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Proximal Composition and Colour of Maize Grains after Intermittent and Continuous Drying

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Abstract **– The objective of this study was to evaluate the effect of continuous and intermittent drying with different rest periods on the quality and centesimal composition of maize (Zea mays). Grains of the cultivar Cargo TL were harvested with moisture content of 25.37% (wet basis, w.b.) and subjected to drying at 100 ºC and air flow of 1.5 m^3 min^{-1} m^{-2}. Drying was conducted with five rest periods (0, 4, 8, 12 and 16 h) and four replicates in a completely randomized design. Drying was carried out until the grains reached final moisture content of 14 ± 0.3% w.b. It was concluded that the proximal composition was not influenced by the drying conditions; the grains showed browning resulting from intermittent drying; increased rest period contributed to reduced damage and increased moisture reduction rate.**

Keywords **– Drying Rate, Starch, Colour, Proximal Composition, Rest Period.**

I. Introduction

Maize (*Zea mays*) grains are widely used as the main energy source in cattle, swine and poultry feed. As grains are biological materials, for long use, they must be stored properly to preserve their quality [1]. It is essential to determine the moisture content of the grains from the time of harvest due to its influence on the metabolic activity of the product and associated organisms (pest insects and microorganisms), as well as on the quality throughout the storage period. In cases of moisture content above the recommended, drying should be carried out to reduce excess water and ensure a longer storage period of the product without deterioration and loss of quality [2].

Among the post-harvest stages, the drying process has a significant impact on post-harvest losses, because inadequate management can cause grain deterioration immediately or throughout the storage period. According to Bala [3], between the harvest and the final consumer, the losses range between 10 and 25%, varying according to the conditions of the drying and conservation infrastructures. High temperatures of the drying air, allied to the type of grain and its purpose, can cause physical damage (internal and superficial cracks) and alteration of grain quality, generally resulting in a low-value product.

Conventional drying exposes agricultural products such as grains to high temperatures and for varying periods and can cause serious damage, such as alterations of flavour, colour, composition and nutrient concentration [4], possibly resulting in products that are entirely different or with different purpose [5].

Colour analysis assists in the quality analysis of agricultural products in post-harvest processes, with emphasis on the consumer, whose decision on the acquisition is based on the visual aspect of the product [6]. Therefore, for Gasparin *et al*. [7] and McGuire [8], the best way to analyse the colour of agricultural products is through the hue angle (H*) and chroma (C*), which include in their deduction the values of the coordinates a* and b*, allowing the colour to be evaluated in terms of intensity and saturation.

Isquierdo *et al*. [9], studying the quality of coffee subjected to intermittent drying, reported that colour changes result from oxidative processes and biochemical transformations of enzymatic nature, with negative effects on the quality of the product.

High temperatures during drying, besides resulting in over-drying, burning, cracking and hardening of the grain, can cause denaturation of proteins and alterations in the capacity of gelatinization of starch in maize, compromising its digestibility [2]. Coradi *et al*. [10], evaluating the effect of different drying temperatures (80, 100 and 120 ºC) on maize grain quality, found that, for the lowest temperatures, 80 and 100 ºC, the quality of the grains was better with regard to crude protein ratio, and the ash content was not affected at temperature of 80 ºC.

For Isquierdo *et al*. [11], the rest period, contrary to what occurs with continuous drying, promotes benefits for product quality, as it allows water to move from the interior to the periphery of the grain, increasing its moisture reduction rate and consequently reducing the risk of fissures and cracks caused by the combination of low moisture reduction rate and overheating in the grain mass. Physical damage to the grains, such as fissures and cracks, in addition to increasing the susceptibility to breakage, can intensify the attack and development of pests during storage [12].

According to Bala [3], there is no general recommendation for drying of all species, so each species should be analysed individually and the ideal air temperature for the drying process constitutes an operational, economical, qualitative and ecological decision. Even for the same dryer, operational changes can have an impact on the quality and economic efficiency of the drying process. Therefore, the objective of this study was to evaluate the effect of intermittent drying on the maintenance of maize grain quality.

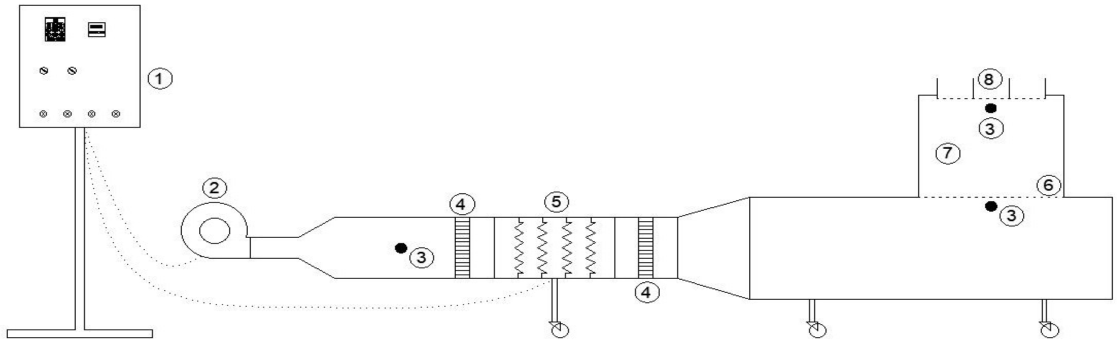
II. Material and Methods

This study was conducted at the Laboratory of Post-Harvest Processes (LPPC) of the Faculty of Agrarian Sciences (FCA), Federal University of Grande Dourados (UFGD), in the city of Dourados/MS, Brazil, and in the Laboratory of the Brazilian Agricultural Research Corporation (Embrapa) Maize and Sorghum, in Sete Lagoas/ MG, Brazil.

Maize grains of the cultivar *Cargo TL* produced in the FCA experimental farm were manually harvested and threshed with moisture content of 25.37% on wet basis (w.b.). Subsequently, they were placed in a transparent polyethylene package, inside a cold chamber at 5 ºC for 72 hours, in order to standardize the moisture content in all grain mass. Moisture content was determined using the gravimetric method of the oven, according to the ASAE standards, by placing 15-g triplicate samples in a forced air circulation oven at temperature of 103 ± 1 ºC for a period of 72 hours [13].

The grains were subjected to drying in an experimental fixed-layer dryer (Figure 1) at temperature of 100 ºC and drying air flow of 1.5 m^3 min^{-1} m^{-2}, with precise conditions of temperature and air flow control. The experiment was conducted in a completely randomized design using five rest periods: 0, 4, 8, 12 and 16 h, where zero corresponds to continuous drying and the others to intermittent drying, with four replicates.

Air flow was indirectly established based on the velocity (0.02 m s^{-1}) using a digital anemometer after passing through the grain mass. Each drying procedure was conducted using a grain volume of 0.035 m^3 in a drying chamber with fully perforated base area of 0.283 m^2 and grain layer height of 0.124 m.



1 - Temperature and air flow control panel; 2 - Centrifugal fan; 3 - Temperature measurement point; 4 - Air homogenizers; 5 - Set of electrical resistances; 6 - Perforated screen for thick-layer drying; 7 - Thick-layer drying bed; 8 - Set of trays for thin-layer drying.

Fig. 1. Experimental fixed-layer dryer used in the drying of maize grains.

Throughout the drying process, the grain mass was turned to avoid the formation of temperature and moisture content gradients. Drying was monitored with the aid of three fully perforated polyethylene packages, containing 100 g of product and randomly placed in the middle of the grain mass. The drying process ended with moisture content of 14 ± 0.3% (w.b.), whereas in the treatments with rest, it was interrupted with moisture content of 18 ± 0.2% (w.b.) and resumed after the rest until reaching a moisture content of 14 ± 0.3% (w.b.).

During the rest, inside an expanded polystyrene box, fully closed in order to simulate the silo conditions, air temperature and relative humidity conditions were measured in the grain mass using a digital data logger, HT-4010 model, placed inside, and the data were collected using *HT Communication* software.

The expanded polystyrene box with capacity for 100 L was adjusted to have the following dimensions: 0.510 m, 0.300 m and 0.160 m for length, width and height, respectively, reducing the volume to 24.48 L (24.48 x 10^{-3} m^3) (Figure 2).

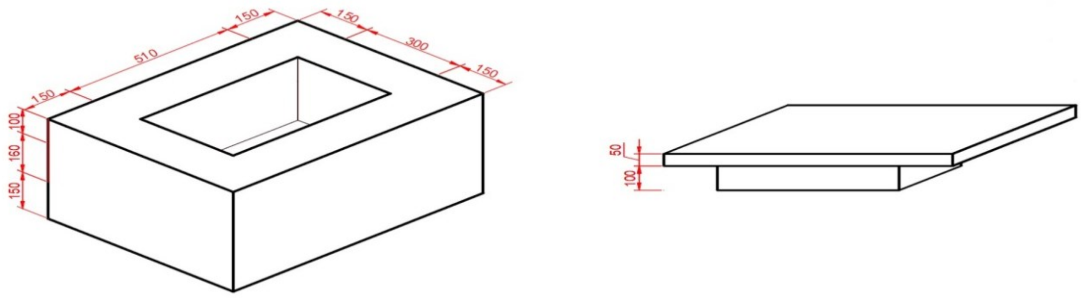


Fig. 2. Characteristics and dimensions of the expanded polystyrene box used to hold maize grains during the rest period.

With this adjustment, a 0.150 m thickness was adopted on all sides, including the upper and lower parts, equivalent to 1,142 m thickness of the grain mass considering the thermal conductivity of the material (0.024 W m^{-1} $°C^{-1}$) and that of the product at the temperature and moisture content of rest (0.183 W m^{-1} $°C^{-1}$) [14, 15]. After the drying process, the variables referring to the proximal composition, damage and colour of the maize grains were evaluated.

Drying rate

The drying rate was determined numerically by the ratio between the difference in moisture contents and the difference in drying times, using Equation 1, considering the initial and final moisture contents at the various intervals along the drying.

$$DR = \frac{X_0 - X_i}{t_i - t_0} = \frac{mw_0 - mw_i}{DM\ (t_i - t_0)} \quad (1)$$

Where *DR* is the drying rate (kg H_2O kg^{-1} DM h^{-1}), X_0 is the previous moisture content (decimal d.b.), X_i is the actual moisture content (decimal d.b.), t_i is the actual total drying time (h), t_0 is the previous total drying time (h) and *DM*, mw_0 and mw_i are the dry matter, initial mass of water and mass of water at time *i* (kg).

Iodine Reaction Test

The test was adapted according to the methodology described by Cicero and Silva [16], establishing a time of 25 minutes for the imbibition of maize grains, obtained by means of tests with different periods, using 5 minutes as a starting point. The period was established so that the imbibition period showed any damage resulting from the drying process.

According to the methodology, four replicates of 100 grains in duplicate were used for each treatment. The samples were placed in 100-mL disposable plastic cups, which received a 4% iodine dye solution, completely covering the grains. After the imbibition period, the grains were washed in running water, dried on paper towels, and those with purple colour, as a result of the positive reaction of the starch with the iodine dye solution, and visible cracks were counted. The result was expressed in percentage.

Colour Evaluation

Maize grain colour after drying was evaluated using the HunterLab System, based on the reading of the L*, a* and b* coordinates, where L* is associated with lightness and corresponds to the variation from black (L* = 0) to white (L* = 100); a* is associated with green to red colour, and the chromatic coordinate b* corresponds to the variation from blue to yellow, as represented in the three-dimensional scale shown in Figure 3.

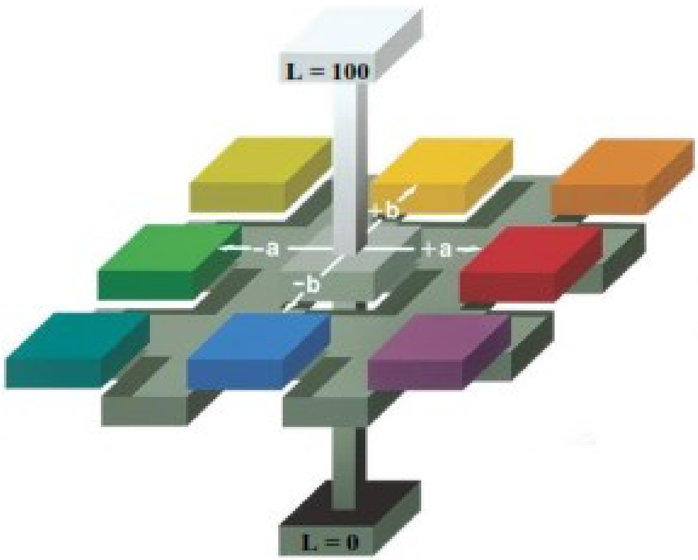


Fig. 3. Representation of the colour parameters on the Hunter scale: L*, a*, b* [17].

Readings were taken using the Konica Minolta® CR-410 Chroma Meter (colorimeter), with aperture of 50 mm in diameter. The device was previously calibrated using as reference the combination D65 (Y = 93.58; x = 0.3169 and y = 0.3334), which represents the average daylight. The readings were taken in triplicate by placing the grains in Petri dishes on a white background, in a set of four replicates for each treatment.

After reading the chromatic coordinates, chroma (C*) (Equation 2) and Hue angle (H*) (Equation 3) were calculated [8, 18, 19]. Chroma (C*) indicates the level of saturation or intensity of the colour, while the Hue angle (H*) indicates the observable colour (hue) considering the coordinates a* and b* [20].

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \tag{2}$$

$$H^* = \arctan\left(\frac{b^*}{a^*}\right) \tag{3}$$

Where C* is the chromaticity (chroma) or colour saturation, H* is Hue angle (º), a* is the chromatic coordinate with variation from green to red, b* is the chromatic coordinate with variation from blue to yellow and L* is the lightness, ranging from white to black.

Proximal Composition of Maize Grains after Drying

Proximal composition analyses were conducted in the Chemistry Laboratory of Embrapa Maize and Sorghum in Minas Gerais. The proximal composition analysis consisted in determining the contents of carbohydrates, proteins, dry matter, ash, crude fibre and ether extract in each of the five treatments, with four replicates and in triplicate. The samples were prepared by grinding in a Wiley-type knife mill, Solab SL model, in a thickness of 1 mm.

After grinding, the samples were subjected to the Near Infrared Reflectance (NIR) spectrophotometer, commonly referred to as NIR, in a BUCHI Nirflex 500 device (Buchi Labortechnik, Flawil, Switzerland) equipped with InGaAs detector. For reading, the samples were placed in a borosilicate glass Petri dish. The spectra of the samples were obtained in triplicate, in the region from 4,000 to 10,000 cm^{-1}, with resolution of 4 cm^{-1} and 32 scans per spectrum, and the results were obtained according to the methodology described by Simeone *et al.* [21]. The NIR spectrophotometer has good accuracy and high precision, using the principle of electromagnetic radiation emission and, by applying mathematics to analytical chemistry, it determines the precise values based on the calibrated curves according to the material to be evaluated.

The contents of dry matter, protein, ashes, crude fibre and ether extract were obtained directly, whereas the carbohydrate content was deduced by difference with the sum of the other variables, considering a total of 100% [22].

Statistical Analysis

Data were analysed using the programs Sisvar 5.6 and SigmaPlot 11.0. Linear regression models were constructed and analysed according to their trends and characteristics related to the biological phenomenon under study. The models were validated based on the values of the significance of regression by F test, coefficients of the model and coefficient of determination (R^2) at 10% significance level ($p<0.1$). The analysis was carried out considering the completely randomized design, with 5 treatments and 4 replicates.

III. Results and Discussion

The effective drying times were equal to 1.67 h for the rest periods of 8, 12 and 16 hours, 2 h for the rest period of 4 hours and 2.17 hours for continuous drying (Table 1). According to Isquierdo *et al.* [11], intermittent drying provides a higher drying rate of the product and, consequently, a shorter drying time. Therefore, the process of water redistribution within the maize grain lasted 8 hours, with no changes to the point of reducing the drying time for longer periods of rest.

Table 1. Drying rate of maize grains before and after the rest period.

Rest period (h)	Effective drying time (h)	Drying rate (kg H_2O kg^{-1} DM h^{-1})		
		Before rest	After rest	Mean
0 (continuous)	2.17	-	-	0.081
04	2.00	0.059	0.126	0.086
08	2.00	0.080	0.137	0.104
12	1.67	0.078	0.159	0.105
16	1.67	0.067	0.135	0.104

DM-Dry matter.

The average drying rate was also higher for the intermittent drying, with more significant values in the rest periods of 8, 12 and 16 hours compared to continuous drying, in which the drying rate was 0.081 kg H_2O kg^{-1} DM h^{-1}. This behaviour is due to the values of drying rate observed with the resumption in the post-rest period because, except for the period of 8 hours, in all cases the increase was greater than 100%. A similar situation was observed in the studies conducted by Zhang and Litchfield [23], with intermittent drying of maize under laboratory conditions.

Although the average drying rate in the cases of rest is higher, this process contributes to a lower risk of damage to the grain, since the continuous drying results in a higher tension force exerted on the superficial part of the grain, because the water is more strongly bound as the moisture content decreases, a fact that culminates with greater damage, as observed in Figure 4.

According to Elias [2], intermittent drying poses low risk of damage and thermal shocks, and this contributes to the behaviour observed in Figure 4, in which the longer the rest period, the lower the level of damage.

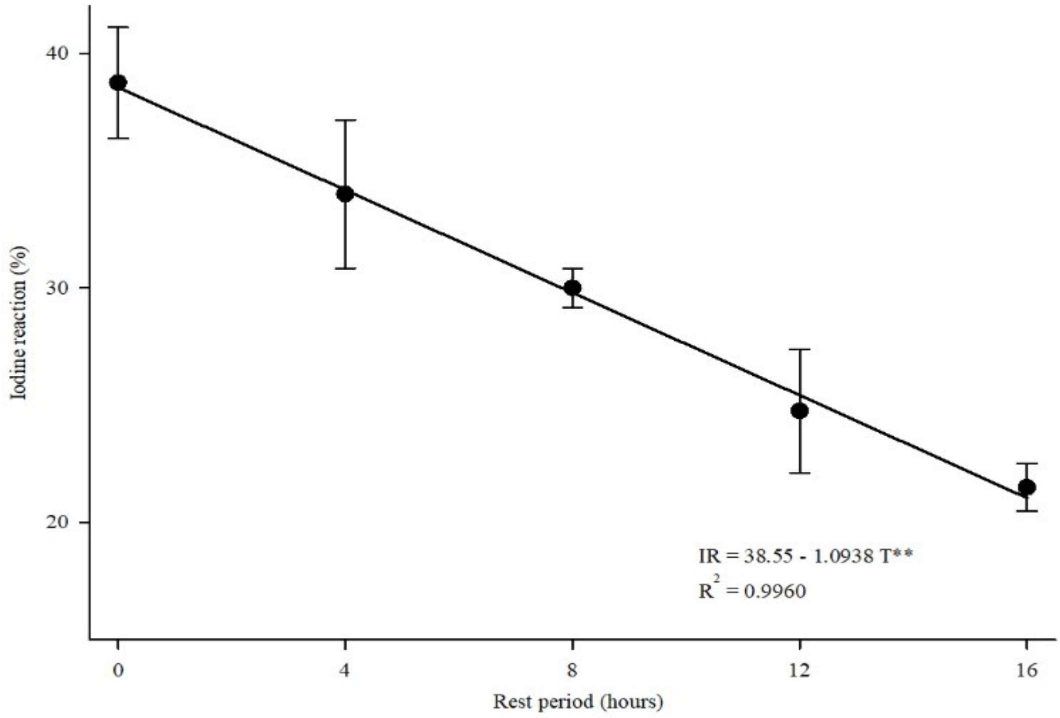


Fig. 4. Percentage of drying damage according to iodine reaction in maize grains after continuous and intermittent drying.
** Significant at 1% probability level by F test.

The values of moisture content at the time of the proximal composition evaluation were: 11.91, 11.46, 11.58, 11.74 and 11.94% for continuous and intermittent drying with 4, 8, 12 and 16 hours of rest period. These values are considered low when compared to those obtained after drying, reflecting the effect of heating to which the product was exposed during the grinding process.

Apart from the variables dry matter and ash, there was no effect of continuous or intermittent drying (Table 2). Therefore, in terms of proximal composition, the other variables were not influenced by the rest period.

Table 2. Analysis of variance for the variables dry matter, carbohydrates, protein, ash, ether extract and crude fibre in maize grains after continuous and intermittent drying with different rest periods. DFR - Degrees of freedom of the residuals, MST - Mean square of treatments.

Variable	DFR	MST	F	Mean value (%)	CV (%)
Dry matter	15	0.171493	9.66**	88.28	0.15
Carbohydrates	15	0.184618	0.84^{ns}	84.54	0.56
Protein	15	0.068532	1.62^{ns}	9.12	2.26
Ashes	15	0.060845	3.44*	1.50	8.86
Ether extract	15	0.022525	1.48^{ns}	4.81	2.57
Crude fibre	15	0.049125	1.67^{ns}	1.02	16.76

** Significant effect at 1% by F test, * Significant effect at 5% by F test and ^{ns} Not significant by F test.

Although the percentages of dry matter and ashes were influenced by the rest period, the regression curves were not significant by F test at 5% probability level. It is observed in Figure 5 that, in general, the variation was not significant; the values of proximal composition recorded in each of the variables analysed do not dependent on the rest period. Although there was a reduction of damage in terms of iodine-starch reaction (Figure 4) as the rest period increased, this did not result in immediate alteration in the composition of the flour. Such alteration is expected to occur during storage, due to the reduction of storage potential in the latent period for the temperature conditions adopted.

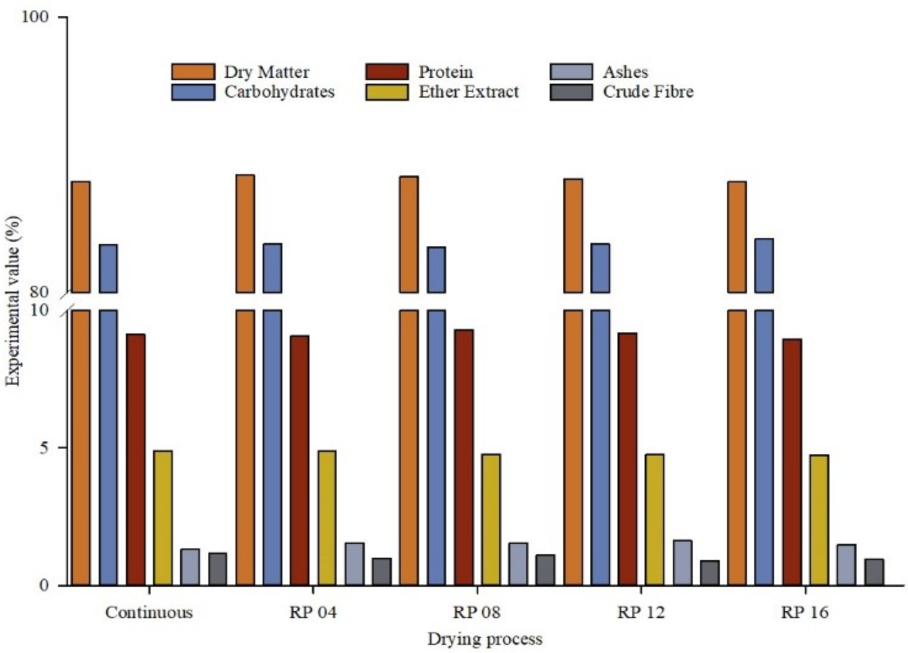


Fig. 5. Proximal composition (d.b.) of maize grains as a function of the rest period after drying.

Compared to the data reported by Sundhu *et al*. [22] for the percentage of carbohydrates in several varieties studied (87 to 92%), the average value obtained (84.54%) was lower. However, the values were closer to those obtained by Schuh *et al*. [24], who studied the physicochemical quality of off-season maize subjected to two drying methods, which had initial composition of 83.82% carbohydrates, 10.48% protein, 4.32% fat and 1.38% ash content.

The colour parameters a* and L* tended to decrease with the increase in the rest period (Figures 6 and 7), and L* showed quadratic behaviour and a minimum value, which indicated highest level of browning at 9.98 hours of rest period. The reduction in L* was more pronounced in the interval from zero to 4 hours of rest, whereas for the period from 4 to 16 hours, the level of variation was proportionally lower (Figure 7). The parameter b* did not show a tendency resulting from the adoption of continuous and intermittent drying with different rest periods, with an average value of 38.07.

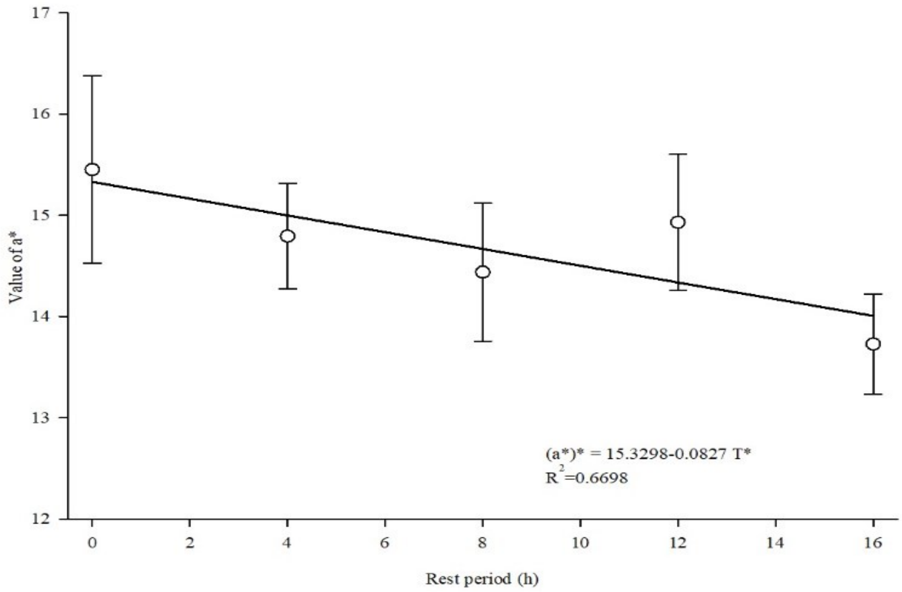


Fig. 6. Behaviour of the variable a* after continuous and intermittent drying with different rest periods.
*Significant at 10% probability level by F test.

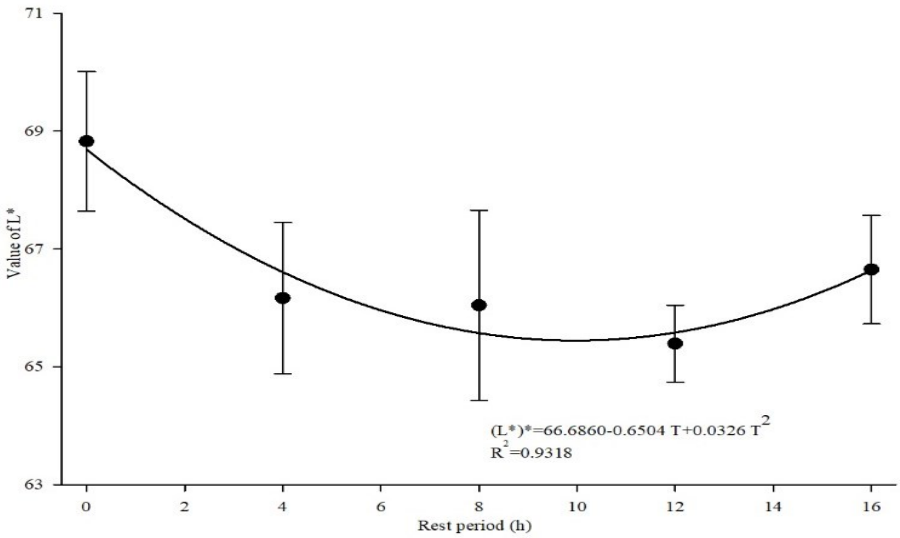


Fig. 7. Lightness (L*) of maize grains after continuous and intermittent drying with different rest periods.
*Significant at 10% probability level by F test.

Browning can be associated with the effect of the prolonged exposure of the product to heat during drying and at rest because, according to Paulsen *et al.* [25], moist maize grains exposed to heat during drying, in extreme cases, may become dark brown. For Isquierdo *et al.* [9], changes in colour result from oxidative processes and biochemical transformations of enzymatic nature, which can negatively affect product quality.

For Chou *et al*. [26], non-enzymatic browning of agricultural products is associated with long periods of exposure to high temperatures. During the rest period, maize was subjected to thermal insulation conditions, so the temperature and relative humidity conditions in the grain mass were kept with little variation; however, it was sufficient to promote alterations. The time elapsed with the rest did not lead to loss of product quality in terms of proximal composition and reduced the occurrence of damage, due to the increase in the moisture reduction rate after rest. A similar situation of browning due to the thermal effect in intermittent drying was observed by Barbosa *et al*. [27], in the rice crop, as the grains tended to become yellow.

Although the grains turned brown when the rest technique was used (Figure 7), this behaviour was not observed in a significant manner for chroma (C*) and Hue angle (H*) (Figure 8).

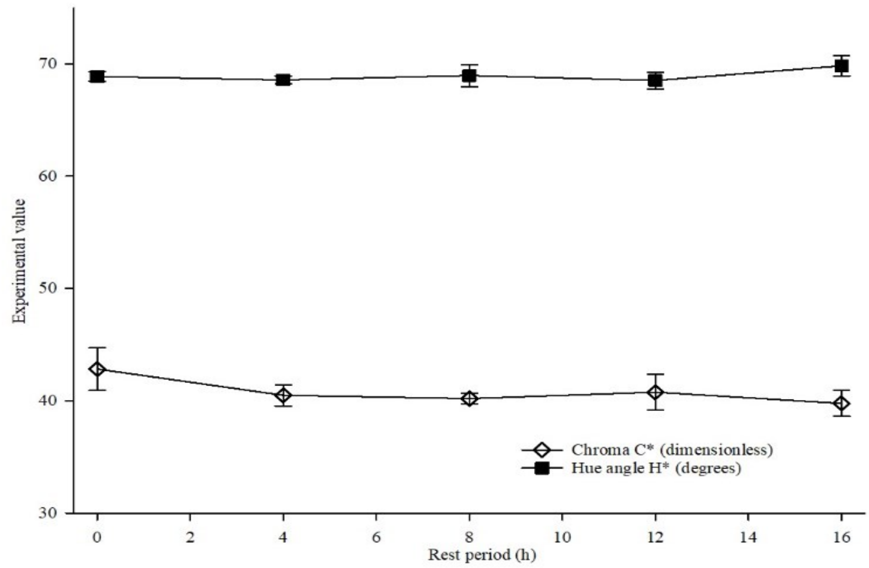


Fig. 8. Behaviour of colour parameters of maize grains after drying.

In general, the calculated values showed small variation. This situation corroborates the behaviour observed by Isquierdo *et al.* [9], when assessing the use of different rest periods or intermittent drying for coffee.

The colour of a product is the result of oxidative reactions and biochemical reactions of enzymatic nature, as reported by Isquierdo *et al*. [9]. Considering that the change has an effect on product quality, the results of colour, in relation to the parameters Hue angle (H*) and chroma (C*) presented in Figure 8, are in agreement with those referring to the centesimal composition of maize, because the variation occurred in all variables showed no significant tendency.

The rest period allowed the diffusion of water from the centre to the periphery and, consequently, there was an elevation in the moisture reduction rates, thus reducing the negative effect caused by the high pressure exerted by the drying air. The improvement in terms of moisture reduction rate did not translate into significant gains in the maintenance of protein quality, one of the components associated with temperature and drying conditions, that is, continuous drying did not promote an immediate protein degradation in the product.

IV. Conclusions

Intermittent drying with different rest periods, despite influencing the drying rate of maize grains, did not alter their parameters of proximal composition. Maize grains tended to turn brown with the increase of rest period during intermittent drying. Damage in maize grains was reduced with the rest technique, a progressive reduction with the increase of the intermittency time.

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