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Crambe fruit drying with natural air in stationary dryers[1]

Secagem de frutos de crambe com ar natural em secador estacionário

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ABSTRACT - The aim of this study was to assess the drying behavior and quality of crambe fruit seeds dried with natural air and submitted to different airflows in stationary dryers. Dryings were carried out in July and September 2014. The experiment consisted of three treatments of drying the crambe fruits with natural air in stationary dryers with airflows of 10.08, 15.05, and 25.03 $m^3\ min^{-1}\ t^{-1}$ and a control treatment composed of crambe fruits with an initial moisture content without going through the drying process. After drying, tests of moisture content, germination, germination rate index, and electrical conductivity were performed in order to compare the treatments. The data were submitted to analysis of variance and mean comparison by the Tukey's test at 5% significance. Among the airflows used in the experiment in both natural air dryings in July and September, no interference was observed for crambe fruit quality. Drying carried out in September was faster and showed a lower expenditure and cost of electricity when compared to that performed in July, which is due to better climatic conditions. No difference was observed in the drying times between airflows, but the drying with natural air using an airflow of 15.05 $m^3\ min^{-1}\ t^{-1}$ was more profitable.

Key words: Moisture content. Physiological quality. Biodiesel.

RESUMO - O objetivo nesse trabalho foi avaliar o comportamento da secagem e a qualidade das sementes secas com ar natural em frutos de crambe submetidos a diferentes fluxos de ar em secadores estacionários. As secagens foram realizadas em dois períodos, uma em julho e outra em setembro do ano de 2014. O experimento compreendeu três tratamentos "A", "B" e "C" que consistiram na secagem dos frutos de crambe com ar natural em secador estacionário com fluxos de ar de 10,08 $m^3\ min^{-1}\ ton^{-1}$; 15,05 $m^3\ min^{-1}\ ton^{-1}$; 25,03 $m^3\ min^{-1}\ ton^{-1}$, respectivamente e uma testemunha "T" composto por frutos de crambe com teor de água inicial sem passar pelo processo de secagem. Após as secagens, foram realizados testes de teor de água, germinação, índice de velocidade de germinação e condutividade elétrica para comparação dos tratamentos. Os dados obtidos foram submetidos à análise de variância e comparação de médias pelo teste de Tukey a 5% de significância. Dentre os fluxos de ar utilizados no experimento em ambas as secagens com ar natural nos meses de julho e setembro, não houve interferência na qualidade dos frutos de crambe. A secagem realizada no mês de setembro foi mais rápida e apresentou menor gasto e custo de energia elétrica quando comparada com a secagem realizada no mês de julho devido às melhores condições climáticas. Não houve diferença no tempo de secagem entre os fluxos de ar utilizados, porém, a secagem com ar natural utilizando o fluxo de ar de 15,05 $m^3\ min^{-1}\ ton^{-1}$ mostrou ser mais rentável.

Palavras-chave: Teor de água. Qualidade fisiológica. Biodiesel.

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INTRODUCTION

The search for alternative and renewable sources of energy has become a constant in the world due to scarcity and environmental impacts generated by the use of non-renewable sources in urban, road, rail, and waterway transport, power generators, stationary engines, etc. (JASPER *et al.*, 2010). In this context, biodiesel emerged as an alternative in relation to petroleum and its byproducts since its production is obtained through renewable sources such as oilseeds and animal fat, reducing pollutant emission into the atmosphere (PEREIRA *et al.*, 2012).

A higher supply of raw material is required to increase the demand for biodiesel by investing in promising and profitable alternatives such as the cultivation of crambe (*Crambe abyssinica* Hochst) fruits (FERREIRA; SILVA, 2011).

Crambe belongs to the family Brassicaceae and has shown to be a promising source of vegetable oil for biodiesel production due to its high oil content, which ranges between 40 and 44% (BITTENCOURT, 2010; SOUZA *et al.*, 2009). Crambe is a plant that adapts in areas that would not be used for food cultivation due to its rusticity and its oil does not compete with oils used in the food sector due to the high contents of erucic acid (COLODETTI *et al.*, 2012).

According to Araujo *et al.* (2014), to produce high-quality grains, it is preferable that high-moisture content fruits be harvested in the field aiming at reducing losses caused by insects and microorganisms. Resende *et al.* (2011) stated that drying is the most used process to ensure grain quality considering that a reduced moisture content decreases its biological activity and physical and chemical changes that occur during storage.

Grain drying at low temperatures is one of the alternatives that allow obtaining a final product of better quality due to a slow grain movement in the silo, avoiding mechanical damages and thermal shocks. In addition, it requires a low initial investment when compared to drying systems that use high temperatures (ELIAS, 2008).

According to Silva (2005), drying using natural ambient air in stationary dryers is classified as artificial with forced ventilation. In this modality, heating the drying air above the ambient temperature is not required when the drying potential of the ambient air in the region and months performed is ideal for the management.

Schuh *et al.* (2011) concluded that grain drying with natural air could be an excellent alternative for small producers because it is a viable method in terms of quality. Oliva, Biaggioni and Cavariani (2012) reported that drying using natural air ventilation at ambient temperature preserves grain quality, but it may require an extended period.

Considering the lack of studies on drying with natural air relating its influence on crambe fruit quality and considering the economic importance of this crop, this study aimed to assess the drying behavior and quality of crambe fruit seeds dried with natural air and submitted to different airflows in stationary dryers.

MATERIAL AND METHODS

The experiment was carried out in Rio Verde, Goiás, Brazil, at the Laboratory of Post-Harvest of Plant Products of the Federal Institute of Education, Science and Technology of Goiás (Campus of Rio Verde). Crambe fruits of the cultivar FMS Brilhante were randomly selected from plants cultivated by producers from the region of Inaciolândia, Goiás, in the agricultural season of 2014 and provided by Caramuru Alimentos S/A.

Fruits were mechanically harvested in June 2014 and were initially mechanically pre-cleaned. Subsequently, cleaning was carried out using flat sieves to remove impurities. In order to minimize the loss of moisture content until the second drying, crambe fruits were packed into sealed plastic containers and stored in cold chambers with a temperature of 10 °C for two months.

The experiment was divided into two dryings carried out on July 7-12 and September 19-22, 2014. The first drying with natural air was performed by turning on the dryers in the morning and evening and turning them off at night, which resulted in a break of 12 hours. The second drying with natural air was carried out by turning the dryers on in the afternoon and turning them off at night and in the morning, resulting in an 18-hour break. The initial crambe moisture content in the first and second dryings was 10.26 and 9.84% (w.b.), respectively, being dried to a final moisture content of approximately 6.00% (w.b.) by using a forced air circulation oven at 105 ± 3 °C for 24 h (BRASIL, 2009).

The average temperature and relative humidity (RH) of the ambient air during the drying were 22 ± 4 °C and 58 ± 22% in July, and 26 ± 6 °C and 62 ± 30% in September, respectively. Temperature and UR data of the ambient air and the temperature of crambe fruit mass were collected by means of thermocouples every 20 min.

Dryings were carried out with natural air in experimental stationary metallic dryers with a capacity of 40 kg adapted for drying in a fixed bed, with a flat bottom, and perforations in the metallic plate. The dryers had an aeration system composed by a centrifugal fan of curved blades forward driven by a 1.5 hp (1,103 kW) three-phase motor and diaphragm to control the air intake near the fan. Drying airspeed that composed the airflows of the experiment was regulated using an AD-250 digital rotary blade anemometer. After two homogenization, 32.5, 39.9, and 34.9 kg of crambe fruits were used in treatments A, B, and C, respectively, and a control. Treatment A used an airspeed of 0.3 m s^{-1}, with an airflow of 10.08 m^3 min^{-1} t^{-1}. Treatment B used an airspeed of 0.55 m s^{-1}, with airflow of 15.05 m^3 min^{-1} t^{-1}. Treatment C used an airspeed of 0.8 m s^{-1}, with an airflow of 25.03 m^3 min^{-1} t^{-1}. In addition, the control treatment was composed of crambe fruits with initial moisture content without going through the drying process.

The ambient air had an increase in temperature due to a low heating caused by the fan. The dimensioning of this increase in temperature of the drying air was carried out subtracting the average temperature of the crambe fruit mass by the average temperature of the ambient air during the drying periods.

In order to follow the loss of moisture content of crambe fruits, three samples of 50 g were wrapped with voil tissue and distributed in the fruit mass of each dryer. These samples were weighed every 1 h and crambe fruits were homogenized after each weighing. The loss of mass of crambe fruits due to drying was calculated by the percentage breakage by Equation (1):

$$Mwr = [(Xi - Xf)/(100 - Xf)] \times TGM \quad (1)$$

where: *Mwr* is the water mass removed (kg), *Xi* is the initial moisture content of the product (%, w.b.), *Xf* is the final moisture content of the product (%, w.b.), and *TGM* is the total grain mass (kg).

The result obtained by Equation (1) means the breakage mass due to the exit of water from the grains. Subtracting this result from the total fruit mass we have the total mass after drying (PIMENTEL; FONSECA, 2011).

After drying, we performed the tests of germination (%), germination rate index (GRI), and electrical conductivity (μS cm^{-1} g^{-1}). Germination was carried out with four replications with 25 crambe seeds in each treatment. Seeds were conditioned in Gerbox containers on blotting paper moistened with distilled water equivalent to 2.5 times the dry substrate mass aiming at an appropriate moistening and test standardization. Subsequently, these containers were maintained in a Mangelsdorf germinator regulated at a constant temperature of 25 ± 2 °C (BRASIL, 2009).

Germination rate index was determined from the germination test data and calculated by means of the sum of the number of crambe seeds germinated each day divided by the number of days elapsed between sowing and germination, according to Equation (2):

$$GRI = n_1 \times d_1^{-1} + n_2 \times d_2^{-1} + n_3 \times d_3^{-1} + \ldots + n_n \times d_n^{-1} \quad (2)$$

where: n_1, n_2, and n_3 are the seeds germinated on the first, second, and third count day, respectively, n_n is the seeds germinated on n-th count day, d_1, d_2, and d_3 are the first, second, and third days, respectively, and d_n is the n-th day (MAGUIRE, 1962).

Electrical conductivity test was performed according to the methodology described by Oliveira *et al.* (2012). For this, 50 crambe fruits from each treatment (4 replications) were weighed in a 0.01 g precision scale. Samples were placed in plastic cups for soaking in 75 mL of deionized water and maintained in a biochemical oxygen demand (BOD) incubator under a controlled temperature at 25 °C for 24 h. Solutions containing fruits were slightly stirred for leachate homogenization and immediately read on a portable digital conductivity meter CD-850 Instrutherm, being the results divided by the mass of 50 fruits and expressed in μS cm^{-1} g^{-1} of product.

The amount and cost of total electricity consumed during the tests were calculated by monitoring the total turn-on time of dryers. The three-phase electric motors that drove the centrifugal fans had a power of 1.5 hp (1,103 kW). Thus, when multiplying the number of hours spent in the drying process by the motor power, we have the amount of electricity consumed per hour in each treatment (kW h^{-1}). Moreover, when multiplying the amount of electricity consumed per hour by the electricity value in the region (CELG DISTRIBUIÇÃO, 2015), we have the electricity cost of each treatment (BRL). The electricity value in kW h^{-1} (0.29805 BRL) used in the calculations refers to the amount charged for use in rural properties (CELG DISTRIBUIÇÃO, 2015). Electricity cost related to the mass of dried fruits was calculated by dividing the cost of electricity consumed by each treatment by the mass of crambe fruits after drying.

The experiment was carried out in a completely randomized design. The obtained data were submitted to the analysis of variance (ANOVA) and normality test of Shapiro-Wilk. Subsequently, means were compared by Tukey's test at 5% significance.

RESULTS AND DISCUSSION

The average temperature and RH of the ambient air during the drying periods of crambe fruits in July was 24 ± 1 °C and 54 ± 5%, respectively, being the averages of the first, second, and third days of 25 °C and 53%, 23 °C and 59%, and 24 °C and 49%, respectively. In September, the average temperature was 29 ± 4 °C and RH was 48 ± 19%, being the averages for temperature and RH of the first, second, third, and fourth days of 33 °C and 32%, 29 °C and 50%, 26 °C and 67%, and 29 °C and 41%, respectively.

The average temperature for the first drying with natural air of the crambe fruit mass during the three days was 25.7, 26.3, and 25.0 °C for treatments A, B, and C, respectively. For the second drying with natural air, the average temperature of the crambe fruit mass during the four days was 30.3, 30.8, and 30.0 °C for treatments A, B, and C, respectively.

When subtracting the average temperature of the crambe fruit mass from the average temperature of the ambient air during the first drying periods, we observed that the drying air heating from the fan operation was 1.7 °C for treatment A, 2.3 °C for treatment B, and 1.0 °C for treatment C. For the second drying, drying air heating from the fan operation was 1.3, 1.8, and 1.0 °C for treatments A, B, and C, respectively. The calculated values are in accordance with those found by Silva (2008), who observed that the drying air heating varied from 1.0 to 3.0 °C, thus increasing the drying potential. The author also highlighted that this heating should be taken into account for dimensioning the grain drying.

A period of 28.83 h with dryers turned on was needed during three days on the first drying so that the moisture content of crambe fruits reached approximately 6.00% (w.b.). For the second drying, it took 22.58 h during four days to reach a moisture content of crambe fruits of approximately 6.00% (w.b.). During the second drying in September, we observed a higher average temperature and lower RH of the ambient air (29 ± 4 °C and 48 ± 19%, respectively) when compared to the first drying in July (24 ± 1 °C and 54 ± 5%, respectively). This result shows that the drying performed under the climatic conditions of September is faster when compared to that carried out in July.

A precipitation of 13 mm (data from the Meteorological Station of the University of Rio Verde, UniRV, Rio Verde, Goiás) was observed on the third day of drying in September, decreasing the temperature and increasing the RH of the ambient air, thus reducing the drying efficiency with natural air Schuh *et al.* (2011) stated that when drying with natural air under a high RH and low temperatures, the hygroscopic balance of grains should be taken into account since it may preclude the water removal process.

The initial crambe fruit mass at the beginning of drying was 32.5, 39.9, and 34.9 kg for treatments A, B, and C, respectively, both in the first and second dryings, with moisture contents of 10.26 and 9.84% (w.b.), respectively. At the end of the first drying, crambe fruit mass was 31.03, 38.09, and 33.32 kg for treatments A, B, and C, respectively. On the other hand, at the end of the second drying, crambe fruit mass was 31.17, 38.27, and 33.47 kg for treatments A, B, and C, respectively. This difference between the first and second drying occurred because the initial moisture content of crambe fruits in each drying was different.

Figures 1 and 2 show the reductions in moisture content during the drying of crambe fruits from the process using natural air with different airflows performed in July and September, respectively.

Figure 1 shows that moisture content curves presented variations with increases in values after the break period (12 h with the system turned off). These variations are due to a decrease in temperature and an increase in RH at night. Thus, crambe fruits absorb water to reach a hygroscopic equilibrium with the environment.

Figure 1 - Drying curves of crambe fruits with natural air under different airflows performed in July

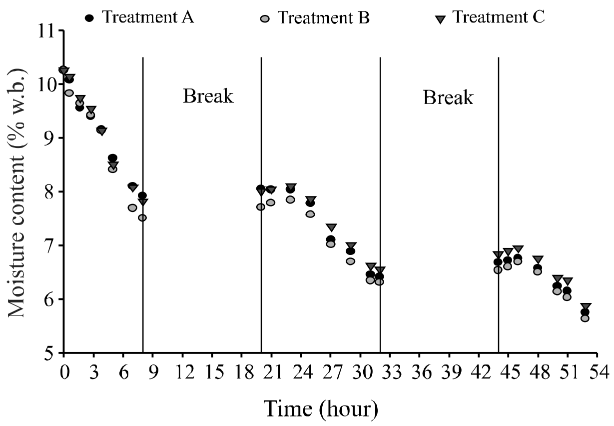

Figure 2 - Drying curves of crambe fruits with natural air under different airflows performed in September

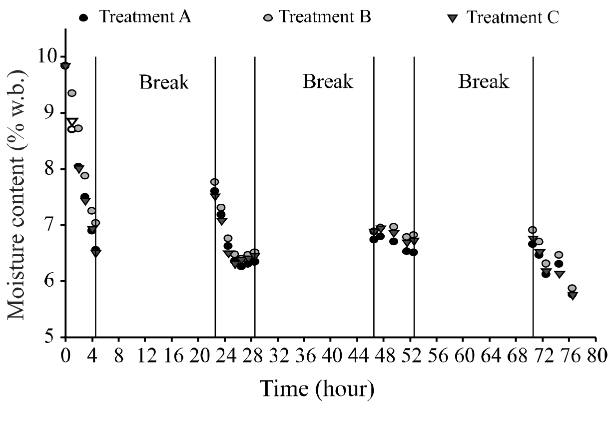

Figure 2 shows that moisture content curves presented oscillations due to the break period (18 h with the system turned off). Between 46.58 and 52.58 h, which comprises the time of the third day of drying, a precipitation that occurred during the drying period (13 mm) led to an increased RH and a decreased in temperature, with an increase in moisture content due to the hygroscopic balance of crambe fruits. This behavior emphasizes the importance and attention that must be taken in relation to RH and temperature during grain dryings using natural air (SCHUH *et al*. 2011).

Variations in the decrease of moisture contents (Figures 1 and 2) are explained by Corrêa *et al.* (2010) in a study on drying of agricultural products, in which several products had two stages of drying: water evaporation from the surface of grains to the surrounding air and water migration from inside to the surface of grains. The second stage is slower since the migration occurs through capillary movements and vapor pressure gradients, and the hotter the air is, the greater the amount of water the air retains, increasing its drying efficiency.

Table 1 shows that the coefficient of variation indicated a homogeneous behavior for all variables and a low data dispersion for the percentage of moisture content, germination, GRI, and electrical conductivity expressing reliability (PIMENTEL; GARCIA, 2002). In Table 1 is the summary of the analysis of variance. Based on the data analysis of the physiological quality assessments of crambe, a difference for moisture content was observed for July and September, with no difference for the other variables.

Table 2 shows the values of moisture content, germination, germination rate index, and electrical conductivity of crambe fruits in the drying with natural air with different airflows performed in July and September.

Treatments A, B, and C (Table 2), which consisted of drying the crambe fruits with natural air in stationary dryers with airflows of 10.08, 15.05, and 25.03 m^3 min^{-1} t^{-1}, respectively, did not differ from each other for germination, germination rate index, and electrical conductivity. Even when these treatments were compared to the control treatment (T), which consisted of crambe fruits with initial moisture content without going through the drying process, no difference was observed regarding fruit quality considering the variables mentioned above, influencing only the moisture content.

In general, we observed a low germination percentage of crambe seeds, which is in accordance with the results found by Faria *et al*. (2014) when drying crambe at 30, 40, 50, 60, and 70 °C and Silva *et al*. (2014) when drying crambe in the field, courtyard, shade, and with heated and unheated air. These latter authors observed that the shade drying system caused less damage to seeds.

Regarding the moisture content, treatments A, B, and C did not differ from each other since crambe fruit mass was dried until a moisture content close to 6.00%

Table 1 - Summary of the analysis of variance for Moisture content (MC), germination (G), germination rate index (GRI), and electrical conductivity (EC) of crambe fruits in the drying on fixed layer dryers with different airflows of natural air in July and September 2014

JULY					
SV	DF	Mean square			
		MC	G	GRI	EC
Treatment	3	19.36**	262.67^{NS}	4.56^{NS}	1513.11^{NS}
Error	12	0.10	136.67	2.33	601.52
Mean		6.96	75.50	7.77	284.07
CV (%)		4.56	15.48	19.64	8.63
SEPTEMBER					
SV	DF	Mean square			
		MC	G	GRI	EC
Treatment	3	15.62**	132.00^{NS}	1.19^{NS}	40.48^{NS}
Error	12	0.05	105.33	1.42	327.22
Mean		6.88	77.50	8.30	157.08
CV (%)		3.24	13.24	14.35	11.52

** Significant at 1% and ^{NS} Not significant by the F-test; SV: Source of variation. CV: Coefficient of variation. DF: Degree of freedom

Table 2 - Moisture content, germination, germination rate index (GRI), and electrical conductivity (EC) of crambe fruits in the drying on fixed dryers with different natural airflows performed in July and September 2014

Treatment	Mean	
	July	September
	Moisture content (%)	
A	5.72 a	5.91 a
B	5.86 a	5.93 a
C	6.03 a	5.84 a
T	10.26 b	9.84 b
	Germination (%)	
A	65 a	82 a
B	79 a	70 a
C	74 a	76 a
T	84 a	82 a
	GRI	
A	6.25 a	8.65 a
B	8.36 a	7.50 a
C	7.85 a	8.64 a
T	8.65 a	8.46 a
	EC (μS cm^{-1} g^{-1})	
A	298.38 a	156.10 a
B	298.81 a	154.16 a
C	281.65 a	161.61 a
T	257.48 a	156.48 a

Means followed by the same letter in the column do not differ statistically from each other by the Tukey's test at the 5% significance level. Treatment A: airflow of 10.08 m^3 min^{-1} t^{-1}; Treatment B: airflow of 15.05 m^3 min^{-1} t^{-1}; Treatment C: airflow of 25.03 m^3 min^{-1} t^{-1}; Control T: crambe fruits with initial moisture content without going through the drying process

(w.b.). However, it differed from the initial sample, which did not undergo the drying process.

The amount of electricity consumed by each stationary dryer in July and September was 31.82 and 24.92 kW h^{-1}, respectively. Considering the value of 0.29805 BRL per kW h^{-1} for supplying rural properties (CELG DISTRIBUIÇÃO, 2015), the electricity cost was 9.48 BRL in July and 7.43 BRL in September for each stationary dryer. Thus, relating the electricity cost to the dry mass of fruits, the costs for the first drying were 0.31, 0.25, and 0.28 BRL kg^{-1} and for the second drying were 0.24, 0.19, and 0.22 BRL kg^{-1} for treatments A, B, and C, respectively.

The drying carried out under the climatic conditions of September presented a lower consumption and cost of electricity when compared to that performed in July due to a better air temperature and RH conditions for drying with natural air. Among treatments of the first and second drying, the most viable airflow to be used in terms of profitability was 15.05 m^3 min^{-1} t^{-1}. Among the treatments within each drying, the airflow of 10.08 m^3 min^{-1} t^{-1} showed to be the least profitable.

CONCLUSIONS

1. Among the airflows used in the experiment in both natural air dryings carried out in July and September, no interference was observed in the physiological quality of crambe seeds;
2. The drying carried out in September was faster and presented a lower expenditure and cost of electricity when compared to that performed in July;
3. No difference was observed in the drying time between airflows, but the drying with natural air using an airflow of 15.05 m^3 min^{-1} t^{-1} was more profitable.

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