Modelling of the Soaking and Drying Stages for Senia-type Pre-cooked Rice

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ABSTRACT

BACKGROUND AND OBJECTIVES: The production of pre-cooked rice has mainly been applied to long rice varieties, while japonica varieties are significantly less represented, especially Spanish varieties. The aim of this paper was to model the water mass flow process in pre-cooked round-shaped rice (Bahía-Senia) for the soaking (Peleg model) and drying phases (drying by hot air and by combined hot air and microwaves, Fick, Midili and Page models). Optical and mechanical properties after drying were recorded. Cooking tests were also performed.

FINDINGS: The results show that optimum soaking process was achieved at 35°C during 20 minutes. For the drying stage, water loss increases using microwave energy at 2.45 GHz and no variations with air temperature were registered. Thus, the optimal drying conditions were achieved at 40°C combined with microwave during 42 min.

CONCLUSIONS: Precooked round rice processing conditions have been established. This treatment would reduce the final cooking time (96 ºC) for the user by 94%, which implies that in only 3 minutes the precooked rice would reach the same level of moisture as the control rice after 20 minutes of cooking.

SIGNIFICANCE AND NOVELTY: These findings can be used by food industry in selecting the proper soaking and drying conditions that favours the production of pre-cooked round-shaped rice.

KEYWORDS

Rice, precooked, kinetics, drying, microwave, Peleg, Fick, Page, Midili

1. INTRODUCTION

Modern lifestyle and concern for healthy eating have directly influenced the eating habits and the time spent at home cooking for consumers in developed countries. Nowadays, consumers demand food products with reduced cooking or preparation times that retain their full aroma, texture and flavour qualities, as well as their nutritional contents. In this context, rice is not only consumed as a staple food in many Asian countries but it enjoys increasing interest and acceptance in Europe and the United States as well (Suwannaporn et al., 2008, Suwansri et al., 2002). One way of cutting cooking times down while eating healthy is resorting to pre-cooked rice. This rice is achieved with two stages: soaking and drying (Xu et al., 2019).

During the soaking phase, the configuration of the starch undergoes certain changes. After reaching a given temperature (65°C), the starch of the endosperm in the hydrated grain gelatinizes (Bello et al., 2007). This leads to the solubilization of amyloses from the starch, which is known as retrogradation. This effect is not desirable, since it may affect the product during the storage, making the grains more liable to enzyme attacks by reducing the hardness of the grains (Mohamed et al., 2006). Soaking for a long time at low temperatures results in different texture than soaking for shorter times at higher temperatures, even though the water content may be similar (Zhu et al., 2019). The pattern of water diffusion and distribution through the grain mass is mostly non-uniform due to non-homogeneous packing arrangement of the starch, protein and fat molecules in the rice grain (Panda et al., 2019). In addition, it should be born in mind that this is a suitable stage to enrich rice with vitamins. In this sense, Kyritsi et al. (2011), found that the average retention of all vitamins in brown rice using spraying as well as soaking was above 53%.

Drying is considered the most critical stage of the pre-cooking process, since the characteristics of cooked rice depend mainly on this step. Solar drying usually lasted up to 2 days, but nowadays this step can be accelerated by applying higher temperatures and other heating sources such as microwave, infrared, fluidized-bed or high-pressure technologies (Xu et al., 2019; Ding et al., 2018). It has been found that high temperature fluidized-bed drying (130 and 150°C) (Jaisut et al., 2009) plus tempering can significantly increase the hardness of cooked or thermally treated brown rice as compared to conventionally aged brown rice (Ding et al., 2018), but for black rice this process reduces the level of phenolic compounds (Lang et al., 2019). Different drying conditions and techniques result in different starch structures (Attanasio et al., 2004). Structural changes in the rice grain are the result of contractions due to water loss and the expansions caused by the generated gas (Krokida & Marinos-Kouris, 2003).

The combination of hot air with microwaves has been widely used in rice drying (Jiao et al., 2014, Olatunde & Atungulu, 2018, Jafari et al., 2018). Microwave is a non-ionising energy which generates heat after penetrating in materials by dissipating the power of the wave due to different mechanisms, including molecular friction and conduction losses. The resulting heat enhances water evaporation and migration to the surface of products (Horrungsiwat et al., 2016). In this regard, hot air and microwave drying accelerate the removal of water from the surface (Le & Jittanit, 2015), reducing drying time. Furthermore, no significant effects were found in the starch structures of rice dispersed in deionized water and dried by microwave (Fan et al., 2013). In fact, rice grains subjected to microwave irradiation absorbed more water and lost less leached solids compared to pre-cooked rice obtained by using only hot air drying. It is also remarkable that microwave favours protein solubility, improving the pre-cooking stage (Rockembach et al., 2019).

The water absorption capability of rice has been considered an important parameter in the final properties of rice grains, affecting the final quality of rice (Bui et al., 2018). The rehydration capacity depends on the grain structure, which differs with each rice variety (Aguilera, 2005), and the cooking temperature. The higher the temperature, the more water absorbed, but at certain values it can affect nutritional contents (Batista et al, 2019).

One of the most important factors that differentiates round-shaped *japonica* and long *indica* rice types is their microstructure (Goebel et al., 2019), which is given by the amylose content of its starch (Bertoft, 2017). *Japonica* type has a lower proportion of amylose than *indica* type which influences the way in that water is absorbed. Amylose has a strong affinity to ions that are usually dissolved in water (iodine), which means that the more amylose, the more water can be tied to this molecule. Therefore, it is easier to absorb water for *indica* than for *japonica* rice types (Takeda et al., 1987).

The production of pre-cooked rice has mainly been applied to long rice varieties (Luangmalawat et al., 2008; Rewthong et al., 2011; Xu et al., 2019), while *japonica* varieties are significantly less represented (Kamruzzaman et al., 2017), especially Spanish varieties (Senia, Bomba…). The aim of this work is to model the soaking and drying stages of the pre-cooked rice production process for the Spanish "Senia" variety.

2. MATERIALS AND METHODS

2.1 Materials

The rice grains, which were a mixture of varieties obtained from the parental Senia and Bahia (Senia, J. Sendra, Montsianei and Gleva varieties, mainly), were sourced from from crops of Sollana (Valencia region, Spain) owned by the company Arrocerías Antonio Tomás. The rice was harvested in November 2017 and has an average moisture of 0.16 g w/g dm.

2.2 Soaking

A ratio of one part of rice to three parts of water was used in the soaking stage, which was carried out in a thermostat bath (Selecta Precisdig, Spain) at 35, 50 and 60°C. The samples were weighed before and after 2, 4, 6, 8, 10, 20, 30, 45 and 60 minutes soaking to establish the kinetics of water absorption. To that end, soaking samples were washed for 30 seconds to eliminate excess water and their moisture level was determined by a gravimetric method (934.06 AOAC, 2000). All experiments were performed in triplicate. The water content was expressed in grams of water per dry matter (g water/g dm) to compare the results on the same basis.

2.3 Drying

The drying tests were performed in a specially designed hot air-microwave oven (2.45 GHz) equipped with continuous output-power microwave energy as described by Heredia et al., (2010). This equipment allowed microwave power, oven temperature and air speed to be controlled. Microwave power levels were set at 0 (Hot Air (HA) treatment) and 140 W per 25 g of rice (5.6 W/g) (Hot Air+Microwave (HA+MW) treatment) at different air temperatures (40, 50, and 60°C) and with and air rate of 4 ± 0.2 m/s. For each experiment, samples of hydrated rice were distributed in single layer to remove water properly, for 60 and 100 minutes till reaching a constant moisture content.

2.4 Cooking

25 g of rice were placed in beakers submerged in a water bath with a 1:3 ratio rice: water, once the temperature of the water reached 96°C. Every minute, for five minutes, samples of rice were taken out and cooled down with a water spray to stop the cooking process, assessing their water

content. Following the same methodology, commercial rice (of the same variety) was evaluated to use it as a control reference.

2.5 Analysis

2.5.1 Water Content

The moisture level of the grains was analysed by the gravimetric method (934.06 AOAC, 2000), at 60°C for 48 hours at atmospheric pressure and then at subatmospheric pressure (-0.5 bars) till reaching constant weight.

2.5.2 Optical Properties

The colour analysis of cooked rice grains was conducted by means of a spectrophotometer Minolta (CM-3600D) with a window of 4 mm in diameter. Grains were placed in 4 mL plastic trays covered with black paper to prevent light alterations during the measurement. For each treatment, measurements were taken from four different samples. CIE-L*a*b* coordinates were obtained using D65 illuminant and 10° observer as reference system. Whiteness index (WI) of rice grains was determined using the Equation 1 (Jaiboon et al., 2009)

$$WI=100-[(100-L^*)^2+a^2+b^2]^{0.5} \quad (1)$$

Following the same methodology, commercial rice (of the same variety) was evaluated as a control reference.

2.5.3 Mechanical Properties

A TPA (Texture Profile Analysis) test was performed by means of a texture analyzer (TA.XT.plus, Microsystems stable, Godalming, UK) using a probe of 4 mm diameter, at a speed of 10 mm/s, 5 g of activation force and 90% deformation. One grain of rice was placed horizontally on a flat surface and it was crushed by the probe. 15 replicates were performed for each type of drying treatment. Following the same methodology, commercial rice (of the same variety) was evaluated as a control reference.

3. RESULTS

3.1 Kinetics of Water Absorption during Soaking Stage

The increase in moisture during the soaking phase of the grains at different temperatures is shown in Figure 1. All samples achieved an equilibrium moisture of approximately 0.5 g water / g dm.

The increase in water content during the soaking phase was modelled according to the Peleg model (Peleg, 1988) (Equation 2). This model has also been used to model soaking of peas and chickpeas (Shafaei et al., 2016) as well as wheat grains (Paquet-Durand et al., 2015).

$$X_{wt}=X_{w0}+\frac{t}{k_1+k_2 t} \quad (2)$$

Being X_{w0} the initial moisture in dry basis, X_{wt} the moisture in dry basis in time t, and k_1 and k_2 the kinetic constants of the model. Table 1 shows the parameters of the model and the value of the fittings obtained.

The constant k_1 of the Peleg model is related to the mass transfer rate: The smaller the values of k_1, the greater the initial water absorption rates (Turhan et al., 2002). This coefficient can also be related to the diffusion coefficient (Shafaei et al., 2016). The constants k_1 for this experiment decreased with increasing temperature, as shown in Table 1. Other authors have also reported that the constant k_1 decreases with temperature in rice (Corrêa et al., 2017; Zhu et al., 2019) or other grains like of bean and chickpea (Shafaei et al., 2016)

The constant k_2 of the Peleg model is related to the water absorption capacity: The lower the value, the higher the water absorption capacity (Resende & Corrêa, 2007). In this study, at 25°C, the water absorption speed was slower than at higher temperatures, while at the end of the process the rate of water absorption decreased at high temperatures reaching a similar equilibrium moisture (0.45 g water / g dm). To reach this level, 20 or 30 minutes of soaking will be required depending on the temperature range used.

As a result of the above, our study established the soaking conditions for the drying stage at 35°C with lower energy consumption than the other conditions, since it needs the lowest temperature.

3.2 Drying Stage

Figure 2 shows the drying curves of rice grains as a function of temperature for each drying system (HA or HA+MW). During this stage the grain moisture decreased up to the equilibrium moisture, which is similar in all cases (0.15 g water / g dm). Samples dried with HA+MW lose water faster, achieving the equilibrium moisture in a shorter time (15 minutes with HA+MW regardless of temperature, whereas more than 1 hour was required for HA).

The drying speed values resulting from the reduction of the sample's moisture during the process can be attributed to different water transport mechanisms. In this study, rice dried using HA only showed the typical drying curves, with an initial period, in which the drying process begins (called induction period), then a constant rate period, which lasts while there is superficial water, until critical moisture (X_c) is reached at a critical time (t_c). At this point, a falling rate period starts, in which water evaporation depends on the different mass transport phenomena (Singh & Kumar 2012). Above the X_c value, the diffusion of the water steam inside the grain is the predominant mechanism: water comes out to the surface through the grain's porous structure. Once the moisture content is less than X_c, the residual water is closely tied to the grain structure (Chen et al., 2019).

On the other hand, HA+MW drying curves presented a more highlighted constant rate period, reducing the induction period and the falling rate period. Microwave energy is considered a fast way of heating by making the water molecules rotate, which releases thermal energy (Pozar, 2011). The induction period was probably reduced due to the fast heating mentioned above. The increase of temperature inside the grains led to immediate water loss, while for HA, it required a certain time to reach the drying temperature. More concretely, the constant rate period for HA+MW starts at time 0, while for HA drying, it starts at 480, 540 and 660 seconds, respectively (Table 2). This reduced induction period was also detected by Le & Jittanit (2015), who used higher air temperatures (50, 70 and 90°C) and hot air at the same temperatures with microwave energy at 595, 425, and 255 W for drying *indica* rice grains.

The increase of the drying speed in the constant rate period is reflected by the slopes in the fitting (Table 2). Statistical analysis showed that there is a significant difference between HA and HA+MW, while no significant differences were found with respect to temperature. HA+MW implied an increase of this rate by around 40%. This speed increase can be explained by the fact that microwave energy heated the grains volumetrically. Therefore, when the water arrived to the grain's surface, it was already at an evaporation temperature, while the HA drying provides only a surface heating. Similar drying speed increases were found by Jiao et al., (2014), who reduced drying time by 30% using a combination of microwave energy (300 W) and hot air at 80°C in hybrid indica rice (Type 9718). The most significant difference in moisture levels between samples dried with HA and those dried with HA+MW is achieved at t_c 900 seconds, in which the constant rate period of HA+MW is finished, while for HA it is just starting. In addition, differences were observed in X_c values (0.158 ± 0.014 in HA + MW and 0.258 ± 0.016 in HA), and t_c (900 s in HA + MW and 1800 s in HA).

The falling rate period was also shortened, as the moisture was removed faster along the constant rate period and remaining water was closely tied to the grain. It has to be noted that both methods (HA and HA+MW) were capable of achieving the EU target moisture for pre-dried rice and that the values were close when the falling rate period was starting. The chosen treatment was HA+MW at 40°C because it achieved similar values than the use of higher temperatures with a lower energy cost, since it was the lowest studied temperature with the shortest time. The increase of drying speed when microwave energy is applied has also been tested with apple plates (Cuccurullo et al., 2018) and pumpkin leaves (Cuccurullo et al., 2017) with orders of 40 to 70%.

3.2.1 Fick Fitting

A second Fick's Law of diffusive model for a spherical geometry (Crank, 1975) was used to fit the water loss of grains in different drying conditions. Thus, effective diffusivity (D_e) was calculated considering the first term of the long process time equation. Given the shape of rice grains, a spherical geometry was considered, assuming a diameter equivalent value of 4.1 mm (Equation 3):

$$Y=\frac{X_t-X_e}{X_0-X_e}=\left(\frac{6}{\pi^2}\right)\exp\left(-D_e\pi^2\left(\frac{t}{r^2}\right)\right) \quad (3)$$

In this equation, X_t is the water content (d.b.) of the sample in time t; X_e (d.b.) is the water content of the sample in equilibrium; X_0 (d.b.) is the initial water content of the sample and r the equivalent radius (m). The constant D_e is the effective diffusivity (m^2/s).

This model assumes that the initial moisture of the grains is uniformly distributed, that the samples are symmetrical, that the flow of water is uniform throughout its surface and that diffusivity remains constant in the moisture range evaluated. For this reason, this model was adjusted to X_c values (Figure 3).

Table 2 shows the values obtained from effective diffusivity. A multifactorial analysis of the variance showed a significant effect of the interaction between the temperature and the type of drying performed. When the sample was dried using HA, effective diffusivity increased with temperature increases from 40 to 50°C without differences with respect to 60°C. For HA+MW, there was no influence on the temperature on the value of effective diffusivity. Values obtained for the effective diffusivity were two orders smaller than those found by Dutta et al., (2020), who modelled the diffusivities of moisture in white rice kernels at drying temperatures between 25 and 80°C and found diffusivity values from $6.791 \cdot 10^{-8}$ to $1.239 \cdot 10^{-7}$ (m^2/s).

3.2.2 Page and Midili Modelling

The Page model (Equation 4) has been used in studies of dehydration of Jatropha seeds (Siquiera et al., 2012) and drying of leeks (Doymaz, 2008). Besides, the Midili model (Equation 5) has been used by many authors to dry products, such as leek plates (Doymaz, 2008), mint leaves (Hosseinzadeh et al., 2011), corn (Corrêa et al., 2011), mushrooms (Guo et al., 2014), coffee beans (Corrêa et al., 2010) and long rice beans (Corrêa et al., 2017).

$$Y=\frac{X_t-X_e}{X_0-X_e}=\exp^{(-kt^n)} \qquad (4)$$

$$Y=\frac{X_t-X_e}{X_0-X_e}=\exp^{(-kt^n)}+bt \qquad (5)$$

In the equations of Midili and Page, the value X_t corresponds to the value of the water content (d.b.) in time t; X_e is the water content in the equilibrium (d.b.); X_o is the initial water content (d.b.) and k, n and b are drying model constants.

An example of modelling of the driving force (Y) values throughout time and the predicted values for the two models can be seen in Figure 3. Table 3 shows the parameter values of the models obtained for all samples, the correlation coefficient R^2, the estimated standard error (SE) and the mean absolute error (MAE). Constants k, and n have an inversely proportional effect on the driving force, whereas the parameter b has an opposite effect. As can be seen, the constant k, related to effective diffusivity during the falling rate period (Siqueira et al., 2012), was notably lower for HA drying without significant differences due to air temperature although for HA+MW the value increased with temperature. The parameter n is related to the internal resistance of the grain to water diffusion during the drying phase. It would be expected that at a higher air temperature, the pressure vapour difference between the interior of the grain increases, favouring the migration of water to the outside and thus reducing drying time. As can be seen in Table 3, no differences were observed in the n parameter. These results differed from those obtained by Zhong et al., (2020) and Lang et al., (2019), who detected significant differences but at higher temperatures (from 20 to 100 at intervals of 20). In the results exposed by Ondier et al., (2010), who applied temperatures between 26 and 34°C to Jupiter and Wells cultivars rice grains, the k and n values obtained were significantly higher than those of this study (k between 0.18 and 0.32 and n between 0.63 and 0.81). No clear relation between drying temperature and drying type was found for parameter b. The SE and the MAE obtained with both models are very similar, consequently, for dry samples of rice, they could be modelled with both predictive models.

3.3 Characterization of the Dry Product

3.3.1 Optical Properties

During the drying process, the temperature may influence the colour of the grain. The results obtained for luminosity (L*) and whiteness index (WI) are shown in Figures 4A and 4B, respectively.

As shown in Figure 4A, microwave treatment significantly increases grain luminosity, regardless of air temperature. Luangmalawat et al. (2008) evaluated the colour changes due to dry air temperature (50, 60, 80, 100 and 120°C) in Jasmine rice for two levels of final moisture (7 and 10 g water / 100 g dm). It was noted that the value of the L* parameter, the coordinate b* and a* did not vary significantly when the temperature was less than 100°C. On the other hand, dried samples showed a whiteness index greater than that of control rice (Figure 4B), possibly due to migration of starch from the inside out of the grain in the soaking stage, concentrating on the surface. This behaviour is more significant when combining drying air with microwaves due to the greater vibratory and diffusive movement of the water molecules. According to Zhong et al., (2020), the MW pretreatment could undo the entanglements between starch chains by inducing violent movement of the chains of rice starch affecting colour.

The values of the coordinates a* and b* were between -0.8 and -1.2 and between 5 and 9 respectively. The variance analysis did not show significant differences in the samples with air temperature or drying system. Similar results were obtained by other authors such as Inprasit & Noomhorm (2001), who dried *indica* grains with solar air at 35°C and Ondier et al. (2010) who dried Jupiter and Wells cultivar between 25 and 35°C.

3.3.2 Mechanical Properties

As the product is to be stored, it needs certain resistance so that it can withstand time and transport without deteriorating. The EU classification of rice, which includes pre-cooked rice (European Commission, 2016/1238), establishes the threshold limit value for resistance force at 18 N. Figures 4C, 4D and 4E shows the maximum breaking force, the distance at which this breakage occurs (breaking distance) and the area under the ‘resistance to compression’ curve (consistency) for different drying conditions.

As expected, the soaking and drying stages reduced the grains’ resistance to compression of grains as a result of deterioration of their internal structure (Figure 4C). In addition, resistance to fracture decreased significantly with temperature. This might be related to the speed of the water outflow. At high temperatures, the major driving force and its related water flow produces structural tensions within the grain, leading to cracks and ruptures in the interior that affect the quality of the rice (Inprasit & Noomhorm, 2001; Ondier et al., 2010). This effect begins to be significant at 50°C for HA+MW and at 60°C for HA. As specified in the drying stage, the drying rate was greater in HA+MW 50°C, which affected the structure. On the other hand, no significant differences were observed in the distance at which maximum force occurs with respect to control or applied treatments (Figure 4D). Regarding consistency, the HA+MW reduced this parameter significantly as compared to HA, especially at lower temperatures (40ºC). The significant contrast with untreated grains is remarkable (Figure 4E).

3.4 Cooking Tests

Cooking test were carried out on the samples drying at 40°C with HA+MW, which were considered the optimal conditions due to the fact that they accelerate the drying process without damaging the product. This test was performed until the grain surpassed the water content reached by control rice (0.52 g water / g dm). Figure 5, shows the water content of grains during cooking time at 96°C.

As can be seen in Figure 5 rice grains absorb water quickly, reaching an equilibrium moisture close to 0.6 g water / g dm. In addition, in minute 3, the moisture level of control rice at minute 20 (around 0.52) was reached. The results obtained for the control sample are coherent with the ones obtained by Bello et al., (2007) who cooked long grain rice at 90°C during 20 min and found moisture values of up to 0.48 g water / g dm.

4 CONCLUSIONS

Successful models were found for the soaking and drying stages of pre-cooked rice and the ideal conditions established. The evolution of moisture in the soaking phase was modelled according to the Peleg model, choosing a temperature of 35°C for 20 minutes as optimal conditions for this stage. Fick, Midili and Page models were properly fitted, establishing the drying kinetic parameters for the different conditions studied. The effective diffusivity values obtained with the Fick model showed that water loss in HA+MW treatments at different temperatures was greater than in HA. The soaking and drying stages increased luminosity (L*) and the whiteness index (WI) with respect to untreated rice. 40°C HA+MW, using 5.6 W/g, would be recommended for the drying stage since it is more efficient and faster. In addition, cooking time for this kind of rice was reduced by 94% with respect to traditional conditions. Therefore, soaking and drying conditions to prepare pre-cooked japonica rice have been established. Thus, food industry might use Senia and Bahia round rice to offer new possibilities of consumption, enhancing the local economy where this kind of rice is produced.

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Table 1. Peleg model parameters and fitting of the soaking stage of rice grains

T (°C)	**k_1 (s·g water/g dm)**	**k_2 (g water/g dm)**	**R^2**
25	1418 ± 110^A	2.52 ± 0.09^a	0.95
35	506 ± 38^B	2.72 ± 0.06^b	0.94
50	191 ± 27^C	3.09 ± 0.06^c	0.81

Table 2. Linear fitting of the constant rate period and average values of effective diffusivity

Drying	Temperature (°C)	Slope (g water·g $dm^{-1}cs^{-1}$) 10^{-4}	Start time (s)	Final time (s)	R^2	$D_e \times 10^9$ (m^2 / s)	$R^{2\,(1)}$
HA	40	-1.8±0.5^{A}	480	1500	0.99	1.2 ± 0.3 ^{a}	0.93
	50	-2.1±0.3^{A}	540	1800	0.99	2.3 ± 0.4 ^{b}	0.93
	60	-2.2±0.4^{A}	660	1800	0.99	2.0 ± 0.5 ^{b}	0.85
HA + MW	40	-3.5±0.5^{B}	0	900	0.99	3.5 ± 0.7 ^{c}	0.88
	50	-3.7±0.3 ^{B}	0	900	0.99	3.0 ± 0.3 ^{c}	0.87
	60	-3.6±0.6 ^{B}	0	900	0.94	2.5 ± 0.4 ^{bc}	0.95

(1) corresponds to the lowest correlation coefficient (R^2) value
Equal letters in the same column refer to homogeneous groups (p-value<0.05)

Table 3. Midili and Page parameters and statistical values

	Model	T (°C)	k x10^5 (min^{-1})	n	b x10^7 (min^{-1})	R^2	SE	MAE
HA	**Midili**	**40**	2.7 ± 1.4 ^{A}	1.43 ± 0.09 ^{A}	59 ± 49 ^{BCD}	98.03	0.0460	0.0293
		50	3.87 ± 0.06 ^{A}	1.26 ± 0.17 ^{A}	-109 ± 165 ^{B}	88,82	0.1236	0.0922
		60	3.54 ± 0.14 ^{A}	1.35 ± 0.00 ^{A}	-475 ± 24 ^{A}	90,66	0.1286	0.0899
	Page	**40**	33.8 ± 5.9 ^{a}	1.074 ± 0.007 ^{a}	-	87.95	0.1007	0.0748
		50	21.7 ± 13.9 ^{a}	1.184 ± 0.106 ^{a}	-	86.66	0.1216	0.0891
		60	26.6 ± 18.2 ^{a}	1.157 ± 0.16 ^{a}	-	84.88	0.1295	0.0932
HA + MW	**Midili**	**40**	10 ± 3 ^{B}	1.40 ± 0.03 ^{A}	-34 ± 33 ^{BC}	96.51	0.0479	0.0337
		50	76 ± 14 ^{C}	1.40 ± 0.43 ^{A}	169 ± 17 ^{D}	97.92	0.0418	0.0308
		60	221 ± 33 ^{D}	0.92 ± 0.1 ^{A}	162 ± 194 ^{CD}	97.50	0.0416	0.0296
	Page	**40**	113 ± 88 ^{c}	1.094 ± 0.156 ^{a}	-	94.14	0.0626	0.0448
		50	69.4 ± 36.2 ^{b}	1.123 ± 0.048 ^{a}	-	95.95	0.0489	0.0359
		60	383 ± 163 ^{d}	0.926 ± 0.572 ^{a}	-	97.18	0.0431	0.0310

Equal letters means that there are no significant differences (95%).

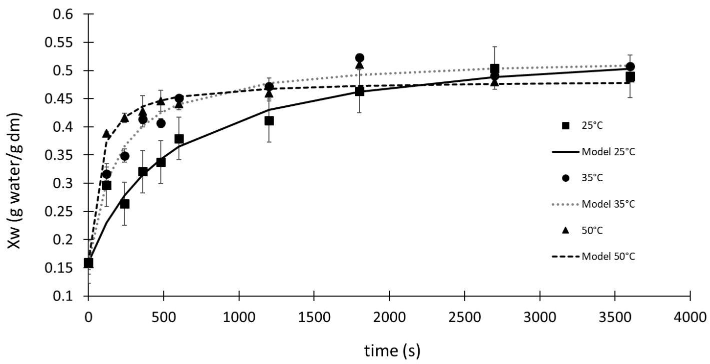

Figure 1. Evolution of moisture during soaking phase as a function of temperature

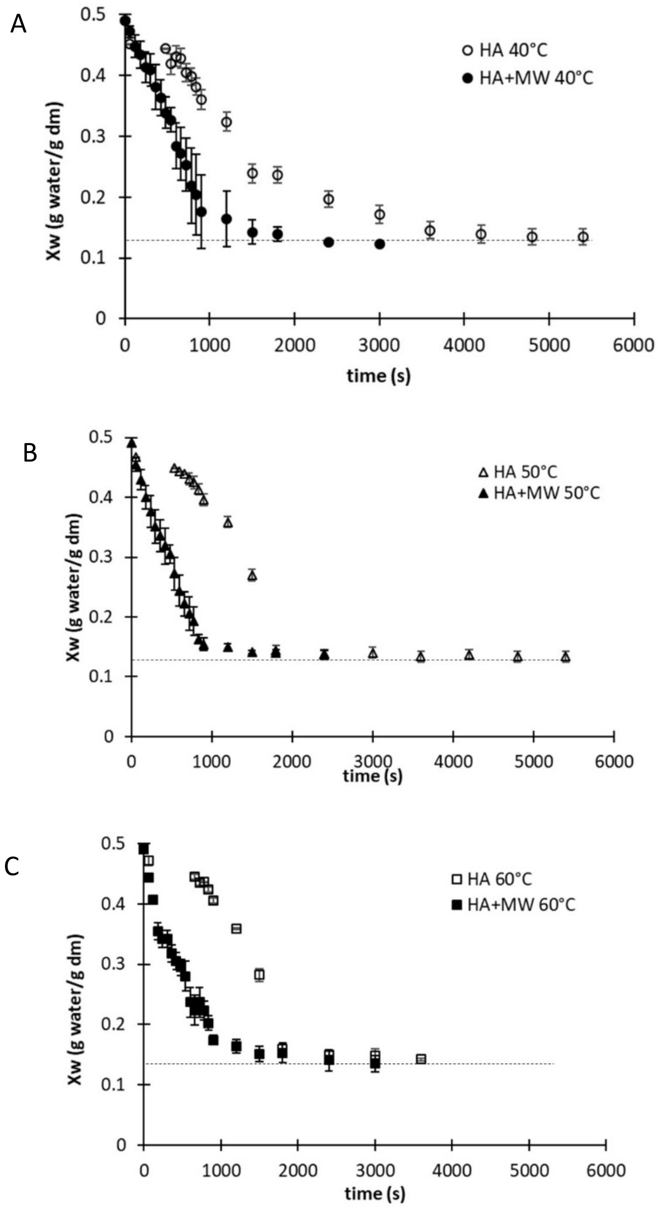

Figure 2. Drying curves A (40°C), B (50°C) and C (60°C). Grey line represents the moisture content of pre-cooked rice according to EU 2016/1238

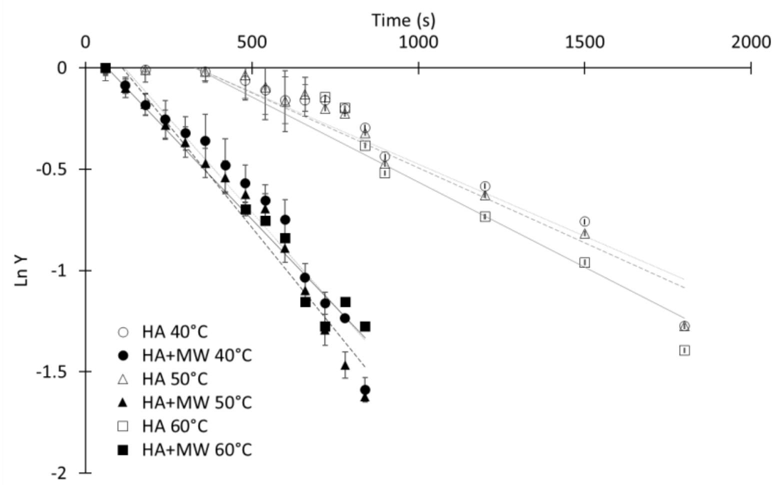

Figure 3. Relationship of the driving force and the process time (for Fick's law model) (grey lines refer to HA and black ones to HA+MW, dot lines to 40°C, discontinuous lines to 50°C, and continuous lines to 60°C). Symbols refer to experimental data

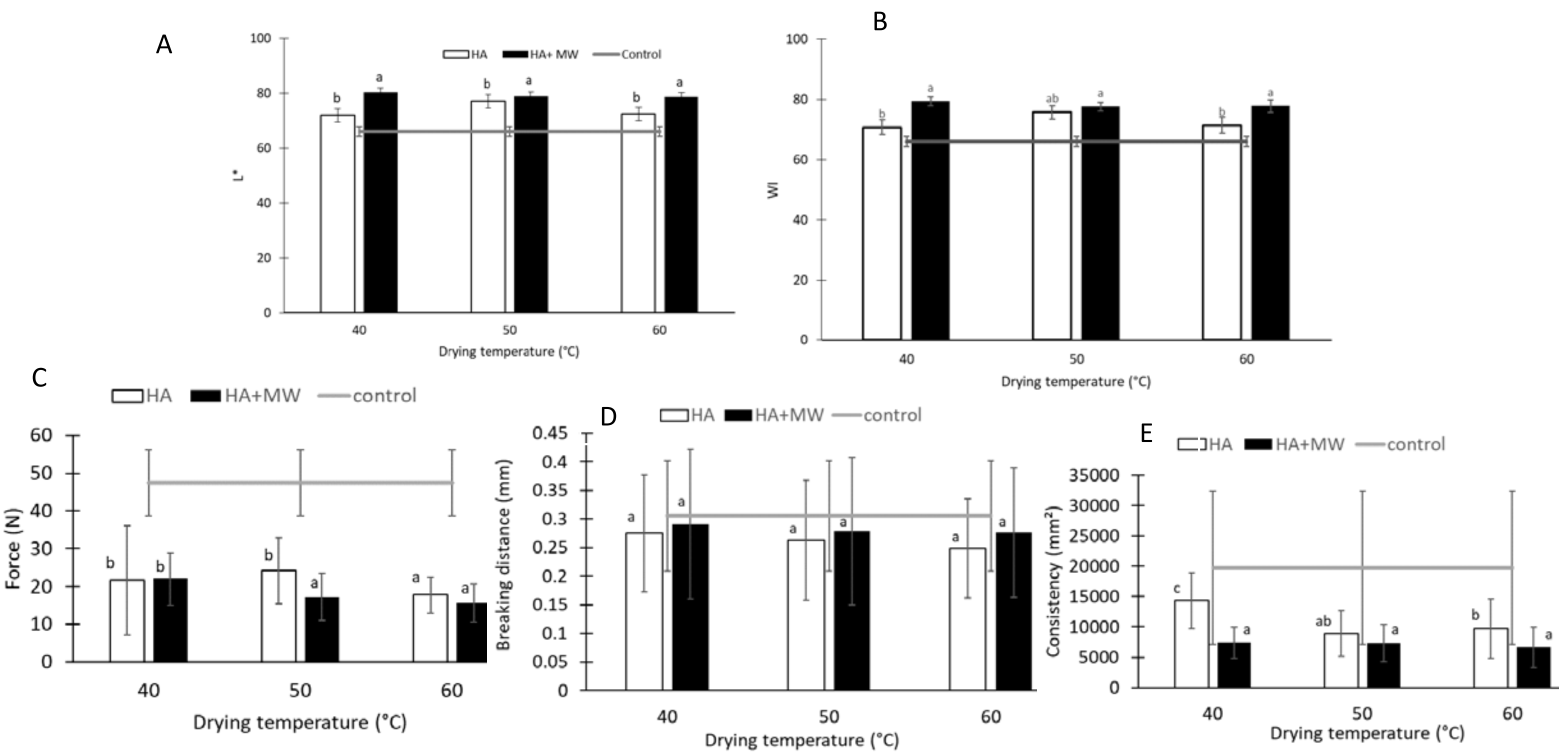

Figure 4. Luminosity (A) and whiteness index (B) as a function of drying temperature. Breaking force (C), distance at which the most strength is produced (D) and Consistency (E) for pre-cooked rice treatments and control rice

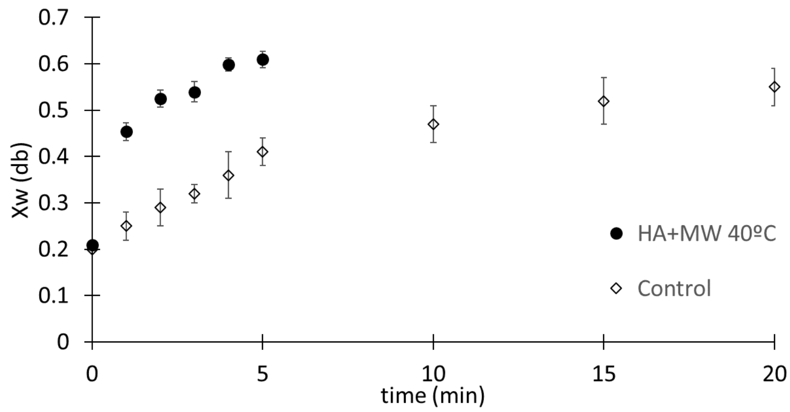

Figure 5. Water content (d.b.) vs time at the cooking stage