REVISTA DELOS DESARROLLO LOCAL SOSTENIBLE

Technological properties of aromatic Basmati rice accessions

Propriedades tecnológicas de acessos de arroz Basmati aromático

Propiedades tecnológicas de las accesiones aromáticas de arroz Basmati

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ABSTRACT

The objective of this study was to characterize the paste profile of basmati-style aromatic rice accessions. The evaluation of the 56 rice accessions by the Mean of Distances Method yielded seven groups of rice accessions based on the evaluated parameters (elongation, apparent amylose content (AAC), aroma, and paste properties). Group 1 was represented by the control sample IRGA417, a non-aromatic cultivar with the highest AAC (22.5%). The aromatic cultivars Jasmine, Empasc 104, IAC500, and Jasmine85 constituted the third group. Group 4 consisted of 41 Basmati accessions and exhibited the highest average elongation ratio (greater than 2.0). Groups 3 and 4 exhibited comparable aroma scores (2.9 and 2.8, respectively) and retrogradation processes (final viscosity: 285.37 and 291.26 RVU, and setback: 136.84 and 166.01 RVU, respectively). Group 5 was constituted with seven Basmati accessions, while groups 6 and 7 were formed with one and two Basmati accessions, respectively. Groups 5 and 6 exhibited comparable paste properties, with peak viscosities of 186.06 and 153.1 RVU, respectively, and final viscosities of 210.27 and 236.7 RVU, respectively, which were lower than those observed in the other groups. In contrast, group 7 exhibited intermediate parameters between the control IRGA417 and groups 3 and 4. Groups 3, 4, 5, 6, and 7 were classified as low amylose grains, with an AAC of 12-20%. The Basmati accession (group 4) exhibited a comparable paste profile, with a notable distinction in its high elongation, aroma, and low AAC. Consequently, these cultivars may be well accepted by consumers of aromatic rice.

Keywords: aroma evaluation, amylose content, paste properties, rice elongation, *Oryza sativa* L.

RESUMO

O objetivo deste estudo foi caracterizar o perfil de pasta de acessos de arroz aromático do tipo basmati. A avaliação dos 56 acessos de arroz pelo método da média das distâncias resultou em sete grupos de acessos de arroz com base nos parâmetros avaliados (alongamento, teor de amilose aparente (AAC), aroma e propriedades de pasta). O Grupo 1 foi representado pela amostra de controle IRGA417, uma cultivar não aromática com o maior AAC (22,5%). As cultivares aromáticas Jasmine, Empasc 104, IAC500 e Jasmine85 constituíram o terceiro grupo. O Grupo 4 consistiu de 41 acessos de Basmati e apresentou a maior taxa de alongamento médio (maior que 2,0). Os grupos 3 e 4 apresentaram escores de aroma comparáveis (2,9 e 2,8, respectivamente) e processos de retrogradação (viscosidade final: 285,37 e 291,26 RVU, e recuo: 136,84 e 166,01 RVU, respectivamente). O grupo 5 foi constituído por sete acessos de Basmati, enquanto os grupos 6 e 7 foram formados por um e dois acessos de Basmati, respectivamente. Os grupos 5 e 6 apresentaram propriedades de pasta comparáveis, com viscosidades de pico de 186,06 e 153,1 RVU, respectivamente, e viscosidades finais de 210,27 e 236,7 RVU, respectivamente, que foram menores do que as observadas nos outros grupos. Em contrapartida, o grupo 7 apresentou parâmetros intermediários entre o IRGA417 de controle e os grupos 3 e 4. Os grupos 3, 4, 5, 6 e 7 foram classificados como grãos de baixa amilose, com um AAC de 12 a 20%. O acesso Basmati (grupo 4) apresentou um perfil de pasta comparável, com uma distinção notável em seu alto alongamento, aroma e baixo AAC. Consequentemente, essas cultivares podem ser bem aceitas pelos consumidores de arroz aromático.

Palavras-chave: avaliação de aroma, teor de amilose, propriedades de pasta, alongamento do arroz, *Oryza sativa* L.

RESUMEN
El objetivo de este estudio era caracterizar el perfil de la pasta de las accesiones de arroz aromático tipo basmati. La evaluación de las 56 accesiones de arroz mediante el método de la media de las distancias dio lugar a siete grupos de accesiones de arroz basados en los parámetros evaluados (elongación, contenido aparente de amilosa (CAA), aroma y propiedades de la pasta). El grupo 1 estaba representado por la muestra de control IRGA417, un cultivar no aromático con el mayor CAA (22,5%). Los cultivares aromáticos Jasmine, Empasc 104, IAC500 y Jasmine85 constituyeron el tercer grupo. El grupo 4 estaba formado por 41 accesiones Basmati y presentaba la relación de elongación media más alta (superior a 2,0). Los grupos 3 y 4 exhibieron puntuaciones de aroma comparables (2,9 y 2,8, respectivamente) y procesos de retrogradación (viscosidad final: 285,37 y 291,26 RVU, y retroceso: 136,84 y 166,01 RVU, respectivamente). El grupo 5 se constituyó con siete accesiones Basmati, mientras que los grupos 6 y 7 se formaron con una y dos accesiones Basmati, respectivamente. Los grupos 5 y 6 presentaron propiedades de pasta comparables, con viscosidades máximas de 186,06 y 153,1 RVU, respectivamente, y viscosidades finales de 210,27 y 236,7 RVU, respectivamente, inferiores a las observadas en los otros grupos. Por el contrario, el grupo 7 exhibió parámetros intermedios entre el control IRGA417 y los grupos 3 y 4. Los grupos 3, 4, 5, 6 y 7 se clasificaron como granos de bajo contenido en amilosa, con un CAA del 12-20%. La accesión Basmati (grupo 4) exhibió un perfil de pasta comparable, con una notable distinción en su alta elongación, aroma y bajo AAC. En consecuencia, estos cultivares pueden ser bien aceptados por los consumidores de arroz aromático.

Palabras clave: evaluación del aroma, contenido de amilosa, propiedades de la pasta, alargamiento del arroz, *Oryza sativa* L.

1 INTRODUCTION

The aromatic rice (*Oryza sativa* L.) is well known worldwide for its typical aroma and attracts superior prices in many international markets. Many compounds (more than 300 volatiles) have been recognized in different aromatic and non-aromatic rice, but the characteristic aroma of the aromatic group is due to the accumulation of the volatile compound 2-acetyl-1-pyrroline (2AP) (Renuka *et al.*, 2022). In addition to the pleasant aroma, aromatic rice has long, slender grains that elongate after cooking, and has cooked grains with a dry appearance and soft texture. Aromatic rice demand is growing progressively throughout the world due to its taste, flavor, and quality. The quality of rice grain is based on grain size, nutritive value, milling quality, appearance, and other cooking characteristics (Dias *et al.*, 2022; Kaewmungkun *et al.*, 2022; Sen; Chakraborty; Kalita, 2020).

The nutritional profile of aromatic rice includes many bioactive constituents in the bran (e.g., antioxidant compounds), 7–10% protein, 1.6-3% fat, 0,9-3% fiber, 1.2-1.8% minerals, and 75−80% carbohydrate mainly in the form of starch composed of 14 – 23 g / 100 g of amylose (Dias *et al.*, 2022; Sen; Chakraborty; Kalita, 2020). Eating and cooking qualities are mostly defined by the properties of the starch (90% of milled rice) (Dias *et al.*, 2022; Kaewmungkun *et al.*, 2022). As the main component of rice, starch directly influences the cooking of the grains, then studying the behavior of starch in the formation of paste helps to determine the culinary and functional quality of rice. That is, the paste properties of the rice starch provide information about the cooking quality, relating to aspects of texture and cohesiveness (Huang *et al.*, 2020; Thakare *et al.*, 2023). The variation in the rice pasta behavior is due to the ratio of amylose (linear fraction of starch) and amylopectin (branched fraction of starch) in the rice grain. Based on many scientific reports, rice with low amylose content present a soft and sticky texture when cooked and is preferred by Northeast Asian and Japanese consumers. Instead, Latin American, Indian, and European consumers prefer grains with intermediate and high amylose amounts which present firm and loose grains after cooking (Teixeira *et al.*, 2021; Zhang *et al.*, 2021). It is also known that rice with similar amylose content may show distinct culinary characteristics since the fine structure of amylose and amylopectin influence their texture properties and pasting properties (Li *et al.*, 2019).

Therefore, the study of the physical-chemical, thermal, and paste aspects of rice starch is of prime importance in determining the quality of rice cultivars. Considering the importance of evaluating the rice paste profile, and that the aromatic rice group (derived from Basmati rice cultivar) has not yet been fully characterized in terms of its paste properties, the objective of this work was to characterize the viscoamylographic profile of accessions basmati-type aromatic rice.

2 MATERIAL AND METHODS

2.1 MATERIAL

Initially, a search was performed for aromatic Basmati accessions from the Germplasm Bank of the United States Department of Agriculture (USDA/ARS). This research was carried out on the GENESYS platform database, a global information portal on Plant Genetic Resources for Food and Agriculture (PGRFA). 115 accessions were identified and, after a request to the Embrapa Arroz e Feijão Active Germplasm Bank, 52 accessions of Basmati rice were obtained (Table 1). In addition to the Basmati rice accessions, the experiment was composed of four more controls, being the cultivar IRGA 417 (non-aromatic), and the cultivars Empasc 104, IAC 500, and Jasmine 85, as Jasmine-type aromatic samples. There was a total of 56 treatments.

The study was conducted with grains grown and harvested in the 2015-2016 harvest at Embrapa Arroz e Feijão, Experimental Field at Fazenda Palmital, in Goianira, Goiás, Brazil. The harvested grains were dried naturally until they reached 13% moisture, which was estimated with the aid of the Grainer II PM 300 (*Kett Electric Laboratory*) moisture determiner. The dried rice grains were husked and polished in a rice mill (MT 8, Suzuki).

2.2 RICE GRAIN ELONGATION MEASURE

The samples, rice 60 days after harvest, (20 whole grains) were immersed in 20 mL of distilled water for 30 minutes. Subsequently, they were cooked on an electric hot plate (Thermo Scientific HP 131220-33Q Barnstead Thermolyne), with a controlled temperature between 98 and 100 ºC, for 10 minutes (time counted after the beginning of boiling). Length measurements of raw and cooked grains were performed, with 10 measurements for each state of the grain, using a digital caliper (CD-6" C Mitutoyo Corporation). Thus, the relationship between the length of cooked grains and the length of raw grains was obtained (Martínez; Cuevas, 1989).

2.3 SENSORY ANALYSIS OF AROMA

For the rice aroma evaluation, the rice was processed on the day of analysis, 60 days after harvest. The samples (2 g of raw polished rice) were transferred to Petri dishes and 10 mL of 1.7% KOH were added. Then, the plates were covered and kept in an oven (255G Fisher) at 30 °C for 10 minutes. Immediately afterward, the plates were opened, and the aromas emitted were compared to the commercial standard (Basmati 370 cultivar, which is classified as having an intense aroma), by six trained panelists. The aroma data were recorded on a scale of scores from 1 to 4, in which score 1 refers to no aroma, score 2 mild aromas, score 3 moderately intense aroma, and score 4 intense aroma.

2.4 DETERMINATION OF APPARENT AMYLOSE CONTENT (AAC)

The rice samples (100 mg) previously ground in a knife mill (Perten Laboratory Mill 3100, country), were fully gelatinized in an alkaline solution. Then it was injected into the FIA System – Flow Injection Analysis System from Foss Tecator (FIASTar 5000, Denmark), and the absorbance of the complex formed with iodine solution was determined in a UV-Visible spectrophotometer through a "Dual-Wavelength (DDW)" digital detector at 720 nm. The AAC was calculated using a calibration curve, which was prepared with standard rice cultivars pre-selected with known amylose contents (0%, 4.18%, 11.4%, 17.03%, 23.69%) and previously determined by Gel Permeation Chromatography (SEC/GPC) (Fitzgerald; Mccouch; Hall, 2009) by IRRI (International Rice Research Institute). The analysis was performed in duplicate for each field repetition. The classification of the samples were made according to Juliano (2003), in which amylose content between 25 and 33% is classified as high, 20 to 25% as intermediate, 12 to 20% as low, 5 to 12% as very low from 0 at 4% waxy.

2.5 PASTE PROPERTIES BY RAPID VISCOSITY ANALYZER (RVA)

The evaluation of the viscosity profile of the rice samples was performed using the Rapid Viscosity Analyzer (RVA) (RVA 4, Newport Scientific, Sydney, New South Wales, Australia) using the Thermocline for Windows software (TCW 2.2). A sample suspension of ground rice grain, in the proportion of 3 g of sample to 25 mL of distilled water, corrected for 14% moisture, was subjected to the following time/temperature parameters: 50 °C for 1 minute, heating 50 °C to 95 °C at a rate of 11.84 °C/min, keeping the paste at 95 °C for 2.5 minutes and cooling to 25 °C at a rate of 11.84 °C/min, totaling 12 minutes of analysis. The samples were analyzed in triplicate and the viscosity was expressed in RVU (Rapid Visco Units).

2.6 STATISTICAL ANALYSES

The experimental design used was the 8x7 alpha lattice, with three field replications. A Cluster Analysis of treatments was performed based on the 187 variables of the RVA curve.

Then, the Distance Mean Method was used, considering a deviation of 0.8. For each RVA group, boxplots were generated with data on CAA, grain elongation, and aroma intensity.

3 RESULTS AND DISCUSSION

The characterization of the 56 rice accessions by the Mean of Distances Method regarding the evaluated parameters (elongation, AC, aroma, and paste properties), seven groups of rice accessions were obtained (Table 1). Group 1 was represented by the control sample IRGA 417, a non-aromatic cultivar, reference in quality of the long-slender class in the Brazilian market. Group 2 was composed solely of the Basmati A46 access. The aromatic cultivars Jasmine, Empasc 104, IAC 500, and Jasmine 85 formed the third group. Group 4 consisted of most Basmati accessions, totaling 41 treatments in this group. Group 5 was formed with seven Basmati accessions and groups 6 and 7 with one and two Basmati accessions, respectively (Table 1).

Table 1: List of rice genotypes: Group, Identification (ID), Common name, USDA/ARS Code BGA Code and Source.

Group	ID	Common name	USDA/ARS code	BGA code	Source
1	1	IRGA 417	IRGA 417	IRGA 417	Pakistan
2	46	Basmati	Clor12524	BGA017143	Índia
3	2	Empasc 104	Empasc 104	Empasc 104	Pakistan
3	3	IAC 500	IAC 500	IAC 500	Pakistan
3	4	Jasmine 85	PI595927	Jasmine 85	Pakistan
4	6	Basmati	PI385407	BGA018526	Pakistan
4	7	Basmati	PI385408	BGA018527	Pakistan
4	8	Basmati Sufaid	PI385415	BGA018529	Pakistan
4	9	Basmati Sufaid	PI385417	BGA018531	Pakistan
4	10	Basmati	PI385418	BGA018532	Pakistan
4	11	Basmati	PI385421	BGA018534	Pakistan
4	12	Basmati	PI385422	BGA018535	Pakistan
4	13	Basmati	PI385424	BGA018536	Pakistan
4	14	Basmati Fine	PI385428	BGA018538	Pakistan
4	15	Basmati	PI385430	BGA018540	Pakistan
4	16	Basmati	PI385436	BGA018541	Pakistan
4	17	Basmati	PI385439	BGA018542	Pakistan
4	18	Basmati	PI385440	BGA018543	Pakistan
4	19	Basmati	PI385442	BGA018545	Pakistan
4	20	Basmati	PI385443	BGA018546	Pakistan
4	21	Basmati	PI385444	BGA018547	Pakistan
4	22	Basmati	PI385446	BGA018549	Pakistan
4	23	Chak 48	PI385447	BGA018550	Pakistan
4	24	Basmati	PI385453	BGA018555	Índia
4	25	Basmati	PI385454	BGA018556	Pakistan
4	26	Basmati	PI385456	BGA018558	Pakistan
4	27	Basmati	PI385780	BGA018561	Pakistan
4	28	Basmati	PI385781	BGA018562	Pakistan

4	29	Basmati	PI385782	BGA018563	Pakistan
4	30	Basmati Surkh	PI385783	BGA018564	Pakistan
4	31	Basmati Lal	PI385785	BGA018566	Pakistan
4	32	Basmati 10	PI385786	BGA018567	Pakistan
4	33	Basmati Surkh	PI385791	BGA018568	Pakistan
4	34	Basmati	PI385806	BGA018571	Pakistan
4	35	Basmati	PI385807	BGA018572	Pakistan
4	41	Basmati No. 12	PI385416	BGA018530	Pakistan
4	42	Basmati	PI385427	BGA018537	Pakistan
4	43	Basmati	PI5816	BGA014912	Pakistan
4	45	Basmati	Clor12201	BGA016878	Índia
4	47	Basmati Medium	PI385429	BGA018539	Pakistan
4	48	Basmati	PI385441	BGA018544	Pakistan
4	49	Basmati	PI385448	BGA018551	Pakistan
4	50	Basmati	PI385455	BGA018557	Pakistan
4	51	Basmati Nahan	PI385801	BGA018569	Índia
4	52	Basmati	PI385805	BGA018570	Pakistan
4	56	Basmati C622	PI412771	BGA018699	Pakistan
5	36	Basmati Pardar	PI385809	BGA018573	Pakistan
5	37	Basmati Medium	PI385816	BGA018574	Pakistan
5	38	Basmati	PI385817	BGA018575	Pakistan
5	39	Basmati Awned	PI392125	BGA018632	Pakistan
5	40	Basmati Awned	PI392126	BGA018633	Pakistan
5	54	Basmati Awned	PI392127	BGA018634	Pakistan
5	55	Basmati Awned	PI392128	BGA018635	Pakistan
6	53	Basmati	PI385822	BGA018576	Pakistan
7	5	Basmati	PI385403	BGA018525	Pakistan
7	44	Basmati 3	Clor8982	BGA015376	Pakistan

Source: Elaborated by the authors.

3.1 GRAIN ELONGATION

During cooking, rice grains absorb water and expand in volume by increasing length or width. Grain elongation after cooking is an important trait of rice as most consumers prefer longitudinal elongation. The increase in width is not desirable, while the increase in length without an increase in girth is a desirable characteristic in high-quality premium rice (Golam; Prodhan, 2013).

In Figure 1, it is possible to verify the average elongation ratio of the different groups. The control IRGA 417 (group 1, non-aromatic pattern) presented a ratio of 1.83, and the accession Basmati A46 (group 2), 1.90. Group 3 of the Jasmine controls had an average of 1.77 and group 4 of 2.07. Groups 5, 6, and 7 showed a mean elongation of 1.67, 1.97, and 1.85, respectively. The cultivar Pusa Basmati 1121 (PB 1121) is a reference in the Basmati rice group, launched in 2003, and has a high elongation ratio (2.7) as a prominent feature (Kamath *et al.*, 2008). It is important to emphasize that in this study, group 4, constituted by the majority of

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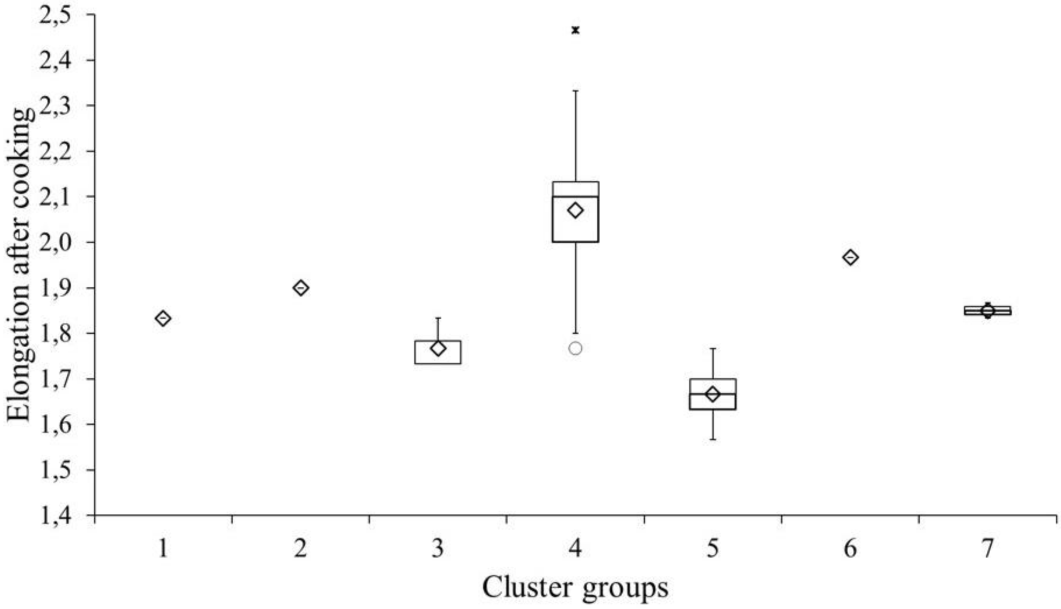
Basmati accessions, was the one that presented the highest average elongation ratio (greater than 2.0). In this group, accession A33 is found with an elongation capacity of 2.47, which is closest to the reference cultivar PB 1121.

The high elongation rate is considered a characteristic property of Basmati rice. Anatomical features, such as endosperm cells, affect grain elongation. Basmati rice has pentagonal or hexagonal cells, in contrast to long rectangular cells arranged radially in other cultivars (Golam; Prodhan, 2013; Kamath *et al.*, 2008).

Figure 1. Cluster Groups as to the ratio of rice grain elongation.



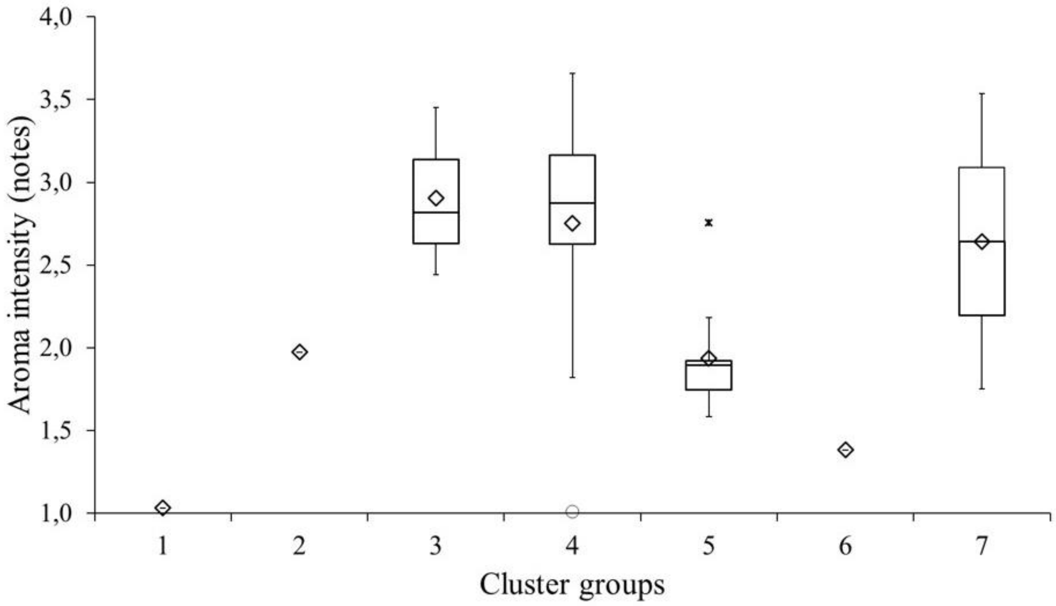
Source: Elaborated by the authors.

3.2 AROMA

The cultivar IRGA 417 presented a score of 1 (no aroma), as expected for a non-aromatic cultivar (Figure 2). The accession Basmati A46, belonging to the second group, presented a score of 2, classified as a little intense aroma. The group of Jasmine-type aromatic controls (group 3) had an average of 2.9, the highest among the seven groups. The perception of the aromas of the samples is because the aromatic rice has a characteristic odor that distinguishes it from common rice due to the volatile components released (Kaewmungkun *et al.*, 2022; Prodhan; Qingyao, 2020; Renuka *et al.*, 2022).

Among the groups of Basmati accessions studied, group 4 had an average aroma intensity of 2.8, a value such that presented by the group of Jasmine reference, with a moderately intense aroma (Figure 2). Rice aroma is an important quality trait of the Basmati grains, being a determining factor in the market price (Mahajan *et al.*, 2018; Prodhan; Qingyao, 2020). It was expected that the group of Basmati accessions would present an intense aroma (Mahajan *et al.*, 2018), which did not happen. This result can be justified by the fact that the accumulation of 2AP in aromatic rice depends on the interaction of various genetic and environmental factors, such as response to abiotic stress, response to temperature, and response to the cultivation process (Prodhan; Qingyao, 2020). Groups 5, 6, and 7 had aroma intensities of 1.9, 1.4, and 2.6, respectively (Figure 2).

Figure 2. Cluster Groups of rice in terms of aroma intensity (notes).

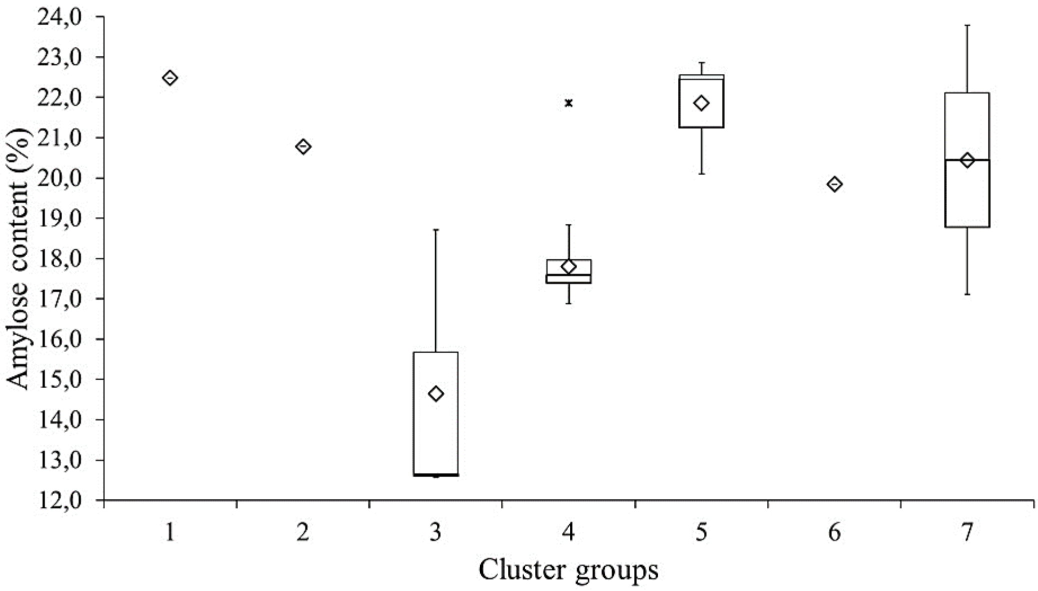


Source: Elaborated by the authors.

3.3 APPARENT AMYLOSE CONTENT (AAC)

The apparent amylose content of the different rice accessions ranged from 13 to 23% (Figure 3). According to amylose content, the rice can be categorized as waxy (1–2%) or very low amylose (2–12%), low amylose (12–20%), intermediate amylose (20–25%), or high amylose (>25%) (Govindaraju *et al.*, 2022). Thus, we have that groups 3, 4, 5, 6, and 7 can be classified as low amylose grains (Figure 3). On the other hand, the cultivar IRGA 417 (group 1) presented an AAC of 22.5%, and the accession Basmati A46 (group 2) 20.8%, both classified as intermediate amylose content. The results found are in agreement with those reported in the literature, in which aromatic rice has a low to intermediate amylose content (Bao, 2019). The AAC an affect directly the rice eating quality since rice with low amylose content has a soft and sticky texture when cooked and grains with intermediate and high amylose amounts present firm and lose grains after cooking (Teixeira *et al.*, 2021; Zhang *et al.*, 2021). The molecular sizes and the proportion of amylose chains also influence the eating quality of rice (Li *et al.*, 2016). Speaking about the nutritional value of rice, a higher amylose content in the grains is related to lower glycemic response. This happens because the structure of amylose is more resistant to enzymatic attack during digestion (Dias *et al.*, 2022; Fernandes *et al.*, 2020).

Figure 3. Cluster Groups of rice in terms of amylose content.



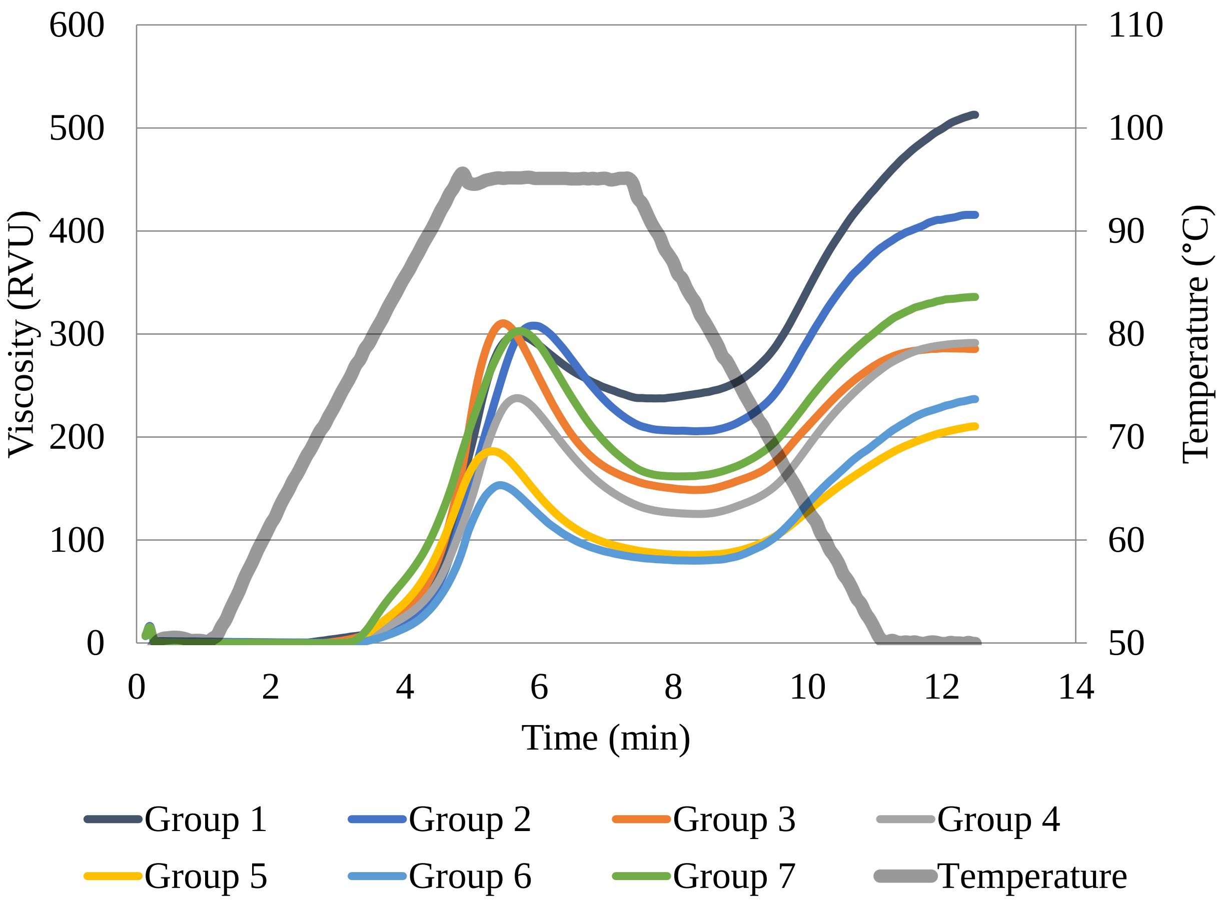
Source: Elaborated by the authors.

3.4 PASTE PROPERTIES

The RVA curves of the seven rice groups are shown in Figure 4. There are differences in the behavior of the viscoamylographic profiles of the groups. Variations in paste properties in different rice genotypes can be attributed to differences in amylose content, as well as other factors such as protein, fat, and minerals that can interact with starch to varying degrees and influence its viscoamylographic behavior (Balindong *et al.*, 2018; Thakare *et al.*, 2023).

The paste temperature ranged from 77.55 °C (in group 5) to 83.2 °C (in group 1). Paste temperature registers the beginning of the viscosity increase and can be indicative of the minimum temperature necessary to cook the rice. It was possible to observe a big difference in the viscosity peaks, ranging from 153.1 RVU (group 6) to 310.33 RVU (group 3). Peak viscosity refers to the maximum point on the curve during heating and reflects the ability of the starch granules to bind with water molecules and swell (Wani *et al.*, 2012). The starch swelling behavior of cereal is primarily a property of amylopectin molecules, but amylose acts as a diluent and granule swelling inhibitor (Govindaraju *et al.*, 2022; Li *et al.*, 2019).

Figure 4. Viscoamilographic profile of aromatic rice groups.



Source: Elaborated by the authors.

The holding viscosity corresponds to the minimum viscosity of the hot paste and ranged from 79.97 RVU (group 6) to 237.4 RVU (group 1). The breaking viscosity indicates the resistance of the starch paste to heat and shear caused by the rupture of the gelatinized granules and higher values indicate good cooking quality (Teixeira *et al.*, 2021). In this study, the breakdown viscosity ranged from 61.6 RVU (group 1) to 161.8 RVU (group 3).

The final viscosity ranged from 210.27 RVU, in group 5, to 512.7 RVU in group 1. The final viscosity is one of the most important parameters to determine the quality of the grains, as it indicates the ability of the material to form a viscous gel after heating and cooling. Higher final viscosity values indicate a firmer texture of the gel and consequently of the rice grains when cooked. High AAC is related to a high final viscosity since a starch suspension with high AAC has more swollen granules during cooling and greater viscosity and firmness (Li *et al.*, 2016; Wang *et al.*, 2015).

The setback ranged from 124.87 RVU to 305.3 RVU in groups 5 and 1, respectively. This property evaluates the behavior of starch during cooling and is generally related to the amylose content which, due to its essentially linear structure, tends to form new hydrogen bonds during cooling, releasing water molecules. The release of water molecules from the gel matrix (syneresis) can lead to rice grains' hardening (Huang *et al.*, 2020; Li *et al.*, 2016; Li *et al.*, 2021; Wani *et al.*, 2012). That is, the grain loses elasticity because the amylose rapidly retrogrades forming crystalline regions due to the association of short-chain branches (Li *et al.*, 2016). Thus, rice grains with higher amylose content, higher paste temperature, higher final viscosity, and setback tend to be harder grains after cooking. On the other hand, rice grains with low amylose content have greater swelling power and less tendency to retrograde (Teixeira *et al.*, 2021; Thakare *et al.*, 2023).

IRGA 417, used as a control and represented in group 1, showed the behavior already expected for a cultivar with intermediate amylose content, with higher values of paste temperature (83.2 ºC), minimum viscosity (237.4 RVU), final viscosity (512.7 RVU) and tendency to retrograde (305.3 RVU). Group 2, composed of the Basmati A46 accession, presented the curve with the closest behavior to the IRGA 417.

Group 3, regarding Jasmine aromatic controls, and group 4, composed of the majority of Basmati aromatic accessions, presented values close to paste temperature of 78.5 ºC and 79.95 ºC, respectively, indicating that they need the same amount of energy for the cooking. Group 4 had lower peak viscosity and lower maintenance viscosity than group 3, which is consistent with Bett-Garber *et al.* (2017)' results who reported lower water absorption, peak viscosity, and holding viscosity for the Basmati rice class when compared to the Jasmine class. In addition, groups 3 and 4 showed similarities in the retrogradation process, with values close to final viscosity of 285.37 RVU and 291.26 RVU, and retrogradation tendency of 136.84 RVU and 166.01 RVU, respectively. This fact indicates that after cooking, the grains of the Basmati accessions belonging to group 4 may have a texture similar to the grains of the Jasmine reference.

Groups 5 and 6 showed similar viscoamylographic behavior, with peak viscosity of 186.06 RVU and 153.1 RVU; and final viscosity of 210.27 RVU and 236.7 RVU, respectively, lower than the other groups. On the other hand, group 7 showed intermediate parameters between the control IRGA 417 and groups 3 and 4.

Li *et al.* (2016) reported a positive relationship between grain hardness and paste retrogradation, and an inverse trend between cooked rice firmness and breakage viscosity. Analyzing figure 4, it is possible to observe that all the aromatic genotypes, represented in groups 2,3,4,5,6 and 7, presented lower retrogradation and higher breaking viscosity than the non-aromatic cultivar IRGA 417, indicating a greater softness of the aromatic grains.

Group 4 stands out among the groups of Basmati accessions. As previously mentioned, it is possible to infer that this group may have a soft texture similar to the Jasmine controls, which are cultivars already accepted in the aromatic rice market. In addition, group 4 also excelled in the parameters of elongation, with an average ratio above 2.0, and aroma, with a score close to those of the Jasmine controls.

4 CONCLUSIONS

The statistical evaluation of the aromatic rice accessions allowed the identification of seven distinct groups using the Mean Distance Method. In group 1, the non-aromatic cultivar IRGA 417 did not present aroma, intermediate AAC, low grain elongation and higher paste temperature, minimum viscosity, final viscosity, and tendency to retrogradation. Accession A46, represented by group 2, also with intermediate AAC, with little aroma and low elongation, showed higher minimum viscosity, final viscosity, and tendency to retrograde than the other Basmati accessions. Group 3 was formed by the three Jasmine aromatic cultivars used as reference in the study. Group 4 was composed of the majority of Basmati accessions and presented interesting characteristics for future research on Genetic Breeding Programs, such as low AAC, elongation greater than 2.0, and moderately intense aroma. In addition, group 4 presented a paste retrogradation process like group 3, indicating the expected softness for this type of rice. Groups 5, 6, and 7 showed low grain elongation and little intense aroma, characteristics not very interesting for Basmati rice.

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