Available at www.sciencedirect.com

INFORMATION PROCESSING IN AGRICULTURE 3 (2016) 133–145

journal homepage: www.elsevier.com/locate/inpa

Analytical study of friction coefficients of pomegranate seed as essential parameters in design of post-harvest equipment

S.M. Shafaei, A. Nourmohamadi-Moghadami *, *S. Kamgar*

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

ARTICLE INFO

Article history:
Received 25 February 2016
Accepted 23 May 2016
Available online 28 May 2016

Keywords:
Duncan's multiple range test
Analysis of variance
Multiple linear regression technique
Moisture content
Sliding velocity

ABSTRACT

Friction coefficients (static friction coefficient (SFC) and dynamic friction coefficient (DFC)) of pomegranate seed on different structural surfaces (glass, aluminum, plywood, galvanized steel and rubber) as affected by moisture content (4–21.9% (d. b.)) and sliding velocity (1.4–16 (cm/s)) were investigated. Analysis of variance (ANOVA) was performed to determine the effect of main treatments and their interactions on SFC and DFC. Significance of single or multiple effect of the main treatments with five levels was assessed using Duncan's multiple range test (DMRT). To predict SFC and DFC, multiple linear regression (MLR) modeling technique was applied for each type of structural surface. The goodness of fit of each MLR model was evaluated using statistical parameters: coefficient of determination, root mean square error and mean relative deviation modulus. Results showed that the minimum and maximum SFC or DFC were in minimum and maximum moisture content on glass and rubber surface, respectively. ANOVA table indicated the significant effect of main treatments and their interactions on SFC and DFC at significance level of 1% ($P < 0.01$). According to DMRT results, SFC linearly increased as moisture content increased and DFC increased also linearly as individual or simultaneous increment of moisture content and sliding velocity occurred, for all experimental conditions. According to the obtained statistical parameters, both SFC and DFC were properly predicted by means of MLR modeling technique.

1. Introduction

Pomegranate (*Punica granatum* L.) is one of the popular fruits in the world. This horticultural product has not only been consumed as fruit in human food, but also used as an industrial crop. Hence, it is cultivated and processed in many horticultural units in the world. An edible part of pomegranate is its aril. Aril contains liquid part (juice) and seed.

* Corresponding author. Tel.: +98 09163616318; fax: +98 07132286104.
E-mail address: a.nourmohamadi@shirazu.ac.ir (A. Nourmohamadi-Moghadami).

Peer review under responsibility of China Agricultural University.

Abbreviations: 3D, three dimensions; ANOVA, analysis of variance; DFC, dynamic friction coefficient; DMRT, Duncan's multiple range test; GMD, geometric mean diameter; MRDM, mean relative deviation modulus; MLR, multiple linear regression; RMSE, root mean square error; SFC, static friction coefficient

http://dx.doi.org/10.1016/j.inpa.2016.05.003

Nomenclature

F	friction force (N)
FC	friction coefficient
S	sphericity (%)
W	width (mm)
W_w	mass of added distilled water (g)
W_t	initial mass of sample (g)
M_f	final moisture content of sample (d. b.%)
M_i	initial moisture content of sample (d. b.%)
x_i	ith MLR model variable
E_a	average of experimental data
N	normal force (N)
D_g	GMD (mm)
L	length (mm)
T	thickness (mm)
S_a	surface area (mm^2)
a_0	MLR model constant
P_i	ith predicted data
E_i	ith experimental data
a_i	ith MLR model constant
n	number of used data

Although the traditional application of pomegranate is juice production, in recent years, a common industrial product extracted from pomegranate seed is its oil. Therefore, attempts are now being made on optimization of oil extraction from pomegranate seeds [1–4]. Besides, pomegranate seeds are used in manufacturing medicinal products as raw material. Accordingly, sufficient information of physical properties and characteristics of each part of pomegranate fruit will be necessary to obtain the best condition in mechanized processing.

Major dimensions (length, width and thickness), mass, GMD, surface area, sphericity and friction coefficient are some important physical characteristics which are frequently used in designing handling and processing equipment such as conveyors, separation, cleaning, drying and storing equipment [5].

Friction coefficients of grains, forage materials, and other agricultural products on wood, metal and other structural surfaces are necessary for logical designing and predicting the material flow in harvesting or handling equipment. These coefficients are also essential in determining the pressure of grain on container walls [6].

Friction forces appear between two contact surfaces. Before starting the movement of an object, static friction force acts as a resistive force, while dynamic friction force occurs between moving surfaces. The friction force is a function of friction coefficient. Relation between friction force and friction coefficient is formulated by the following equation [7].

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

According to Eq. (1), friction coefficient directly affects the friction force. Thus, knowing friction coefficients is necessary to determine friction force value. From industrial standpoint, it indirectly helps in optimization of equipment designing to prevent mechanical injuries to product during mechanized processes.

Friction coefficients are categorized as SFC and DFC regarding static and dynamic friction force, respectively. The SFC and DFC of agricultural materials depend on moisture content. Furthermore, they are changed as structural surface is changed. In case of DFC, the sliding velocity of materials is important, too [6].

A review of published papers demonstrated that both SFC and DFC of some horticultural products were determined as influenced by moisture content or structural surface. Such studies were carried out for watermelon [8], hazel [9], apple [10], almond [11], orange and sweet lemon [12], strawberry [13], cactus pear [14], walnut [15] and tomato [16]. Overall outcome obtained from comparison of their results indicated that the SFC or DFC of each product is unique and it is not possible to generalize it. Therefore, exact determination of SFC and DFC of each product taking experimental conditions into consideration is valuable.

During post-harvest process of pomegranate aril and seed, it is desirable to prevent seed or aril from slipping and escaping from the defined location of equipment. Thus, according to level of moisture content of samples and type of structural surface, estimation of holding force seems to be of great importance. Furthermore, at each specific level of sliding velocity or moisture content and type of structure surface, handling force for transferring samples through the equipment must overcome the dynamic friction force. Therefore, required holding and handling forces are indirectly related to SFC and DFC, respectively.

Despite comprehensive investigations on some physical properties of pomegranate seed which can be found in literature [17–19], there is no extensive study on determination of SFC and DFC of pomegranate seed as affected by several conditions. Results of such a study are useful for design and optimization of associated equipment for processing pomegranate aril and seed, especially in separating seed from aril and seed oil extraction. Hence, the aims of the present study were limited to below items:

1- Exact determination of SFC as affected by moisture content and structural surface, and DFC as influenced by moisture content, structural surface and sliding velocity.
2- To perform statistical analysis for determination of the effect of moisture content, structural surface and their interaction on SFC, and moisture content, sliding velocity, structural surface and their interaction on DFC.
3- Evaluation of significant deference between treatment levels.