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# Eficiência da extração mecânica de *Moringa oleifera* de acordo com diferentes condições de secagem de grãos

## Efficiency of mechanical extraction of *Moringa oleifera* according to different grain drying conditions

## Eficiencia de la extracción mecánica de *Moringa oleifera* según diferentes condiciones de secado del grano

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**Bárbara Lemes Outeiro Araújo**
ORCID: https://orcid.org/ 0000-0001-5350-5174
Universidade Federal de Lavras, Brazil
E-mail: barbara@oleo.ufla.br
**Ednilton Tavares de Andrade**
ORCID: https://orcid.org/ 0000-0002-8448-8781
Universidade Federal de Lavras, Brazil
E-mail: ednilton@deg.ufla.br
**Kariny Carvalho Vieira Nolasco**
ORCID: https://orcid.org/ 0000-0003-1440-3655
Universidade Federal de Lavras, Brazil
E-mail: kariny.quimica@hotmail.com
**Rafael Peron Castro**
ORCID: https://orcid.org/ 0000-0002-0063-2302
Universidade Federal de Lavras, Brazil
E-mail: peron@oleo.ufla.br
**Pedro Castro Neto**
ORCID: https://orcid.org/ 0000-0002-3836-5553
Universidade Federal de Lavras, Brazil
E-mail: oleo@deg.ufla.br

**Resumo**

*Moringa oleifera* Lam. é uma planta resistente à seca e capaz de sobreviver em solos pobres, obtendo até três colheitas por ano. Assim, o objetivo deste trabalho quantitativo foi estudar o comportamento durante o processo de secagem laboratorial, nas temperaturas do ar de 40 ºC, 55 ºC e 70 ºC, aplicando modelos matemáticos aos dados experimentais, selecionando o melhor modelo de acordo com as curvas cinéticas de secagem, bem como avaliar o efeito desse fenômeno na eficiência da extração mecânica de óleo. A secagem artificial foi realizada para uma massa constante de grãos, usando um secador mecânico de laboratório em camada fixa com convecção forçada, a uma velocidade do ar de 0,33 m $s^{-1}$, com temperaturas de ar de secagem controladas de 40 °C, 55 °C e 70 °C. A análise de regressão não linear foi realizada usando o método Quasi-Newton para ajustar 12 modelos matemáticos aos dados experimentais. O óleo foi extraído usando uma prensa mecânica do tipo expeller. O rendimento e a eficiência da prensa foram calculados a partir da diferença no conteúdo lipídico obtido pela extração química inicial do grão e do resíduo da torta. A Equação Exponencial de Dois Termos foi a que melhor se adequou aos dados experimentais para todas as temperaturas do ar de secagem. O aumento da temperatura do ar de secagem causou maior contração volumétrica dos grãos de moringa, o que afetou o rendimento da extração de óleo, resultando em menor eficiência da prensa mecânica.

**Palavras-chave:** Processamento; Produtos agrícolas; Rendimento de óleo.

**Abstract**

*Moringa oleifera* Lam. Is a drought-resistant plant and able to survive in poor soils, obtaining up to three harvests per year. Thus, the objective of this quantitative work was to study the behavior during the laboratory drying process, at air temperatures of 40 ºC, 55 ºC and 70 ºC, applying mathematical models to the experimental data, selecting the best model according to the kinetic curves of drying, as well as to evaluate the effect of this phenomenon on the efficiency of mechanical oil extraction. Artificial drying was carried out for a constant mass of grains, using a mechanical laboratory dryer in a fixed layer with forced convection, at an air speed of 0.33 m $s^{-1}$, with controlled drying air temperatures of 40 ° C , 55 ° C and 70 ° C. Nonlinear regression analysis was performed using the Quasi-Newton method to fit 12 mathematical models to the experimental data. The oil was extracted using an expeller mechanical press. The yield and the efficiency of the press were calculated from the difference in the lipid content obtained by the initial chemical extraction of the grain and cake residue. The Exponential Equation of Two Terms was the one that best suited the experimental data for all drying air temperatures. The increase in the temperature of the drying air caused greater volumetric contraction of the moringa grains, which affected the oil extraction yield, resulting in lower efficiency of the mechanical press.

**Key words:** Processing; Agricultural products; Oil yield.

**Resumen**

*Moringa oleifera* Lam. Es una planta resistente a la sequía y capaz de sobrevivir en suelos pobres, obteniendo hasta tres cosechas por año. Así, el objetivo de este trabajo cuantitativo fue estudiar el comportamiento durante el proceso de secado de laboratorio, a temperaturas del aire de 40 ºC, 55 ºC y 70 ºC, aplicando modelos matemáticos a los datos experimentales, seleccionando el mejor modelo según las curvas cinéticas de secado, así como para evaluar el efecto de este fenómeno en la eficiencia de la extracción mecánica de aceite. El secado artificial se realizó para una masa constante de granos, utilizando un secador de laboratorio mecánico en una capa fija con convección forzada, a una velocidad del aire de 0,33 m s-1, con temperaturas controladas del aire de secado de 40 °C. , 55 °C y 70 °C. El análisis de regresión no lineal se realizó utilizando el método Cuasi-Newton para ajustar 12 modelos matemáticos a los datos experimentales. El aceite se extrajo usando una prensa mecánica de expulsión. El rendimiento y la eficiencia de la prensa se calcularon a partir de la diferencia en el contenido de lípidos obtenido por la extracción química inicial del grano y el residuo de la torta. La ecuación exponencial de dos términos fue la que mejor se ajustó a los datos experimentales para todas las temperaturas del aire de secado. El aumento en la temperatura del aire de secado causó una mayor contracción volumétrica de los granos de moringa, lo que afectó el rendimiento de extracción de aceite, lo que resultó en una menor eficiencia de la prensa mecánica.

**Palabras clave:** Procesamiento; Productos agrícolas; Producción de aceite.

## 1. Introduction

*Moringa oleifera* Lam. is a tropical plant cultivated initially in India and introduced in Brazil almost 70 years ago, resistant to drought and able to survive in poor soils, obtaining up to three harvests per year (Alves et al., 2005; Rashid et al., 2008). Grains have approximately 40% oil, with a high percentage of oleic acid, around 78% (Anwar & Bhanger, 2003; Rashid et al., 2008; Santana et al., 2010). In addition, the oil has excellent oxidative stability, with the presence of δ-tocopherol, aiding in preservation during processing and storage, and is used industrially to lubricate watches, delicate machinery, in the manufacture of perfumes, biodiesel, as has also been studied its antioxidant effect when added to other oils (Anwar & Bhanger, 2003; Anwar et al., 2007; Amaglo et al., 2010; Atawodi et al., 2010; Boukandoul et al., 2017).

The temperature during the processing of the moringa grains is one of the main factors that can cause the degradation or low yield of its products. For drying, high temperatures speed up the process, making energy consumption less, and therefore more economical. However, they can cause physical and chemical changes in these, as well as affect efficiency in oil extraction (Almeida et al., 2013). Characteristics of the drying process, such as, particularities of the material, relative humidity, temperature and air speed are represented by the drying kinetics, using statistical modeling for this.

The mathematical simulation of the drying process is essential for the development and improvement of equipment used for drying grains. Such information is of great importance for mathematical simulations of drying in thin layers, which demonstrate the behavior of the reduction of water content during the process, allowing the promotion of improvements in the system and the development of new equipments (Araújo et al., 2017; Martins et al., 2018).

Thus, the objective of this work was to study the behavior during the drying process of *Moringa oleifera* grains, at temperatures of 40ºC, 55ºC, 70ºC, applying mathematical models to the experimental data, thus selecting the best model according to the kinetic curves drying, as well as evaluating the effect of this phenomenon on the efficiency of mechanical extraction of moringa oil, due to the scarcity of research related to the processing of these grains.

## 2. Material and Methods

The scientific method used in this work was a laboratory research using the quantitative method. In this method, collections of numerical data are performed through the use of measurements of quantities that generate data sets that are analyzed by mathematical techniques such as statistical analysis and non-linear mathematical models.

This research was carried out at the Federal University of Lavras (UFLA). Pre-dried *Moringa oleifera* grains were used, from the city of Barreirinhas (MA), from the second semester of 2018. Drying was done at the Agricultural Products Processing Laboratory and oil extractions and analyzes at the Oil Plants, Oils, Fat and Biodiesel, both in the Agricultural Engineering Department of this institution.

The beans were harvested shortly after reaching the point of physiological maturity, which is identified by the dark brown color of the pods (Agustini et al., 2015), from which they were manually removed and subsequently passed through pre-cleaning.

Artificial drying was carried out to a constant grain mass, using a mechanical laboratory dryer in a fixed layer with forced convection, at an air speed of 0.33 ms-1, with

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controlled drying air temperatures of 40 °C, 55 °C, and 70 °C. The water content of the samples was made before and after drying, according to the recommendations of the Rules for Seed Analysis (Brasil, 2009), where the greenhouse method at 105 ± 3 °C was used for 24 hours . The experiment consisted of triplicates, each with a mass of ± 1.7 kg, dried at different temperatures. During the process, the samples were weighed initially at smaller intervals, every 30 min (during the first 3 h) and later at more spaced intervals (1 h), until they reached hygroscopic balance, at which point the mass became constant.

The adjustment of the experimental drying data to the mathematical models was performed by means of non-linear regression analysis, by the Quasi-Newton method, in the computer program Statistica 5.0®, which were: Two terms, Exponential of two terms, Henderson and modified Pabis , Henderson and Pabis, Midilli, Newton, Page, Thompson, Verma, Wang and Sing, Valcam and Approximation of diffusion, which are the most used and available in the scientific literature (Table 1).

**Table 1** – Mathematical models applied to the drying curves.

| Model | Model designation | Equation |
|---|---|---|
| Diffusion Approach | $RU = a \exp(-k t) + (1 - a) \exp(-k b t)$ | (1) |
| Two terms | $RU = a \exp(-k_0 t) + b \exp(-k_1 t)$ | (2) |
| Exponential of two terms | $RU = a \exp(-kt) + (1-a) \exp(-kat)$ | (3) |
| Henderson & Pabis Mod. | $RU = a \exp(-k t) + b \exp(-k_0 t) + c \exp(-k_1 t)$ | (5) |
| Henderson & Pabis | $RU = a \exp(-k t) + c$ | (5) |
| Midilli | $RU = a \exp(-k t^n) + bt$ | (6) |
| Newton | $RU = \exp(-k t)$ | (7) |
| Page | $RU = \exp(- k t^n)$ | (8) |
| Thompson | $RU = \exp((-a(a^2 + 4bt)^{0,5})/2b)$ | (9) |
| Verma | $RU = a \exp(-kt) + (1-a) \exp(-kt)$ | (10) |
| Wang & Sing | $RU = 1 + a t + b t^2$ | (11) |
| Valcam | $RU = a + b t + c t^{1,5} + d t^2$ | (12) |

Source: Own elaboration

on what,

RU: water content ratio;

t: drying time (h);

k, ko and k1: drying constants;

a, b, c, d, n: model coefficients.

The water content calculations were calculated using the expression described below:

$$U_t = \frac{M_{ai} - (M_{ti} - M_{tt})}{M_{ms}} \tag{13}$$

on what,

$U_t$: Water content at time t (kg of water . kg of dry matter$^{-1}$ (bs));

$M_{ai}$: Initial water body (kg);

$M_{ti}$: Initial total mass (kg);

$M_{tt}$: Total mass at time t (kg);

$M_{ms}$: Mass of dry matter (kg).

To determine the water content ratios of the moringa grains during drying, the following expression was used:

$$RU = \frac{U - U_e}{U_i - U_e} \tag{14}$$

on what:

RU: product water content ratio (dimensionless);

U: water content of the product (kg of water . kg of dry matter$^{-1}$);

$U_i$: initial water content of the product (kg of water . kg of dry matter$^{-1}$);

$U_e$: equilibrium water content of the product (kg of water . kg of dry matter$^{-1}$).

For the calculation of equilibrium humidity ($U_e$), the hygroscopicity of the moringa grains was performed to identify the mathematical model that best fitted the experimental data, which was determined by the Sabbah model (Abreu et al., 2019). Thus Eq. 15 was used:

$$U_e = 0.2574 \frac{UR^{0.3912}}{T^{0.2385}} \tag{15}$$

on what,

$U_e$: Water content of the product (bs);

UR: relative humidity of the drying air (decimal);

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T: Temperature of the drying air (°C).

The drying kinetics analysis has the representativeness of the experimental data in the models, the experimental values were compared with the estimated data, the percentage of relative average error (P, %), estimated average error (SE) and test of the chi-square ($\chi^2$), with the following equations (Mathai & Haubold, 2018).

$$P = \frac{100}{n} \sum \frac{|Y - Y_0|}{Y} \tag{16}$$

$$SE = \sqrt{\frac{\sum (Y - Y_0)^2}{GLR}} \tag{17}$$

$$\chi^2 = \sum \frac{(Y - Y_0)^2}{GLR} \tag{18}$$

on what,

Y - value observed experimentally

$Y_0$ - value calculated by the model

n - number of experimental observations

GLR - model degrees of freedom

The specific gravity of the grains was made before drying, to determine the volumetric contraction at each drying air temperature. The apparent specific mass was carried out by hectoliter weight analysis, according to the Seed Analysis Rules (Brasil, 2009).

The oil was extracted using an expeller-type mechanical press. The yield (Rm, %) and the efficiency (Ef, %) of extraction were calculated from the difference in lipid content obtained by the initial chemical extraction of the grain and residual of the cake, with n-hexane solvent, since this was determined universal for oilseeds, for being practically total efficiency, using equations 19 and 20, respectively.

$$R_m = T_g - T_t \tag{19}$$

on what,

$R_m$ - Mechanical oil extraction yield (%)

$T_g$ - Grain oil content (%)

$T_t$ - Pie oil content (%)

$$E_f = (R_m\ 100)\ T_g^{-1} \tag{20}$$

on what,

Ef - Mechanical press efficiency (%)

Rm - Mechanical oil extraction yield (%)

Tg - Grain oil content (%)

The extractions, as well as the analyzes, were performed in three repetitions. The experimental design adopted was that of blocks randomized. The data obtained were subjected to analysis of variance and the means were compared with each other by the Tukey test, ($p<0.05$), using the Sisvar program, version 5.5 (Ferreira, 2014).

## 3. Results and Discussion

According to the models described, in Table 1, the most representative modeling was developed for the experimental data of humidity and time ratio, based on in the parameters of determination coefficients ($R^2$), relative mean errors (P), estimated (SE) and chi-square test ($\chi^2$), for each applied mathematical model. Among them, the most representative was the Two Term Exponential, shown in Table 2, having the best adjustment at different temperatures.

**Table 2** – Parameters, relative average errors, estimated and chi-square obtained from the Two-Term Exponential model, adjusted to the drying data of the moringa grains, for the different drying air temperatures.

| Temperature (°C) | k0 | k1 | $R^2$ (%) | P (%) | SE (decimal) | $\chi^2$ (decimal) |
|---|---|---|---|---|---|---|
| 40 °C | 0.3799 | 1.1475 | 99.80 | 6.51 | 0.1670 | 0.0279 |
| 55 °C | 0.1954 | 4.7755 | 99.98 | 6.71 | 0.3991 | 0.1592 |
| 70 °C | 0.2949 | 4.3926 | 99.73 | 1.37 | 0.8634 | 0.7455 |

Source: Own study

According to Teixeira et al. (2012) adjustments where $R^2$ is less than 90% and P is greater than 10%, do not ideally represent the data. Among the values of the statistical parameters obtained for the applied models, Page and Valcam presented satisfactory adjustment coefficients for the lowest drying temperature, 40 °C, with the determination coefficient ($R^2$) being 99.74% and relative average error, respectively. (P) 8.71%; $R^2$ 99.44% and P 0.68%. For drying temperature of 55 °C, the Diffusion Approximation and Midilli models had significant adjustments, respectively of $R^2$ 99.98% and P 5.98%; $R^2$ 99.97% and P 3.64%.

The Two Term Exponential model was the one that presented satisfactory values for all drying air temperatures, with high values of $R^2$ and low values of P, SE and $\chi^2$, being the best to represent the drying kinetics of the grains of *Moringa oleifera*, presenting coefficients of determination above 99.73%, and mean relative errors, estimated and chi-squares, respectively, below 6.71%; 0.8634; 0.7455.

Nascimento et al. (2015) evaluated the fit of the Page, Midilli, Newton and Fick's second law models to the experimental data of convective drying with infrared radiation application of *Moringa oleifera* L. grains, for temperatures of 30 °C, 45 °C and 60 °C and drying air speed from 0.55 to 1.05 m $s^{-1}$, finding Midilli as the best model adjusted to the experimental data for all variables.

According to Sousa et al. (2017), Maciel et al. (2017) and Melo et al. (2015) the Midilli model had the best fit in drying different agricultural products, however Radünz et al. (2011) states that the best fit to the model depends on the product, requiring individual study and at different temperatures for this determination.

The drying curves at different air temperatures for the moringa grains, related to the values simulated by the Two Term Exponential model, are shown in ~~Figures 1 to 3~~. Figure 1 illustrates drying kinetics of moringa grains with moisture ratio values from experimental data and simulated by Two Term Exponential model at drying air temperature of 40 ºC.

**Figure 1** – Drying kinetics of moringa grains with moisture ratio values from the experimental data and simulated by the Two Term Exponential model, at the drying air temperature of 40 °C.

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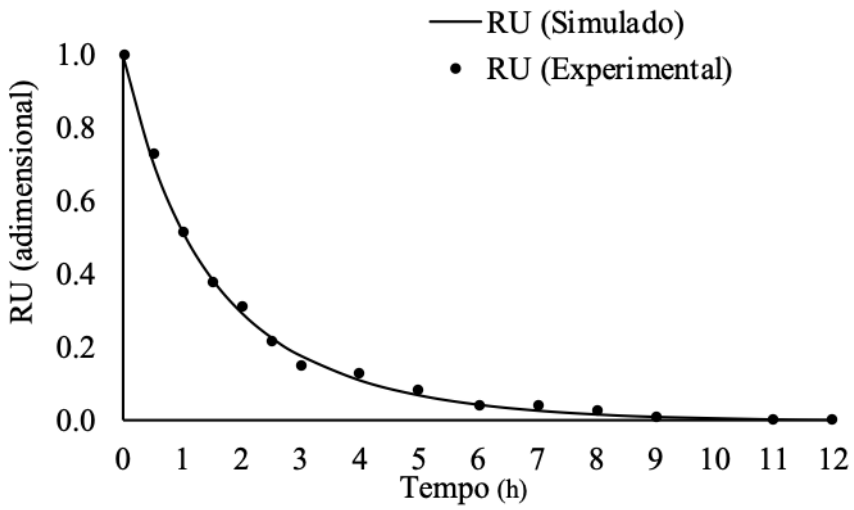
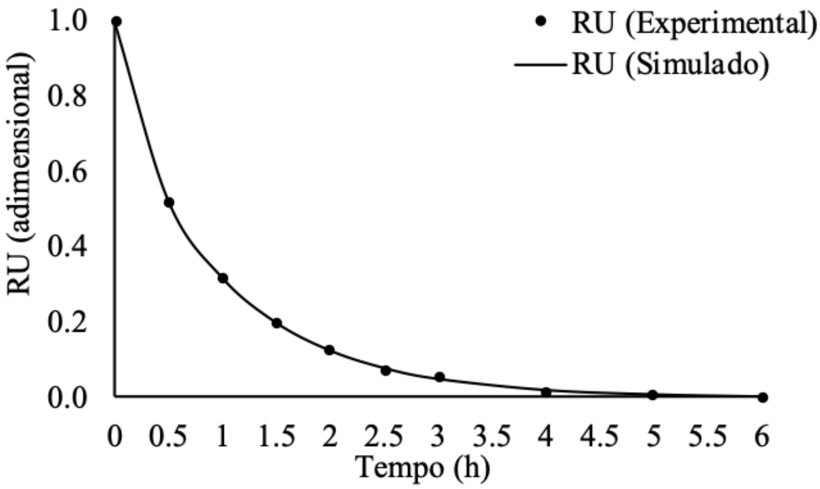



Source: Own study

It can be observed that it took about twelve hours to dry moringa grains at temperature of 40 ºC. Furthermore, it is seen that the experimental data is very similar to its simulation using the Two Term Exponential model. The proximity of the adjusted experimental values in relation to the curve estimated by the model, demonstrate that it was significantly adapted to the different temperatures of the drying air.

Figure 2 illustrates drying kinetics of moringa grains with moisture ratio values from experimental data and simulated by Two Term Exponential model at drying air temperature of 55 ºC.

**Figure 2** – Drying kinetics of moringa grains with moisture ratio values from the experimental data and simulated by the Two Term Exponential model, at the drying air temperature of 55 °C.

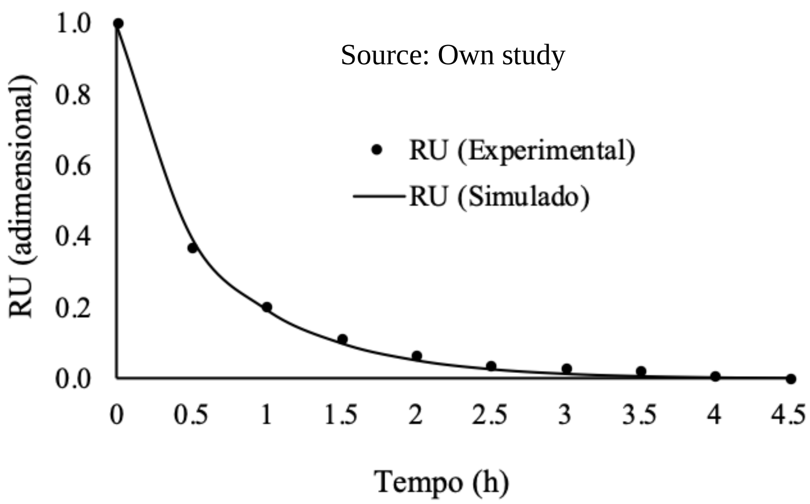



Source: Own study

Temperature at 55 ºC dried moringa grains within six hours. It also can be observed that there is a strong similarity among the experimental data and the simulation using the Two Term Exponential model.

Figure 3 illustrates drying kinetics of moringa grains with moisture ratio values from experimental data and simulated by Two Term Exponential model at drying air temperature of 70 ºC.

**Figure 3** – Drying kinetics of moringa grains with moisture ratio values from the experimental data and simulated by the Two Term Exponential model, at the drying air temperature of 70 °C.




Source: Own study

From Figure 3 it can be seen that air temperature significantly affected the drying kinetics of the moringa grains, it took 4,5 hours to dry it completely. The time the product was in equilibrium was inversely proportional to the temperature. This occurs due to the reduction of water viscosity with the elevation of the drying air temperature, directly affecting the fluid resistance to flow, facilitating the diffusion of water molecules in the product capillaries (Elhussein & Sahin, 2018; Lentzou et al., 2019).

The air temperature in the drying process of the grains can cause changes in the physical structure of the grains, and affect the extraction yield, concomitantly with the efficiency of the mechanical press. Table 3 shows the results of the effects of this phenomenon on the extractor's performance in obtaining moringa oil.

**Table 3 –** Effects of drying on the oil extraction yield by the mechanical method.

| | Specific mass ($g.cm^{-3}$) | Extraction yield (%) | Press efficiency (%) |
|---|---|---|---|
| Witness | 0.1370 a | 16.50 a | 67.26 a |
| 40 °C | 0.1434 ab | 16.29 a | 67.48 a |
| 55 °C | 0.1548 b | 6.08 b | 26.32 b |
| 70 °C | 0.1773 c | 4.57 b | 18.51 c |
| CV (%) | 2.77 | 6.79 | 7.50 |

* The values with the same letters in the column, do not differ at the level of 5% of significance, according to the Tukey test. CV: coefficient of variation.
Source: Own study

The increase in the temperature of the drying air was directly proportional to the specific mass of the grains, indicating a significant volumetric contraction of these, since they were dried until reaching the same water content. According to Souza et al. (2019) one of the most important physical changes that occur in agricultural products during drying is the reduction of their external volume, as the loss of water causes damage to the cellular structure of the product, leading to changes in the shape and shape of the product. decrease in its dimension. This occurs due to the reduction in cell size during the process, which can be modified by drying conditions, such as different drying air temperatures, affecting the parameters of heat and mass transfer (Nguyen et al., 2018; Koua et al., 2019).

The oil extraction yield, as well as the efficiency of the mechanical press, differed significantly according to the applied statistical test, between the dry grains with different drying air temperatures. With the increase of these, there was less efficiency and efficiency of the extractor, being, respectively, of 16.29% and 67.48% for that of 40 °C; 6.08% and 26.32%

for 55 °C and 4.57% and 18.51% for dry products at 70 °C. According to Wiesenborn et al. (2001) the oil yield is affected by constructive parameters of the press, such as dimensioning of the endless shaft and the cage, pressure applied on the grain mass, as well as by the prior preparation of the raw material to be processed, such as the physical structure of this, pressing temperature and water content of the samples. Correlating the oil extraction efficiency with the specific mass.

## 4. Conclusion

The Exponential Two Terms model showed the most satisfactory values to represent the drying kinetics of moringa grains, with high $R^2$ and low P, SE and $\chi^2$, at drying air temperatures of 40 °C, 55 °C and 70 °C.

The Page and Valcam showed good adjustment coefficients for drying air temperature of 40 °C, and Midilli and Diffusion Approximation for temperature of 55 °C.

The increase in the temperature of the drying air caused greater volumetric contraction of the moringa grains, which affected the oil extraction yield, resulting in lower efficiency of the mechanical press.

As a future work, it could be studied other phenomena that occurs with moringa grains such as hygroscopicity and thermal properties.

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**Percentage of contribution of each author in the manuscript**

Bárbara Lemes Outeiro Araújo – 35%

Ednilton Tavares de Andrade – 20%

Kariny Carvalho Vieira Nolasco – 15%

Rafael Peron Castro – 15%

Pedro Castro Neto – 15%