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Experimental analysis and modeling of frictional behavior of lavender flowers (*Lavandula stoechas* L.)

Seyed Mojtaba Shafaei, Arash Nourmohamadi-Moghadami*, Saadat Kamgar

Department of Biosystems Engineering, College of Agriculture, Shiraz University, Shiraz 71441-65186, Iran

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ABSTRACT

Static friction coefficient (SFC) and dynamic friction coefficient (DFC) of lavender flowers were determined as influenced by moisture content (4.9–22.4 d. b.%), contact surface (plywood, galvanized steel, rubber, glass and aluminum) and sliding velocity (0.75–13.7 cm/s). Analysis of variance (ANOVA) was carried out to determine the effect of main treatments on SFC and DFC. Duncan's multiple range test was used to compare levels of treatments. To predict the SFC and DFC of lavender, simple linear regression (SLR) and multiple linear regression (MLR) were applied. Predictive ability of linear regression models was assessed regarding the coefficient of determination, root mean square error and mean absolute percentage error. Results indicated that the highest and lowest SFC were obtained in moisture contents of 22.4 and 4.9 d. b.% on rubber and glass, respectively. Maximum and minimum DFC were also found in maximum and minimum sliding velocities of 13.7 and 0.75 cm/s, respectively. ANOVA results showed that not only the effects of main treatments, but also the interactions of them were significant on SFC and DFC ($P < 0.01$). The SFC increased as moisture content increased. The DFC increased in a linear trend as moisture content and sliding velocity increased. Demonstrating statistically acceptable parameters, SLR and MLR could satisfactorily model SFC and DFC, respectively.

1. Introduction

Investigations on medicinal plants are being developed recently, because they have been recognized as an essential supply for healthcare treatments. Also, the attempts for collecting information on the use of medicinal plants is growing to improve their production stages (Kala, 2015).

Lavender is known as a powerful aromatic medicinal plant, traditionally used in treating some nervous diseases. Additionally, it is well known for its good smell. The most usable part of lavender plant is the flower (Hajhashemi et al., 2003). Therefore, it is important to attain information about processing and commercial applications of lavender in related industries.

Determination of physical properties of agricultural products is a favorite subject for researchers. Among numerous physical properties, some are of more importance in achieving the best operation cycle of the processing machines.

Frictional properties of agricultural products are important parameters for designing handling machines such as packaging, cleaning, conveyors, augers and other equipment. The friction force acts as a resistive force against the motion of solid objects. The friction forces are static and dynamic. The static friction force is a force which exists between two static objects, while the dynamic friction force appears between two moving objects. Static and dynamic friction forces are functions of SFC and DFC, respectively. The relation between friction force and friction coefficient can be described by the following equation:

$$F = \mu \times N \quad (1)$$

where F is frictional force N, μ is SFC or DFC and N is normal force N. The friction coefficient (μ) of agricultural products is a basic engineering parameter related to the frictional behavior of the products. The energy required to overcome the frictional forces appearing at the time that equipment starts to and when continues to work (at a specific velocity) depends on SFC and DFC, respectively. Hence, the SFC and DFC should be determined in different conditions.

SFC of agricultural products is a function of moisture content and contact surface. Also, DFC of agricultural products not only

Abbreviations: ANOVA, analysis of variance; DFC, dynamic friction coefficient; DMRT, Duncan's multiple range test; GMD, geometric mean diameter; MAPE, mean absolute percentage error; MLR, multiple linear regression; RMSE, root mean square error; SFC, static friction coefficient; SLR, simple linear regression.

* Corresponding author.
E-mail address: a.nourmohamadi@shirazu.ac.ir (A. Nourmohamadi-Moghadami).

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depends on moisture content and contact surface, but also depends on sliding velocity (Mohsenin, 1986).

There are some reports available in the literature presenting the SFC of various aromatic and medicinal plants. The effect of content surface and/or moisture content on SFC was investigated for fenugreek (Altuntas et al., 2005), African nutmeg (Burubai et al., 2007), coriander (Coskuner and Karababa, 2007a), flaxseed (Coskuner and Karababa, 2007b), fennel (Ahmadi et al., 2009), basil (Razavi et al., 2010b), cumin (Gharib-Zahedi et al., 2010), wild sage (Razavi et al., 2010a), castor (Gharibzahedi et al., 2011), asparagus (Sarabi et al., 2011), kenaf (Bakhtiari et al., 2011), psyllium (Ahmadi et al., 2012), cardamom (Gebreselassie, 2012), plantain (Fadavi et al., 2015) and Azivash (*Corchorus Olitorious* L.) (Azadbakht and Pourbagher, 2015). The authors who carried out the studies found that increasing moisture content led to the increment of SFC and it significantly varied on different contact surfaces.

A review of published papers revealed that the effect of moisture content and contact surface have been only studied on DFC of fenugreek (Altuntas et al., 2005), psyllium (Ahmadi et al., 2012) and safflower seeds (Kara et al., 2012). However, many works reported the effect of sliding velocity on DFC of some agricultural products (Chen and Squire, 1971; Gupta and Das, 1998; Sharobeem, 2007; Asli-Ardeh et al., 2010; Shafaei et al., 2016), there have been no published data on the effect of sliding velocity on DFC of studied medicinal seeds.

Although the effects of contact surface and moisture content on SFC and DFC of different aromatic and medicinal plants have been reported, there is no comprehensive attempt to accurately determine SFC and DFC of lavender. These coefficients can be used in designing of post-harvest equipment such as cleaning, sorting and packaging of lavender at different levels of moisture content. Thus, the aims of this study were concentrated on below items:

1. To precisely measure SFC as affected by moisture content and contact surface.
2. To accurately determine DFC with changes in moisture content, sliding velocity and contact surface.
3. Carrying out statistical analysis for the effect of moisture content, sliding velocity and contact surface on DFC and moisture content and contact surface on SFC.
4. To assess the ability of SLR and MLR model in estimating SFC and DFC, respectively.

2. Materials and methods

2.1. Raw material

Flowers of lavender (*Lavandula stoechas* L.) were provided from Agricultural Research Center, Medicinal and Aromatic Plants Unit of Fars province, Iran. Before starting the tests, they were manually cleaned to eliminate all foreign materials such as dust, gravel and injured flowers. Some physical properties of the cleaned flowers were then determined.

2.1.1. Physical properties

To determine physical properties of the flowers, samples of 100 cleaned flowers were randomly selected. Three major dimensions of the flowers were measured using an electronic digital caliper, reading to an accuracy of 0.01 mm. To obtain the mass of flowers, each flower was weighed by a precision electronic balance with a reading to 0.001 g. Moreover, GMD and sphericity of flowers were calculated using following equations (Mohsenin, 1986):

$$\mathrm{GMD} = (\mathrm{LWT})^{1/3} \quad (2)$$

$$\mathrm{Sphericity} = (\mathrm{GMD}/\mathrm{L}) \times 100 \quad (3)$$

where L is length mm, W is width mm and T is thickness of samples mm.

2.2. Determination of initial moisture content

The initial moisture content of cleaned flowers was determined by drying 10 g of samples in an air convection oven at $105 \pm 2\,^{\circ}\mathrm{C}$ until a constant weight was obtained (AOAC, 1990). To reduce error, the experiments were carried out three times and mean value was used. The initial moisture content of flowers was less than 2 d. b.%.

2.3. Sample preparation

To achieve the desired moisture contents (4.9, 10.2, 14.8, 18.7 and 22.4 d. b.%), amount of distilled water to be added to each sample was calculated according to the following equation (Balasubramanian, 2001; Bart-Plange and Baryeh, 2003; Kashaninejad et al., 2006):

$$\mathrm{W_w} = \mathrm{W_t}(\mathrm{M_f} - \mathrm{M_i})/(100 - \mathrm{M_f}) \quad (4)$$

where W_w is mass of added distilled water g, W_t is initial mass of sample g, M_f is final moisture content of sample d. b.% and M_i is initial moisture content of sample d. b.%. The samples mixed with distilled water were sealed in separate polyethylene bags and kept at $5 \pm 0.5\,^{\circ}\mathrm{C}$ in a refrigerator for ten days to allow the water uniformly be absorbed into the products (Nimkar et al., 2005; Baumler et al., 2006). Two hours before the experiments, the required quantity of samples was kept at ambient condition to warm up to room temperature (Abalone et al., 2004).

2.4. Frictional tests

Exact SFC was measured for each contact surface (plywood, galvanized steel, rubber, glass and aluminum) and determined moisture content of samples using a SFC measuring instrument which was initially proposed by Lorestani et al. (2012) and modified by Shafaei et al. (2015). A schematic of the used instrument is depicted in Fig. 1. The details of designing and other aspects of the instrument can be found in the literature.

DFC was also obtained for all contact surfaces, determined moisture contents and sliding velocities (0.75, 5.3, 8.1, 10.9 and 13.7 cm/s) using a DFC measuring instrument. The instrument was initially proposed by Clark and Mcfarland (1973) and then improved by other researchers (Tavakoli et al., 2002). The instrument is shown schematically in Fig. 2. The technical specifications of the instrument are available in the literature.

Prior to the tests, the contact surface was cleaned by compressed air to eliminate any contamination from previous test. Each test was completed in five replications.

2.5. Data analysis

For SFC and DFC, respectively, 125 and 625 data were collected from experimental frictional tests. Then, the data were applied in statistical analysis system using SPSS 21 software. The effect of contact surface and moisture content on SFC and also the effect of sliding velocity, moisture content and contact surface on DFC were evaluated based on the ANOVA method. The analysis was done on the basis of factorial experiments in completely randomized design with two and three treatment factors for SFC and DFC, respectively. Significant differences between the mean of levels of treatments were also compared by means of DMRT at 99% probability level.