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FOOD TECHNOLOGY

Integration of physicochemical and instrumental quality data to estimate the texture of polished rice

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ABSTRACT: This research evaluated different rice genotypes regarding physicochemical and instrumental parameters of grain quality and associated the data with sensory analysis to support the creation of rules for classification of the culinary quality of rice (texture), based on isolated or combined parameters. The combination of amylose content and gelatinization temperature was able to predict the rice quality. According to the sensorial panel, the instrumental stickiness was able to segregate rice with very low amylose content or waxy to the other ones. Regarding pasting properties, rice that presented high final viscosity (310–480 RVU), setback (165–245 RVU), and pasting temperature (78 – 88 °C), and low values for breakdown (15–120 RVU), associated with a high stickiness (>-5N) was desirable by the Brazilian consumers. The classification rules created through the relationship between the physicochemical parameters and the texture profile evaluated by the sensory panel will help to verify the culinary profile of the rice samples (through free software), which makes it easier to predict the probability of rice meeting the desired quality standards.
Key words: *Oryza sativa*, rice stickiness, amylose, paste properties.

Integração de dados físico-químicos e instrumental para estimar a textura de arroz polido

RESUMO: Este trabalho avaliou diferentes genótipos de arroz quanto a parâmetros físico-químicos e instrumentais de qualidade do grão e associou os dados à análise sensorial para subsidiar a criação de regras de classificação da qualidade culinária do arroz (textura), com base em parâmetros isolados ou combinados. A combinação do teor de amilose e temperatura de gelatinização foi capaz de predizer a qualidade do arroz. De acordo com o painel sensorial, a pegajosidade instrumental foi capaz de segregar arroz com baixo teor de amilose ou ceroso dos demais. Em relação às propriedades de pasta, o arroz que apresentou alta viscosidade final (310–480RVU), retrogradação (165–245RVU) e temperatura de pasta (78–88 °C) e baixos valores de quebra pasta (15–120RVU), associados a uma alta pegajosidade (> -5N) será desejável pelos consumidores brasileiros. As regras de classificação criadas por meio da relação entre os parâmetros físico-químicos e o perfil de textura avaliado pelo painel sensorial ajudarão a verificar o perfil culinário das amostras de arroz (por meio de um software livre), o que torna mais fácil prever a probabilidade de o arroz atender aos padrões de qualidade desejados.
Palavras-chave: *Oryza sativa*, pegajosidade do arroz, amilose, propriedades de pasta.

INTRODUCTION

The grain quality of rice directly reflects on the market value and the acceptance of the product by the consumer. However, the definition of this quality becomes complex due to regional traditions and customs; what often represents a good quality product for one group of consumers may be unacceptable for another (BAO, 2016; JUEMANEE et al., 2018; MESTRES et al., 2019). Various characteristics such as texture, size, color, translucency, and aroma contribute to the culinary profile of the rice. The texture of the cooked grain is one of the main factors determining the acceptance of the product, followed by the water absorption capacity, volumetric increase, grain elongation (FITZGERALD et al., 2009; BAO, 2016; BORRIES et al., 2018; MESTRES et al., 2019).

Rice texture is a consequence of the internal structure of the grain and can be defined by attributes such as hardness and stickiness, usually assessed by sensory analysis or instrumental testing (BORRIES et al., 2018). The sensory test requires a group of

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periodically trained tasters, for the evaluation of the quality of cooked rice, as it is a subjective analysis that demands the aptitude of the analysts and clarity of the standards of the grading scales. In large analytical routines, this test fatigues analysts, increasing the chances of errors (PARK et al., 2019; TAO et al., 2020). In addition, a relatively large number of cooked samples and availability of people and time are needed to carry out the evaluations. In addition to this, there is a wide range of methodologies used in sensory tests in the literature, both in terms of rice preparation and culinary quality classification criteria and scales, demonstrating a lack of standardization of methods (BORRIES et al., 2018).

Given the difficulties in adopting the sensory method to assess the culinary quality of rice, some research centers have proposed the use of a texturometer for the instrumental assessment of the stickiness and hardness of cooked grain, seeking to standardize the method, which increase the reproducibility and reliability of the results. This method allows evaluating a larger number of samples daily and does not require many professionals to perform the analysis, eliminating the subjectivity of the sensory test and a better cost-benefit ratio. Instrumental measurements are easier, cheaper, and invaluable for screening, but only useful if they correlate with human data for the type of food being considered (JUEMANEE et al., 2018; TAO et al., 2020). The parameters evaluated in the RVA (Rapid Visco Analyzer) can also be used to assess the culinary quality of rice-based on its viscoamylografic profile. The behavior of starch in the formation of paste helps to determine the culinary and functional quality of rice since starch is the main component of the grain. That is, the properties of the paste provide information about the cooking, relating to aspects of texture and cohesiveness (KONG et al., 2015; BALINDONG et al., 2018; HUANG et al., 2020). Conversely, there is still no practical guidance for interpreting the texture instrumental data or the viscoamylographic profile, which are generally evaluated in comparison with each other, using as reference the field experiment controls or standard commercial cultivars. Although, this is a valid strategy, it could be improved by establishing a relationship between quantitative texture and paste property data with sensory data (BORRIES et al., 2018).

Thus, in rice breeding programs, the evaluation of the cooking quality of grains is indirectly estimated through various physical and physicochemical parameters, determined by different methods based on starch characterization, more specifically on amylose and paste properties (BORRIES et al., 2018). These data are rarely integrated into the rice quality classification, which often causes some confusion in the interpretation of so much data by breeders or different labs abroad. Thus, the data are not always predictive, as they are individually subjected to errors or limitations in quality estimation, which is known to be multifactorial and complex. This leads researchers to resort to sensory tests as an apparent safer way to conclude about the culinary quality of the product.

In this sense, research that seeks a way to facilitate a better and holistic interpretation of the data obtained in the evaluation of rice quality and the reduction of sensory analysis for the selection of rice cultivars is valid. Thus, this research evaluated different rice genotypes regarding physicochemical and instrumental parameters of grain quality and associated the data with sensory analysis to support the creation of rules for classification of the culinary quality of rice (texture), based on parameters isolated or combined. The classification rules were created by evaluating the physicochemical and instrumental parameters of grain quality, based on sensorial analysis, using descriptive statistical analysis. The rules created were applied in free software, developed to classify the culinary quality of polished rice.

MATERIALS AND METHODS

Plant material

In this study, it was evaluated samples of white rice (700) submitted to physical-chemical and culinary quality evaluations in the laboratory of grains and by-products of EMBRAPA Rice and Beans, with an amylose content (AC) range of 1% to 29% (Figure 1). The white rice genotypes were multiplied at the Palmital Farm of EMBRAPA Rice and Beans, in Brazabrantes/GO, Brazil, on September 2016, 2017, 2018, 2019, and 2020. The materials were planted (three field replications) in plots with three rows spaced 30 cm apart and 50 m long. The samples were placed in cotton bags and dried in an oven with forced circulation air (45°C) until reaching a final humidity of 12-14%. The grain processing was carried out in a rice mill (Suzuki MT 10), to obtain whole grains of polished rice, and the milling degree was monitored (range 95 to 105) in a Milling meter model MBZ-1.

Apparent amylose content (AC)

The AC was determined using the FIA System – Flow Injection Analysis System from Foss Tecator (FIAStar 5000, Denmark). Rice samples, previously

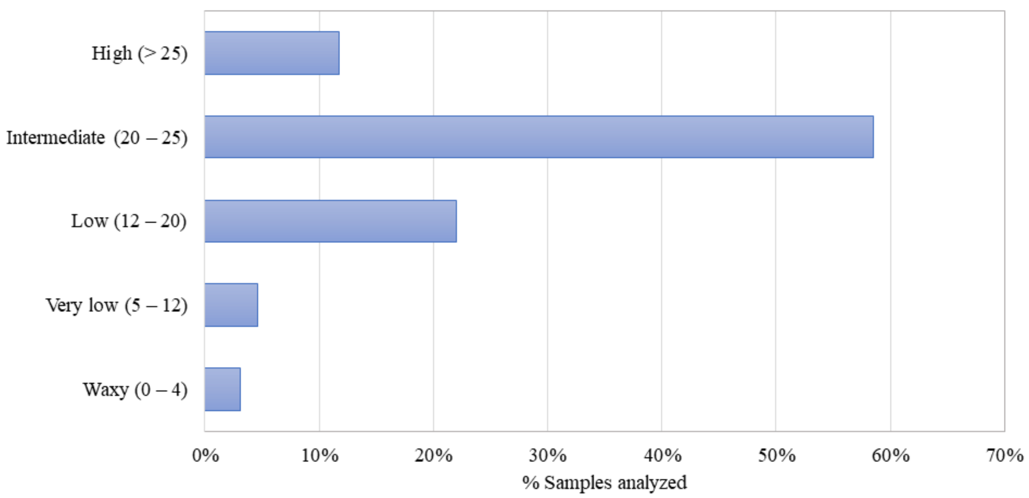

Figure 1 - Sample distribution according to its amylose content (n = 700).

ground in a knife mill (Perten Laboratory Mill 3100, country), were injected after complete dispersion and gelatinization in alkaline solution, 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 AC was calculated using a calibration curve, which was prepared with standard rice cultivars pre-selected with known amylose contents and previously determined by Gel Permeation Chromatography (SEC/GPC) (FITZGERALD et al., 2009) by IRRI (International Rice Research Institute).

Gelatinization temperature (GT)

The GT of the samples was obtained indirectly, by the alkaline dispersion test described by MARTÍNEZ & CUEVAS (1989). The test consists of estimating the degree of alkaline dispersion and clarification of raw rice grains (10 whole and polished grains) when placed in contact with a 1.7% potassium hydroxide (KOH) solution.

Viscoamylographic analysis

The viscoamylographic profile of the rice samples was obtained in a Rapid Visco Analyzer (RVA) series 4 Newport Inc.® (Sydney, New South Wales, Australia). The ground sample (3g) was suspended in 25 mL of distilled water corrected to 14% moisture. The suspension (starch and water) was initially stirred at 960 rpm for 10 seconds and analyzed according to the following time/temperature regime: 50 °C for 1 minute, heating from 50 °C to 95 °C at a rate constant speed of 11.84 °C/min, and temperature maintenance at 95 °C for 2.5 minutes. Then, the suspension was subjected to cooling from 95 °C to 25 °C (11.84°C/min), totaling 12 minutes of analysis per sample according to the standard method approved by the AACC (2012). The parameters evaluated were peak viscosity (Peak_Visc), final viscosity (Final_Visc), breakdown, and setback, expressed in Rapid Visco Units (RVU).

Instrumental texture analysis

About 10 g of rice grains and 20 g of distilled water were placed in Petri dishes superimposed on the crockpot grid (Cadence, 2L capacity) and cooked for 30 minutes. The cooked grains were distributed on the base of a texturometer (TA-XT Plus, Surrey, England) for evaluation of mechanical properties, stickiness, and hardness. The uniaxial compression method was performed as describe by SESMAT & MEULLENET (2001), with modifications, using a 50 kg load cell and 40 mm cylindrical probe.

Sensory evaluation

For the sensorial evaluation of rice, the grains were cooked in a 2L crockpot (Mondial) at a ratio of 1:2 (rice/water) and cooked for 30 minutes. The stickiness and the hardness of the rice samples were accessed using a routine analyze carried out daily on the Embrapa Grain Laboratory (BORRIES et al., 2018): The stickiness was visually assessed by checking whether the cooked rice sample crumbled when poured onto the plate; Hardness was evaluated by pressing the cooked samples between the fingers (45 ºC). Attributes were rated using a five-point scale (1 = 'very loose' and 5= 'very sticky' for stickiness, and 1= 'very soft' and 5 = 'very firm' for hardness) by a panel of six trained tasters.

Statistical analyses

All analyzes were evaluated in triplicate. Univariate and multivariate analysis techniques (principal component analysis - PCA) and cluster analysis were used. The results were presented as means ± standard deviation, evaluated by analysis of variance. Levene test was applied to verify the variance homogeneity, and the differences among the means were certified by the Tukey test ($P < 0.05$). To conduct the PCA it was used the standardized or normalized PCA, based on Pearson's correlation matrix provided by XLSTAT software (ADDINSOFT, 2021). Five components were analyzed, and the PCA biplot was made based on the Euclidean distance in the p-dimensional variable space (distance biplot).

Integration of quality attributes: classification rules to estimate the culinary quality of rice

The results of this research were used to create a software (QualiArroz) to predict the texture (stickiness) of rice through the association of viscoamylographic measurements, amylose content, gelatinization temperature, and instrumental texture (not available on the internet yet). QualiArroz software was made using Javascript, PHP, and HTML5 with CSS. The rules to classify the quality of each grain were developed from AC, GT, RVA, and instrumental stickiness data considered as input data (x), and the respective quality classifications (the result of the sensory evaluation), considered as output data y=f(x). The classification rules were created by evaluating the amylose, GT, and RVA profile, based on sensorial analysis. These rules are implemented in QualiArroz with code made in javascript and PHP languages. The software was validated using data from around 300 rice cultivars available by the Embrapa Grain Laboratory. The QualiArroz system will be accessed through different browsers, both for computers (desktop or notebook) and for mobile devices such as cell phones or tablets and has a page on the Internet, with guidance to the user on the use of the system.

RESULTS AND DISCUSSION

Amylose content (AC), gelatinization temperature (GT), and instrumental stickiness

According to amylose content, the rice samples could be classified as a group of waxy, very-low, low, and intermediate amylose (Table 1). Rice with low amylose content has a soft and sticky texture when cooked and is preferred by Northeast Asian and Japanese consumers. Conversely, grains with intermediate and high amylose amounts present firm and loose grains after cooking, and are enjoyable to the taste of Latin American, Indian, and European consumers (TEIXEIRA et al., 2021; ZHANG et al., 2021). Additionally, rice varieties with reduced amylose molecular sizes and with elevated proportions of long amylose chains may present a harder texture after cooking (LI et al., 2016). According to sensorial evaluation, rice with AC < 17% was very sticky or sticky; rice with AC between 17 – 25 may present slight stick/ slight loose, and grains with AC >25 may be loose (Figure 2A).

The alkali spreading test allows the indirect evaluation of GT, which classified the rice as high GT (2.85±0.18), intermediate (4.21±0.87), and low (6.93±0.19) GT. In general, grains with low (6-7) and intermediate GT (4-5) need less time and water to cook; on the other hand, rice with high GT (1-3) require more water and time to cook and the center of the grain remains hard after cooking (MESTRES et al., 2019). The GT is mainly influenced by amylose content and the amylopectin chain length distribution which is associated with cooking time (BALINDONG et al., 2018). The GT results were not able to properly predict the cooking quality of the rice by itself since they did not present a significant difference when grouped according to amylose content (Table 1) nor with the sensorial perception of stickiness (Figure 2 B).

AC and GT are important indirect indicators of rice cooking quality. However, these tests do not accurately assess all grains' quality traits, such as texture. In some cases, amylose content is similar, but the measured stickiness and the sensorial panel still vary significantly (Figure 2D). This is because of the other structural elements such as amylose and amylopectin chain-length distributions, proteins, etc. (LI et al., 2017; BALINDONG et al., 2018). Therefore, the results showed that AC and GT, as proposed by the literature, are not accurate tools to trace the culinary behavior of rice, because when checking the rice classification according to each analysis, the results were not always satisfactory (Figure 2A, B). That is, they do not allow obtaining conclusive results about the quality of grains in rice with similar amylose content (main grains with low and intermediate AC) as they do not show a pattern with the sensory test (Figure 2D, F). This is due to the low correlation between these two parameters ($r = 0.27$).

Table 1 - Amylose content, gelatinization temperature, and instrumental stickiness according to amylose groups.

AC group[*]	AC (%)	GT	Stickiness (N)
Waxy (0 – 4)	2.3 ± 0.7^{e}	4.9 ± 0.3^{ab}	-12.5 ± 1.5^{a}
Very low (5 – 12)	11.3 ± 0.5^{d}	3.1 ± 1.0^{b}	-12.7 ± 2.1^{a}
Low (12 – 20)	16.8 ± 2.4^{c}	3.8 ± 1.3^{ab}	-7.3 ± 3.2^{b}
Intermediate (20 – 25)	22.7 ± 1.4^{b}	5.3 ± 1.9^{ab}	-5.4 ± 1.2^{b}
High (> 25)	25.6 ± 0.5^{a}	6.2 ± 1.6^{a}	-5.2 ± 0.24^{b}

[*]Classes were grouped according to JULIANO (2003). [1] Values correspond to the mean ± standard deviation.

Another parameter that could be used to predict the cooking quality of rice is the instrumental texture analysis. Both hardness and stickiness were analyzed but only the stickiness was significant (Table 1, Figure 2C). During cooking, the leached starch molecules attach onto the surface of cooked rice grains, thus producing bonding and debonding forces with textural profile analyzer (TPA) probe upon TPA test and creating a stickiness value (LI et al., 2021a). Rice with a high amount of amylopectin can produce more bonding forces, i.e., with increasing total amylopectin amount, molecular size, and proportion of short chains with X < 37 in the leachate, rice is classified as very sticky or sticky (LI et al., 2017; LI et al., 2021b). Additionally, the protein surface present in the rice can reduce the bonding capacity of amylopectin, therefore reducing the stickiness of cooked rice (ZHANG et al., 2019).

The grains with a low and intermediate amount of amylose presented the lowest absolute values for stickiness (smaller negative area), so the rice is loose or slightly sticky (Table 1). According to the sensorial panel, the instrumental stickiness was able to segregate rice with very low amylose content or waxy to the other ones (Figure 1C). TAO et al. (2020) founded a strong correlation between hardness and

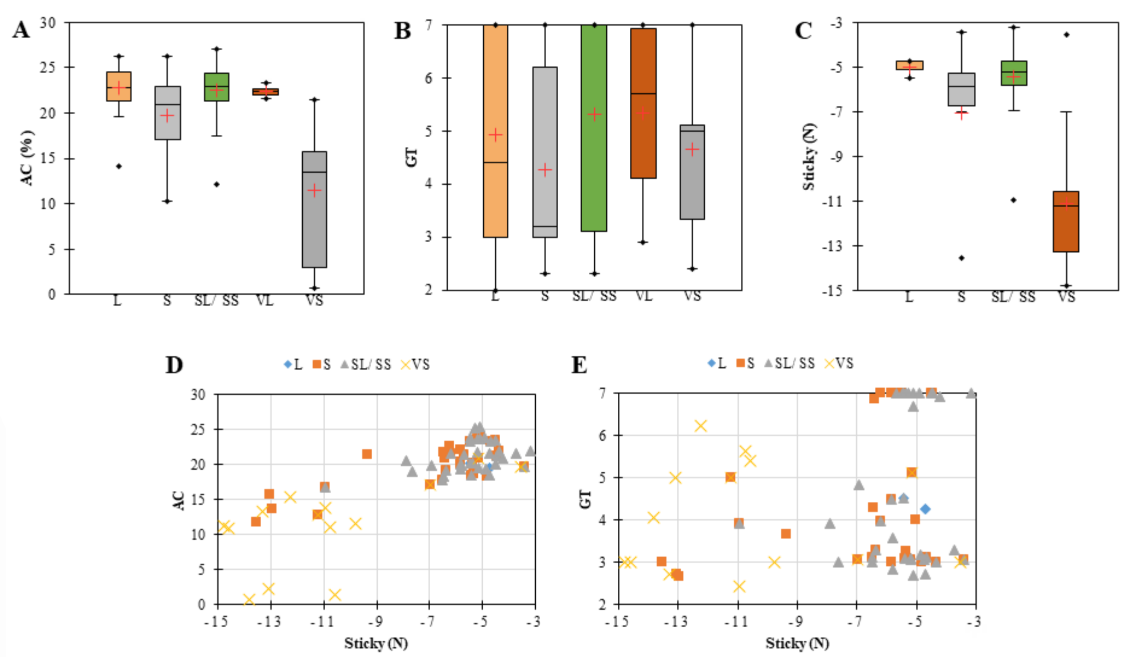

Figure 2 - Box plot (A) amylose content (AC), (B) gelatinization temperature (GT), and (C) instrumental stickiness. Scatter plot of (D) AC and (E) GT versus instrumental sticky (N). Results are expressed according to the sensorial perception of stickiness: L: loose; S: sticky; SL/ SS: slight loose/slight sticky; VS: very sticky.

stickiness measured by texture profile analysis (TPA) and by panelists, suggesting that TPA can be used to measure hardness and stickiness of cooked rice. The segregation into groups of the intermediate and high amount of amylose was not possible, probably due to the effect of the proportion of amylopectin chains (i.e., short, or long branches) that can increase or reduce bonding and molecular interaction (PENG et al., 2021). Moreover, the texturometer proved to be advantageous, mainly because it is an analysis that has a lower cost (number of samples), fewer analysts, and is not subjective.

Pasting properties

The viscoamylograph profiles of the samples were grouped according to amylose content (Table 2). The peak viscosity of the rice groups ranged from 180 to 291 RVU, for rice with high and very low amylose content, respectively. The peak viscosity reflects the ability of the granules to bind to water or the extent of the increase in the volume of the starch granules, i.e., it is the maximum viscosity value of the starch during the heating cycle. Peak viscosity is related to the quality of the final product, since swollen and collapsed starch granules affect the texture of the products (WANI et al., 2012). The genotypes with very low AC, in general, showed the highest peak viscosities, indicating greater binding capacity with water of the starch granule. Conversely, waxy rice presented a low peak of viscosity (189 RVU), which is not related to amylose content but with the amylopectin chain branches bonds and length; and the resistance of the granules to rupture during stirring under heating can be affected by the content of proteins and lipids (LEE et al., 2012; BALINDONG et al., 2018; LI et al., 2019).

The breakdown of the rice groups ranged from 54 to 165 RVU (Table 2). In general, breakdown indicates the resistance of starch to heating caused by the rupture of the swollen granules in the gelatinization stage. Therefore, a high breakdown value can be considered as low heat stability since a low value indicates thermal stability which indicates that rice with very low AC may present low thermal stability, i.e., the rice may cook faster than rice with high AC.

The lowest final viscosity was observed in waxy rice (113 RVU), and the highest was in the rice with intermediate AC (312 RVU) (Table 2). The final viscosity indicates starch firmness, i.e., the starch's ability to form a gel. Higher final viscosity values indicate a firmer texture of the gel; and consequently, of the rice grains when cooked, due to the greater reassociation of the amylose molecules present in the starch granules (WANI et al., 2012; LI et al., 2016; HUANG et al., 2020; LI et al., 2021a). 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). Therefore, rice that presents a high final viscosity tends to be looser and harder.

The waxy genotypes showed lower setback values (Table 2), while rice with high and intermediate AC presented the highest values. The setback is the result of the recrystallization of amylose and amylopectin molecules, resulting from the grouping of linear parts of starch molecules by the formation of new hydrogen bonds (WANG et al., 2015). The higher amylose content increases the stability of the granules to rupture under mechanical agitation, contributing to a greater tendency to retrograde, due to a greater amount of leached amylose. As a result, the suspension has more swollen granules during cooling and greater viscosity and firmness (LUCISANO et al., 2009; WANG et al., 2015; LI et al., 2016). The larger the setback, the firmer the rice texture, and this parameter can be used in rice breeding programs as a selection tool for rice cooking quality (FITZGERALD

Table 2 - Paste properties of polished white rice samples according to amylose content range.

Amylose content	Peak viscosity[1]	Trough[1]	Breakdown[1]	Final Viscosity[1]	Setback[1]	Peak time[2]	Pasting temperature[3]
High	180 ± 80[d]	126 ± 51[a]	54 ± 33[d]	272 ± 117[b]	147 ± 67[ab]	5.6 ± 0.2[b]	80.9 ± 5.4[a]
Intermediate	228 ± 58[bc]	148 ± 42[a]	81 ± 33[c]	312 ± 82[a]	165 ± 42[a]	5.7 ± 0.2[a]	80.4 ± 3.7[a]
Low	248 ± 46[ab]	130 ± 32[a]	119 ± 37[b]	265 ± 65[b]	135 ± 37[b]	5.7 ± 0.2[a]	80.1 ± 4.0[a]
Very Low	291 ± 18[a]	126 ± 7[a]	165 ± 13[a]	226 ± 13[b]	100 ± 9[c]	5.5 ± 0.1[b]	80.2 ± 1.1[a]
Waxy	189 ± 32[cd]	87 ± 16[b]	102 ± 21[bc]	113 ± 22[c]	26 ± 7[d]	3.5 ± 0.1[c]	69.0 ± 0.8[b]

1: RVU; 2: min; 3: °C; Results presented as mean ± standard deviation; Different letters in the same column present statistical difference by Tukey test ($P < 0.05$).

et al., 2009; BALINDONG et al., 2018). According to HUANG et al. (2020), a higher breakdown combined with a small setback value indicates good rice cooking quality (for Asian consumers), due to its high tendency to be sticky. Conversely, rice that present high setback, low breakdown associated with a high stickiness (>-5N) were desirable by the sensorial panel (Brazilian consumers).

In general, the rice classification according to AC or sensorial perception of stickiness was not able to segregate well the rice samples regarding their pasting properties. This may be due to the fact that other factor affects the rice pasting properties (e.g., starch crystallinity, protein, and lipids content, etc.). Therefore, even when the rice presents a similar AC it may present a significant difference in its pasting properties or cooking quality (WANI et al., 2012; BAO, 2016; BALINDONG et al., 2018). Moreover, the molecular size and chain length of amylopectin control the rice stickiness, i.e., the large amylopectin molecules with a high proportion of short chains result in a higher stickiness between the rice grains. Likewise, the amylose molecular size is negatively correlated with rice hardness (LI et al., 2017). It was possible to observe that genotypes with similar amylose content had different breakdown values, which indicates that using pasting properties may be suitable for predicting rice-eating quality than the traditional classification considering the amylose content only.

Principal aomponent analysis (PCA)

The correlation of the parameters from paste properties, instrumental stickiness, AC, and GT was evaluated with PCA (Figure 3). AC was positively correlated with the absolute value of instrumental sticky and setback which means that rice with high values of setback and amylose may present low values of stickiness. Therefore, they will potentially present good eating quality for American consumers. Other studies also identify that AC was correlated with pasting properties (MOREIRA et al., 2014; GAYIN et al., 2015), and instrumental texture (LUCISANO et al., 2009), ;therefore, it can predict the cooking quality of rice. This indicates the possibility of replacing analyses, especially sensory ones, and reducing costs and operations, with the possible use of instrumental testing to assess rice quality (BORRIES et al., 2018). In general, in the laboratory routine, the use of AC, GT, and sensory analysis is common. The total cost of these three analyzes (equal to 5X) is greater than the cost of the instrumental texture or RVA analyzes (equal to 4.5X and 4X, respectively) (Table 3). Thus, these simpler

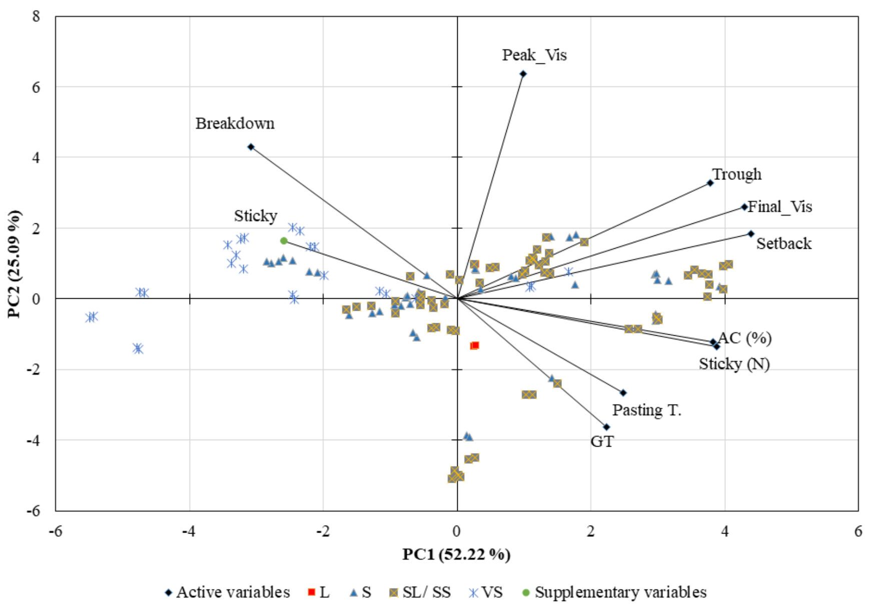

Figure 3 - Principal component analyses showing the two main axes (PC1 and PC2) with 77.31% of the explained variance. L: loose; S: sticky; SL/ SS: slight loose / slight sticky; VS: very sticky.

analyses, which use a small amount of sample and have relatively low costs, can be recommended in the initial stages of selection of lines/genotypes with desirable grain quality, for advancement in the genetic improvement program.

Integration of quality attributes to estimate the culinary quality of rice

Rice quality attributes were integrated and used to create quality classification rules applied in a free software application to predict the cooking behavior of rice. To identify the rice eating profile (very sticky, sticky, slight sticky or slight loose, loose, and very loose), the samples were segregated by AC and them by the sensorial evaluation. Later, for each segregated group, the eating profile was identified using descriptive statistical analyses (Table 4).

According to the sensory panel, polished rice grains with an AC of less than 10% are classified as very sticky. As for the viscosity profile, the very sticky polished grains presented low values for setback (15 – 40 RVU), and final viscosity (80 – 140). For rice with an AC of 10 to 17%, the sensory panel rated the grains as very sticky or sticky. For this group of grains, the setback value ranged from 80 to 165 RVU and the final viscosity was 190 to 270 RVU. A third classification rule for sticky rice was obtained considering the AC of 18 to 19% (Table 4). It was not possible to identify a pasting pattern profile able to discriminate slight sticky or slight loose (SS/ SL) samples because of the large standard deviation of this group. This is because the sensorial panel tends to classify the samples as SS/ SL when they have doubts about the rice quality. Thus, the polished rice grains with amylose content between 20 and 24 were considered as slight sticky or slight loose grains. This range of amylose was the one with the lowest percentage of correct answers (63%) when compared to the result indicated by the sensory panel (Table 4).

It is noteworthy that sensory analysis is a subjective analysis, which depends a lot on the analyst's capacity, which can interfere with the result. Thus, it is clear the need for constant training of the sensory panel to obtain reliable results. It is also known that grains with intermediate amylose content can present a high variation in culinary quality, which is a result of the characteristics of the molecules of amylopectin and amylose. Additionally, we highlighted the need for further testing to identify possible viscosity profiles in this sample group. For samples with amylose content above 25%, we identified the viscosity profile that classifies polished rice grains as loose grains (i.e., the culinary quality preferred by consumers in Latin America). Rice grains classified as loose by the sensory panel, showed high final viscosity (310 – 480 RVU), setback (165 – 245 RVU), and pasting temperature (78 – 88 RVU), and low values for breakdown (15 – 120 RVU) (Table 4).

The GT was not able to properly segregate the rice sample, consequently, was not possible to identify a rice quality profile using it. Therefore, GT is not indicated to predict rice quality by itself. Conversely, the combination of AC and GT values, based on the amylose content and sensorial perception of stickiness, may be useful to predict rice quality (Table 5) and presented 72.3% of accuracy. This proposal for the classification of polished rice grains, using only the AC and GT content, has the lowest analysis cost (3.5X) (Table 3). This makes it advantageous for evaluating large volumes of samples in the early stages of the process of selecting cultivars for genetic improvement.

As for the results of the instrumental texture, it was also not possible to determine classification rules with acceptable success percentages for the classification of rice grains. This result reflects the inexistence of a correlation between the results obtained in the texturometer and

Table 3 - Cost, time, and quantity of sample per analysis studied. Values are presented for each analysis repetition.

Analyses	Cost	Time (min)*	Sample (g)
Gelatinization temperature (GT)	X	8	5
Amylose content (AC)	2.5X	18	5
Instrumental texture	4.5X	>25	25
Paste properties	4X	20	10
Sensorial analyses	1.5X	> 30	125

*The time needed for receiving the samples, identifying them, computing the results, and washing the glassware/utensils in the laboratory was not considered.

Table 4 - Pasting properties profile for rice classification: ranges proposed according to amylose content and sensorial perception of stickiness.

Parameters	Very sticky[1]	Very sticky / Sticky[1]	Sticky[1]	Slight loose /slight sticky[1]	Loose [1]
Amylose content (%)	< 10	10 – 17	18 – 19	20 – 25	>25
Peak viscosity (RVU)	150 – 250	250 – 320	220 – 260	-	120 – 310
Trough (RVU)	60 – 110	100 – 140	110 – 180	-	140 – 180
Breakdown (RVU)	70 – 140	140 – 190	100 – 130	-	15 – 120
Final viscosity (RVU)	80 – 140	190 – 270	260 – 360	-	310 – 480
Setback (RVU)	15 – 40	80 – 165	140 – 200	-	165 – 245
Peak time (min)	5.5 – 5.9	5.3 – 5.8	5.5 – 5.9	-	5.5 – 5.9
Pasting temperature (°C)	76 – 79	78 – 84	76 – 79	-	78 – 88
Percentage of accuracy[2]	100%	82%	65%	63%	87%

1. Sensorial evaluation; 2. Percentage of accuracy of the rules of classification according to the sensorial analyses.

the evaluation of stickiness by the sensory panel. It is important to highlight that the instrumental stickiness analysis is an analysis that requires a lot of practice from the analyst, in addition to presenting high variation between the results. That is, both the low reproducibility of the analysis and the subjectivity of the sensory panel may have contributed to the non-existence of a correlation between the results.

From the integration of data in the application, it was possible to verify the culinary profile of the sample, which makes it easier to predict the probability of rice meeting the desired quality standards. The application has intelligence that aims to automate and streamline the interpretation of instrumental laboratory data, without the need for sensory testing, by any interested individual, regardless of being a grain quality specialist. In general, the classification rules, used in the free software, presented a satisfactory percentage of accuracy considering that most of the cultivars used presented a similar amylose content (about 60% presented AC between 20 – 24%), which might reduce the accuracy of the application (Figure 1). Rice with similar amylose content may present different culinary qualities since the fine structure of amylose and amylopectin influence their texture properties and pasting properties (LI et al., 2016; LI et al., 2019). Therefore, for better results, the study of the length of chains should be used to identify the rice cooking quality with higher accuracy. But unfortunately, the

Table 5 - Stickiness of cooked rice estimated according to the amylose content (AC) and gelatinization temperature (GT) combination. Results are expressed based on the sensorial test. ND: Not determined; L: loose; S: sticky; SL/ SS: slight loose / slight sticky; VS: very sticky.

AC	Gelatinization temperature					
	1.0 - 1.9	2.0 - 2.9	3.0 - 3.9	4.0 - 4.9	5.0 - 5.9	6.0- 6.9	7.0
< 18%	VS	VS	VS	VS	VS	VS	VS
18%	SL/ SS	SL/ SS	VS	VS	VS	ND	ND
19%	SL/ SS	SL/ SS	VS	L	VS	ND	ND
20%	L	L	VS	SL/ SS	VS	ND	VS
21%	L	L	SL/ SS	SL/ SS	VS	L	VS
22%	L	L	SL/ SS	VS	VS	L	VS
23%	L	L	SL/ SS	VS	VS	VS	SL/ SS
24%	L	L	SL/ SS	VS	VS	VS	SL/ SS
25%	L	L	SL/ SS	VS	VS	VS	SL/ SS
26%	L	L	SL/ SS	VS	VS	VS	SL/ SS

n = 400.

analyses of the molecular size distribution of whole branched and debranched starch molecules are not available in most of the laboratories and may not be indicated for the selection of cultivar in the first stages of genetic programs, but they could be applied to improve the software rules and prediction accuracy.

CONCLUSION

It was possible to verify that the indirect evaluation of gelatinization temperature was not efficient to predict the rice stickiness. Conversely, amylose content associated with the gelatinization temperature may be useful to classify rice stickiness. The association of amylose content with pasting properties improved the precision of rice classification. In general, the rice culinary quality (sensorial perception of stickiness) is better related to the paste properties and amylose content. The rice with an amylose content of up to 17% presents a specific viscosity profile (low setback and final viscosity, and high breakdown), which classifies these grains as very sticky or sticky. The rice grains classified as loose (good cooking quality for Latin American consumers) presented amylose content above 25%, high values of setback and final viscosity, and low breakdown. Conversely the rice grains with amylose content between 20 and 24% require more studies to determine a correlation between the amylopectin chains, viscosity properties, and the sensorial evaluations and then create a classification rule with a better percentage of accuracy. For improve its accuracy we suggested some specific analyses, such as FITIR, XRD, and the study of amylose and amylopectin chains, which might better define the profile of rice grains with intermediate amylose content.

Finally, it was possible to associate the classification rules in the free software application to estimate the culinary quality of the grains through the integration of data from the culinary parameters. The free software will be continuously improved by the addition of new data on its database according to the EMBRAPA laboratory availability, to improve its accuracy to predict the rice cooking quality. This tool is something innovative that can help breeding programs to verify the stickiness of rice grains and will be available for users after final validation in progress by our team.

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DECLARATION OF CONFLICT OF INTEREST

We have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

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