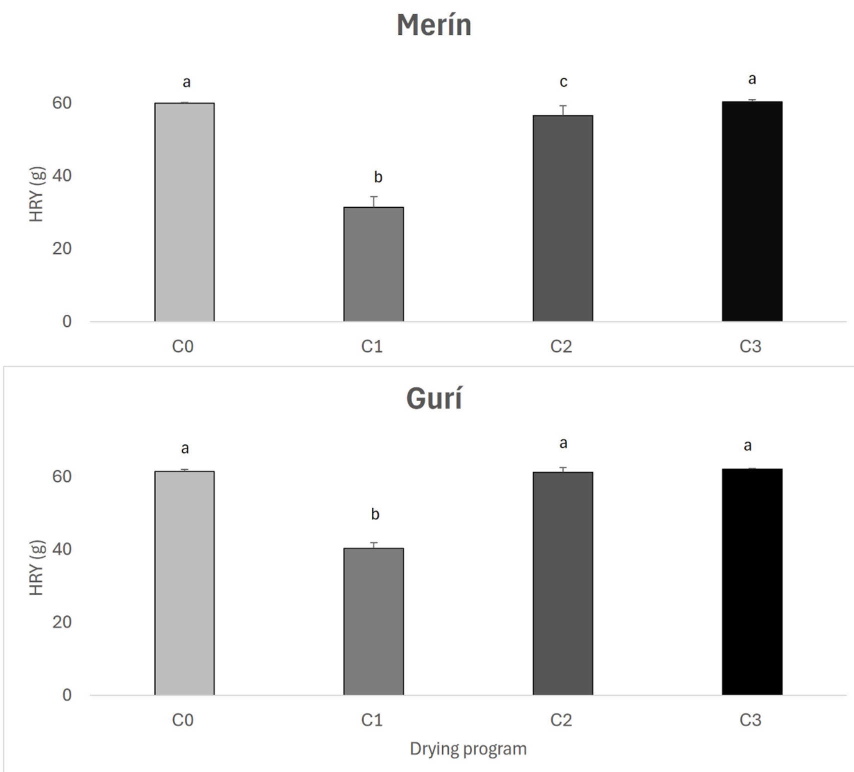

Fig. 5. Head Rice Yield (HRY) (g/100*g* paddy) of samples dried with different tempering periods.
* Each bar represents the average of two repetitions and the error bar represents ± 2 std.dev. For each variety, different characters indicate significant differences among samples. C0: mild drying at drying air $T = 20.5$ °C and RH= 60 %, C1-C3 drying air $T = 55$ °C, RH= 13 % and temperings as shown in Fig. 3.

3.3. Effect of tempering

To evaluate the effect of tempering, drying of both varieties was carried out varying the number of tempering periods (see Fig. 3). Fig. 5 shows the HRY results for these experiments and the control samples (C0), dried under mild conditions in a controlled temperature and relative humidity chamber. ANOVA demonstrated that there were significant differences among the drying treatments. The Tukey significance test showed that applying 1-hour tempering every 2 % MC dried, avoided HRY reduction in both varieties. When the amount of temperings during drying was reduced, the HRY decreased, for both varieties.

Assar et al. (2016) found that the MC gradient inside a kernel was directly related to the tempering time. The same results were informed by Ondier et al. (2012) for long and medium-grain rice dried in a lab-scale dryer under controlled drying air conditions. In the present study, reducing by >2 % the grain MC in a single drying pass probably induced more pronounced MC gradients. This increases the tensions inside the kernels and may lead to fissures formation (Dong et al., 2010; Sharma & Kunze, 1982).

Comparing both varieties, it can be concluded that the response to drying conditions differed between them. Guri could be dried with no intermediate temperings to a MC of 15 % without affecting the HRY. However, for Merin, all the intermediate temperings were necessary to avoid HRY reduction.

The influence of the physicochemical composition and kernels dimensions on the susceptibility to fissuring was pointed out by several authors (Buggenhout et al., 2013). In this regard, the kernel's dimensions could explain the difference between both varieties, making Merin kernels more susceptible to breakage. Fan et al. (2000) studied the HRY of two long-grain (Cypress and Keybonnet) and one medium-grain (Bengal) rice varieties exposed to different drying conditions. They found that Bengal, with a thick kernel shape, was more prone to fissuring than the other two varieties. Odek et al. (2018) studied the impact of kernel thickness on rice fissuring during drying. They concluded that the fissured kernels' percentage increased as the kernels' thickness increased. In the present study, thickness was not significantly different between both varieties, but length, width and shape were (see Table 3). Merin was wider and shorter than Guri and had a smaller length/width ratio, which could make it more susceptible to fissure formation. Guri, being a slenderer variety, is expected to allow a higher water-migration rate inside the kernels, preventing pronounced MC gradients. The latter is crucial for a variety to be more resistant to severe drying processing conditions.

The chemical composition could also influence a variety's response to drying (Maldaner et al., 2021). In the present research, there were no significant differences in the protein, fat, amylose and amilopectin contents between both varieties (see Table 3). However, the proteins composition and arrangement inside the kernels could be different (Chrastil & Zarins, 1992), influencing the response to drying. One hypothesis is that the proteins of the Guri variety have a more compact packing around the starch granules than Merin, making the granules more resistant to breakage. The kernels microstructure could also be different in both varieties, affecting the mechanical properties and response to drying (Karim et al., 2018). This should be corroborated by subjecting both varieties to scanning electron microscopy (SEM).

In industrial drying, all long-grain varieties are dried using the same drying program. However, these findings suggest that different varieties respond differently to the drying process. Guri could be dried at 55 °C until a MC of 15 % without intermediate temperings, while Merin needed temperings every 2 % MC reduction to maintain the HRY (compared to the control samples). Therefore, the varieties should be studied individually, developing industrial drying programs based on each variety response. The implementation of customized drying programs at a commercial scale is expected to improve HRY and eventually

Table 4
Color space coordinates (L, a, b) and color difference between the drying treatments and the control.

	L	a	b	ΔE
Merin				
C1	76.0 ± 0.3 [a]	1.35 ± 0.14 [a]	17.13 ± 0.10 [a]	1.2 ± 0.3
C2	76.0 ± 2.6 [a]	1.13 ± 0.82 [a]	16.91 ± 1.76 [a]	1.2 ± 0.7
C3	75.4 ± 1.3 [a]	1.42 ± 0.41 [a]	17.17 ± 0.83 [a]	1.8 ± 1.5
Guri				
C1	75.4 ± 0.5 [a]	1.14 ± 0.25 [a]	16.72 ± 0.17 [a]	1.1 ± 0.5
C2	74.7 ± 0.6 [b]	1.26 ± 0.20 [a]	16.82 ± 0.71 [a]	1.9 ± 0.9
C3	76.2 ± 0.9 [c]	1.04 ± 0.08 [a]	16.85 ± 0.10 [a]	1.0 ± 0.1

Each value is the average of two repetitions ± 2 std.dev. For each variety, different characters indicate significant differences among samples. C1-C3 drying air $T = 55$ °C, RH= 13 % and temperings as shown in Fig. 3.

reduce drying duration of the drying process.

Color is another rice quality parameter that could be affected by temperature and exposure duration (Ambardekar & Siebenmorgen., 2012). Several researchers related rice yellowing with exposure to high temperatures (Belefant-Miller et al., 2005; Dillahunty et al., 2001; Soponronnarit et al., 1998). The main cause for color changes in rice was attributed to Maillard reactions between the carbonyl group in starch reducing sugars and the amino group in protein aminoacids (Liu et al., 2022). Table 4 presents the results for the L, a and b coordinates and the color difference (ΔE) for the different drying conditions. The color difference, a parameter used to compare the color of two samples, was calculated between each drying treatment and the control (C0) (Mokrzycki & Tatol, 2011). Results, presented in Table 4, showed that all the ΔE values were lower than 2. This means that an observer would not be able to perceive the color difference between the samples (Martin, 2015; Mokrzycki & Tatol, 2011). Therefore, it can be concluded that the different drying treatments did not affect the color of rice in a way that was perceptible, for either of the two rice varieties studied.

The viscosity profiles of Merin and Guri for all the drying treatments were plotted in Fig. 6 (only one profile was plotted for each condition, to facilitate visualization). Guri's profiles were almost superimposed, except for the setback of the control samples. However, Merin showed quite a different behavior, presenting relevant differences among the profiles. An ANOVA test was conducted with the values of peak viscosity, breakdown and setback of both varieties, to determine whether the observed differences were significant. The results are shown in Table 5. Merin had significant differences in all three viscosity parameters. The Tukey test showed that, as the amount of temperings during drying increased, the peak viscosity and breakdown also tended to increase. This could be related to the time of exposure of rice to a high temperature, since an increase in the tempering periods increases the time of exposure of the rice kernels to the drying temperature.

Table 5
Peak viscosity, breakdown and setback for Merin and Guri rice subjected to different drying treatments.

	Peak	Breakdown	Setback
Merin			
C0	1886 ± 37[a]	206 ± 13[a]	1297 ± 10[a]
C1	1994 ± 24[b]	233 ± 13[b]	1253 ± 52[a,b]
C2	2120 ± 7[c]	267 ± 6[c]	1193 ± 10[b]
C3	2086 ± 55[c]	308 ± 6[d]	1371 ± 28[c]
Guri			
C0	2730 ± 195[a]	552 ± 55[a]	1731 ± 3[a]
C1	2624 ± 11[a]	518 ± 3[a]	1448 ± 4[b]
C2	2703 ± 42[a]	557 ± 45[a]	1465 ± 68[b]
C3	2635 ± 127[a]	520 ± 8[a]	1501 ± 66[b]

For each variety, different characters indicate significant differences among samples.
Each value is the average of two repetitions ± 2 std.dev.

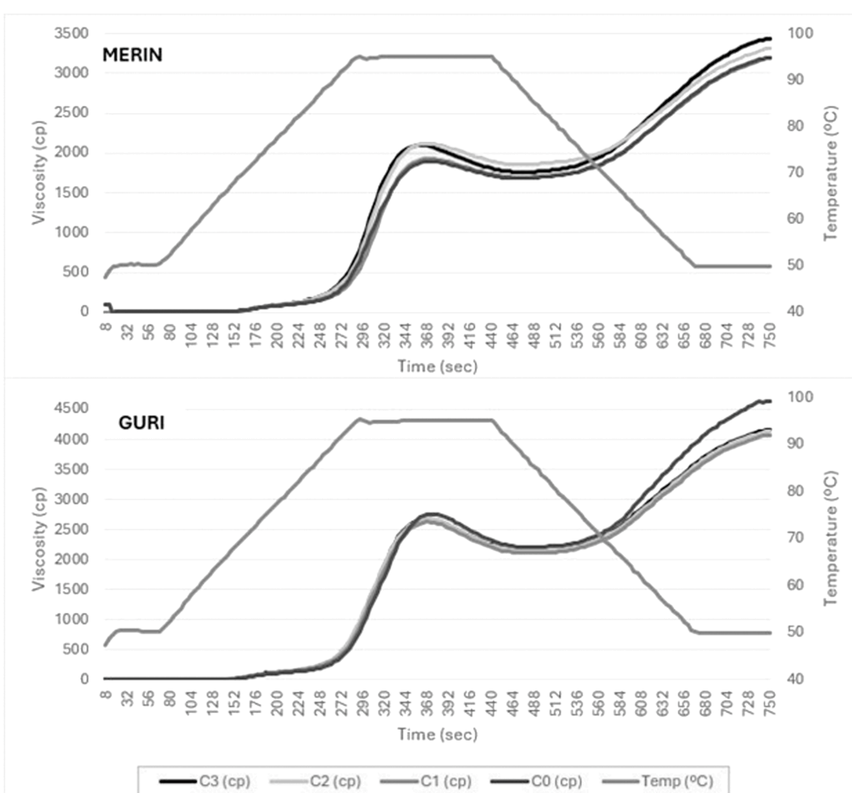

Fig. 6. Viscosity profiles of Merin and Guri rice samples dried under different drying conditions.
C0: mild drying at drying air $T = 20.5$ °C and RH= 60 %, C1-C3: drying air $T = 55$ °C, RH= 13 % and temperings as shown in Fig. 3.

Exposure of rice to high temperatures induces changes in the chemical composition and physicochemical properties of the kernels. This was extensively studied in artificial rice ageing, a process in which rice is subjected to high temperatures to intentionally change its pasting and cooking properties. The extent of the changes induced depend on the temperature and duration of the process. Changes of the starch, proteins and lipids affect the rice cooking properties (Zhou et al., 2015). One of the main changes occurs in the proteins that encase the starch granules. Proteins are suggested to be the main responsible for the variations in the pasting properties (Zhou et al., 2003b; Teo et al., 2000). At high temperatures, proteins lose their tridimensional structure, oxidation is favored, and they reassociate forming larger molecules linked by disulfide bridges (Chrastil & Zarins, 1992). This structural change in the starch granule-associated proteins makes starch granules more resistant to water migration during cooking. As the amount of bonds increase, together with an increase in the strength of micelle binding of starch, there is an inhibition of swelling of starch granules and the leaching, particularly of amylose, decrease (Zhou et al., 2003b; Zhou et at., 2002).

These chemical changes directly impact the pasting properties of rice. Peak viscosity and breakdown are the most sensitive indices, but the extent of the impact is dependent on the variety, temperature and duration of exposure (Zhou et al., 2015, 2002). Wiset et al. (2005) found that both peak viscosity and breakdown decreased as the drying temperature increased from 100 to 150 °C. This was probably related to the structural changes mentioned above. The inhibition of swelling of starch granules makes the rice flour paste have less friction, decreasing the peak viscosity. In addition, a decrease in the leaching of amylose chains from the granules increase the resistance to shear, decreasing the breakdown (Likitwattanasade & Hongsprabhas, 2010).

There are a few research works studying the impact of drying on the pasting properties of rice. Maldaner et al. (2021) studied the effect of intermittent drying on rice quality. They found that the time rice was held at high temperatures affected the proteins, fat and starch content of rice. This could explain the changes in the pasting properties observed in the present study for Merin as the time the rice was exposed to high temperatures increased.

Ondier et al. (2013) studied two long-grain and one medium-grain varieties and found that the drying air relative humidity did not have any significant effect on peak viscosity. However, peak viscosity increased with increasing drying air temperature (70 – 80 °C) for the three varieties. They hypothesized that at such high temperatures, the denaturation of the proteins occurs, allowing the starch granules to swell to a larger size. This is opposed to the results of Wiset et al. (2005) previously mentioned, where the peak viscosity and breakdown decreased as the drying temperature increased from 100 to 150 °C for three varieties of paddy rice. The higher temperatures used in this research work, compared to those used by Ondier et al. (2013), probably induced the formation of disulfide bridges among proteins, increasing the granules resistance. This could explain the apparently contradictory results of both studies. Graham-Acquaah and Siebenmorgen (2021) found that in addition to the individual effects of temperature and tempering on paste viscosities, there were significant interactions between them and air relative humidity. They suggested this could be a possible cause of some contradictory results found in literature.

In the present study, both peak viscosity and breakdown of Merin variety increased as the exposure duration to a high temperature increased. During drying, the temperature was moderate (55 °C) and the time of exposure was just a few hours (increasing as the amount of temperings increased). This temperature-duration combination was probably enough to induce chemical changes in the proteins, loosening their tridimensional structure, but not to rearrange the protein molecules by intermolecular disulfide bridges. This loosening of the proteins structure probably led to an increase of the swelling capacity of the starch granules, which was reflected in an increase of the peak viscosity (see Table 5). Another relevant phenomenon that is accelerated at high temperatures (below 80 °C) is the degradation of starch components due to α-amylase activity (Sari, 2021) This generates changes in the structure of the starch, making the granule more susceptible to rupture and leaching of amylose, resulting in a greater breakdown, as observed for Merin.

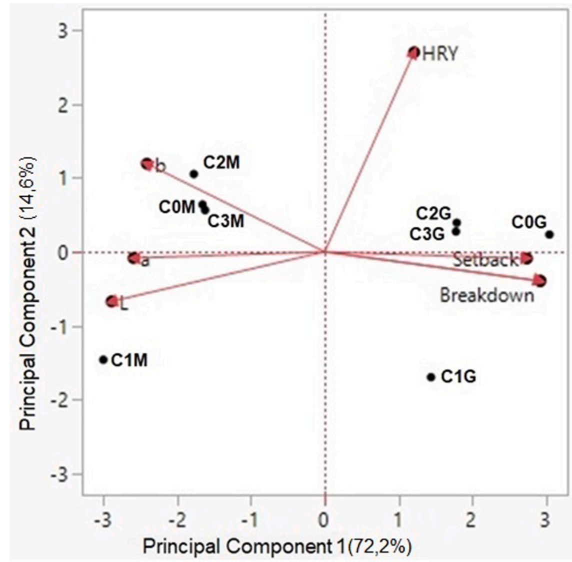

Fig. 7. Principal Component Analysis and the corresponding eigenvectors for the variables included in the analysis.
C0: mild drying at drying air $T = 20.5$ °C and RH= 60 %, C1-C3: drying air $T = 55$ °C, RH= 13 % and temperings as shown in Fig. 3. M: Merin, G:Guri.

Contrarily to Merin, Gurís peak viscosity and breakdown were not affected by drying. This confirms the results previously reported of variety dependence on the changes of the pasting properties due to temperature and time of exposure. Zhou et al. (2003a) studied three rice varieties and found that they all behaved differently during rice ageing.

A possible hypothesis to explain the different behavior of Merin and Guri, is that they have a different protein composition. The proteins surrounding the starch granules play an important role in the pasting properties (Ondier et al., 2013). If these proteins are more resistant to structural changes induced by high temperatures, the pasting properties would be less affected by temperature (as is the case of Guri). Another possible explanation is the starch composition of both varieties. Patindol et al. (2003) found that differences in the starch fine structures could explain why the pasting properties of Bengal rice were affected by the drying temperature while those of Cypress rice were not. This could also be the case for Merin and Guri.

Regarding the setback, both Merin and Guri showed significant differences depending on the drying procedure. The setback is related to the retrogradation of starch, particularly the soluble amylose chains that leach during cooking and rearrange forming a gel structure. In this study, the increase in setback observed at high temperatures for Merin can be explained by the rearrangement of leached amylose chains.

The most used quality parameter in industrial drying is the HRY. However, as discussed above, drying could also impact the pasting properties of rice. This should be taken into consideration to define the drying conditions for different rice varieties, especially if the rice will be placed in markets that demand specific cooking properties.

PCA was applied using all the variables (HRY, L, a, b, peak viscosity, breakdown and setback) to evaluate the overall effect of the drying conditions and the variety on the quality parameters of rice. Fig. 7 shows the results obtained. PC1 explained >72 % of the variance and the eigenvectors showed that it was mainly a measurement of the pasting properties: peak viscosity (0.43), breakdown (0.43) and setback (0.40), and luminosity (−0.42). PC2 explains almost 15 % of the variance and measured the HRY (0.88). The samples represented in the PC1-PC2

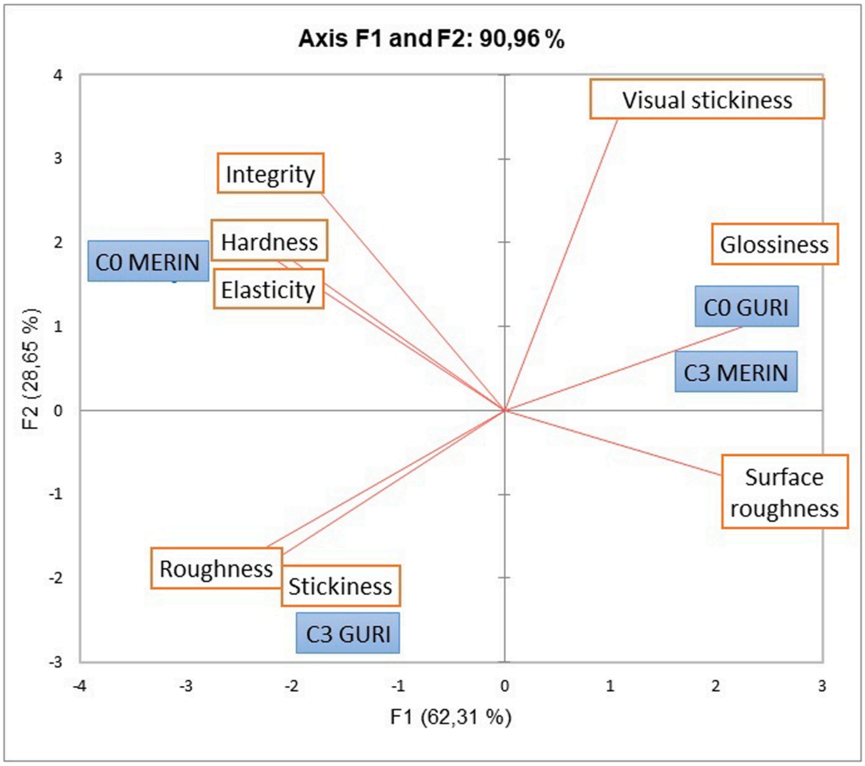

Fig. 8. Principal Component Analysis: Relationship between sensory attributes and rice samples.
C0: mild drying at drying air $T = 20.5$ °C and RH= 60 %, C1-C3: drying air $T = 55$ °C, RH= 13 % and temperings as shown in Fig. 3.

plane show that PC1 discriminated mainly by rice variety, meaning that the pasting properties were more influenced by variety than by the drying condition used. Contrarily, PC2 discriminated mainly by the drying condition. In this sense, the samples with only one tempering (C1) were separated from the rest for having a lower HRY. As shown in Fig. 7, samples C0, C2 and C3 of Guri had the highest HRY, while sample C1 of Merin (which appears in the opposite quadrant) had the lowest.

3.4. Sensory characterization

To investigate the sensory attributes of rice samples, a principal component analysis (PCA) was conducted on four samples: one control (C0) and one three tempering periods (C3) sample for each variety (Merin and Guri). These samples were selected based on their significant differences in pasting properties, which are closely linked to sensory characteristics.

Fig. 8 shows the PCA results, which revealed distinct sensory profiles among the samples. C3 MERIN exhibited characteristics more similar to C0 GURI than to its control, C0 MERIN. Both C3 MERIN and C0GURI were perceived as having more glossiness and less roughness and stickiness, opposite to C3 GURI. In contrast, C0 MERIN was characterized by higher levels of hardness, elasticity, and integrity compared to the other samples. Therefore, drying not only affected some pasting properties of both rice varieties, but also some of the sensory attributes.

4. Conclusions

The impact of drying on two Uruguayan long-grain rice varieties was studied. Drying had no impact on the HRY, provided enough tempering was applied. When the tempering periods were reduced, the HRY of both varieties decreased, being Merin more affected than Guri.

Drying also affected the pasting properties of both varieties. Increasing the tempering periods, increased the time rice was exposed to high temperatures. Therefore, the drying programs with more tempering periods affected the properties more. In this case, Merin was also more affected than Guri.

A sensory analysis of the cooked rice showed that drying caused differences in some sensory attributes, perceived by a panel of semi-trained judges.

In conclusion, the two long-grain rice varieties studied behaved differently when dried under the same conditions. This suggests that using a single drying program applied to all varieties should not be recommended. Instead, the response of each variety to drying should be studied individually. The changes that drying could induce in the kernel's composition, leading to perceived differences in the sensory attributes, should also be considered. This would allow the development of drying programs that satisfy markets that seek certain sensory characteristics in rice.

CRediT authorship contribution statement

Laura Garcia-Llobodanin: Writing – original draft, Resources, Project administration, Methodology, Formal analysis, Conceptualization. **Belén Pazos:** Methodology, Investigation, Formal analysis. **Catalina Pirotti:** Methodology, Investigation, Formal analysis. **Agostina Rossido:** Methodology, Investigation, Formal analysis. **Horacio Stirling:** Methodology, Investigation, Formal analysis. **Patricia Arcia:** Writing – original draft, Formal analysis. **Alejandra Billiris:** Writing – review & editing, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declarations

Ethics Statement: Sensory analysis was performed with a panel of judges trained for sensory evaluation of rice, in compliance with relevant laws and institutional guidelines. The judges were informed, before starting the training, about the food matrix they would evaluate and gave their free consent to participate in the panel. An informed written consent was signed by each panelist.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2025.100731.

Data availability

Data will be made available on request.

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