Revista Ciência Agronômica, v. 54, e20207656, 2023
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Physico-chemical characteristics of the oil from macauba kernels stored after drying at different temperatures[1]

Características físico-químicas do óleo de amêndoas de macaúba armazenadas após secagem em diferentes temperaturas

Marcela Silva Carvalho[2], Paulo Cesar Corrêa[3], Gutierres Nelson Silva[4], Adalberto Hipólito de Sousa[5]*, Lucas Martins Lopes[5]

ABSTRACT - Studies of post-harvest storage and drying in macauba fruit (*Acrocomia aculeata* (Jacq.) Lodd. Mart) are still in the early stages. The aim of this work was to investigate the effect of drying on the quality of macauba kernel oil during storage. Drying was carried out under three different air temperatures: 40 °C, 50 °C and 60 °C. Four replications were used for each temperature. After drying, the kernels were stored for 0, 60, 120, 240 and 360 days, and the following physico-chemical analyses were carried out for each period: kernel oil content, acidity index, oxidative stability, water activity and oil colour. An increase in storage time resulted in an increase in the acidity index and a reduction in the oxidative stability of the oil in all treatments. The mean value for water activity in the oil ranged from 0.56 to 0.68. The mean values of the L* and b* coordinates did not differ from the control, except for the storage times of 0 and 60 days. There was a difference in the a* coordinate between the drying processes when compared to the control. No significant differences were seen for oil content. It was concluded that drying can be efficient tool in controlling the quality of kernel oil during storage.

Key words: *Acrocomia aculeata*. Post-harvest. Dehydration. Oil quality.

RESUMO - Investigações sobre as etapas de armazenamento e secagem na pós-colheita de frutos de macaúba (*Acrocomia aculeata* (Jacq.) Lodd. Mart) ainda são incipientes. Desta forma, objetivou-se estudar o efeito da secagem na qualidade do óleo de amêndoas de macaúba durante o armazenamento. A secagem foi realizada em três condições de ar: 40; 50 e 60 ºC. Foram utilizadas quatro repetições para cada temperatura. Após a secagem, as amêndoas foram armazenadas durante 0; 60; 120; 240 e 360 dias, e em cada período, foram realizadas as seguintes análises físico-químicas: teor de óleo da amêndoa; índice de acidez; estabilidade oxidativa; atividade de água e cor do óleo. O aumento no período de armazenamento ocasionou elevação no índice de acidez e redução na estabilidade oxidativa do óleo para todos os tratamentos. Os valores médios de atividade de água no óleo variaram de 0.56 – 0.68. Os valores médios das coordenadas L* e b*, não diferiram do controle, com exceção dos períodos de armazenamento de 0 e 60 dias. Com relação à coordenada a*, houve diferença entre os processos de secagem, quando comparados ao controle. Não foram observadas diferenças significativas para o teor de óleo. Conclui-se que a secagem pode ser tornar ferramenta eficiente no controle da qualidade do óleo de amêndoa ao longo do armazenamento.

Palavras-chave: *Acrocomia aculeata*. Pós-colheita. Desidratação. Qualidade do óleo.

DOI: 10.5935/1806-6690.20230001
Editor-in-Article: Prof. Alek Sandro Dutra - alekdutra@ufc.br
*Author for correspondence
Received for publication on 15/10/2020; approved on 15/02/2022
[1]Part of the doctoral thesis presented to the Graduate Course in Agricultural Engineering, Federal University of Viçosa (UFV), funded by the Research Support Foundation of the State of Minas Gerais – FAPEMIG
[2]State University of Mato Grosso do Sul (UEMS), Glória de Dourados-MS, Brasil, marcelasc.eng@gmail.com (ORCID ID 0000-0002-8996-5743)
[3]Federal University of Viçosa (UFV), Viçosa-MG, Brasil, copace@ufv.br (ORCID ID 0000-0001-9843-1455)
[4]Federal Institute of Education, Science and Technology of Mato Grosso do Sul (IFMS), Nova Andradina-MS, Brasil, gutierres.silva@ifms.edu.br (ORCID ID 0000-0002-4272-0634)
[5]Federal University of Acre (UFAC), Rio Branco-AC, Brasil, adalberto.sousa@ufac.br (ORCID ID 0000-0002-3089-2762), lucas.lopes@ufac.br (ORCID ID 0000-0001-7686-4997)

INTRODUCTION

The macauba palm, *Acrocomia aculeata* (Jacq.) Lodd. Mart, has a production potential of approximately 6.7 tons of oil per hectare; this can be compared to the African palm (*Elaeis guinnensis* Jacq.), the agricultural crop with the highest production of oil per cultivated hectare (SILVA *et al*., 2020). The oil extracted from the macauba kernel has high levels of saturated fatty acids that vary from 71.2% to 84.6%, with a predominance of lauric acid (C12), which varies from 39% to 59% of the total fatty acid content (CÉSAR *et al*., 2015). The stability of lauric acid and its creamy consistency mean the kernel oil is of great importance to the cosmetics industry.

The oil production chain comprises several stages, ranging from coconut production and harvesting to the final processing of derived products. The post-harvest stage of the fruit has been poorly studied, with the oil being extracted by applying technology adapted from other oilseeds (PIMENTEL *et al*., 2015; SILVA *et al*., 2017). Such factors contribute to the low quality of the oil marketed by extractive industries in the cerrado region of Brazil. After harvesting, macauba oil can reach high levels of free fatty acids in only a few days. This rapid degradation of the oil is one of the most limiting factors in the economic exploitation of the crop, as it reflects in products (oil) of low quality and, consequently, of low added value. To overcome this problem, it is necessary to develop systems for storing and/or processing the fruit that can maintain the quality of the oil in the fruit, and allow the period of industrial processing to be increased (EVARISTO *et al*., 2016, 2017; IHA *et al*., 2014).

Drying agricultural products is one of the most common processes of physical conservation used to ensure quality and stability during storage (COSTA *et al*., 2016; KUMAR; KARIM; JOARDDER, 2014; SILVA *et al*., 2017). Physical methods can act directly on pathogens and indirectly on the physiology of the fruit, delaying their ripening and senescence, and maintaining their quality for a longer period (BENNAMOUN; KHAMA; LÉONARD, 2015). Various physical agents can be used: the main ones being temperature, radiation, ventilation and light (GHINI; BETTIOL, 1995).

A reduction in the amount of water in the material reduces biological activity and the physico-chemical changes that occur during the post-harvest period. Conservation by drying is based on the fact that not only microorganisms, but enzymes and the entire metabolic mechanism, need water for their activities. Therefore, reducing the amount of available water to safe levels for storage reduces the speed of the chemical reactions in the product and controls the development of microorganisms (SILVA *et al*., 2019).

According to Silva *et al*. (2017), drying at 60 °C is an efficient method of storing macauba fruit, which maintains the low acidity of the mesocarp oil. Taking into account the effectiveness of the drying process in conserving agricultural products, and the need to maintain the quality of the oil in the macauba fruit after harvest, the hypothesis was raised that drying the fruit can prolong shelf life. The aim of this study, therefore, was to analyse the effect of different drying temperatures on the quality and quantity of kernel oil from macauba fruit during storage for 360 days at room temperature.

MATERIAL AND METHODS

The experiment was conducted at the Laboratory of Physical Properties and Quality of Agricultural Products of the National Centre for Storage Training (CENTREINAR) at the Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil.

Macauba kernels

Macaúba fruit that were harvested manually at physiological maturity were used in the experiment. The plants were from the Capela farm in the district of Acaiaca, Minas Gerais, Brazil, located at 20.76° S and 42.86° W, at a height of 481 m above sea level; the climate is humid subtropical, Cwa.

Adult plants were selected to make up the samples. The palm trees had been previously identified and georeferenced, and bunches of ripe fruit were harvested during the production period when the fruit detached naturally from the bunches. During harvesting, a mattress equipped with side nets was used to cushion the fall of the bunches, and minimise any mechanical damage to the fruit.

After harvesting, the fruit was threshed and pre-selected in the field, when damaged fruit, or fruit showing visible deformation or disease, were removed in order to obtain a homogeneous product to comprise the experimental units. After selection, the fruit was transported to the Laboratory of Physical Properties and Quality of Agricultural Products and stored for 20 days, for the oil to fully accumulate in the kernel.

Physico-chemical characterisation of the macauba kernel after drying

Water content

The kernels, both with and without protection of the endocarp, were quantified by the difference in the initial and final weight after drying in an oven at 105 °C for 24 hours, measured using an analytical balance with a precision of 0.001 g, with the results expressed on a wet basis (wb) by equation (1):

$$TA(wb) = \frac{iw - fw}{fw} \times 100 \quad (1)$$

where TA (wb.) = water content on a wet basis; iw = initial weight in kg; fw = final weight in kg.

Drying

After 20 days, the fruit was pulped with the aid of a pulper, and the endocarp ruptured using a bench vice. The kernels were then taken for drying, which was carried out in an atmosphere-conditioning unit (Aminco-Aire 150/300 CFM) equipped with devices to control the temperature and relative humidity of the supplied air. The air flow was kept constant at around 4 m^3 min^{-1} m^{-2}. Removable trays with a mesh bottom were placed inside the equipment to allow air to pass through the sample.

The macauba kernels were dried under three different conditions of temperature and relative humidity of the air used for drying: 40 ºC and 40.26% RH; 50 °C and 24.07% RH; and 60 ºC and 14.91% RH. The samples were weighed periodically until reaching a moisture content of between 4.5% and 5.0% wb. Immediately after drying, an initial analysis of the kernels was made. After drying, the kernels were stored for periods of 60, 120, 240 and 360 days, and the kernel oil was analysed.

Oil content

To extract the kernel oil, a hydraulic press with a compressive-force capacity of 15 t was used. The kernels were then placed in amber flasks and frozen to -20 °C in order to avoid degrading the oil due to the action of light or temperature. The method adapted by the Instituto Adolfo Lutz (1985) was used to determine the oil content. The samples were dried in an oven, ground and placed in a filter-paper cartridge, and the oil extracted with a 'Soxhlet' type oil and fat extractor, using n-Hexane organic solvent.

During the extraction process, the samples were immersed in the solvent for two hours at 80 °C. After cooking, the samples were washed at 110 °C with the hexane accumulated in the condenser. This process was repeated six times. Following extraction, the cartridges were placed in a forced air circulation oven at 65 °C for 24 h for the excess n-hexane in the sample to evaporate. The cartridges containing the samples were then weighed on an analytical balance with a resolution of 0.01 g. The oil content was calculated using equation (2):

$$OC(\%) = \frac{(w1 - w2)}{(w1 - w)} \times 100 \quad (2)$$

where OC(%) = oil content as a percentage; P = weight of the cartridge in g; P1 = weight of the cartridge containing the sample before extracting the oil, in g; P2 = weight of the cartridge containing the sample after extracting the oil, in g.

Acidity index

The acidity index was determined as per the Ca 5a-40 method (AMERICAN OIL CHEMISTS' SOCIETY, 1997). Around 2.00 ± 0.10 g of the oil samples were weighed in a 125.0 mL Erlenmeyer flask; 25.00 mL of neutral ethyl ether-alcohol solution (2:1) was then added. Due to the low acidity of the oil, and in order to increase the precision of the analysis, two drops of 0.4% phenolphthalein indicator were added when titrating with a standardised NaOH 0.01 M solution. The acidity index was calculated using equation (3):

$$AI = \left(0.561 \frac{v_a f}{w}\right) \quad (3)$$

where AI = acidity index, expressed in mg $KOH.g^{-1}$; Va = volume of standardised 0.1 M sodium hydroxide solution used in titrating the sample, in mL; f = correction factor for the 0.1 M sodium hydroxide solution found by standardisation, dimensionless; m = weight of the sample, in g.

The acidity index was expressed in a percentage of oleic acid by dividing the result of the AI (in mg KOH g^{-1}) by 1.99.

Oxidative Stability

Oxidative stability was determined following the methodology proposed by the American Oil Chemists' Society (1997), using the Metrhom 873 Biodiesel Rancimat® equipment. For this, 2.50 ± 0.01 g of macauba kernel oil were placed in a test tube, and the tubes placed in the equipment, which was programmed to operate at 110 °C at an air flow velocity of 10.0 L h^{-1}. Oxidation was induced by passing air through the sample, which was maintained at a constant temperature. The volatile products of the reaction were collected in distilled water and determined by the change in electrical conductivity of the water. These products were expressed as a curve, whose peak of electrical conductivity was recorded. The device determined the induction period that characterised the loss of oxidative stability, calculated by the intersection of two lines: the tangent of the slope and the tangent to the curve. As such, the shorter the induction period, the lower the oxidative stability of the oil.

Water activity (WA)

The water activity was determined using the Aqualab 4 TE equipment from Decagon Devices, which provides readings of water activity from 0.050 to 1,000, with an accuracy of ± 0.003 and a resolution of 0.0001, at a temperature of 25 ºC.

Colour

The samples were analysed with the aid of a tristimulus colorimeter (MiniSacn XE - Plus 45/0-L), used to take a direct reflectance reading of the L* coordinate (luminosity), a* coordinate (red to green content) and b* coordinate (yellow to blue content), using the CIE scale and a 10°/D65 illuminant.

Experimental design and statistical analysis

The experiment was set up in a split-plot scheme, using the drying temperatures in the plots (control, 40, 50 and 60 °C) and the storage times in the sub-plots (0, 60, 120, 240, 300 and 360 days), in a completely randomised design (CRD) with four replications. Dunnett's test was used at 5% probability to compare the mean value of the control temperature with the mean value of the other temperatures within each storage time. For the quantitative factor, the models were chosen based on the significance of the regression coefficients using the t-test, on the coefficient of determination (R^2) and on the biological phenomenon. Irrespective of the significance of the greatest degree of interaction, it was decided that it was of interest to the study to break the interaction down. For experimental values where a model could not be chosen, descriptive statistics were used.

RESULTS AND DISCUSSION

Oxidative stability of the kernel oil (OS)

The mean values for oxidative stability (OS) of the macauba kernel oil submitted to the drying process showed a significant difference ($p < 0.05$) compared to the control (with no drying), for all storage times (Table 1).

The OS of the oil from the kernels dried at 40 °C showed a significantly lower mean value ($p < 0.05$) compared to the control treatment (with no drying) for all storage times (0, 60, 120, 240 and 360 days). The mean values for oxidative stability of the oil from the kernels dried at 50 °C were significantly lower ($p < 0.05$) than the control, but only for 60, 120 and 240 days of storage. The mean values for OS in the control treatment did not differ ($p > 0.05$) from those seen for the oxidative stability of the oil from the kernels dried at 60 °C for all storage times except that of 240 days.

The OS data of the macauba kernel oil dried at 40 °C and 60 °C, and with no drying (control), as a function of the storage time, adjusted to the quadratic model (Figure 1). However, the OS data of the macauba oil dried at 50 °C adjusted to the square root model. A reduction was seen in the OS of the kernel oil during storage in each of the treatments. After the storage time of 360 days, it was found that this reduction was more pronounced in the treatment that included drying at 40 °C (induction period: 27.6 h), while the highest mean values for OS were seen in the control treatment and when drying at 60 °C. Both treatments had OS values greater than 60 h up to 120 days of storage. The fitted models that show this variation can be seen in Table 2.

The oxidative stability of an oil is important when determining the conditions and storage time to which the oil can be subjected, as well as whether the use of antioxidant agents is necessary (CORSINI; JORGE, 2006). During the process of oxidative degradation, there is an initial period, known as the induction period (IP), where the greater the IP the more stable the oil (SILVA *et al*., 2011). In the present study, the greatest values for IP during storage were generally found in the treatment at 60 °C and the treatment with no drying (control). These results show that drying macauba kernels at a temperature of 60 °C can be a viable alternative for the oil processing industry.

During storage, the OS of the macauba kernel oil decreased in all treatments. This behaviour was also noted by Silva *et al*. (2011), who studied the oxidative stability of macadamia nut kernels dried by microwave-hot air, and found that both treatments showed mean values for stability that decreased over 180

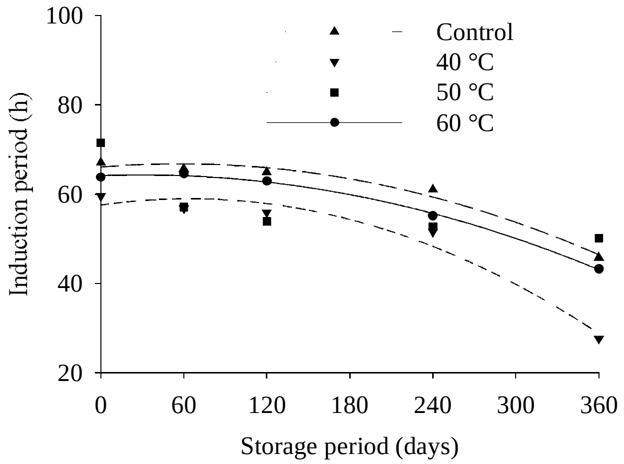
Table 1 - Mean values for oxidative stability (h) of macauba kernel oil submitted to drying (no drying, 40, 50 and 60°C), for different storage times (0, 60, 120, 240 and 360 days)

Treatment	Storage time (days)				
	0	60	120	240	360
ND (control)	67.15	65.59	64.87	61.09	45.79
40 °C	59.54*	56.86*	55.83*	51.62*	27.60*
50 °C	71.44	57.11*	53.90*	52.69*	50.10
60 °C	63.78	64.61	62.93	55.15*	43.27

Mean values with * in a column differ ($p < 0.05$) from the value of the treatment with no drying (ND), by Dunnett's test

days of storage. The reduction in oxidative stability during storage was probably due to the drying process increasing both the rate of oxidation and the chemical reactions of hydrolysis (MORETTO; FETT, 1998).

Figure 1 - Oxidative stability of the kernel oil from macauba fruit submitted to different treatments with drying (control, 40, 50 and 60 °C) during storage (0, 60, 120 240 and 360 days)



Acidity index of the kernel oil (AI)

The mean values for the acidity index (AI) of the macauba kernel oil submitted to the drying process showed a significant difference ($p < 0.05$) compared to the control (with no drying) for all storage times, except for 0 and 120 days (Table 3). In general, the mean values for AI in the treatments that included drying did not differ ($p > 0.05$) from the control treatment up to 120 days. For 240 and 360 days of storage, the mean values for AI of the kernel oil in the treatments at 50 °C and 60 °C were significantly higher ($p < 0.05$) than in the control treatment.

The regression curves that describe the behaviour of the AI in the kernel oil of the macauba fruit during storage when submitted to different drying temperatures are shown in Figure 2. With the increase in the storage time of the kernels, there was an increase in the AI in each of the treatments (control, drying at 40 °C, drying at 50 °C and drying at 60 °C), with the greatest increases seen in in the treatments with no drying (control) and with drying at 40 °C. The fitted models that show this variation can be seen in Table 2.

The increase in the AI of the kernel oil during storage seen in the control treatment may be associated

Table 2 - Fitted regression equations and their respective coefficient of determination (R^2), for acidity index and oxidative stability, as a function of the different treatments

Variable	Treatment	Fitted equation	R^2
Acidity index	Control	$\hat{y} = 0.2304 + 0.0015^{*}x$	0.82
	40 °C	$\hat{y} = 0.1556 + 0.0017^{**}x$	0.97
	50 °C	$\hat{y} = 0.2233 + 0.0007x$	0.71
	60 °C	$\hat{y} = 0.2371 + 0.0010^{**}x$	0.98
Estabilidade oxidativa	Control	$\hat{y} = 66.0731 + 0.0250x - 0.0002^{*}x^2$	0.97
	40 °C	$\hat{y} = 57.5642 + 0.0437x + 0.0003x^2$	0.96
	50 °C	$\hat{y} = 71.2413 + 0.0601^{*}x - 2.2158^{*}x^{1/2}$	0.99
	60 °C	$\hat{y} = 64.1585 + 0.0111x - 0.0002^{*}x^2$	0.99

* Significant at 5%, ** significant at 1%, significant at 10% by t-test

Table 3 - Mean values for the acidity index (% lauric acid) in macauba kernel oil submitted to drying (control, 40, 50 and 60 °C), for different storage times (0, 60, 120, 240 and 360 days)

Treatment	Storage time (days)				
	0	60	120	240	360
ND (control)*	0.16	0.44	0.31	0.67	0.72
40 °C	0.18	0.25*	0.29	0.60	0.75
50 °C	0.18	0.31	0.25	0.47*	0.42*
60 °C	0.23	0.30	0.34	0.42*	0.58*

Mean values with * in a column differ ($p < 0.05$) from the value of the treatment with no drying (ND), by Dunnett's test

with the high moisture content of the kernels in this treatment (Table 4). A high water content was found in all treatments before the drying process. Under such circumstances, there is a high rate of infestation by microorganisms. According to Ali, Shamsudin and Yunus (2014), microbial attack favoured the hydrolysis of palm oil (*Elaeis guineenses*) and, as such, increased the level of free fatty acids. According to Tan *et al*. (2014), lipase activity is improved in the presence of water, which may explain the increase in the acidity index in the kernel oil during storage.

After dehydration by artificial drying to 5.5% (Table 4), lipase activity is reduced, and low levels were therefore seen for the AI. Silva *et al*. (2011), studying the acidity index of macadamia nut oil after the drying process, also found that the AI of the oil remained low during storage, probably due to the inactivation of enzymes responsible for the hydrolytic process.

It is important to note that despite the linear increase in kernel oil acidity in all treatments, the increase was relatively small, the acidity content going from 0.2% to 0.8% lauric acid in one year. The values for acidity in this study are within the maximum values recommended by Brazilian legislation (AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA, 2005), which vary from 0.8% (for extra virgin olive oil) to 2% (for virgin olive oil). The results suggest that macauba kernel oil is of excellent quality for use in the food industry.

Kernel oil content (OC)

The mean oil content of macauba kernels submitted to the drying process generally showed a significant difference ($p < 0.05$) compared to the control (with no drying) for 0 and 60 days of storage only (Table 5).

The mean value for OC in the macauba fruit kernels ranged from 45.55% to 58.85% (db), irrespective of the treatment (control, drying at 40 °C, 50 °C or 60 °C) or storage time (Figure 3). The mean values for OC in the

Figure 2 - Acidity index (% lauric acid) in the kernel oil from macauba fruit submitted to different treatments with drying (control, 40, 50 and 60 °C) during storage (0, 60, 120, 240 and 360 days)

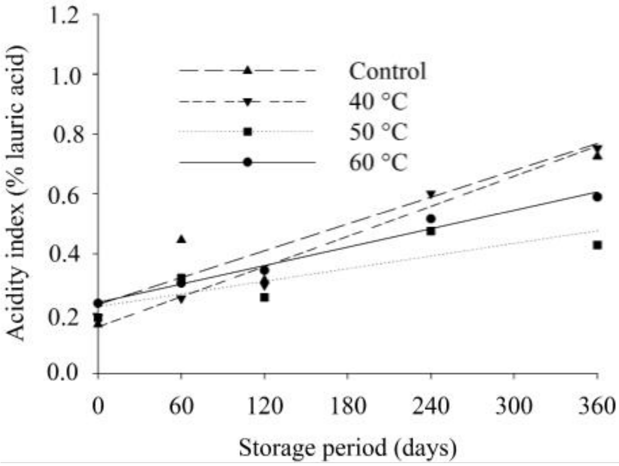


Table 4 - Mean values for water content in macauba kernels before drying (BD) and after drying (AD)

Drying temperature	Water content (%)	
	BD	AD
No drying	13.35 ± 0.03*	-
40 °C	13.79 ± 0.01	5.5
50 °C	13.20 ± 0.03	5.5
60 °C	13.20 ± 0.03	5.5

* mean ± SE

Table 5 - Mean values for the oil content (% db) of macauba kernels submitted to drying (control, 40, 50 and 60 °C), for different storage times (0, 60, 120; 240 and 360 days)

Treatment	Storage time (days)				
	0	60	120	240	360
ND (control)*	56.20	45.55	53.01	52.28	53.31
40 °C	49.63*	56.61*	52.09	52.99	50.28
50 °C	47.00*	58.85*	53.90	55.79	48.53*
60 °C	50.92*	41.88	54.12	54.97	52.06

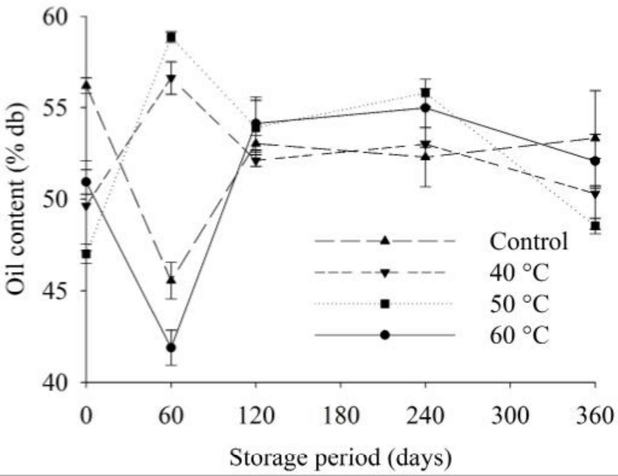
Mean values with * in a column differ ($p < 0.05$) from the value of the treatment with no drying (ND), by Dunnett's test

macauba fruit kernels did not vary significantly after 360 days of storage in any of the treatments. After 120 days of storage, there was a tendency in all treatments for the OC in the kernel to stabilise.

Therefore, drying at different temperatures for 360 days does not generally interfere with the OC of the kernel. Amaro *et al*. (2020), studying maturation, drying and storage on the quality of seeds of *Crambe Abyssinica*, also found that different drying temperatures (30, 45 and 60 °C) had no effect on the oil content of the seeds.

The kernels were stored for 20 days after collection under ambient conditions (temperature of 30 ± 2 °C and relative humidity of 70 ± 5%), only then was the drying process carried out. In general, the results of this study suggest the increase in OC of the kernel tends to stabilise after 20 days of storage under ambient conditions. Studies carried out by Evaristo *et al*. (2017) and Silva *et al*. (2020) confirm these results. Those authors suggest that macauba fruit show climacteric behaviour, accumulating oil during the first 20 days of storage only. Given the above, the kernels probably also only accumulate oil during the first 20 days.

Figure 3 - Variation in the oil content (% db) of the kernels of macauba fruit submitted to different treatments with drying (control, 40, 50 and 60 °C) during storage (0, 60, 120, 240 and 360 days)



Water activity of the oil (WA)

The mean value for water activity (WA) in macauba kernel oil submitted to the drying process (40, 50 and 60 °C) did not differ ($p > 0.05$) from the mean value of the control (with no drying) by Dunnett's test, for each of the storage times (Table 6).

The mean values for WA in the kernel oil from the macauba fruit ranged from 0.56 to 0.68, irrespective of the treatment (control, drying at 40 °C, 50 °C or 60 °C) or storage time (Figure 4). After 360 days of storage, there were no significant differences in WA between the treatments, both with and without drying. During storage of the kernels, there was a general trend towards higher mean values for WA in the treatment that included drying at 40 °C and in the treatment with no drying.

Knowledge of the water activity of a stored agricultural product is fundamental, especially as this variable is a determining factor in the growth of fungi (SILVA *et al*., 2017). Water activity represents the availability of water for the development of microorganisms, and also for browning, oxidation and hydrolysis reactions (PARK *et al*., 2007; TORREZAN; JARDINE; VITALI, 1997).

As can be seen in Table 5 and Figure 4, there was no significant difference in WA during storage, however, the use of the drying temperatures of 50 °C and 60 °C afforded lower mean values for WA than in the other treatments. Using these two temperatures might therefore be a viable alternative for storing macauba kernels for use in the industry, since under such conditions there would probably be a low rate of infestation by microorganisms, resulting in quality preservation.

Studies carried out by Borompichaichartkul *et al*. (2009) into the quality of macadamia nuts (*Macadamia integrifolia*) after drying, found higher mean values for water activity at a drying temperature of 70 °C, compared

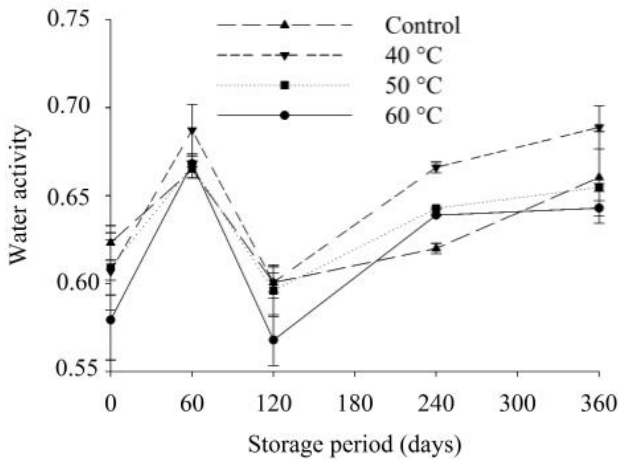
Table 6 - Mean values for water activity (WA) in the oil of macauba kernels submitted to drying (control, 40, 50 and 60 °C), for different storage times (0, 60, 120, 240 and 360 days)

Treatment	Storage time (days)				
	0	60	120	240	360
ND (control)*	0.62	0.66	0.60	0.61	0.66
40 °C	0.60	0.68	0.60	0.66	0.68
50 °C	0.60	0.66	0.59	0.64	0.65
60 °C	0.57	0.66	0.56	0.63	0.64

Mean values with * in a column differ ($p < 0.05$) from the value of the treatment with no drying (ND), by Dunnett's test

to lower temperatures (50 °C and 60 °C). According to the same authors, at 70 °C, the water in the product may have been removed quickly, hardening the surface and blocking the remaining water in the nucleus, with the result that water activity remained high. In view of the above, drying macauba kernels at a temperature of 60 °C might be a promising method for preserving the quality of the product during storage.

Figure 4 - Variation in the water activity of the kernel of macauba fruit submitted to different treatments with drying (control, 40, 50 and 60 °C) during storage (0; 60; 120; 240 and 360 days)



Colour of the kernel oil (CO)

The mean values of the L* and b* coordinates did not differ (p > 0.05) from the mean values of the control, except for the storage times of 0 and 60 days (Table 7). For the a* coordinate, there was a statistical difference ($p < 0.05$) by Dunnett's test between the drying processes (40 °C, 50 °C and 60 °C) compared to the control treatment, for each of the storage times.

The mean value for the L* coordinate in the kernel oil from the macauba fruit ranged from 42.65 to 60.30 irrespective of the treatment (control, drying at 40 °C, 50 °C or 60 °C) or storage time (Table 7 and Figure 5). For the a* coordinate, it can be seen that regardless of the treatment, the lowest values were generally seen after 120 days of storage, with the highest mean values after 240 days. For the b* coordinate, the maximum value (9.04) was seen in the treatment that included drying at 60 °C and a storage time of zero. The lowest mean values for the L* coordinate were generally seen after the storage time of 240 days in each of the treatments.

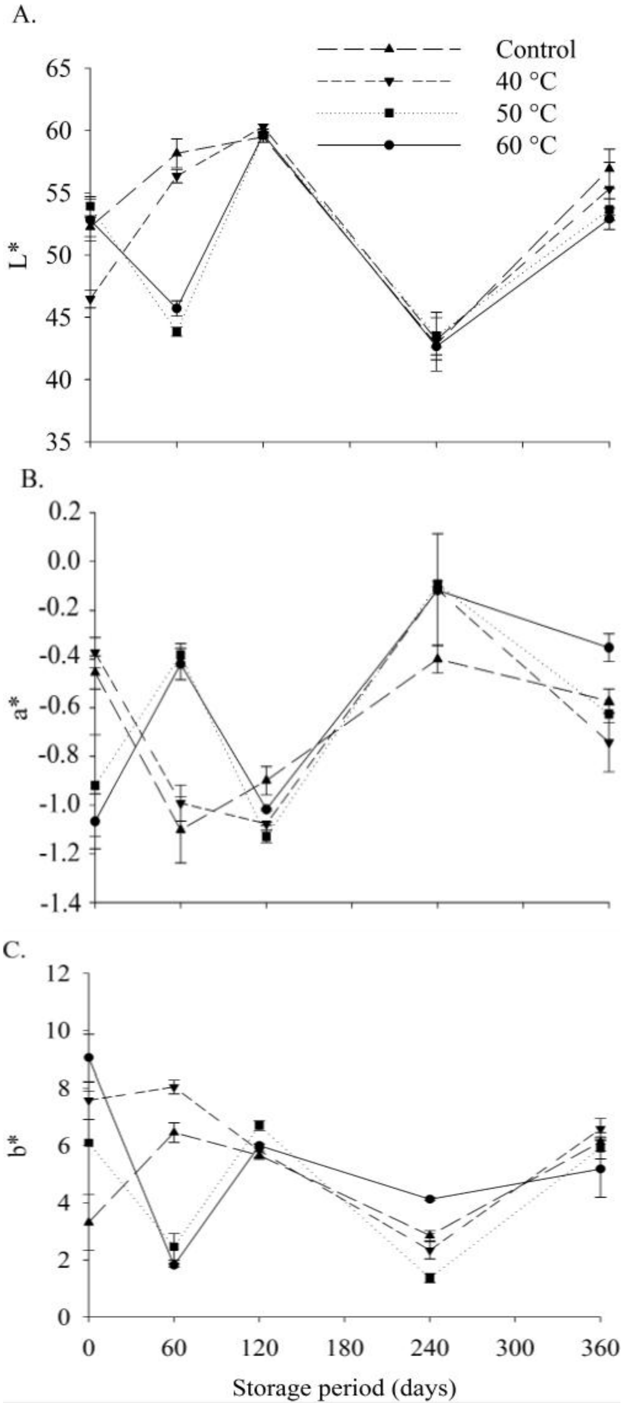
Table 7 - Mean values for L*, a*, b* in the oil of macauba kernels submitted to drying (control, 40, 50 and 60 °C), for different storage times (0, 60, 120, 240 and 360 days)

Treatment	L*				
	0	60	120	240	360
ND (control)*	52.26	58.16	59.49	42.82	56.92
40 °C	46.46*	56.34	60.30	43.18	55.32
50 °C	53.92	43.83*	59.63	43.50	53.65
60 °C	52.80	45.70*	59.69	42.65	52.90*
Treatment	a*				
	0	60	120	240	360
ND (control)*	-0.45	-1.10	-0.90	-0.40	-0.57
40 °C	-0.37	-0.99	-1.07*	-0.11*	-0.74*
50 °C	-0.92*	-0.38*	-1.13*	-0.09*	-0.62
60 °C	-1.06*	-0.42*	-1.01	-0.11*	-0.35*
Treatment	b*				
	0	60	120	240	360
ND (control)*	3.31	6.45	5.65	2.85	6.12
40 °C	7.57*	8.04	5.82	2.33	6.58
50 °C	6.09*	2.46*	6.69	1.36	5.91
60 °C	9.04*	1.81*	6.00	4.12	5.18

Mean values with * in a column differ ($p < 0.05$) from the value of the treatment with no drying (ND), by Dunnett's test

One important attribute when analysing the quality of any given product is colour; visual appreciation is the first of the senses to be used, so this parameter is decisive in product acceptance (LIMA; FIGUEIRÊDO; QUEIROZ, 2007). The kernel oil obtained at the drying temperatures under study had mean values that were generally similar to those seen in the control treatment (with no drying) for the L* coordinate, which on a scale from 0 to 100 varies from black (0) to white (100). The values related to b* are measured in relation to hue: yellow, if positive, and blue if negative.

Figure 5 - Variation in the L* (A), a* (B) and b* (C) coordinates of macauba fruit kernels exposed to different treatments (control, and drying at 40, 50 and 60 °C) during storage (0, 60, 120, 240 and 360 days)



During storage, and irrespective of the treatment (with or without drying), it was found that the mean values for b* were all positive, meaning the oil kept its characteristic colour during storage in each of the treatments, with no unwanted darkening. In addition, the mean values for the a* coordinate did not change statistically over time, regardless of the treatment; the term a* refers to a red hue, if positive, or green, if negative. All the mean values seen for this coordinate were negative.

During storage of the kernels from the four treatments (no drying, 40 °C, 50 °C and 60 °C), the air temperature and humidity were controlled. The colour of the kernel oil remained statistically unchanged throughout storage, probably due to the storage environment not changing during the experiment. The storage environment (temperature and relative humidity), as well as the period, can easily affect the quality and appearance of the stored product (ALENCAR *et al*., 2009; BIABANI *et al*., 2011; SMANIOTTO *et al*., 2014).

CONCLUSIONS

1. The longest induction periods during storage were seen in the drying treatments at 60 °C and the treatment with no drying (control). With the increase in the storage time of the kernels, there was an increase in the acidity index in all treatments;
2. The mean value for oil content in the macauba fruit kernels did not vary significantly during the 360 days of storage for any of the treatments;
3. Drying can be an efficient tool for controlling the quality and quantity of the oil from macauba fruit kernels throughout the 360 days of storage.

REFERENCES

ALENCAR, E. R. *et al*. Qualidade dos grãos de soja armazenados em diferentes condições. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 13, n. 5, p. 606-613, 2009.

ALI, F. S.; SHAMSUDIN, R.; YUNUS, R. The effect of storage time of chopped oil palm fruit bunches on the palm oil quality. **Agriculture and Agricultural Science Procedia**, v. 2, n. 1, p. 165-172, 2014.

AMARO, H. T. R. *et al*. Storage *of Crambe abyssinica* Hochst. ex R. E. Fr. seeds after drying at different temperatures. **Revista de Ciências Agrárias**, v. 43, n. 2, p. 210-2019, 2020.

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA (BRASIL). **Resolução de diretoria colegiada - RDC nº 270, de 22 de setembro de 2005**. Brasília, DF: Ministério da Saúde, 2005. Disponível em: http://www.anvisa.gov.br. Acesso em: 25 ago. 2020

AMERICAN OIL CHEMISTS' SOCIETY. **Official methods and recommended practices of the American Oil Chemists' Society**. Champaign: AOCS Press, 1997. 54 p.

BENNAMOUN, L.; KHAMA, R.; LÉONARD, A. Convective drying of a single cherry tomato: modeling and experimental study. **Food and Bioproducts Processing**, v. 94, p. 114-123, 2015.

BIABANI, A. *et al*. Effects of seed deterioration and inoculation with *Mesorhizobium ciceri* on yield and plant performance of chickpea. **Australian Journal of Crop Science**, v. 5, n. 1, p. 66-70, 2011.

BOROMPICHAICHARTKUL, C. *et al*. Improving quality of macadamia nut (*Macadamia integrifolia*) through the use of hybrid drying process. **Journal of Food Engineering**, v. 93, n. 3, p. 348-353, 2009.

CÉSAR, A. S. *et al*. The prospects of using *Acrocomia aculeata* (macaúba) a non-edible biodiesel feedstock in Brazil. **Renewable and Sustainable Energy Reviews**, v. 49, n. 9, p. 1213-1220, 2015.

CORSINI, M. S.; JORGE, N. S. Estabilidade oxidativa de óleos vegetais utilizados em frituras de mandioca palito congelada. **Ciência e Tecnologia de Alimentos**, v. 26, n. 1, p. 27-32, 2006.

COSTA, C. F. *et al*. Mathematical modeling and determination of thermodynamic properties of jabuticaba peel during the drying process. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 20, n. 6, p. 576-580, 2016.

EVARISTO, A. B. *et al*. Caracterização fisico-química de frutos de macaúba provenientes de três regiões do estado de Minas Gerais. **Revista Agrotecnologia**, v. 8, n. 2, p. 81-92, 2017.

EVARISTO, A. B. *et al*. Harvest and post-harvest conditions influencing macauba (*Acrocomia aculeata*) oil quality atributes. **Industrial Crops and Products**, v. 85, p. 63-73, 2016.

GHINI, R.; BETTIOL, W. Diagnose. *In*: KIMATI, H. **Manual de fitopatologia**. São Paulo: Agronômica Ceres, 1995. p. 786-803.

IHA, O. K. *et al*. Physicochemical properties of *Syagrus coronata* and *Acrocomia aculeata* oils for biofuel production. **Industrial Crops and Products**, v. 62, p. 318-322, 2014.

INSTITUTO ADOLFO LUTZ. **Normas analíticas do Instituto Adolfo Lutz**: métodos químicos e físicos para análise de alimentos. São Paulo: IMESP, 1985. p. 116-118.

KUMAR, C.; KARIM, M. A.; JOARDDER, M. U. H. Intermittent drying of food products: a critical review. **Journal of Food Engineering**, v. 121, p. 48-57, 2014.

LIMA, E. E.; FIGUEIRÊDO, R. M. F.; QUEIROZ, A. J. M. Cinética de secagem de polpa de facheiro. **Revista Brasileira de Produtos Agroindustriais**, v. 9, n. 1, p. 17-28, 2007.

MORETTO, E.; FETT, R. **Tecnologia de óleos e gorduras vegetais na indústria de alimentos**. São Paulo: Varela, 1998. 150 p.

PARK, K. J. *et al*. Conceitos de processo e equipamentos de secagem. 2007. Disponível em: http://www.feagri.unicamp.br/ctea/projpesq.html. Acesso em: 31 mar. 2020.

PIMENTEL, L. D. *et al*. Effect of nitrogen and potassium rates on early development of macaw palm. **Revista Brasileira de Ciência do Solo**, v. 39, n. 6, p. 671-1680, 2015.

SILVA, F. A. da *et al*. Estabilidade oxidativa de amêndoas de noz macadâmia secas por micro-ondas com ar quente. **Pesquisa Agropecuária Tropical**, v. 41, n. 2, p. 286-292, 2011.

SILVA, G. N. *et al*. Air drying of macauba fruits: maintaining oil quality for biodiesel production. **Acta Scientiarum-Agronomy**, v. 42, p. e43451, 2020.

SILVA, G. N. *et al*. Drying of macaw palm fruits and its influence on oil quality. **Semina: Ciências Agrárias**, v. 38, n. 5, p. 3019-3030, 2017.

SILVA, G. N. *et al*. Post-harvest quality of ozonated macauba fruits for biodiesel production. **Revista Caatinga**, v. 32, n. 1, p. 92-100, 2019.

SMANIOTTO, T. A. S. *et al*. Qualidade fisiológica das sementes de soja armazenadas em diferentes condições. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 18, n. 4, p. 446-453, 2014.

TAN, Z. *et al*. Optimized microemulsion production of biodiesel over lipase-catalyzed transesterification of soybean oil by response surface methodology. **Green Processing and Synthesis**, v. 3, n. 6, p. 471-478, 2014.

TORREZAN, R.; JARDINE, J. G.; VITALI, A. A. Preservação de alimentos com o uso dos métodos combinados: uma revisão. **Boletim SBCTA**, v. 31, n. 2, p. 214-228, 1997.