DETERMINATION OF PHYSICAL PROPERTIES OF CRAMBE FRUITS DURING DRYING

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ABSTRACT: The Knowledge of the physical properties of agricultural products has great importance for the construction and operation of equipment for drying and storage, to achieve increased efficiency in post-harvest operations. The aim was to determine and analyze the physical properties of crambe fruits during drying at different temperatures. Crambe fruits with an initial moisture content of 0.36 (decimal d.b.) which was reduced by drying at 37.0; 58.8 and 83.5 ºC and relative humidity of 29.4; 11.2 and 3.2%, respectively, to 0.09 ± 1 (decimal d.b.). At different levels of moisture contents (0.36; 0.31; 0.26; 0.21; 0.17; 0.13 and 0.09 decimal d.b.), was evaluated the intergranular porosity, the bulk density, the true density as well as the volumetric shrinkage and the fruit mass. The study was installed by the factorial 3 x 7, and three drying temperatures and seven moisture contents in a randomized design. Data were analyzed using regression. The bulk density and the true density decreases along the drying process; the volumetric shrinkage and the mass increased with lower moisture content and the intergranular porosity decreased sharply with the increasing drying temperature.

KEYWORDS : *crambe abyssinica,* moisture content, dries temperatures.

DETERMINAÇÃO DAS PROPRIEDADES FÍSICAS DE FRUTOS DE CRAMBE DURANTE A SECAGEM

RESUMO - O conhecimento das propriedades físicas dos produtos agrícolas tem grande importância para a construção, adaptação e operação de equipamentos de secagem e armazenagem, visando a obter maior rendimento nas operações de pós-colheita. Objetivou-se determinar e analisar as propriedades físicas do crambe ao longo da secagem em diferentes temperaturas. Foram utilizados frutos de crambe com teor de água inicial de 0,36 (decimal b.s.), que foi reduzido por meio de secagem a 37,0; 58,8 e 83,5 ºC e umidades relativas de 29,4; 11,2 e 3,2%, respectivamente, a 0,09±1 (decimal b.s.). Nos diferentes níveis de teores de água (0,36; 0,31; 0,26; 0,21; 0,17; 0,13 e 0,09 decimal b.s.), avaliaram-se a porosidade intergranular, as massas específicas aparente e unitária, bem como as contrações volumétricas unitária e da massa de frutos. O experimento foi montado segundo esquema fatorial 3 x 7, sendo três temperaturas de secagem e sete teores de água, em delineamento inteiramente casualizado. Os dados foram analisados por meio de regressão. As massas específicas aparente e unitária dos frutos de crambe diminuem ao longo do processo de secagem; as contrações volumétricas unitária e da massa aumentam com a redução do teor de água, e a porosidade intergranular apresentou redução acentuada com o aumento da temperatura de secagem.

PALAVRAS-CHAVE - *Crambe abyssinica,* teor de água, temperaturas de secagem.

INTRODUCTION

The Crambe *abyssini*ca is a plant of the *Brassicaceae* family, of Mediterranean origin and is usually used as forage for grazing, develops in different climatic conditions, from frosts typical of

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the south of the country until hot and dry climates, such as the Brazilian Midwest. It is a culture considered potential for industrial production of biodiesel based on the characteristics of cultivation and high proportion of oil. A study realized with crambe grown in the state of Mato Grosso do Sul with the variety FMS brilhante indicated 40% of oil in the grain (SOUZA et al., 2009).

The reduction of the moisture content of the grains directly influence changes in their physical properties during drying, so the correct determination of these characteristics is relevant for the optimization of industrial processes, study of the dynamics, design and sizing of equipment used in harvest and post-harvest operations (RESENDE et al., 2008).

Among the used processes to maintain the quality of agricultural product after harvest, drying is one of the most used in order to reduce the water activity in the product. By reducing the water content to safe levels, inhibits the growth of microorganisms, reduces the possibility of proliferation of pest and insects, besides minimizing physical and chemical changes during storage, which contributes significantly to the loss of quality product (GONELI et al., 2011).

At the start of drying, apparently, the structure of the product remains intact and maintains its original form. However, with the removal of moisture, the volumetric shrinkage occurs which is accompanied by deformation of the particles, forming pores and other micro structural changes (KOÇ et al., 2008).

Several authors have investigated the variations of the physical properties as a function of moisture content and other factors during the drying, for several products, such as fruits and grain chickpeas (NIKOOBIN et al, 2009;. ISIK & ISIK, 2008); nuts and shelled grains of pistachio (RAZAVI et al, 2007a, b.), wheat (KARIMI et al, 2009), Niger seed (SOLOMON & ZEWDU, 2009), cowpea (LANARO et al, 2011), and beans (RESENDE et al., 2008), among others.

Given the above, the aim of the present study is to determine and analyze the physical properties of crambe fruit along the reduction of moisture content at different drying temperatures.

MATERIALS AND METHODS

Fruits of crambe (*Crambe abyssinica*) produced in the 2010 crop on the experimental farm of the Federal Institute of Science Education and Technology from Goiás, Campuses of Rio Verde - GO, were used in this study. The experiment was conducted at the Postharvest Laboratory of Vegetable Products (IF Goiano-Campus Rio Verde).

The culture was monitored during the cycle so that products were obtained with the maximum quality and at the same location. To avoid influence on the results, manual harvesting of crambe fruit was accomplished when it was found that the moisture content stood at 0.36 (decimal d.b.) after homogenization and sample preparation, the product was subjected to drying in a forced air ventilation under three temperature conditions: 37.0; 58.8 and 83.5 °C and relative humidity of 29.4; 11.2 and 3.2%, respectively. The reduction of moisture content during drying was followed by gravimetric method (mass loss), knowing the initial moisture content of the product until reach the final moisture content of 0.09 ± 1 (decimal d.b.). The monitoring of the mass reduction during drying was performed with the aid of an analytical balance with a resolution of 0.01 g. The moisture content in the crambe was determined using the greenhouse method at 105 ± 1° C for 24 hours in three replicates (BRAZIL, 2009). During the drying of each moisture content obtained (0.36, 0.31, 0.26, 0.21, 0.17, 0.13 and 0.09 decimal d.b.), samples were homogenized and submitted to determining their physical properties, in three replications.

The physical properties were analyzed: bulk and true density, volumetric shrinkage of the mass and porosity.

The bulk density (ρ_{ap}), expressed in kg m^{-3}, was determined using an electronic scale of hectoliter weight with resolution of 0.1 g (GEHAKA - BK 4001), using a container with a capacity of 252.3 ml.

The true density (ρ_u), expressed in kg m^{-3} was obtained indirectly as a function of porosity and the bulk density according to the equation described by (MOHSENIN, 1986):

$$\rho_u = \frac{\rho_{ap}}{(1-\varepsilon)} \quad (1)$$

where,

ρ_{AP}- Bulk density, kg m^{-3};

ρ_u- True density, kg m^{-3};

ε- Porosity, decimal.

The volumetric shrinkage of the mass (ψ) was determined using a 250 ml beaker. For each moisture content, the crambe fruits were placed in a beaker with the aid of a funnel with a pre-established high of 0.36 m, and the volumetric shrinkage of the mass was obtained by checking the reduction in volume during drying and using the following expression:

$$\psi = \frac{V_t}{V_0} \quad (2)$$

where,

ψ – volumetric shrinkage of the mass, decimal;

V_0 - initial volume, ml;

V_t - volume at time t, ml.

The rate of volumetric shrinkage (Ïψ) was obtained by the following expression, and results were expressed in%:

$$I\psi = (\psi_0 - \psi_t) \cdot 100 \quad (3)$$

where,

Ïψ - index of volumetric shrinkage of the mass,%;

ψ_0 - initial volumetric shrinkage of the mass, decimal;

ψ_t - volumetric shrinkage at time t, decimal.

The porosity (ε) was determined according to the methodology described by SILVA (2008) with modifications. We used a beaker containing 100 ml of crambe fruit, in which hexane was added with the aid of a 50 ml burette, to fill the empty spaces of the mass. The porosity was obtained by measuring the amount of hexane added to the mass of product and the results were expressed in%.

The experiment was conducted using a factorial 3 x 7, three drying temperatures (37, 58.8 and 83.5 º C) and seven moisture contents (0.36, 0.31, 0.26, 0.21; 0.17, 0.13 and 0.09 decimal d.b) in a randomized design. The data were analyzed by regression.

RESULTS AND DISCUSSION

In Figures 1 and 2 are shown values of bulk density and true density of crambe fruits subjected to three drying air conditions. It is noted that in all the drying conditions, the bulk density and the true density decreased by reducing moisture content, confirming the results by GONELI (2008) for castor fruit dried at 40 °C. According to GONELI, (2008) these variations are due to the combined effect between the presence of empty space inside the fruit and reduced contraction of its dimensions, the volume of the fruit remains practically constant, while there is a reduction of its mass during the drying. These results show that the volumetric shrinkage of the castor and crambe fruits do not follow the reduction of its mass with the drying. However, this behavior contrasts with the observed for the most agricultural products, in which increases the bulk density and true density with the reduction of the moisture content (RAZAVI et al., 2007b).

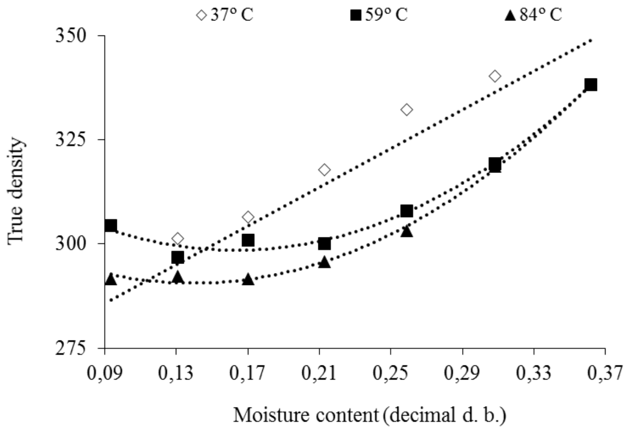

FIGURE 1. Bulk density (kg m^{-3}) of crambe fruits during drying under different conditions of temperature and relative humidity.'

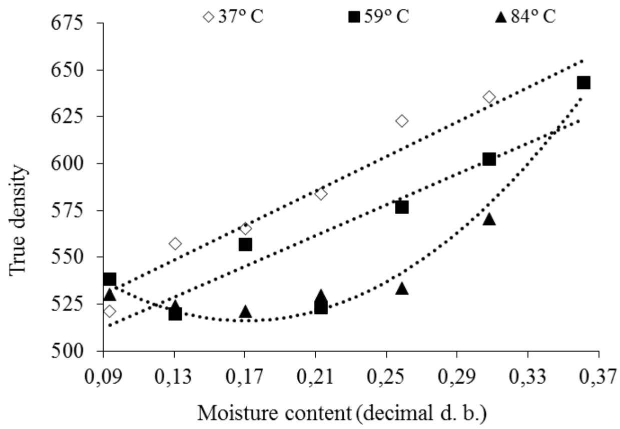

FIGURE 2. True density (kg m^{-3}) of crambe fruits during drying under different conditions of temperature and relative humidity.

It is still observed in Figures 1 and 2 that the bulk density of the crambe fruit reduced from 338.17 kg m^{-3} to 274.57; 304.4 kg m^{-3} to 291,72; 338.27 kg m^{-3} to 291,72 and the true density decreased from 643.04 kg m^{-3} to 521.14; 538.35 kg m^{-3} to 530.14; 643.04 kg m^{-3} to 530.14 at temperatures of 37, 59 and 84 °C respectively, with the moisture content of the product ranging from 0.36 to 0.09 (decimal d.b.). GARNAYAK et al, (2008), working with the method of rewetting of seeds, found values of bulk density ranging from 492 to 419 kg m^{-3} for pine nut seeds with moisture content between 0.049 and 0.243 (decimal d.b.).

The bulk density is of great importance in the marketing of agricultural products, since the transport thereof is usually accomplished by truck, therefore the crambe products require some enhancements to reduce the cost of transport. According to PITOL et al, (2010), one of the alternatives to solve the transportation problem is the peeling of crambe fruits before shipping, so the stripped product has a bulk density of around 740 kg m^{-3}.

It also appears that the reduction behavior in the specific mass due to the moisture content was different among the temperatures of the drying air, as the adjusted models to the bulk density and true density shown in Tables 1 and 2 respectively. The differences in the adjusted models may be related to the desuniform behavior presented in the volumetric shrinkage of the crambe fruits subjected to drying at different air conditions (Figure 3), to the drying temperature at 37 ° C the experimental value was linear and for the other temperatures were quadratic. . RIBEIRO et al. (2005) found that the linear model satisfactorily represented the experimental and calculated data of the bulk density in soybeans.

TABLE 1. Mathematical models adjusted to the experimental values of the bulk density of crambe fruits (ρ_{ap}) submitted to three drying air conditions.

Temperature (ºC)	Model	R² (%)
37	ρ_{ap}= 231.6Ta + 264.9	88.7
59	ρ_{ap}= 1007.1Ta² - 329.6Ta + 325.4	98.8
84	ρ_{ap}= 964.9Ta² - 269. Ta + 309.4	99.7

Ta: water content, d.b. decimal.

TABLE 2. Mathematical models adjusted to the experimental values of the true density of crambe fruits (ρ_u) submitted to three drying air conditions.

Temperature (ºC)	Model	R² (%)
37	ρ_u= 460.9Ta + 488.7	95.2
59	ρ_u= 411.1Ta + 475.4	77.1
84	ρ_u= -3291.0Ta²- 1121.00Ta + 611.6	97.4

In Figure 3 are shown the values of volumetric shrinkage of crambe fruits subjected to drying in three different conditions. It is noted that in the process of drying the volumetric shrinkage decreases for all temperatures and more evident at temperatures of 37 to 84 ° C, indicating that drying at 59 ° C reduced with lower intensity the volume of crambe fruits. The removal of moisture reduces the volume and alters the shape of the product, promoting a reduction in intercellular spaces and promoting the reduction of intensity of volumetric shrinkage during the drying process. According to SIQUEIRA et al. (2012) the pine nut seeds had higher values of volumetric shrinkage when subjected to drying at higher temperatures (90 and 105 º C). According to AFONSO JÚNIOR et al. (2000a) & AFONSO JÚNIOR et al. (2000b) studying the volumetric shrinkage of pearl millet and popcorn, respectively, the reduction in moisture content of grains promoted decrease in the mass of the product when compared to its initial volume due to lower presence of voids and accommodation of the product in the granular mass.

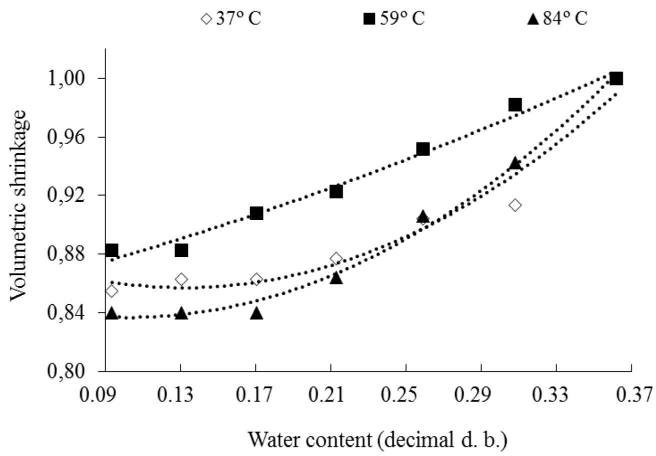

FIGURE 3. Volumetric shrinkage of crambe fruits during drying under different conditions of the temperature and relative humidity.

In Figure 4 are shown the index values of volumetric shrinkage of crambe fruits subjected to drying under three different conditions. It is noted that, in the drying process increases the shrinkage rate for the three temperatures studied, being more evident at temperatures of 37 to 84 °C, indicating that drying at 59 °C increases with lower intensity. The removal of water reduces the volume and alters the shape of the product, promoting a reduction in intercellular spaces, causing an increase in the rate of volumetric shrinkage during the drying process. SIQUEIRA et al. (2012) observed that in the seeds of the pine nut, the unitary volumetric shrinkage was lower for higher temperatures (90 and 105 ° C).

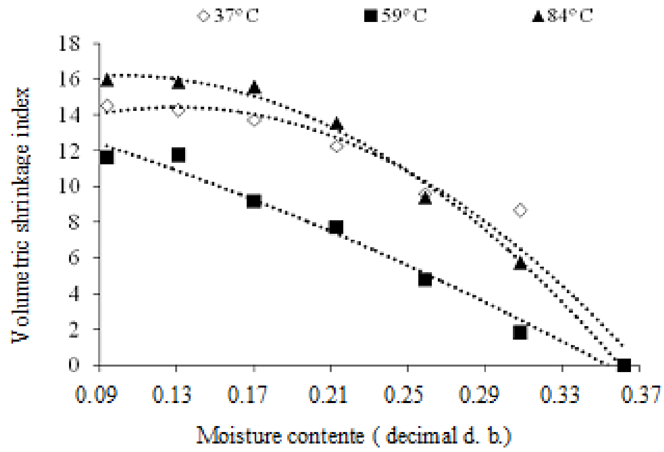

FIGURE 4. Index of volumetric shrinkage of crambe fruits during the drying, under different conditions of temperature and relative humidity.

In Table 3 are shown the models adjusted to the experimental values of shrinkage and the rate of volumetric shrinkage of crambe fruits (ψ) subjected to three drying air conditions. There is a quadratic behavior for volumetric shrinkage and shrinkage rate at all temperatures. This quadratic behavior occurred in a high rate of moisture reduction in onset of drying, resulting in the hardening of the crambe fruit seed coat. Another behavior was verified by AFONSO JÚNIOR & CORRÊA (2000b), where the data were adjusted linearly for the volumetric shrinkage by reducing the moisture content of popcorn grains. These results are due to the physical characteristics of popcorn grains that have less tegument resistance in comparison to crambe fruits.

TABLE 3. Mathematical models adjusted to the experimental values of volumetric shrinkage (ψ) and the index of volumetric shrinkage (Ïψ) of crambe fruits submitted to three drying air conditions.

Temperature (ºC)	Model	R^2 (%)
37	$\psi = 2.508Ta^2 - 0.662Ta + 0.900$	95.4
59	$\psi = 0.386Ta^2 + 0.303Ta + 0.8443$	98.4
84	$\psi = 2.475Ta^2 - 0.508Ta + 0.8633$	99.2
37	$Ï\psi = -242.2Ta^2 + 49.00Ta + 13.73$	99.4
59	$Ï\psi = -248.9Ta^2 + 64.51Ta + 10.25$	95.7
84	$Ï\psi = -42.51Ta^2 - 28.27Ta + 15.28$	98.2

In Figure 5 are shown the values of inter granular porosity of crambe fruits subjected to drying under three conditions of the air. It is observed that the porosity decreased to 0.1; 4.0 and 2.43 percentage points, at temperatures of 37, 59 and 84 ° C respectively, with the reduction of moisture content from 0.36 to 0.09 (decimal d.b.). Although there was a slight reduction in porosity of crambe fruit, especially those subjected to drying at temperatures of 59 and 84 ° C, it was observed that there was variability in values causing the temperatures of 37 and 84 ° C presented a quadratic behavior as described in Table 4. Studying the porosity of pine nut seeds, GARNAYAK et al. (2008), found a range from 27.54 to 45.37% as the moisture content ranged from 0.049 to 0.243 (decimal d.b.). SIRISOMBOON & KITCHAIYA (2009) found that the porosity of pine nut seeds was 46.0; 59.3 and 57.9% when they were dried at temperatures of 80, 60 and 40 ° C respectively. Therefore, it is explicitly the influence of moisture content on inter granular porosity of pine nut, because with the drying process there is a reduction in the porosity of the seeds. However, as the results obtained by SIRISOMBOON and KITCHAIYA (2009), it was not possible to observe a trend in performance of porosity with increasing drying temperature. This behavior differs from the results obtained by GONELI (2008) working with castor beans found the linear behavior for porosity as a function of moisture content.

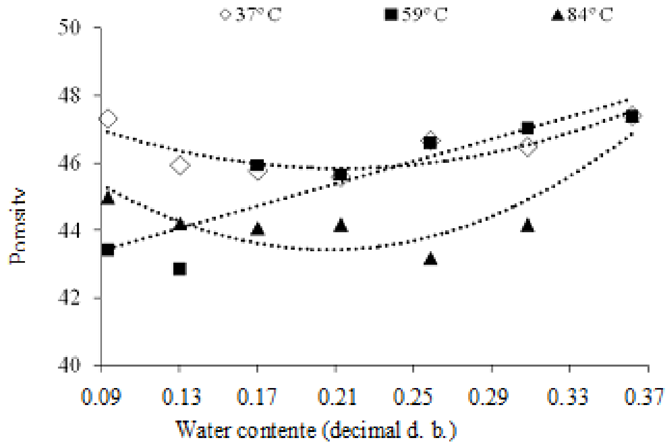

FIGURE 5. Porosity of crambe fruits during drying under different conditions of temperature and relative humidity.

TABLE 4. Mathematical models adjusted to the experimental values of the crambe fruit porosity (ε) submitted to three drying air conditions.

Temperature (ºC)	Model	R^2 (%)
37	$\varepsilon = 16.55Ta + 41.90$	81.7
59	$\varepsilon = 77.5Ta^2 - 32.95Ta + 49.32$	71.7
84	$\varepsilon = 143.6Ta^2 - 59.41Ta + 49.56$	80.8

CONCLUSIONS

Given the above it is concluded that the bulk density and true density, as well as volumetric shrinkage of crambe fruit mass, decrease over the drying process; since the rate of volumetric shrinkage increases with a reduction of moisture content; and inter granular porosity shows sharp reduction with increasing drying temperature.

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