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Drying and intermittence processes on the polished and brown rice physicochemical and morphological quality by near-infrared spectroscopy, X-ray diffraction, and scanning electron microscopy

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A B S T R A C T

In this study was correlate the effects of drying time and intermittence of paddy rice on the physical, physicochemical, and morphological quality of polished and brown rice using near-infrared spectroscopy, X-ray diffraction, and scanning electron microscopy. Rice grain batches from mechanized harvesting with moisture contents between 24 and 20% (w.b.) were immediately subjected to drying and intermittence (average temperature of the grain mass of 40 °C) for a time of 14 h (number of times that the product underwent the drying and intermittence processes). For each drying time, grain sampling was performed to evaluate the physical quality of paddy rice and the physicochemical and morphological quality of polished and brown rice. The accumulated drying time provided an increase in the temperature of the grain mass, altering the physicochemical and morphological quality of polished and brown rice. The intermittence process did not contribute for the quality of the polished rice.

Introduction

Rice is one of the main cereals grown in the world. Much of the world's production comes from irrigated crops, where grain moisture conditions at harvest are often high (Atungulu, Kolb, Karcher & Shad, 2019). Rice grains with high moisture contents are subject to increased biological activity and respiration, and are susceptible to spoilage. Thus, it becomes necessary to dry the rice before processing and storage (Verma & Srivastav, 2020).

A fast and synchronous flow of grain from harvest to the drying system is needed to decrease the effects of moisture, reducing the product's waiting time in the hoppers or trucks (Müller et al., 2022). The most widely used drying method for rice is intermittent drying (Golmohammadi, Assar, Rajabi-Hamaneh & Hashemi, 2015). This technology is composed of a drying chamber where the grains are exposed to heated air and an intermittent chamber where the product remains at rest for a period (Xu, Chen, Huang & Zhou, 2017). The intermittence period aims to provide a resting time for the grain mass so that water is displaced in the form of liquid and vapor from the interior of the grain to the surface, optimizing the transfer of thermal energy and mass when exposing the grain again to heated air in the drying chamber. However, some factors such as recirculating the product several times in the dryer until drying is completed and the high temperature reached by the grain mass throughout drying can impact the rice quality (Ling & Sun, 2021).

While conducting the drying process, several factors should be taken into consideration for the optimization of the process in order to be reconciled: high energy efficiency, high operational capacity, and the qualitative maintenance of the grains (Nunes et al., 2022). Cracked grain resulting from drying is a major challenge for the rice industry, because the grain structure that was compromised in drying can break later, in the burnishing process, leading to reduced whole grain yield (Igathinathane, Chattopadhyay & Pordesimo, 2008). The formations of these

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cracks are correlated with differences in grain properties between the glassy and amorphous states and by tensile and compressive stresses caused by the moisture content gradient in the grain structure, which are directly influenced by the intermittent cycles and the tempering condition after drying (Hung, Chau & Phi, 2016). Thermal damage caused by the increased temperature of the grain mass is also relevant (Jafari & Zare, 2017), being influenced by the drying air characteristics and exposure time, occurring in a more pronounced way at the end of the process where the speed of evaporation and internal water transport is reduced (Hampel, Le, Kharaghani & Tsotsas, 2018).

After the drying process, rice grains are subjected to processing in order to obtain polished, brown, or parboiled rice (Coradi et al., 2021). The physical and structural properties of rice are important and determine the interaction of the grain with the processing. Polished rice is more intensely exposed to abrasion and friction than brown rice and may manifest damage from the drying process in a more pronounced way (Kim & Lee, 2012). As a result of the qualitative and economic impact of drying in rice it is essential to understand the effects of the process, especially the intermittent technology as a result of product recirculation and extended drying time on the heat accumulation in the grain mass and the possible thermal damage caused on grains subjected to polished and whole grain processing (Hampel, Le, Kharaghani & Tsotsas, 2018).

To verify the effects of drying and intermittency on the quality of rice grains, it is important to apply faster and more efficient technological evaluation methods (Li et al., 2016). Near Infrared Spectroscopy (NIR) is a method that can characterize and grain sort from the definition of the properties or rice constitution (Bazoni, Ida, Barbin & Kurozawa, 2017). The Near Infrared (NIR) corresponds to the region behind the visible one comprising wavelengths from 750 to 2500 nm with wave numbers from 13,300 to 4000 cm^{-1}, respectively. NIR mainly reflects the absorption of vibration combinations of hydrogen groups, such as C—H, O—H and N—H bonds (Chen, Li, Pan, Pang, Yao & Chang, 2019). This is because the spectral occurrences in the near infrared region come from bonds in which hydrogen participates, which makes the technique useful for the determination of organic compounds (Purhagen et al., 2018). According to Chen, Li, Pan, Pang, Yao and Chang (2019), most components of the rice, such as starch, fat, protein and moisture contain a large amount of hydrogen groups that are absorbed by spectroscopy. Some applications of the NIR technique were used to determine the amylose content and identify rice seed varieties (Chen, Li, Pan, Pang, Yao & Chang, 2019), however, there are few references that used the NIR technique as a quality analysis tool.

Associated with the number of evaluations carried out by the NIR are the techniques of multivariate analysis. Multivariate statistical analyzes are mainly used to analyze a large amount of data, with emphasis on spectral analyses (Kuo et al., 2016). Principal component analysis is a multivariate statistical analysis applied to reduce the original set of predictors to a reduced number without neglecting the information (Luna, Silva, Pinho, Ferré & Boqué, 2013). The technique can be applied as an exploratory and discriminating tool for spectral data obtained by near-infrared spectroscopy (Chen, Li, Pan, Pang, Yao & Chang, 2019). Thus, the quantitative diagnosis of grain quality is complemented by morphological evaluation by image and by X-ray diffraction, which can detect and characterize the starch granules, as well as the regular ordered repetitions of the amylopectin helices organized inside the granules of starch, reflecting the three-dimensional order of the starch crystals (Jiamjariyatam et al., 2015). In this way, one can identify the crystalline zones and make it possible to classify starches through X-ray diffraction peaks according to their physical properties (Wang & Copeland, 2013).

To understand the limits and effects of intermittent drying of rice as a result of polished and whole grain processing. Such information will be important for the reduction of losses during processing and will contribute to obtaining a final product with higher quality. The cumulative drying time could influence the temperature of the grain mass, accentuating the thermal damage, while the intermittent process could attenuate the mass and heat transfers in the grain mass to obtain better quality results in the processed rice. Thus, the objective of the study was to correlate the effects of drying time and intermittence of paddy rice on the physical, physicochemical, and morphological quality of polished and brown rice using near-infrared spectroscopy, X-ray diffraction, and scanning electron microscopy.

Materials and methods

Characterization of the experiment

Rice grain batches from mechanized harvesting, with grain moisture content between 24 and 20% (w.b.) were subjected immediately to pre-cleaning and drying operations and subsequent processing. Fig. 1A is the flowchart of the rice evaluation process. The treatments analyzed were drying (average temperature of the grain mass of 41 °C, ranging from 29 to 47 °C), intermittence (average temperature of the grain mass of 40 °C, ranging from 29 to 49 °C) and drying time of 14 h (corresponding to the number of times that the product went through the drying and intermittence processes), at an average drying air temperature of 107 °C (ranging from 73 to 130 °C), in three repetitions (Fig. 1B). Grain samples were collected at the drying and intermittence stages of each drying time to evaluate the physical quality of paddy rice and the physicochemical quality, crystallinity, and morphology of polished and brown rice.

Paddy rice drying and sampling

After going through the pre-cleaning process in the air and sieve machine, the paddy rice grain drying was carried out in an intermittent dryer (Fig. 1B), until the moisture content of the grain was reduced to 11% (w.b.). The intermittent dryer was composed of a drying chamber, intermittence chamber, discharge, heating and ventilation system, and an elevator to perform the intermittence. In this system, the product was only exposed to the drying air in this system during the time interval in which it passed through the drying chamber. The time the product circulated outside the drying chamber was considered as equalization time (intermittence chamber).

The grain samples were collected every hour in the intermittence chamber and in the drying chamber. The temperature of the grain mass in the samples collected was measured using a mercury thermometer. The speed and temperature of the drying and exhaustion air were measured simultaneously, as the samples were collected, in the dryer's air inlet and in the hood's outlet, respectively, using a paddle anemometer. The ambient air temperature and relative humidity were measured using a calibrated digital thermo-hygrometer. The moisture content was determined by the indirect method of electrical capacitance (five repetitions) using an equipment model G1000 (Tecnal Company, Limeira, São Paulo, Brazil), checked with the standard method in an oven at 24 h and 105 °C. The samples, with three replicates, were initially weighed and then placed in an oven with forced air circulation and convection at a temperature of 105 °C for 24 h. Then, the samples were cooled and weighed. By the difference in initial and final weight, moisture results (in % w.b.) were obtained (Brazil, 2009).

Rice processing

Grain milling was performed in a rice tester (Zaccaria, PAZ-1/DTA, Limeira, Brazil), which was regulated and treated according to the technical recommendations for rice milling (Brazil, 2009) equipment manufacturer. 100 g of paddy grains were weighed, placed gradually in the "cone" feed inlet hopper of the processing equipment to obtain the brown rice. Another grain sample was polished by the abrasive stones of the burnisher. The samples were submitted to quality analysis after processing. In the same way, the whole rice was processed using the same procedures, except for the burnishing step. The samples were

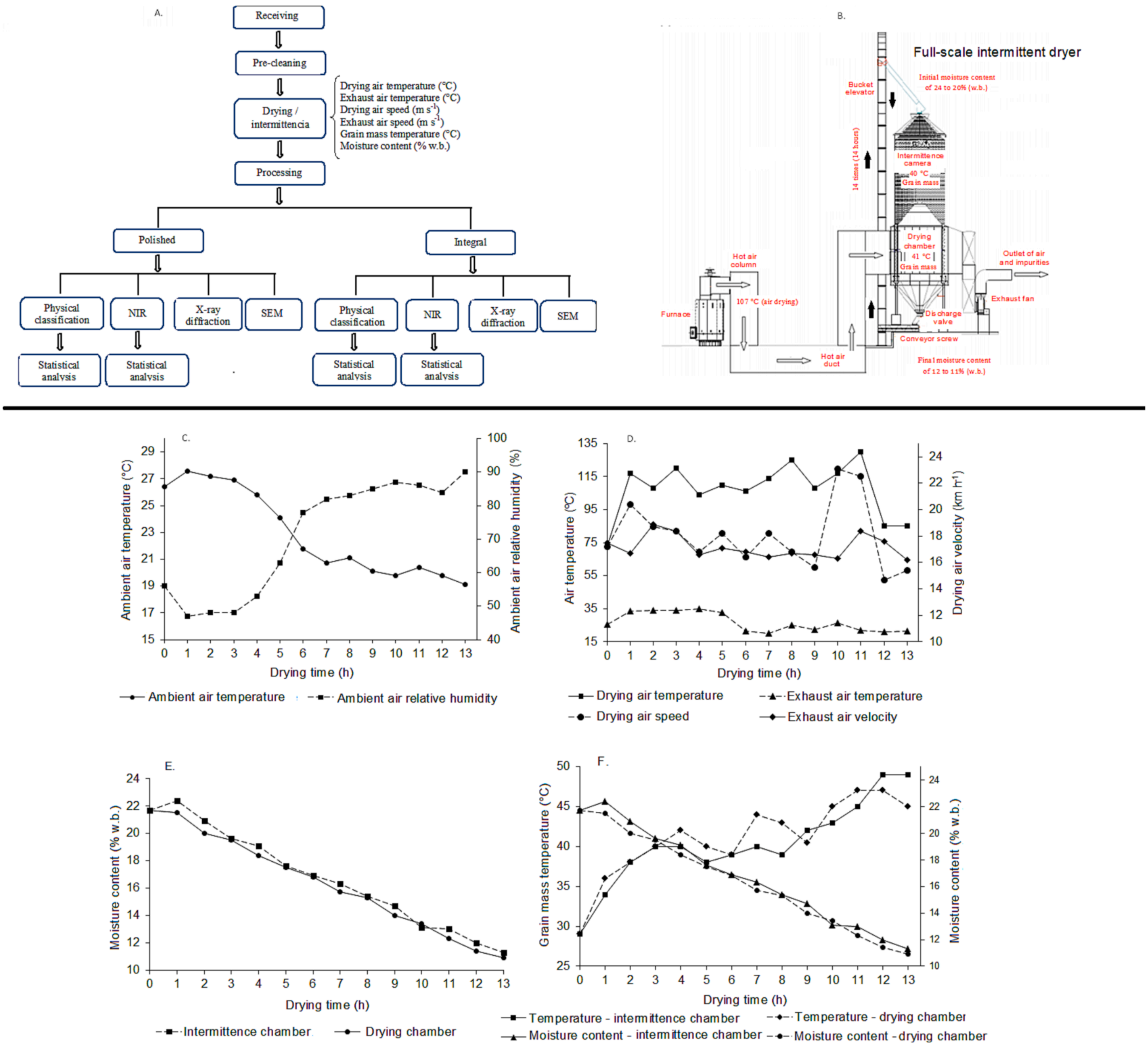

Fig. 1. Flowchart demonstrating the rice evaluation process (A), full-scale intermittent dryer **(B)**, and parameters for monitoring the intermittent drying of rice paddy, ambient air temperature and relative humidity **(C)**, drying and exhaust air temperature and velocity **(D)**, drying curve **(E)**, grain mass temperature and moisture content at drying **(F)**.

separated, identified, and stored in polyethylene bags. The samples were submitted to quality analysis after processing.

Physical classification of rice

A 5.5 mm honeycomb separating cylinder (Zaccaria, Paz-1 / DTA, Limeira, Brazil) was used to classify the whole grains. The rotating separating cylinder had a gravitational function that separated the grains by moving the broken grains to the horizontal mill, while the whole grains were trapped in the cylinder containers for later unloading. The processed samples were weighed on precision scales (Marte Científica, model AD330, São Paulo, Brazil), for subsequent referral to the brown rice classification manual according to Normative Instruction 6/2009 of the Ministry of Agriculture, Livestock and Supply (Brazil, 2009).

Physical-chemical rice quality evaluation

To determine starch (ST), crude protein (CP), fat (F), ash (ASH) and crude fiber (CF) in rice grains, near infrared spectroscopy (NIRS) (Metrohm, DS2500 spectrometer, Herisau, Switzerland) was used. The samples were homogenized and placed in the sampling dish. The analysis was based on illuminating a sample with near infrared radiation and measuring the difference between the amounts of energy emitted by the spectroscopy and reflected by the sample to the detector. This difference was measured in several bands, creating a spectrum for each sample. The spectral data was recorded in reflectance mode, in the spectral range of 400 nm-2500 nm. The spectra were obtained in triplicate.

X-ray diffraction analysis (XRD)

The diffractograms were obtained in a Rigaku X-ray diffractometer, model Miniflex 300, operating in step mode, with a scan speed of 0.5 s, and a scan step of 0.03°, at angles of 5 to 100°. This equipment has Cu Kα radiation (λ = 1.54184 Å) and a power supply with 30 kV and 10 mA. The crystallinity index (X_c) was determined according to Eq. (1):

$$C = H_c/(H_a + H_c) \quad (1)$$

where,
H_c: Height of the crystalline peak.
H_a: Height corresponding to the amorphous phase.

Scanning electron microscopy (SEM) analyses

Microscopic analyses were performed on a scanning electron microscope (SEM) (Carl Zeiss, Sigma 300 VP, Jena, Germany) with a Schotky-type field emission filament (FEG-Fiels Emission Gun) (tungsten filament coated with zirconium oxide) equipped with a Geminii column (Carl Zeiss, Sigma 300 VP, Jena, Germany). Images were obtained using the secondary detector (SE2) in high vacuum mode (1×10^{-9} bar), energy of 1, 5 and 6 KV, working distance of 5 mm and above 35 mm, aperture of 15 µm, magnifications (26X, 30X, 36X, 40X, 44X, 48X, 100X, 300X, 500X, 1000X, 2000X, 3000X and 5000X). For energy dispersive X-ray (EDX), the X-ray EDX detector (Bruker, Quantax 200-Z10, Billerica, Massachusetts, US), equipped with a 10 mm^2 quartz window and ESPRIT software was used. The EDS will be obtained using the secondary detector (SE2) in variable pressure mode, which will consist of inserting nitrogen gas into the sample compartment, allowing the partial pressure variation between 1 and 133 Pa (1 Pa = 1×10^{-5} bar), working distance 8.5 mm, power of 20 kV and aperture of 60 µm.

Statistical analysis

A heat map was constructed based on Table S1, to evaluate polished rice, using the average Euclidean distance and the k-means clustering method. These analyses were performed with the aid of the "ggfortify" package of the free R (R Core Team, 2018) application and followed the procedures recommended by Naldi et al. (2014). Pearson correlations were estimated to verify the association between the variables, and, due to the large number of variables evaluated, the results were expressed graphically in the correlation network. The proximity between the nodes (traces) was proportional to the absolute value of the correlation between these nodes. The thickness of the edges was controlled by applying a cutoff value of 0.60, which meant that only $|\Upsilon XY| \geq 0.60$ had their edges highlighted. Finally, positive correlations were highlighted in green, while negative correlations were represented in red scale.

Results and discussion

Paddy rice drying

The ambient air temperature and relative humidity, and the air temperature and velocity at the dryer inlet and exhaust during drying are presented in Fig. 1C-D. There were oscillations in the temperatures and velocities of the drying air throughout the drying process (Fig. 1C-D), which may have impaired the quality of the grains, especially in physical damages, such as cracks in the tegument, cotyledons, and embryonic axis. Analyzing the drying curves there is a similarity between the drying and intermittence stages, with the curves being linear (Fig. 1E) as a result of drying time. The grain moisture content reduced from 21.7% to 10.9% with grain mass temperature variation from 29 to 49 °C, as per Fig. 1F.

The rice was subjected to the action of the heated air in the drying chamber at regular time intervals and preceded to the intermittence chamber (Franco, Lima, Farias & Silva, 2020). The intermittence ratio kept the temperature of the grain mass below the drying air temperature, even when it has high values (Maldaner et al., 2021). Furthermore, the moisture removal rate increased during the drying stage, reduced drying time, and improved the quality of the rice (Kumar, Karim & Joardder, 2014). However, the high drying speed caused the moisture migration to suffer the effects of internal compression and surface tension, due to the high moisture gradient between the grain's interior and its surface (Kumar, Karim & Joardder, 2014). The moisture directly influenced the temperature variation because its specific heat was higher than that of the grain, and thus, for the same amount of heat supplied, the grain's temperature raised faster (Zhou et al., 2018).

There was a reduction in the grain moisture content and an increase in the temperature of the grain mass over time in the drying chamber, while the moisture content of the intermittence chamber became uniform and migration of moisture in vapor form from the inner layers to the surface, which facilitated the evaporation of the water and the reheating of the grains in the new passage through the drying chamber (Zhou et al., 2018). A sharp increase in the temperature of the grain mass was noted in the first two hours of drying. The initial behavior of the drying curves was similar, that is, the grains with high moisture content in the drying chamber received heat that was absorbed by the water, not markedly changing the temperature of the grain mass at the dryer discharge. The difference between the curves increased during the drying process. This is due to the lower specific heat of the dried grains, and thus most of the absorbed heat is quickly dissipated.

The higher the heating of the drying air, the greater amount of water it is able to retain. The abrupt removal of water from the grains with drying air temperature above 70 °C may have caused thermal damage to the grains (Maldaner et al., 2021). The effects of intermittent drying on rice quality were enhanced by the abrasive effects of polishing and the high initial moisture content of the grains (Kumar, Karim & Joardder, 2014). The moisture content of rice is linked to rice quality and can influence processing steps. Wongpornchai, Dumri, Jongkaewwattana and Siri (2004) highlight that the drying method and time causes significant effects on the quality of the processed rice. Temperature, drying time, and moisture removal rate affect the physical and physicochemical properties of rice, such as whole grain yield, crude protein, and starch (Mittal, Dutta & Issac, 2019). The time of the intermittent drying operation was related to the drying air temperature and the intermittence rate (Fig. 1C-F). The whole grain yield was affected by the formation of cracks during drying. In addition to compromising the yield, the cracks also negatively altered the chemical composition of the grains (Ravikanth, Jayas, White, Fields & Sun, 2017). The imbalance of moisture contents between the grain's center and surface influenced the drying process and may have altered the quality of the grains. Grains with cracks subjected to processing broke, especially during when removing the husks and polishing, leading to yield reduction (Lang, Silva, Ferreira, Hoffmann, Vanier & Oliveira, 2019).

Physical and physicochemical quality of polished and brown rice

Table S2 shows the results of the variance analysis F test, as a result of experimental treatments, drying stage, drying time and type of processing. All variables analyzed had at least one significance at 1 or 5% probability, either in single, double, or triple interaction, except the analysis of physical classification of chopped and stained grains. Table S3 shows the average results obtained by the interaction type of processing × drying stages.

Among the types of processing, it was found that brown rice maintained a higher yield than polished rice, as expected due to the abrasive effects of polishing. The same effect was favorable for obtaining a higher percentage of starch in polished rice and unfavorable on the percentages of ash in brown rice. The results were similar among the drying stages for higher rice yield and lower percentages of starch in the intermittence stage. In the intermittence stage of the rice, moisture migrated from the center to the periphery of the grains through moisture diffusion, decreasing the moisture content and avoiding heat damage and quality degradation. Analyzing the results in Table S4, we found that the initial and intermediate drying times altered the starch yield more intensely, whereas crude protein was more affected in the final stage of drying.

Observing the results in Table 1, the initial stage of drying provided higher percentages of burned and moldy grains, reducing the starch contents, while the percentages of protein and ash were more affected in the final stages of drying. Among the types of processing, greater defects of burned and moldy grains were found in brown rice, as well as greater reductions in starch composition. In contrast, brown rice maintained higher protein percentages; however, it achieved higher ash percentages compared to polished grains. Polished rice is the product resulting from the processing where the germ, the pericarp and most of the inner layer, the aleurone, were removed. This polishing reduced the nutrient content, with the exception of starch, which caused differences in composition between polished and brown rice.

Table 2 shows the effects of the three-way interaction on the physical and physicochemical quality of the polished rice. For polished rice, at the beginning of the drying process we verified the highest percentages of broken grains, while in brown rice; we obtained the highest percentages of whole grains (yield) at the end of the drying process. The intermittency step decreased the effects of drying and the reduction of broken grains at the end of the process. This also occurred for percentages of healthy grains, and the opposite regarding percentages of chalky grains. The final drying time increased the percentage of chalky grains, especially in brown rice. The percentages of crude fibers were alternated with the increase of drying time. The main difference occurred because of the way the grain was processed, where the highest values were observed in brown rice. The fat content was higher in the grains at the beginning of drying, tending to equalize the values between polished and brown rice at the end of the drying time.

Multivariate analysis

In Fig. 2A is the heat map, which considers the two types of processing, type, and drying time. Group (1) gathered the five initial intermittent drying times and polished rice drying. The only brown rice treatment included in this group was the 1 h intermittent time (T29). This group was characterized by obtaining the lowest averages for the variables moisture content (MC), healthy grains (HEA), ash (ASH), fat (FAT), starch (ST), crude protein (CP) and crude fiber (CF). In addition, this group presented the highest averages for the variables moldy grains (MOL), grains broken during processing (BP) and fragmented grains (FG). Group 2 gathered the other treatments related to polished rice and was characterized by obtaining the highest averages for the variable chalky grains (PLA). This group presented intermediate values for the other variables. Group 3 included all the types and drying time of whole rice, with the exception of T29. This group stood out for presenting the highest averages for the variables income (IN), yield (YIE), ash (ASH), crude protein (CP), green grains (GRE), red grains (RED), burnt grains (BUR) and sailor grains (SAI). This group showed similar values to the previous group for the other variables.

Table 1
Significant results of the interaction drying, intermittency, drying time, and type of processing.

Analysis	Type of processing	Drying time		
		Initial	Intermediary	Final
Burning (%)	Brown rice	2.25 Aa	0.96 Ab	0.77 Ab
	Polished rice	0.29 Ba	0.32 Ba	0.05 Bb
Moldy (%)	Brown rice	0.45 Aa	0.00 Ab	0.00 Ab
	Polished rice	0.00 Ba	0.00 Aa	0.00 Aa
Starch (%)	Integral	61.72 Bc	65.73 Bb	68.52 Ba
	Polished rice	71.51 Aa	70.70 Aa	70.42 Aa
Crude protein (%)	Brown rice	11.71 Aa	11.74 Aa	10.69 Aa
	Polished rice	11.39 Aa	7.10 Bb	8.62 Bb
Ashes (%)	Brown rice	1.62 Aa	1.40 Aa	1.34 Aa
	Polished rice	1.31 Aa	0.57 Bb	0.49 Bb

Means followed by capital letters in the column and lowercase letters in the row differ from each other at 1 and 5% probability.

The formation of three groups of treatments with rice quality variables indicated the effects of drying. As verified in Fig. 1E, at the beginning of drying and intermittency (first 5 h) the water removal rate was higher, being intermediate between 5 and 10 h and lower between 10 and 13 h. Regardless of the processing, the increase in rice drying and intermittency time and the reduction in water content affected the physical and physical–chemical quality of the grains, as seen in Fig. 2A. The effects of drying on grain quality are confirmed by other studies (Tran et al., 2018; Zhou et al., 2018; Maldaner et al., 2021) carried out with rice, however, the extension of the intermittence × drying time was still an not clear factor, the main one on the nutritional effects of rice.

Pearson's correlations between the variables evaluated in brown and polished rice are presented in Fig. 2B. The variables IN, TW, YIE, MC, FAT, BUR, CF, PLA, ASH, and CP are highly positively correlated with each other. The variable MOL is negatively correlated with the variables in this group, especially with PLA, CP, CF, MC, and ST, to which it is most closely related. The variables CG, FG and BF are positively correlated with each other, and negatively correlated with GV and GVE. Other positive correlations found were between GRE × RED, RED × SAI, and SAI × BUR. The results confirmed the physical alterations caused by the prolonged intermittency drying, which reflected on the nutritional quality of the processed rice. These variations were observed between the drying and processing methods used, for example, on the aroma and milling quality of rice verified by Wongpornchai, Dumri, Jongkaewwattana and Siri (2004) for different drying methods. Likewise, Xu et al. (2017) verified that drying rice using high air temperatures caused changes in the biophysical characteristics of rice and in the physicochemical properties of starch. However, the combination of intermittent drying for longer periods, starting from 4 to 6 h, did not collaborate to reduce the effects of the drying process on the processed rice quality. The high drying air temperatures compromised the quality of the grains, but the drying time also influenced. Thus, it became evident that the drying speed, that is, the time the grains remain in the process is as important as the air temperature used to reduce the moisture content in the drying.

X-ray diffraction and scanning electron microscopy analyses on polished and brown rice grains

The effect of the number of cycles of the grain mass in the dryer influenced grain cracking. As an increase in temperature, the evaporative capacity of the drying air increased, as well as grain cracking. The percentage of chalky grains was also lower as the number of numbers of dryer cycles. Thus, it was verified in the X-ray diffraction patterns the relative crystallinity of the polished rice (Fig. 3A), indicating a semicrystalline structure of the starch. Regardless of the drying time, the observed 2-theta diffraction peaks showed values of 15°, 17°, 18°, 20°, and 23°, indicating that the rice starch granule exhibits a type A pattern, a crystalline starch structure typically found in cereals. Physicochemical quality was related to the content of starch, protein, lipids, and ash. The relative crystallinity values were similar to found by Donlao, Matsushita and Ogawa (2018) (31.37% and 27.21%), however, despite the peaks found in the same regions, Ramos, Rockenbach, Ferreira, Gutkoski and Oliveira (2019) found lower values of 19.59% in intermittent drying and 25.2% by Ziegler et al. (2017). Timm, Lang, Ferreira, Pohndorf and Oliveira (2020) found that rice crystallinity reduced as drying temperature increased, attributing this possibility to the shortening of the amylopectin chains associated with the use of intense heat treatments and accelerated water removal, resulting in retrogradation of the starch.

The effects of heat treatments on rice grains and starch were also verified by scanning electron microscopy (Fig. 3B-J). Aquerreta, Iguaz, Arroqui and Virseda (2007) studied the effect of the drying cycle on cracking and whole grain yield of rice at different temperature periods. They concluded that the percentages of cracked grains decrease when drying is performed in two or three stages collaborated with results

Table 2
Significant results of drying interaction, intermittency, drying time, and type of processing.

Analysis	Type of processing	Drying step					
		Intermittent			Drying		
		Initial	Intermediary	Final	Initial	Intermediary	Final
Broken (%)	Polished rice	14.38 Ab	9.01 Ac	8.01 Ac	20.26 Aa	10.71 Ac	8.28 Ac
	Brown rice	1.54 Bb	3.67 Ba	4.79 Ba	1.54 Bb	3.40 Ba	4.78 Ba
Yield (%)	Polished rice	52.23 Bc	59.45 Ab	62.57 Ba	43.42 Ad	55.92 Bc	60.19 Ba
	Brown rice	79.92 Aa	76.49 Bb	75.16 Ab	79.92 Ba	76.28 Ab	74.74 Ab
Plastered (%)	Polished rice	1.59 Ac	3.35 Aa	3.69 Aa	1.14 Ac	2.64 Ab	3.32 Aa
	Brown rice	1.57 Ac	2.00 Ab	1.62 Ac	1.57 Ac	2.40 Ab	3.67 Ba
Healthy (%)	Polished rice	38.90 Ac	50.09 Aa	56.34 Aa	34.34 Bc	46.80 Bb	54.48 Aa
	Brown rice	50.52 Ac	58.64 Ab	63.02 Aa	50.52 Ac	58.64 Aa	55.57 Bb
Fat (%)	Polished rice	0.70 Ad	1.93 Ba	1.60 Ab	1.19 Bc	1.77 Aa	1.54 Ab
	Brown rice	2.39 Ba	1.35 Ad	1.70 Bc	2.19 Ab	1.49 Bc	1.53 Ac
Crude fiber (%)	Polished rice	1.12 Ac	1.94 Ba	1.43 Ab	2.09 Ba	1.83 Aa	1.37 Ab
	Brown rice	2.04 Aa	2.08 Aa	1.94 Aa	2.06 Aa	2.06 Aa	2.00 Aa

Means followed by capital letters in the column and lowercase letters in the row differ from each other at 1 and 5% probability.

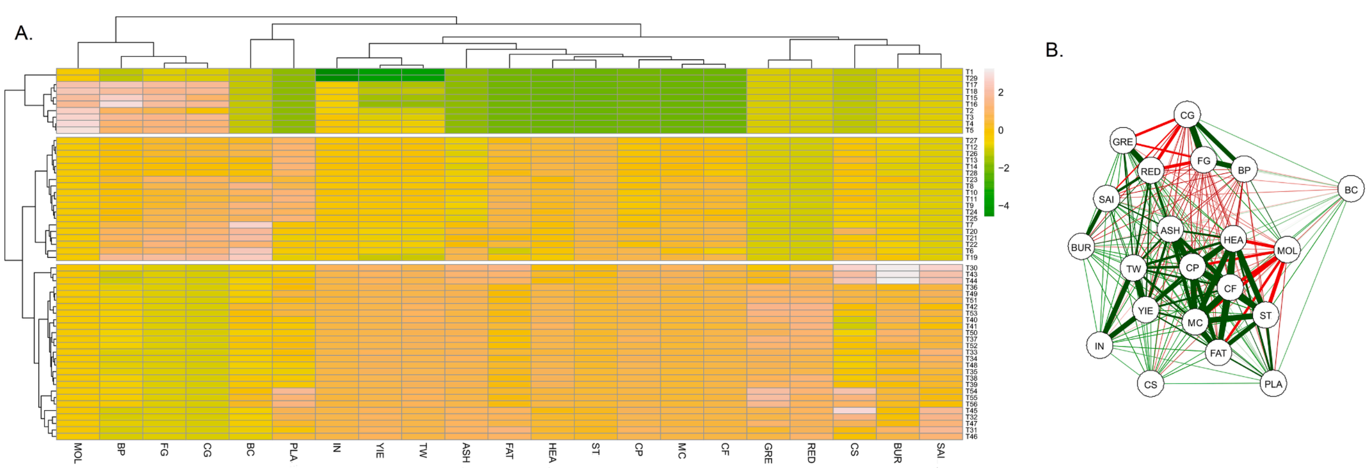

Fig. 2. Euclidean distance heat map for treatments and quality variables evaluated in brown and polished rice **(A)**: income (IN), yield (YIE), broken grains in processing (BP), broken grains in classification (BC), cracked grains (CG), fragmented grains (FG), total weight (TW), healthy grains (HEA), burnt grains (BUR), moldy grains (MOL), plastered grains (PLA), chopped and spotted grains (CS), green grains (GRE), sailor grains (SAI), red grains (RED), moisture contents (MC), crude protein (CP), crude fiber (CF), fat (FAT), starch (ST) and ash (ASH) evaluated in brown and polished rice. Pearson's correlation network between variables **(B)**: income (IN), yield (YIE), broken grains in processing (BP), broken grains in classification (BC), cracked grains (CG), fragmented grains (FG), total weight (TW), healthy grains (HEA), burnt grains (BUR), moldy grains (MOL), chalky grains (PLA), chopped and spotted grains (CS), green grains (GRE), sailor grains (SAI), red grains (RED), moisture contents (MC), crude protein (CP), crude fiber (CF), fat (FAT), starch (ST) and ash (ASH) evaluated in whole and polished rice. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

obtained in this study. Müller et al. (2021) state that the presence of spaces between the starch granules in chalky endosperms influences the grain density, causing the grains to break more easily when drying. Some of the parameters that define the properties of starch were the size of the granules, the power of expansion, solubility, properties of gelatinization and amylose content (Zhu et al., 2019).

In addition, the proteins were affected by the drying operation, a phenomenon observed by Menezes, Pasqualli, Barbieri, Vidal and Conceição (2012), who evaluated the different drying temperatures of 32, 38, 44, and 50 °C on the physicochemical quality of rice grains. They observed that the crude protein content in grains was negatively affected with increasing drying temperature, especially at temperatures from 32 to 50 °C. Scariot, Karlinski, Dionello, Radünz and Radünz (2020) analyzed the drying air temperature and its impact on the industrial quality and chemical composition of rice grains. The authors used the intermittence rate of 1:1, at temperatures of 55 and 65 °C. According to the results, increasing the temperature decreased the grain yield and the lipid contents were reduced, increasing the ash content for polished rice. Polishing processes influenced amylose content and physicochemical properties, indicating changes in quality (Syahariza, Sar, Hasjim, Tizzotti & Gilbert, 2013).

Fig. 3L-N shows that the percentages of micronutrients were altered as the drying time increased. Effects caused by processing associated with the drying time were observed on the physical–chemical quality of grains, mainly as a result of polishing. Polishing rice removed the layers where the bran and germ are, which are rich in protein, fiber, and fat, altering the appearance of the rice. Thus, although the polishing process provides benefits to the physical, sensory, and preservative properties of rice, nutritional properties are diminished (Fig. 3L-N).

The rice polishing determined the proportion of bran and endosperm that was altered. Monks et al. (2013) examined the effects of the polishing (8–14%) on the fatty acid composition of rice, the centesimal composition, amylose content, and technological properties of rice. The results obtained showed that even the lowest degree of polishing caused the decrease of folic acid, ash, and fat content by approximately 72%, 41% and 65% respectively. Polishing also decreased the fatty acid content. Wang et al. (2021) also assessed the effect on the physicochemical quality of divergent rice polishing degrees (0–12%). They observed that as the degree of polishing was increased, yield, protein content, lipids, ash, fiber, vitamin B1, vitamin E, and niacin decreased. Starch and amylose content, however, increased in a non-linear fashion. The yield dramatically decreased according to the degree of polishing,

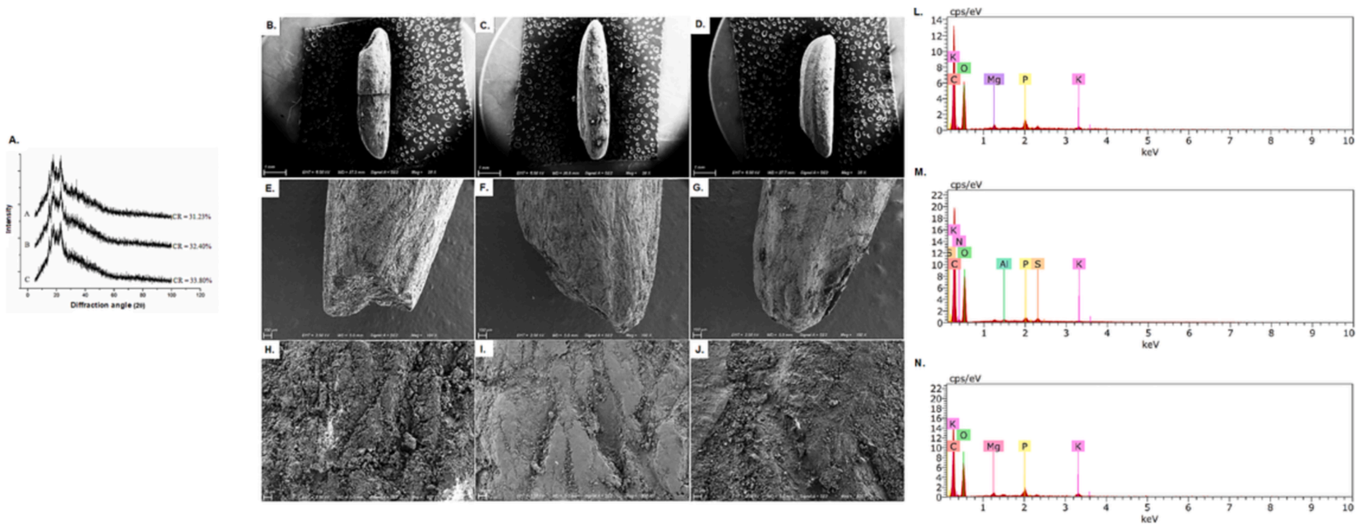

Fig. 3. X-ray diffractograms and the relative crystallinity of polished rice **(A)**. The letters A, B, and C indicate the samples collected at the initial (zero to five hours), intermediate (five to ten hours), and final (ten to fourteen hours) drying times, respectively. Scanning electron microscopy of polished rice as a result of cumulative drying effects processes and intermittence in initial (zero to five hours) **(B, E, H)**, intermediate (five to ten hours) **(C, F, I)**, and final (ten to fourteen hours) drying time **(D, G, J)**. Chemical composition of polished rice as a result of cumulative effects of drying and intermittency in initial (zero to five hours) (**L**), intermediate (five to ten hours) **(M)**, and final (ten to fourteen hours) **(N)** drying times.

from 62.13% to 33.16%.

The X-ray diffraction patterns, and crystallinity obtained from brown rice samples are presented in Fig. 4A. The diffractogram patterns of both samples indicate the brown rice grains have semi-crystalline structures, with diffraction peaks and the formation of an A-type pattern. Fig. 4A shows that the relative crystallinity of brown rice tended to increase as drying time increased. Fig. 4B-J presents the scanning electron microscopy images of rice subjected to drying and whole grain processing. A drying time above ten hours (final) intensified the damage to the morphology of the rice grains, although, whole grain processing preserved much of the grain structure. The chemical composition of minerals had the same behavior in polished and whole grain rice, as a result of drying and intermittent processes, conserving the highest percentages of nutrients at the end of the process and in whole grain rice (Fig. 4L-N). Tempering mitigated the effects of drying on the quality of the grains until the final stages of the process, when the increase in cycles and the temperature of the grain mass outweighed the mild effects of intermittence.

Conclusions

With this, it was concluded in this study that the cumulative drying time and number of cycles the rice underwent in the dryer increased the temperature of the grain mass and accentuated the physical and thermal damage, while, the intermittence lessened the mass transfers, collaborating to the final quality of the processed rice. Finally, the joint drying-intermittence process of rice reduced the physical, physicochemical, and morphological quality, especially that of polished rice. For future full-scale applications with the aim of obtaining high yields of whole grains and physicochemical quality, a maximum time of 5 h is recommended for the intermittent drying stage of paddy rice, when the grains are destined for polishing and 6 h when rice is processed whole grain.

CRediT authorship contribution statement

Samuel Martens: Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Paulo Carteri**

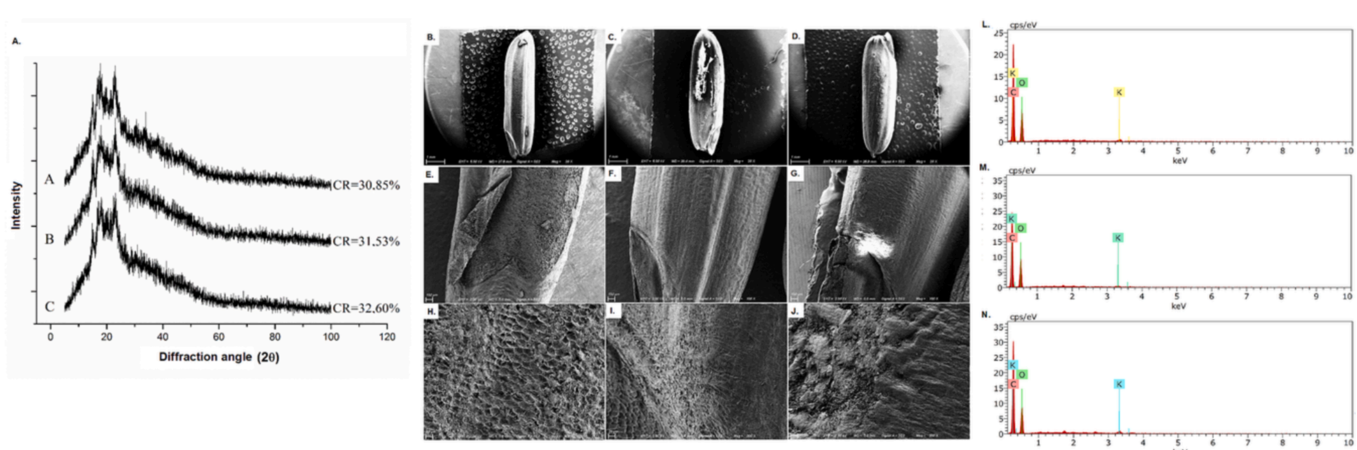

Fig. 4. X-ray diffractograms and the relative crystallinity of brown rice **(A)**. The letters A, B, and C indicate the samples collected at the initial (zero to five hours), intermediate (five to ten hours), and final (ten to fourteen hours) drying times, respectively. Scanning electron microscopy of brown rice as a result of cumulative effects of drying and intermittence processes in initial (zero to five hours) **(B, E, H)**, intermediate (five to ten hours) **(C, F, I)**, and final (ten to fourteen hours) drying time **(D, G, J)**. Chemical composition of brown rice as a result of the cumulative effects of drying and intermittence in initial (zero to five hours) **(L)**, intermediate (five to ten hours) **(M)**, and final (ten to fourteen hours) **(N)** drying times.

Coradi: Methodology, Investigation, Writing – original draft, Writing – review & editing. **Vanessa Maldaner:** Methodology, Formal analysis, Investigation. **Letícia de Oliveira Carneiro:** Investigation. **Paulo Eduardo Teodoro:** Writing – review & editing. **Dágila Melo Rodrigues:** Formal analysis. **Kellen Francine Anschau:** Formal analysis. **Larissa Pereira Ribeiro Teodoro:** Formal analysis. **Érico Marlon Moraes Flores:** Formal analysis, Writing – original draft, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2023.100753.

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