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The influence of drying on the physiological quality of crambe fruits

Lílian Moreira Costa*, Osvaldo Resende, Douglas Nascimento Gonçalves, Kelly Aparecida de Souza, Juliana de Fátima Sales and Juliana Rodrigues Donadon

Instituto Federal de Educação, Ciência e Tecnologia Goiano, Rod. Sul Goiana, Km 1, Cx. Postal 66, 75901-970, Rio Verde, Goiás, Brazil.
**Author for correspondence. E-mail: lilian22moreira@gmail.com*

ABSTRACT. This study was performed to evaluate the physiological quality of *Crambe abyssinica* Hochst fruits subjected to drying under different treatments with air. The crambe fruits, with moisture content of 21.0 ± 1.3 (% w.b.), were manually collected and dried until their moisture content reached 7.0 ± 1.4 (% w.b.). The crambe fruits were dried with natural air (23°C mean temperature and 60.6% average relative humidity) and seven days after harvest in an experimental dryer with forced ventilation at temperatures of 30, 40, 50, 60 and 70°C and relative humidities of 37.4, 22.3, 14.0, 8.3 and 5.1%, respectively. The evaluation was the percent germination, the germination speed index (GSI), the amount of water absorption and the electrical conductivity. The results of the study showed that increases in the drying temperature decreased the drying time and negatively affected the quality of the fruits. The study's findings for the GSI and for the percent germination showed that the drying temperature of 30°C yielded superior results. The moisture content of the crambe fruits after absorption was higher at the drying temperatures of 23, 40 and 70ºC. In contrast, the electrical conductivity measurement was unaffected by drying at high temperatures.

Keywords: oilseed, temperature, *Crambe abyssinica* Hochst.

Influência da secagem na qualidade fisiológica dos frutos de crambe

RESUMO. Objetivou-se avaliar a qualidade fisiológica dos frutos de *Crambe abissynica*, submetidas à secagem em diversas condições de ar. Frutos de crambe foram colhidos manualmente com teor de água de 21,0 ± 1,3 (% b.u) e secas até o teor de 7,0 ± 1,4 (% b.u.). A secagem foi realizada com ar natural (temperatura média de 23ºC e umidade relativa média de 60,6%) e sete dias após a colheita em secador experimental nas temperaturas de 30, 40, 50, 60 e 70°C e umidades relativas de 37,4; 22,3; 14,0; 8,3 e 5,1% respectivamente. A qualidade dos frutos foi avaliada pela porcentagem de germinação, índice de velocidade de germinação (IVG), absorção de água e condutividade elétrica. Com o aumento da temperatura o tempo de secagem reduziu e a qualidade dos frutos foi influenciada negativamente. Para a temperatura de 30ºC o IVG e a porcentagem de germinação foram superiores às demais temperaturas avaliadas. O teor de água dos frutos de crambe depois da absorção de água foi mais elevado para as temperaturas de secagem de 23, 40 e 70ºC. A secagem em temperaturas elevadas não influenciou a condutividade elétrica.

Palavras-chave: semente oleaginosa, temperatura, *Crambe abissynica* Hochst.

Introduction

The potential use of biodiesel as a fuel represents a promising development worldwide. As the demand for fuel continues to accelerate, alternatives to fossil fuels are being implemented to reduce the enormous impact of fossil fuel consumption on the environment. The use of these alternatives has produced both a qualitative and quantitative reduction of environmental pollution levels, mainly in large urban centers (FERRARI et al., 2005).

Several oleaginous plants have been tested or are already in use for biodiesel production. These plants include soybean, castor-oil plant, oil palm, sunflower, peanut, crambe, forage turnip, rape and babassu. Crambe (*Crambe abyssinica* Hochst) is a member of the family Brassicaceae. It is a potential alternative source of the raw materials for biofuel.

The advantages offered by this crop are a high yield of seed oil, tolerance to drought and cold, and an accelerated developmental cycle having a duration of approximately 90 days. These characteristics allow crambe to be cultivated during the winter. Sowing occurs just after the soybean crop is harvested, from March through April; therefore, crambe offers an attractive alternative because it permits the planting of a second crop in the same season (ANDRADE et al., 2006).

To obtain grain/seeds having maximum dry matter content and superior quality and market value, drying should be conducted when the grain is physiologically mature. At this stage, however, the grains are high in moisture and are therefore vulnerable to mechanical damage during processing (ANDRADE et al., 2006). Because the seeds are hygroscopic, their moisture content varies in response to the environmental conditions. When seeds are exposed to air, the air is exchanged until the water vapor pressure of the seeds and the ambient temperature have similar values. They can thus attain energetic, hydric and thermal balance. However, the air temperature used for drying should be controlled within certain limits to avoid possible physiochemical and biological damage to the seeds.

The excessive heating of seeds during the drying process can cause damage. Excessive heating can result in a reduction of both the percentage and speed of germination. It can also cause the production of abnormal seedlings, internal cracks, the breakage of the integument and altered coloration (NELIST; HUGHES, 1973 apud GARCIA et al., 2004).

The physiological potential of the seeds can be determined by considering the characteristics obtained from a germination test. This test is based on the integrity of the cellular membrane system. It estimates the vigor of the seeds and allows any deterioration to be detected during the initial growth phase (MARCOS FILHO, 1999).

According to Andrade et al. (2006), seed germination begins with soaking, which is the water absorption mechanism. In the case of viable, nondormant seeds, the water absorption process invokes a sequence of metabolic changes that culminate with the protrusion of the radicle (CARVALHO; NAKAGAWA, 2000). Assays for the speed and the number of germination events are well-known tests of vigor. These tests are easy to conduct because the data are collected during the germination test itself. In a germination speed test, the lots that provided seeds that germinated more rapidly are considered to be more vigorous. A direct relationship therefore exists between the speed of germination and seed vigor (SILVA; VIEIRA, 2006).

Additional methods are used to identify the most vigorous lots. One such method, the electrical conductivity test, is considered a fast, practical and easy approach to the determination of seed vigor because it does not require specialized equipment or specially trained personnel (VIEIRA; KRZYZANOWSKI, 1999). In this assay, the seeds are soaked in a solution. The electrical conductivity of the solution is a function of the amounts of ions leached from the seeds and is thus directly related to the integrity of the cellular membranes. Poor membrane structure is associated with damaged cells, and the deterioration process is usually associated with seeds of low vigor (VIEIRA; KRZYZANOWSKI, 1999).

Recently, several studies have been conducted with the aim of identifying the characteristics that accompany the drying of various agricultural seed products, including edible bean (CORRÊA et al., 2007; DOYMAZ, 2005a), rough rice (BASUNIA; ABE, 2001), grape (RAMOS et al., 2004, 2005; YALDIZ et al., 2001), okra (DOYMAZ, 2005b), pepper (AKPINAR et al., 2003; KAYMAK-ERTEKIN, 2002), pear (LAHSASNI et al., 2004), carrot (DOYMAZ, 2004), tomato (DOYMAZ, 2007a), pumpkin (DOYMAZ, 2007b), wheat (MOHAPATRA; RAO, 2005), corn (DOYMAZ; PALA, 2003) and coffee (RESENDE et al., 2009, 2010).

However, the available literature lacks information on the specific changes that may occur to crambe fruits during the drying process. Therefore, it is important to obtain theoretical and practical information to allow for the proper treatment of crambe seeds. To this end, a study was carried out to evaluate the effects of different drying conditions on the physiological quality of the fruits of *Crambe abyssinica* Hochst.

Material and methods

The present work was performed in the Laboratório of Pós-colheita de Produtos Vegetais and in the Laboratório de Sementes of Instituto Federal de Educação, Ciência e Tecnologia Goiano - Campus Rio Verde (IF Goiano - *Campus* Rio Verde). The harvest of the crambe fruits (*Crambe abyssinica* Hochst), FMS Brilhante cv. and the selection of the fruits was done randomly and manually.

The moisture content of the crambe fruits was determined by gravimetry, using an oven at 105 ± 1°C with forced ventilation for 24 hours, with three replicates (BRASIL, 2009). The initial moisture content of the fruits was 21.0 ± 1.3% (wet base, w.b.). The experiment was designed with six treatments in an entirely randomized design with four replicates. The crambe fruits were dried 7 days after harvest using natural air (23°C mean temperature and 60.6% average relative humidity) in an experimental dryer with forced ventilation at controlled temperatures of 30, 40, 50, 60 and 70°C and relative humidities of 37.4, 22.3, 14.0, 8.3 and 5.1%, respectively. During the drying process, the trays holding the samples were periodically weighed until the fruit reached a moisture content of 7.0 ± 1.4% (w.b.), the moisture content recommended for safe storage of this product. The temperature and relative humidity of the air were monitored using a psychrometer installed inside the dryer. The data were analyzed using the analysis of variance. The effects of individual treatments were compared using Tukey's test at a 5% probability level.

The germination test was performed on four subsamples of 30 fruits from each lot. The samples were conditioned in 'gerbox'-type boxes on blotting paper moistened with distilled water in an amount equivalent to 2.5 times the dry substrate mass (to create a standard for the assay). The fruits were incubated in a Mangelsdorf-type germinator maintained at a constant temperature of 25 ± 2°C. Beginning on the second day after sowing, evaluations were performed every other day up to 32 days (BRASIL, 2009), and the average germination percentage and germination speed index (GSI) were calculated.

For the determination of the amount of water absorption after drying, the samples were subjected to imbibition in distilled water over a 12-hour period in a controlled-temperature chamber at 25 ± 2°C. The fruits (15 g) were placed in plastic vessels (100-mL capacity) containing 60 mL distilled water (a 4:1 mass ratio) and were slightly agitated with a stick so that all of the fruits were completely submerged. After the hydration period, the samples were removed and blotted on filter paper for two minutes and then weighed. The moisture content after imbibition was obtained using the following equation:

$$X^* = \frac{M_e - M_s}{M_s} \qquad (1)$$

where:

X^*= the moisture content of the product (in dry base, d.b.);

M_e= the mass after soaking (in kg);

M_s= the dry matter mass of the product (in kg) (BRASIL, 2009).

The electrical conductivity (EC) was measured according to the methodology described by Vieira and Krzyzanowski (1999). Fifty fruits were used for the four subsamples of each treatment. The fruits were accurately weighed to two decimal places (0.01 g). The fruits were soaked in plastic vessels with 75 mL deionized water and incubated in a controlled-temperature chamber at 25ºC for 24 hours. The solutions containing the fruits were slightly agitated to ensure uniform leaching, and the EC was immediately measured using a portable digital conductivity meter. The results were expressed in μS cm^{-1} g^{-1} fruits.

Results and discussion

Figure 1 shows the drying curves for the crambe fruits under several different conditions. Based on the reduction of the moisture content from 21.0 ± 1.3 to 7.0 ± 1.4 % (w.b.) and the temperatures of 30, 40, 50, 60 and 70°C, the drying times of the crambe fruits were 20.5, 8.5, 5.0, 5.0, and 2.75 hours, respectively.

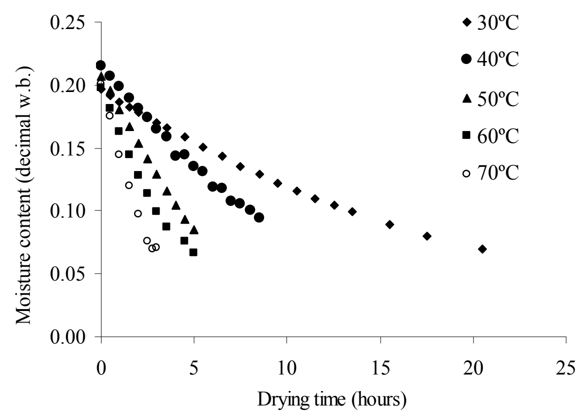

Figure 1. Drying curves of *Crambe abyssinica* Hochst fruits at temperatures of 30, 40, 50, 60 and 70°C.

The reduction of the drying time that was observed as the temperature increased furnished evidence of a higher rate of water removal. The final drying time was affected by temperature, as indicated by the large difference in drying time between the drying temperatures of 70 and 30°C. This result is in agreement with the results of Ullmann et al. (2010) regarding the drying of *Jatropha curcas* at temperatures of 30, 40, 50, 60 and 70°C. These authors also reported that the drying rate was increased and that the relationship between moisture and the time needed for the product to reach a moisture content of 0.09 (decimal dry base, d.b.) was reduced when the temperature increased.

According to Peske and Villela (2003), the use of high temperatures permits faster drying. However, high temperatures can produce a large difference in moisture content between the periphery and the center of the seeds and can generate a pressure gradient that causes cracks, mainly in the kernels of maize and rice.

The values of the percent germination and the GSI for the *Crambe abyssinica* Hochst fruit subjected to drying are shown in Figures 2 and 3. The germination percentages were low for all of the temperatures analyzed. A possible explanation is that the fruits were quiescent at 7 days after harvest, perhaps owing to the presence of such germination inhibitors as abscisic acid (BEWLEY; BLACK, 1994 apud SALVADOR et al., 2007). According to Guimarães (1999 apud GARCIA; NOGUEIRA, 2008), seeds that tolerate desiccation have protection mechanisms that enable them to maintain cellular membranes and macromolecular structures and to reserve substances so that when they are rehydrated, physiological functions can be re-established. When some seeds, such as those of bean and maize, are intensely dehydrated and then soaked in water, they can suffer irreparable damage to their membrane system. Such damage causes leaching of the cellular contents and a consequent reduction of germination (WALTERS et al., 2001). As shown in Figure 2, the high coefficient of variation exhibited by the data indicated that the normality and homogeneity assumptions of the analysis of variance were not satisfied. The analysis of variance could therefore not be used to analyze the percent germination. The average germination percentages for the crambe fruits were 6.5, 17.1, 4.4, 7.1, 3.5 and 4.6% for the drying temperatures of 23, 30, 40, 50, 60 and 70°C, respectively. Note that the value of the germination index observed at 30°C was higher than those observed at the other temperatures tested.

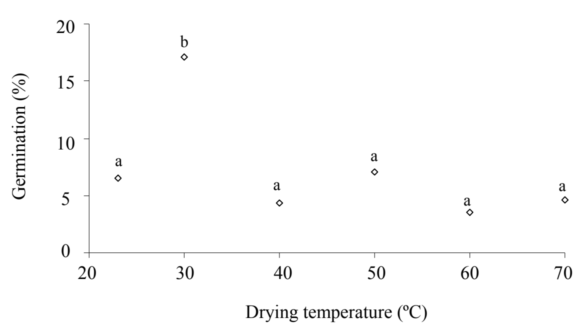

Figure 2. Percent germination of *Crambe abyssinica* Hochst fruits.
The effects of the treatments identified by the same letter are not significantly different (Turkey test, 5% probability level). Coefficient of variation (CV) of 39.6%.

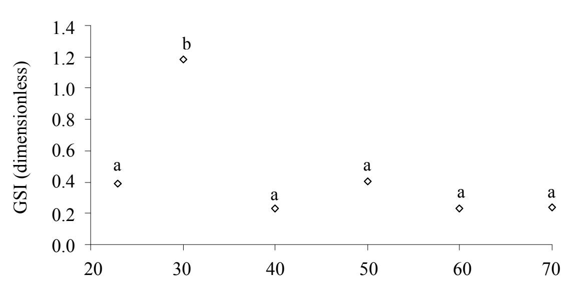

Figure 3. Germination Speed Index (GSI) of *Crambe abyssinica* Hochst fruits.
The effects of the treatments identified by the same letter are not significantly different (Turkey test, 5% probability level). Coefficient of variation (CV) of 47.88%.

The values found for the GSI (Figure 3) were similar to those previously found for germination. The GSI was significantly higher at 30ºC. The only significant difference in the GSI among the desiccation treatments was found at 30°C. These results suggest that drying may not have influenced the vigor of the crambe fruits.

The postabsorption moisture content of the crambe fruits under different drying conditions is shown in Figure 4. The water absorption of the fruits dried at 40 and 70ºC was similar to that of fruits dried with ambient air (23°C). However, the value of absorption was lower after drying at other temperatures. This difference may reflect the fact that the integument of crambe seeds appeared to be resistant to the entry of water during soaking. In general, the amount of water absorbed depends on the species, fruit, variety or cultivar, the environmental temperature, the chemical composition of the fruit, the initial moisture content, the nature of the seed integument and the amount of water available.

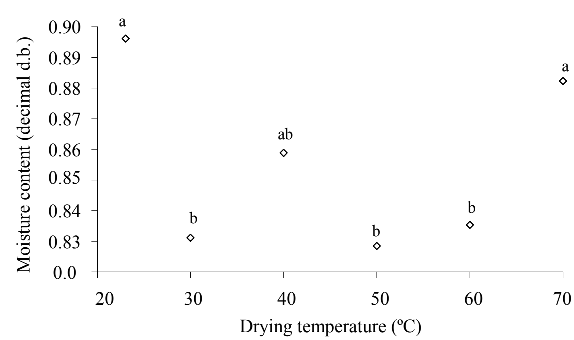

Figure 4. Moisture content after the absorption of water by *Crambe abyssinica* Hochst fruits.
The effects of the treatments identified by the same letter are not significantly different (Turkey test, 5% probability level). Coefficient of variation (CV) of 2.06%.

The results for the electrical conductivity test of the crambe fruits under different drying conditions are presented in Figure 5. The conductivity test evaluates the integrity of the cellular membranes by determining the amounts of ions leached by the soaking solution. In this test, those fruits that have a lower physiological potential release higher amounts of ions because the structural integrity and selectivity of the membranes are relatively low (VIEIRA; KRZYZANOWSKI, 1999). As shown in Figure 5, an increase in drying temperature from 23 to 30°C resulted in increased electrical conductivity, but this effect was not observed at drying temperatures above 40°C. It was expected that the EC values for the crambe fruits dried at higher temperatures would be larger, owing to the potential for greater damage inflicted by the higher rates of water removal. However, no such effect was observed. The electrical conductivity of the fruits dried at temperatures above 30 ºC was similar to that of the fruits dried with natural air. In the drying of soybeans, Silva et al. (2007) have observed that the lowest incidence of damage was accompanied by lower values of electrical conductivity.

Ullmann et al. (2010) have reported an increase in electrical conductivity with an increase of the drying temperature from 30 to 70ºC in seeds of *Jatropha curcas.* These authors found that the leaching was more marked after drying at 70ºC. Evidently, drying temperatures above 60°C more aggressively remove the water from the interior of the fruits and cause microcracks at the cellular level.

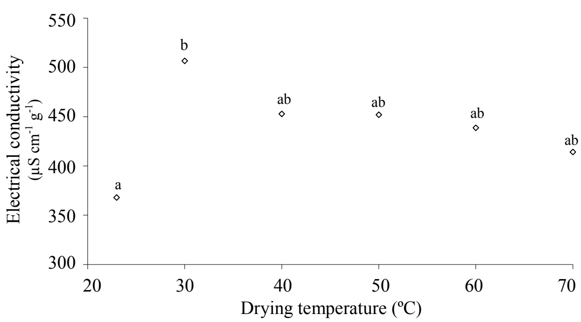

Figure 5. Electrical conductivity EC (μS cm^{-1} g^{-1}) of *Crambe abyssinica* Hochst fruits.
The effects of the treatments identified by the same letter are not significantly different (Turkey test, 5% probability level). Coefficient of variation (CV) of 10.13%.

Conclusion

The drying time of the *Crambe abyssinica* Hochst fruits decreased with an increase in drying temperature. The physiological quality of the crambe fruits was affected by the increase in temperature. The study's findings for the GSI and percent germination show that a drying temperature of 30°C yielded superior results. The moisture content after absorption of the crambe fruits was higher at the drying temperatures of 23, 40 and 70°C. Drying at high temperatures did not affect the electrical conductivity.

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