Original Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.65722

Effect of the drying air conditions on the drying rate and milling quality of a long-grain rice variety

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Abstract

This work aims to study the effect of different drying air conditions on the drying rate and milling quality of a Uruguayan long-grain rice variety. It was observed that increasing the drying air temperature or lowering the drying air relative humidity decreased the milling quality. At temperatures above glass transition, this effect was greater. However, it was possible to dry the rice at a drying rate of up to 3 percentage points of moisture per hour (on a dry basis) maintaining a high milling quality. This was achieved when a 1-hour tempering was performed after drying. At higher drying rates, the milling quality decreased sharply even when tempering was performed. These results aim to contribute to the understanding of the drying process, allowing its optimization by increasing the drying rate without losing milling quality.

Keywords: rice; rice drying; drying rate; milling quality; glass transition.

Practical Application: During the harvest season, large quantities of paddy arrive to the industries and drying fast enough to avoid deterioration is a challenge. As the drying rate increases, the milling quality decreases. Therefore, optimizing the drying rate is of extreme importance. The present work studied thin layer drying of a long grain rice variety under different drying conditions, contributing to the understanding of the drying process and the influence of the drying conditions on the drying rate and milling quality.

1 Introduction

Rice is a cereal produced all around the world, being the most important cereal crop in developing countries and the staple food of over half of the world's population (Juliano, 1993). After harvest, the rice grains are dried, stored, dehulled and milled. The drying process is necessary to assure rice preservation during storage. Rough rice is usually harvested with a moisture content (MC) above 18% (on a wet basis) and dried to a final MC of 12-14% wet basis for a safe storage. During this process, kernels are subjected to fissuring and breakage due to mechanical stresses generated inside them (Buggenhout et al., 2013). Several studies reported that extensive fissure formation inside rice kernels was related to the development of intra-kernel moisture gradients combined with the occurrence of the glass transition phenomenon (Cnossen & Siebenmorgen, 2000; Cnossen et al., 2001; Yang et al., 2003).

Intra-kernel moisture gradients are formed during drying, due to a faster rate of moisture removal in the outer cells of the rice kernels compared to the rate of water migration from the center to the outer layers of the grain. This generates a moisture gradient from the center (more humid) to the surface of the kernel. This period, controlled by water diffusion inside the kernel, is the main mechanism controlling the moisture loss during rice drying (Franco et al., 2020).

The most external layers, at the surface of the kernel, tend to the equilibrium moisture content (EMC) (Cnossen et al., 2002). The EMC is defined as the MC of the kernels after exposing them to certain air conditions for an infinitely long period of time (Brooker et al., 1992). As moisture is lost, the surface cells tend to shrink, causing tension at the surface and compression at the center of the grain (Kunze & Choudhury, 1972). These stresses can cause the kernel to fissure when the failure strength of the rice is exceeded (Dong et al., 2010).

The glass transition phenomenon is related to rice composition, specifically of some parts of the starch. Starch is the main component of rice (around 90% of the dry weight of a milled rice grain), containing crystalline and amorphous areas (Fitzgerald, 2004). Glass transition occurs in the amorphous areas. The glass transition temperature (Tg) is the temperature range of transition from a glassy into a rubbery state (Liu et al., 2010). Tg is an important parameter that influences many physical and mechanical properties, affecting rice fissuring and breakage (Mukhopadhyay & Siebenmorgen, 2018). Below Tg, the amorphous regions are in a glassy state, with low expansion coefficient, specific volume, specific heat and diffusivity, but high viscosity and modulus of elasticity. Above the Tg, the material is in a rubbery state, with higher expansion coefficient, specific heat, specific volume and diffusivity (Cnossen & Siebenmorgen, 2000; Perdon et al., 2000). In the rubbery state, greater drying rates are achieved due to the higher specific heat and diffusivity associated to this state (Mukhopadhyay & Siebenmorgen, 2018). If the MC gradient within a kernel is sufficiently pronounced,

Received 30 June, 2022
Accepted 21 Sept., 2022
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the center of the kernel (more humid) will be in a rubbery state while the outer part (with lower MC) will be in a glassy state. The differences in the property values of these two states generate considerable tensions that may be enough to cause fissures at the interface of the two regions (Schluterman & Siebenmorgen, 2007). Therefore, the combined effect of pronounced intra-kernel MC gradients in the presence of the glass transition phenomenon, which results in the coexistence of starch in different states within the kernels, is thought to be responsible for extensive fissure formation during the drying process.

Fissures may also develop after the drying process, if MC gradients are not allowed to subside (tempering) before cooling the grain (Cnossen & Siebenmorgen, 2000; Cnossen et al., 2001; Ondier et al., 2012).Tempering is a procedure during the drying process in which rice is held without blowing drying air through the grain for a certain period. It is used to allow moisture gradients within a kernel to subside (Cnossen & Siebenmorgen, 2000), preventing the coexistence of starch in different states (glassy and rubbery).This reduces tensions within the kernel and thus, reduces the formation of fissures. Franco et al. (2020) proved that the moisture gradient inside a kernel was minimized when a tempering period was included during the drying process. While drying involves simultaneous heat and mass transfer, tempering only deals with mass conservation within the grains (Assar et al., 2016).

Fissured kernels are more susceptible to breakage during the milling process, in which they are subjected to stress. Therefore, fissures formation must be avoided to prevent a reduction of the milling quality (MQ), defined as the percentage of kernels that remain unbroken after milling.

The objective of this work was to study the effect of the drying air conditions on the drying rate and the MQ of a Uruguayan long-grain rice variety (Uy2). To this purpose, different combinations of drying air relative humidity (RH) and temperature (T), above and below Tg, were used to produce different drying severities (different MC gradients inside the kernels) at a laboratory scale. The drying rate and MQ were determined for each drying condition and compared.

2 Materials and methods

2.1 Rice sample

Rough rice of the long-grain Uruguayan variety Uy2 was collected from a single producer in the south-east region of Uruguay. The harvest MC of the rice lot was 20.5 +/- 1.0%.

The rice sample was homogenized and stored in a refrigerating chamber at 4.3 +/- 1.8 °C until use, to prevent deterioration. Before each experiment, the amount needed was removed from the chamber and left in sealed bags at room temperature for at least two hours.

2.2 Determination of MC

The MC was determined by gravimetry (American Association of Cereal Chemists, 1999). Briefly, the samples were ground in an ultracentrifugal ZM200 mill (Retsch, Germany). Then, approximately three grams were exactly weighed in an aluminum capsule and dried in a forced convection oven (Memmert, Germany) at 130 °C for one hour. The water content of the samples were calculated based on the weight difference and expressed as percentage on a wet basis.

For samples with MC greater than 16%, a two-stage method was used (American Association of Cereal Chemists, 1999). Approximately 20 g of paddy rice were weighed, allowed to dry on the surface of the stove for 24 hours and weighed again (to determine the water loss). Then, approximately three grams of the sample were milled and the same procedure used for samples with MC lower than 16% was followed.

2.3 Glass transition

Figure 1 shows the glass transition temperature diagram for the Uy2 variety (Garcia-Llobodanin et al., 2020). The rice kernel represented in the figure shows that if the MC gradient formed during drying is sufficiently pronounced (center of the kernel above Tg and surface below Tg), the rubbery and the glassy states may coexist. The experimental design was set up to have drying conditions above and below Tg, as detailed below.

2.4 Experimental design

Table 1 shows the experimental design for this study. The drying air velocity was set at 0.4 m/s for all runs. The air T and RH were constant during each run. The air T was chosen to have runs below and above Tg (see Figure 1). Two RH were tested at each air T. The RH were chosen to have the same EMC values (7% and 10%) at all the air T levels. The RHs for each combination of EMC and air T were calculated using the modified Chung-Pfost equation for long grains (Ondier et al., 2011). For some runs, the air conditions set could not be reached (due to limitations of the drying system). In those cases, the runs were set at the closest condition possible (see Table 1). At the air T of 47 °C, a greater variation of the MQ was observed between the two EMC conditions, compared to those observed at the

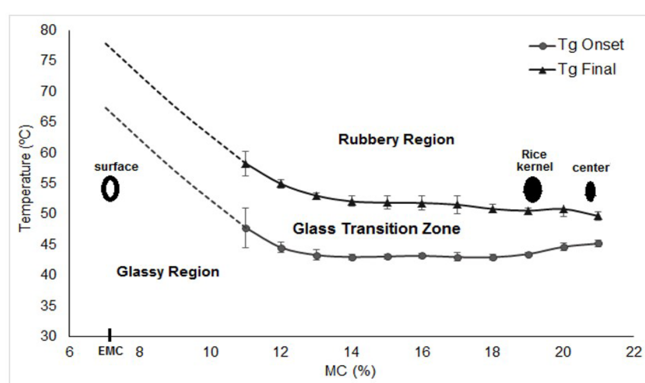

Figure 1. Glass transition temperature (Tg) diagram of brown rice kernels of the Uruguayan variety Uy2 > MC = moisture content expressed as % on a wet basis, EMC = equilibrium moisture content; Tg onset = beginning of the glass transition zone; Tg, final = end of the glass transition zone. The continuous curve was built based on experimental data (markers); the dotted line was a projection.

other air temperatures. Therefore, two runs at two additional RHs (corresponding to EMC of 8.5% and 12%) were added.

The rice samples reached the drying air temperature within the first 2-3 minutes of run, in all cases. Therefore, the grain temperature was considered equivalent to the drying air temperature.

2.5 Drying system

Rice was dried in a laboratory drying equipment especially designed and built for this purpose (Urumáquinas, Uruguay). It allowed controlling the drying air conditions including T, RH and velocity with a precision of +/- 0.6 ºC, +/- 2.6% and +/- 0.02 m/s, respectively. The equipment also monitored the weight loss and grain temperature of the sample during drying. Figure 2 shows a schematic of the drying system used.

The ambient air entered the system with the aid of a blower, which controlled the air velocity. A condenser and a vapor injector regulated the air humidity and resistors regulated the air temperature. A sensor of T and RH together with a sensor of velocity was installed just before the drying chamber. Air conditions were set and controlled with the aid of a Programmable Logic Controler (Secoin, Uruguay).

The rice sample was disposed in a tray with a perforated bottom, to allow air circulation. A temperature sensor was introduced in the rice sample to monitor the grain temperature. The sample weight was measured with the aid of a load cell and the grain MC was calculated at different durations using the initial MC and the weight as shown in the following Equation 1:

$$MCt = 100\left(1 - \frac{IW}{Wt}\left(1 - \frac{IMC}{100}\right)\right) \quad (1)$$

Where MCt is the MC at a time t, IW is the initial weight of the sample, Wt is the weight of the sample at a time t and IMC is the initial MC of the sample expressed on a wet basis.

All parameters (air T, RH, velocity and sample weight) were registered every five minutes.

2.6 Rice drying

Once the drying air reached the set condition, five hundred grams of paddy rice were put on the tray, arranged in a thin layer of one centimeter high, and introduced into the drying chamber.

A drying curve was built for each condition, leaving the rice to dry until no MC change was detected (at least ten consecutive measurements with grain MC differences among measurements lower than 0.5%). The drying curves were fitted to Page's equation (Chen et al., 1997) (Equation 2):

$$\frac{MC - EMC}{IMC - EMC} = \exp\left(-k.t^{n}\right) \quad (2)$$

Where MC is the moisture content at the drying duration t (h), EMC is the equilibrium moisture content, IMC is the initial moisture content, k is the drying rate constant (h^{-1}) and n is a dimensionless constant. MC, EMC and IMC are expressed in a decimal dry basis. The time needed to reach the final MC of approximately 13% at each drying air condition was calculated

Table 1. Experimental design.

T (ºC)	*RH* (%)	EMC (%)
35	25	7.4
35	50	10.0
47	27	7.0
47	42	8.5
47	57	10.0
47	70	12.0
55	30	7.0
55	60	10.0
65	31	6.5
65	45	8.6

T = air temperature (ºC); RH = relative humidity (%); EMC = equilibrium moisture content (%).

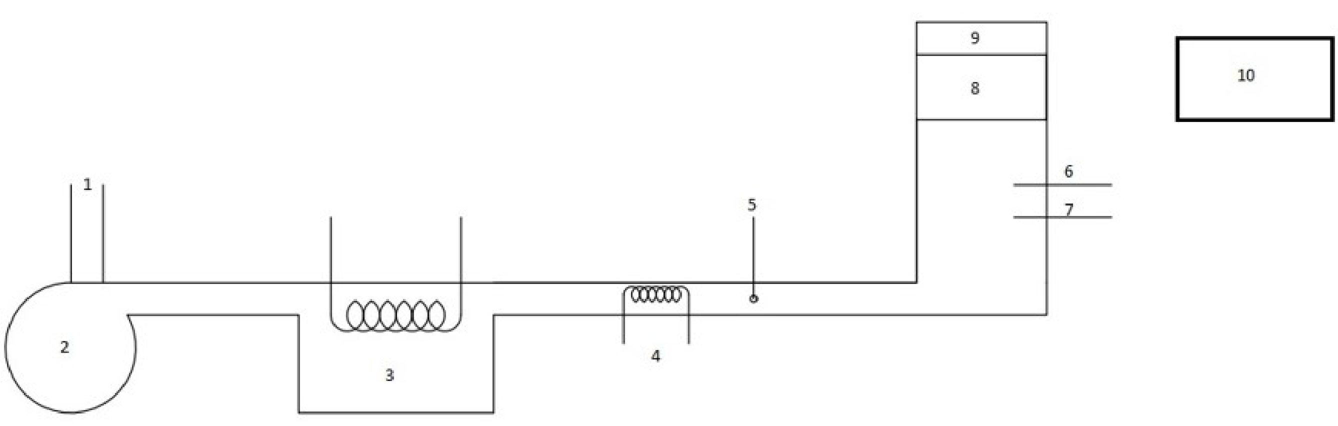

Figure 2. Schematic of the drying equipment. 1 = air entrance; 2 = blower; 3 = condenser; 4 = resistors; 5 = vapor injector; 6 = velocity sensor; 7 = air temperature and relative humidity sensor; 8 = drying chamber; 9 = load cell; 10 = PLC: Programmable Logic Controller.

using each fitted equation. Then, to evaluate the milling quality, new rice samples were dried for the corresponding period of time at each drying air condition, to a final MC of 13 ± 0.7%.

Tempering tests were performed for the runs with the most severe drying air condition (T = 65 °C, RH = 31%) to determine if it reduced the number of broken kernels. The tempering process consisted in keeping the sample in the drying chamber in sealed double plastic bags (to prevent the sample from continuing to dry). No tempering and two tempering conditions: 1 hour and 2.5 hours, were tested and the results were compared. Table 2 shows that there was no significant difference in the number of broken kernels among the samples tempered during 1 and 2.5 hours. However, no tempering resulted in a significant increase of the broken kernels. Therefore, in this study each dried sample was submitted to 1-hour tempering immediately after the drying run.

All experiments were performed in triplicate. The average drying rate of each run was calculated as the percentage points of MC (on a dry basis) lost during the run divided by the run time.

2.7 Milling quality

After drying and tempering, the samples were kept at room temperature for at least 72 hours. Each sample was cleaned with a grain cleaner (Grainman, USA). Then, 100 g of clean paddy were hulled using a paddy husker (THU35B, Satake, Japan). The dehulled rice samples were milled with a laboratory rice polisher (TM05C, Satake, Japan) to a milling degree (MD) of 100 ± 3, measured with a milling meter (MM1D, Satake, Japan). After milling, the broken kernels were separated using a trieur (Satake, Japan) and quantified using an Image Anlyzer (Image 5, Selgron, Brazil). The results were expressed as grams of broken kernels in 100 g of milled rice (g broken kernels/100 g milled rice).

The milling quality loss (MQL) during drying was defined as a function of the broken kernels (Equation 3):

$$MQL = (broken\ kernels)_{final} - (broken\ kernels)_{initial} \quad (3)$$

Where $(\text{broken kernels})_{final}$ was the amount of broken kernels present in the rice after the drying/tempering process and $(\text{broken kernels})_{initial}$ represent the "maximum milling potential" of the rice lot, both expressed as (g broken kernels/100 g of milled rice).

To determine the "maximum milling potential" of the rice lot, four samples were gently dried in a chamber (Alfa-Laval Gruppe, Germany) at 20.5 °C and 60% RH until a final MC of 13% (+/- 0.5%). This air condition produces minimum fissuring and thus, minimal quality loss (Fan et al., 2000; Schluterman & Siebenmorgen, 2007).

2.8 Statistical analyses

Analysis of variance (ANOVA) and the Tukey's Test were used to compare results. Non-linear regression using least squares was used to fit the drying curves to Page´s equation. All statistical analyses were performed using the software JMP 12.0 (SAS Institute Inc., USA).

3 Results and discussion

3.1 Drying rate

Drying takes place when the vapor pressure in a rice kernel is greater than that in the drying air (Fitzgerald, 2004). As water molecules evaporate at the kernel's surface, new molecules migrate from the center to the surface of the grain by diffusion. When the resistance to moisture migration inside the kernel is greater than the resistance to water vapor removal from the surface, a MC gradient is formed within the kernel (Brooker et al., 1992).

In our experiments, the average drying rate was calculated as the percentage points of MC (on a dry basis) removed during the time period of the run (ΔMC/h). Figure 3 shows these results for the different drying air T and RH.

Drying air T and RH impact both the EMC and the occurrence of the glass transition phenomena. The EMC is an indicator of the maximum drying potential that could be achieved at a specific drying air T and RH condition. Higher T and lower RH,

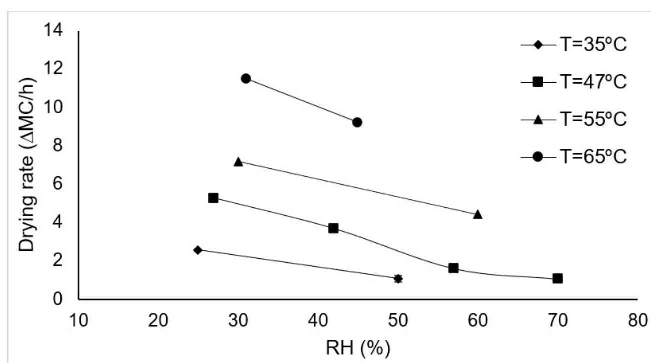

Figure 3. Drying rate at different drying air conditions > T = drying air temperature (°C); RH = drying air relative humidity (%); Drying rate = average percentage points of moisture content (on a dry basis) removed per hour during a drying run (ΔMC/h).

Table 2. Broken kernels (%) for drying runs with different tempering conditions.

Condition	Run 1	Run 2	Run 3	Mean	Std.Dev.	ANOVA	Tukey Test
no tempering	89.4	92.5	93.2	91.7	2.0	p = 0.000037	A
1 h. tempering	72.9	75.4	74.1	74.1	1.2		B
2.5 h. tempering	74.2	69.3	72.9	72.2	2.5		B

All runs were performed at a drying air temperature of 65 °C, relative humidity 31% and air velocity 0.4 m/s. Broken kernels expressed as (grams of broken kernels/100 g milled rice). $p < 0.05$ indicates significative difference among the means (ANOVA). Different characters between two rows indicate significative difference between the means (Tukey Test). h = hour; Std.Dev. = standard deviation.

decrease the EMC (increasing the drying potential). Regarding glass transition, drying above Tg (rubbery state) increase the diffusivity, as previously exposed. Therefore, increasing the drying air T or decreasing the RH is expected to increase the drying rate. Some authors confirmed this behavior for rice drying (Luthra & Sadaka, 2021; Ondier et al., 2010).

Going along with these results, in our experiments it could be observed that for a certain RH, higher drying temperatures caused higher drying rates.

At constant T, drying rates increased as RH decreased. This behavior was expected since lower RH, at a constant T, reduce the EMC (see Table 1), increasing the air drying potential. However, this increase was not linear. This could be clearly observed for the drying runs at 47 °C. When the RH decreased from 57% to 42%, the drying rate increased sharply (increase of 2.1 ΔMC/h), but the increase was not so pronounced when the RH decreased from 42% to 27% (increase of 1.6 ΔMC/h). This could result surprising considering that the decrease of the EMC was the same in both cases (1.5%). This behavior could be attributed to a reduction in water availability at the grain's surface. The drying rate is limited by the availability of water on the grain's surface, which depends on water diffusivity inside the grain (Fitzgerald, 2004). If water diffusivity is limiting water migration to the surface, the drying rate could increase less than expected (less water available to evaporate at the surface).

Water diffusivity is affected by temperature (increases with T) but also by the state of the amorphous parts of the endosperm. As previously exposed, if the kernel is in the glassy region, diffusivity is lower than in the rubbery region. This is the case of the drying runs at 35 °C (see Figure 1). At 47°C, most of the kernel is in the transition zone, while at 55 °C and 65 °C a great part of the kernel is in the rubbery region (higher diffusivity), contributing to a higher drying rate.

It is worth noting that Uy2 is a long grain rice variety, resulting in a greater surface area per unit weight (greater area for water evaporation) and a shorter path for water diffusion within the kernel, if compared with medium grain rice. Cnossen et al. (2002) found that the drying rate of a long grain rice variety (Cypress) was much more affected by the drying air RH at different constant drying air T than a medium grain variety (Bengal), especially when the air T was higher than 40 °C. In our experiments, the drying rate was strongly affected by the drying air RH (at a constant drying air T), confirming the expected behavior for a long grain rice variety.

3.2 Milling quality loss

MQL depends on the drying air conditions (temperature, relative humidity, and velocity), the rice variety, the kernels MC, the physical quality of the rice lot (fissured, chalky and immature grains), and the amount of moisture removed during drying (Buggenhout et al., 2013; Odek et al., 2018; Yang et al., 2003). In our study, all these parameters were kept constant except for the drying air T and RH.

Figure 4 shows the MQL variation with the drying rate for the different drying air conditions (T and RH). It could be observed that MQL increased as the drying rate increased (except for the air conditions at 65 °C). This was expected since higher drying rates may produce more severe moisture gradients inside the rice kernels, resulting in fissures formation (Chen et al., 1997; Fan et al., 2000). Going along with our results, Scariot et al. (2020) observed that the whole grain yield decreased as the rice drying temperature increased, associated to a humidity gradient inside the kernels.

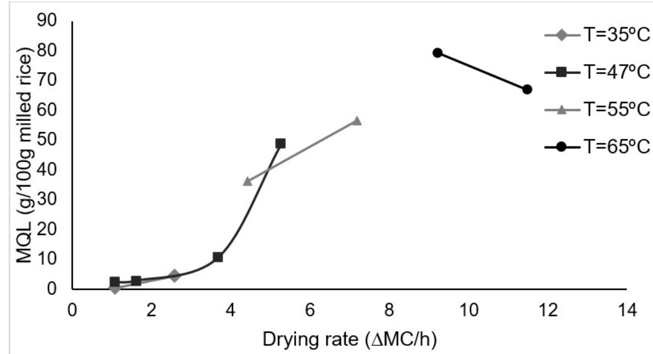

Figure 4. Milling quality loss vs drying rate at different drying air conditions. MQL = milling quality loss (g broken kernels/100 g milled rice); T = drying air temperature (°C). Each marker represents a drying air condition [T, relative humidity (RH)]. RH (from left to right) at T = 35 °C: 50%, 25%; at T = 47 °C: 70%, 57%, 42%, 27%; at T = 55 °C: 60%, 30%; at T = 65 °C: 31%, 45%.

In the runs with drying air at 65 °C, the grains were exposed to an extreme condition (considering that for our set of experiments the air temperature was equal to the grain temperature). It was observed that at the air condition of 65 °C and RH of 45% (the condition at which the grains were exposed to this temperature for a longer period), the polishing time needed to reach a MD of 100 ± 3 was almost 30 seconds higher compared to the rest of the samples (data not shown). This was probably due to chemical and physical transformations inside the kernels, caused by their exposure to a high temperature for a considerably long period of time (Dillahunty et al., 2001). Higher polishing times are associated to an increase in kernels fissure formation and breakage (Reid et al., 1998). This could explain the higher MQL obtained at a RH of 45% compared to that at 31%.

At 35 °C, both RH conditions had low MQL (0.9 and 4.9 g/100 g milled rice at RH 50% and 25%, respectively). At this T, the magnitude of the gradients formed was expected to be relatively low. In addition, under these conditions, the kernels were completely in the glassy state (see Figure 1). Therefore, the intra-kernel tensions generated were not increased by glass transition and thus, grains would be less susceptible to breakage.

At 47 °C, the MQL was low at high drying air RH (2.8 and 2.3 g broken kernels/100 g milled rice at RH of 57% and 70%, respectively), but it drastically increased at lower RH (10.7 and 48.8 g broken kernels/100 g milled rice at RH of 42% and 27%, respectively). This increase coincided with an increase in the drying rate. However, the increase in the MQL was sharper. A possible explanation for this is the formation of pronounced intra-kernel MC gradients while the glass transition phenomenon is occurring. The surface of the rice kernels reaches rapidly the EMC (Cnossen et al., 2002). At an air temperature of 47 ºC and RH of 70% (corresponding to an EMC of 12%), the whole kernel (even the surface) was completely in the glass transition zone (see Figure 1). At the same temperature and an air RH of 57% (EMC of 10%), the kernels may also be completely in the glass transition zone (considering the margin of error of the onset glass transition curve). This would explain the lower MQL at these conditions. Going along with our results, Ondier et al. (2012) found that it was possible to dry a long and a medium-grain rice cultivar (Wells and Jupiter, respectively) at high temperatures (60 ºC and higher) without increasing the MQL if the RH was sufficiently high to avoid that part of the kernel migrated to the glassy state.

On the contrary, for RH of 27% and 42% (EMC of 7% and 8.5%, respectively), the outer layers of the rice kernels were in the glassy region, while the interior was in the transition region (see Figure 1). This could explain the notable increase in the MQL. In addition, the greater quality loss at a RH of 27% compared to that at 42% was probably because of the generation of more severe MC gradients inside the rice kernels. The fact that the drying rate did not increase so sharply from 42% to 27% RH (probably due to a lack of water availability at the kernels' surface) supports this statement.

At 55 °C, the drying rate (for a certain RH) was higher compared to drying at lower temperatures. Therefore, a higher MC gradient inside the kernel, and consequently a higher MQL, was expected (Chen et al., 1997). This behavior was confirmed in our experiments (36.2 and 56.6 g/100 g milled rice at 60% and 30% RH, respectively), as shown in Figure 4. In addition, at this temperature the inner part of the kernel was in the rubbery state while the outside was in the glassy state, increasing the tensions inside the kernel and contributing to a higher MQL.

At 65 ºC, the kernel also had a rubbery and a glassy zone. Considering that in this case the drying air T was higher, a higher MC gradient was probably formed (at a certain RH). Consequently, the higher MQL observed at this drying air T was expected. As previously exposed, the transformations inside the kernels due to high temperature increased the MQL as the time of exposure to this T increased (lower RH).

3.3 Drying rate vs milling quality loss

A compromise should be made between the drying rate and the MQL. According to Figure 4, when a 1-hour tempering was performed, drying at rates below 3 ΔMC/h would keep the MQL low (below 5 g broken kernels/100 g milled rice). This was achieved at drying air T below 50 ºC and RH that depended on the air T. At higher drying rates, the MQL drastically increased.

3.4 Tempering

Tempering prevents MQL by allowing moisture gradients within a kernel to subside (Cnossen & Siebenmorgen, 2000). From our experiments, it was observed that at the most severe drying conditions, the MQL was quite high even with the grains going through a tempering process after drying. This was probably because the drying conditions produced fissures during the drying process itself, causing irreversible damage in some kernels. A pronounced MC gradient and a considerable portion of the surface in the glassy state (while the center was in the rubbery state) were probably responsible for this material failure and fissure initiation during drying (Schluterman & Siebenmorgen, 2007). Therefore, a subsequent tempering was not effective in preventing the MQL. Intermediate temperings after a certain amount of water removal would probably help reduce the MQL by reducing the magnitude of the MC gradient formed. This would be beneficial and should be studied in the future, as it would allow drying at higher drying rates without increasing the MQL.

4 Conclusion

Drying fast with the least MQL is one of the main goals of the rice industry. The present work studied the effect of the drying conditions on the drying rate and the MQL of a Uruguayan long grain rice variety (Uy2). It was observed that increasing the drying air T or lowering the drying air RH increased the drying rate, but it also increased the MQL. At temperatures where the glass transition phenomenon was present, the effect on the MQL was greater. When the drying rate was below 3 points of MC (dry basis) removed per hour, one hour tempering at the end of the drying process proved to be enough to maintain the MQL low (below 5 g broken kernels/100 g milled rice). At higher drying rates, the MQL increased drastically. Therefore, at the drying conditions studied, it is recommended to dry at rates below 3 points of MC (dry basis) removed per hour.

Considering all the findings described in this manuscript, the possibility of intermediate temperings during drying, to avoid the formation of severe MC gradients, should be studied. This could allow drying at higher rates without increasing the MQL, which is crucial for the efficiency of the drying process at a commercial scale, having a positive impact on the profitability of the rice industry.

Acknowledments

We thank the *Laboratorio Tecnologico del Uruguay* (LATU) for the financial support (grant number 1701615).

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