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Moisture-Dependent Physical Properties of Saffron Flower

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ABSTRACT

In order to provide the data needed for the design of saffron processing equipment, physical properties of its flower were investigated. These properties included dimensions, mass, true and bulk densities, porosity, static and dynamic coefficients of friction, and terminal velocity as a function of moisture content. The average range of these properties for the three different parts of saffron flower was about 0.03 to 0.16 gcm^{-3} for bulk density, 0.55 to 1.56 gcm^{-3} for true density, and 85.2 to 95.5% for porosity. Also, the coefficients of friction were measured for three flower parts by using three surface materials including plywood, iron, and galvanized steel sheets. The minimum and the maximum values of static coefficients of friction were found on galvanized steel sheet. They were 0.8 and 2.14 for anther and stigma, respectively. The dynamic coefficient of friction ranged from 0.45 for anther on iron to 1.14 for petal on galvanized steel sheet. The variation range of terminal velocity for three different parts of the flower was recorded between 0.9 and 2.38 ms^{-1}. The results of friction coefficients and terminal velocity measurements suggest that, based on these properties, design of a separator for saffron flower parts is feasible.

Keywords: Physical properties, Saffron flower, Terminal velocity

INTRODUCTION

Saffron, the dry stigmas of saffron flower (*Crocus Sativus* L.), is one of the most expensive spices of the world. Iran, with an annual production of about 170 tones of saffron, approximately 94% of the world production, is the main producer of this crop (1). Spain, India, and Greece, respectively, hold lower ranks as minor producers. Saffron is usually used for cooking as a seasoning and coloring agent. It also has some other applications for medicinal and dye purposes (2). Apart from stigmas, which have economical value, the other two parts of saffron flower (Figure 1) are usually used as animal feed. There are 2170 flowers in each kilo gram of harvested fresh saffron flower. The processing of each 78 kg of fresh flowers results in one kg of dry stigmas (1).

Daily harvesting of saffron flower should be done manually during harvesting season because each plant of saffron produces only three flowers in different heights and days. The manual harvesting, including cutting and picking up the whole flowers, should be carried out in early morning before the stigmas are damaged by the sunshine. Harvest and post-harvest processes should be conducted warily to avoid any harmful effects on taste, color, and aroma of the stigmas. The separation of stigmas from the other parts of saffron flower is the first stage of the post-harvest processes. That should be carried out in the shortest period of time. The next stage is drying up of the stigmas. All processes are currently conducted manually.

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Figure 1: Photo of saffron flower and its three main parts.

The increasing mechanization of post-harvest processes of saffron flower is important due to the time limitation, daily harvesting, and also possible contamination because of manual processing. Studying the physical properties of saffron flower is not only useful for the designing of different processing machines, but it also provides a database for the plant. Such engineering data of the flower is essential for design, manufacturing, development, control, and evaluation of its machinery, including harvesting, conveying, separating, grading, sorting, drying and packing machines.

Although a lot of efforts and progress have been made on the study of the physical properties of agro-food productions, so far, the authors could not find any published work on the physical properties of saffron flower. In the current study, the physical properties of saffron flower were investigated as a function of moisture content. Physical properties including dimensions, mass, true and bulk densities, porosity, static and dynamic coefficient of frictions, and terminal velocity for the three different parts of saffron flower, namely, petal, anther and stigma, were identified. The properties were investigated at different levels of moisture contents, starting almost from the day of harvesting. The ranges of moisture content for the investigation of the physical properties were 4-78.2%, 11.8-77.6%, and 10-87.7% for stigma, anther, and petal, respectively.

MATERIALS AND METHODS

Sample Preparation

Saffron flowers were obtained fresh from farms around the city of Mashhad in Khorasan Razavi Province, Iran, in late harvesting season of 2008. The flowers were taken directly to the lab in the shortest period of time. They were kept in a dark store at ambient temperature (4 ± 1°C) and were taken out daily from the store for sample preparation. Each flower was manually cut from the receptacle point and divided into three parts, namely, stigma, anther, and petal (Figure 1). The moisture content of the flower parts were determined using oven method (50 ± 2°C for 48 hours). The initial moisture content was determined for the fresh flower at harvesting time. To prepare samples with lower moisture contents, the randomly selected samples were dried up to the desired moisture levels. Each sample of flower parts was gently and repeatedly rolled over during drying to let them release the moisture uniformly. The values of moisture content of flower parts at which levels the physical properties were determined are given in Table 1.

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Table1. Moisture content levels of three parts of saffron flower (w.b.%).

Flower parts	Level 1	Level 2	Level 3	Level 4	Level 5
Stigma	78.2	55	36	24	4
Anther	77.6	60	45.7	32	11.8
Petal	87.7	65	48	10	-

Geometrical Characteristics

The principal dimensions of flower parts were measured at the initial levels of moisture content and included length (L_P), width (W_P) and thickness (T_P) for the petal, whole length (L_A), length without tail (l_A), width (W_A), and thickness (T_A) for the anther, and length (L_S), and diameter in four different places including top (D_T), middle (D_M), bottom (D_B) and root (D_R) for the stigma (Figure 2). A digital electronic caliper with an accuracy of 0.001 mm was used for the measurements, which were replicated 20 times.

Physical Properties

Mass of Flower Parts

The mass of flower parts was determined using a digital electronic scale (AND Company, GF 6000 model) with an accuracy of ±0.001g. Each measurement was replicated 20 times.

True and Bulk Densities

The true density (ρ_t) of three flower parts was determined using Toluene (C_7H_8) displacement method (3, 4), to avoid any possible absorption of moisture by flower parts. For each flower part, depending on its size, about 10 to 40 randomly selected samples were weighed and lowered into a burette containing toluene. A narrow rod was used to assure submerging the flower parts during the measurements. The net volumetric displacement of toluene for each individual flower part was recorded as the volume of the sample. The true density was calculated using the following equation:

$$\rho_t = \frac{m}{V} \qquad (1$$

Where, ρ_t is the true density (gr/cm^3), m is mass (gr) and V is the volume(cm^3).

Cylindrical containers of known volumes were employed for the measurement of bulk density (ρ_b). Due to different volumes of the flower parts, three empty containers with

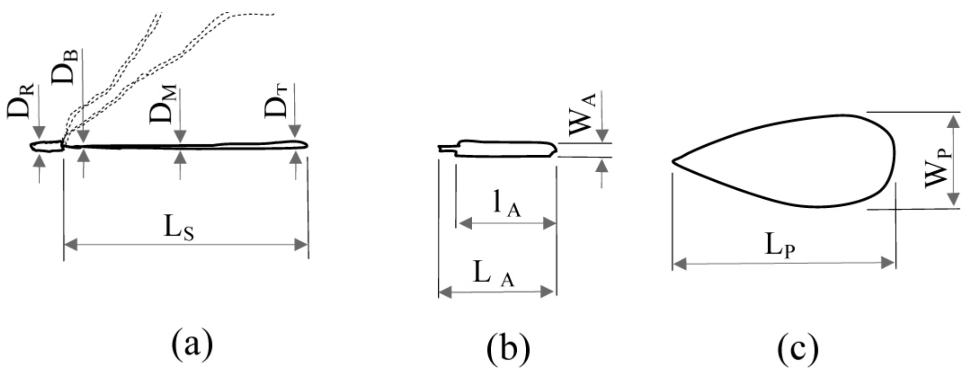

Figure 2: The orientation of dimensions for saffron flower parts: (a) Stigma, (b) Anther, (c) Petal

different volumes of 9.6, 54, and 220 cm^3 were used for petal, anther, and stigma, respectively. Each container was filled by dropping the samples of its designated flower part from the height of 150 mm at a constant rate. Then, the content of the container was carefully weighed using digital electronic scale (±0.001g, AND Company, GF 6000 model) and avoiding any manual compaction. Knowing the volume and the weight of each flower part, the bulk density was obtained using Equation 1. Each measurement was replicated 20 times.

Porosity

Porosity (*P*) was calculated in percentage as follows (5):

$$P = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (2$$

Where, ρ_b is the bulk density (gr/cm^3).

Static and Dynamic Coefficients of Friction

The static coefficient of friction (μ_s) was determined at three different levels of moisture content for the three flower parts. The measurement was conducted on three different materials including plywood, galvanized steel, and iron sheets. The type of the plywood was MDF (Medium Density Fiber Core), hereafter called "plywood". The apparatus used was an adjustable inclined surface equipped with a protractor. The samples were placed on the covered surface with a sheet of the material. The surface was raised slightly until samples started to slide down (6). The angle of inclination (α) was recorded and the static coefficient of friction (μ_s) was calculated from the equation below:

$$\mu_s = \tan\alpha \qquad (3$$

The dynamic coefficient of friction (μ_d) was measured on different materials, namely, plywood, galvanized steel, and iron sheets. Measurements were done according to the method suggested by Amin *et al.* (7). They used a hollow plastic box of 70 mm × 70 mm × 70 mm. After filling the box with lentil seeds, it was moved uniformly on the surface by a gentle push applied parallel to the surface . Similarly, in this study, an empty plastic box of 40 × 56 × 10 cm^3, which was placed on the test sheet and filled with the samples, was used. The filled box was pulled gently at a constant speed through a connected thread tied to a load gage. The traction line of the force through the thread was kept parallel to the surface of the underlying material. The box and the pulley of the thread were made of frictionless plastic material. The dynamic coefficient of friction (μ_d) was calculated by dividing the value of the force shown by the load gage by the total weight of the box and the samples. The box was refilled with new samples for each run of the experiments and the replications.

Terminal Velocity

The terminal velocity of the three different flower parts was experimentally determined using the floating method (8). This method provides blowing air in a vertical duct for the produce particles to be floated. The vertical air duct used was designed and fabricated in the Technical and Engineering Research Center of Khorasan Razavi Province (Iran). The variable air stream could be provided by changing the frequency of electric motor supplier. Terminal velocity i.e. the value of air speed at the time of floating was measured by a hot wire anemometer (Testo, Germany) with an accuracy of 0.1 ms^{-1}.

The experiments were carried out at seven different levels of moisture contents for the three parts of saffron flower including stigma, anther and petal. The moisture contents ranged between 4-79%, 10-87.7%, and 7.4-60% w.b. for stigma, petal, and anther, respectively.

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Statistical Analysis

All experiments and calculations were replicated at least three times. The SPSS software (version 11.5) and Microsoft Excel (2003) were used for calculation of the mean, minimum, maximum, standard deviation, and regression analysis of the data.

RESULTS AND DISCUSSIONS

Flower Parts Dimensions

The mean dimensions of the saffron flower parts at initial level of moisture content are given in Table 2. Dimensions of the flower for the other levels of moisture content were not investigated due to the lack of freshness and high possibility of error. The dimensions of the flower parts are essential for harvesting, separation, sizing, and sorting equipment (9).

Bulk Density

Results of bulk density determination at different moisture content are represented in Table 3. Some data in that table are not reported due to lack of proper samples. The bulk density of petal and anther increased linearly with the increase of moisture content and ranged between. 0.03-0.04 gcm^{-3} and 0.11-0.16 gcm^{-3}, respectively. The bulk density of stigma decreased linearly from 0.14 to 0.09 gcm^{-3} as moisture content increased from 24 to 78.2% w.b. These results showed that the increase of mass as a consequence of moisture absorption was low for stigma and high for the other two parts of the flower in comparison with the accompanying volumetric expansion of their bulk. While the positive relationship of bulk density with moisture content is generally expected and has been reported for many produce (10, 11 and 12), the negative relationship is also shown in some other researches (13, 14 and 15). The data in Table 3 also reveals the significant difference between the bulk densities for petal and the other two parts of saffron flower. The reason may be attributed to the dimensions of the petal that are much bulkier than the other two parts of the flower and result in a low total mass per unit volume (16). The values of bulk density can be applied to the design of drying, storing, and packaging equipment for saffron flower. The relationship between the bulk density of flower parts and their moisture content can be represented by the following equations:

$\rho_{b(Petal)} = 0.0001 M_C + 0.0306$ ($R^2 = 0.80$) (4

$\rho_{b(Anther)} = 0.0007 M_C + 0.1119$ ($R^2 = 0.92$) (5

$\rho_{b(Stigma)} = -0.0009 M_C + 0.1713$ ($R^2 = 0.96$) (6

Table 2. Physical properties of saffron flower parts (initial level of moisture content).

Flower parts	M_C (w.b.%)	Properties	Mean (mm)	Max. value (mm)	Min. value (mm)	St.d. (mm)
Petal	87.7	Length, L_P	38.28	46	30.50	3.28
		Width, W_P	17.15	21	11.50	2.40
		Thickness, T_P	0.15	0.19	0.09	0.02
Anther	77.6	Length, L_A	20.52	23	18	1.54
		Length, l_A	15.25	17.5	13	1.09
		Width, W_A	2.39	3.2	1.7	0.52
		Thickness, T_A	0.26	0.32	0.22	0.02
Stigma	78.2	Length, L_S	30.87	39	23	4.12
		Root diameter, D_R	0.7	0.93	0.3	0.16
		Bottom diameter, D_B	0.43	0.54	0.27	0.09
		Middle diameter, D_M	0.63	0.69	0.53	0.05
		Top diameter, D_T	0.88	1.09	0.78	0.08

Table 3. Bulk density, true density, and porosity of the different parts of saffron flower at various moisture contents (± standard deviation).

Flower parts	M_C (w.b.%)	Bulk density (g/cm^3)	True density (g/cm^3)	Porosity (%)
Petal	10	0.030 (±0.001)	0.555 (±0.032)	94.504 (±0.571)
	48	0.038 (±0.002)	0.758 (±0.035)	94.947 (±0.537)
	65	0.037 (±0.003)	0.834 (±0.026)	95.551 (±0.594)
	87.7	0.039 (±0.002)	0.843 (±0.019)	95.363 (±0.365)
Anther	11.8	0.115 (±0.001)	1.564 (±0.043)	92.594 (±0.286)
	32	0.139 (±0.003)	1.440 (±0.032)	90.346 (±0.464)
	45.7	0.138 (±0.003)	1.290 (±0.019)	89.294 (±0.398)
	60	0.154 (±0.009)	–	–
	77.6	0.160 (±0.007)	1.21 (±0.010)	86.473 (±0.762)
Stigma	4	–	1.08 (±0.052)	–
	24	0.146 (±0.009)	0.992 (±0.042)	85.201 (±1.566)
	36	0.140 (±0.005)	0.985 (±0.029)	85.786 (±1.018)
	55	0.128 (±0.004)	0.952 (±0.013)	86.554 (±0.635)
	78.2	0.098 (±0.002)	0.921 (±0.008)	89.344 (±0.342)

Where, Mc stands for moisture content (%).

True Density

Values of the true densities for petal and stigma followed a similar trend with their bulk densities at the studied moisture content (Table 3). The true density of petal increased linearly from 0.55 to 0.84 gcm^{-3} as moisture content increased from 10 to 87.7% w.b. This means that the relative increase in the weight of the petal is higher than the corresponding volumetric increase owing to moisture absorption. A positive correlation between the true density and moisture content was also reported for many produce including soybean (17), pistachio (18) and sunflower seeds (19). The true density of stigma was found to decrease linearly from 1.08 to 0.92 gcm^{-3} when the moisture content varied between 4 and 78.2% w.b. Contrary to the results of the bulk density for anther, its moisture gain (11.8-77.6% w.b.) demonstrated a linear decrease for true density from 1.56 to 1.21 gcm^{-3}. The negative correlation of the stigma and anther true density with moisture content increase may be attributed to the relative low increase of mass, which is not proportional to its true volumetric expansion. The results are in agreement with other studies conducted on soybean (17), gram (6), and jatropha fruit (14). Similar to the bulk density, values of true density are important for the processing equipment of saffron flower. The relationships obtained between the true density of the flower parts and moisture content are shown below:

$\rho_{t(Petal)} = 0.0039\, M_C + 0.5418$ ($R^2 = 0.91$) (7

$\rho_{t(Anther)} = -\, 0.0055\, M_C + 1.6034$ ($R^2 = 0.92$) (8

$\rho_{t(Stigma)} = -\, 0.002\, M_C + 1.0643$ ($R^2 = 0.90$) (9

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Porosity

Results of the porosity of the three parts of saffron flower at different moisture content, which depend on the bulk and true densities according to Eq.3, are shown in Table 3. The values of porosity exhibited an increase from 94.5 to 95.36% (10- 87.7% w.b.) for petal and from 85.2 to 89.34% (24-78.2% w.b.) for stigma. Similar trends have been reported for sunflower seeds (19), white lupine (20), and corn (21). In contrast to the other two parts of saffron flower, porosity value of the anther decreased from 92.59 to 86.74% for moisture gain in the range of 11.8 and 77.6% w.b. Similar behavior of negative linear values of porosity with moisture increase have been reported by Calisir and Aydin (2004), Deshpande *et al.* (1993), Joshi *et al.* (1993), Konak et al. (2002), Suthar and Das (1996), Tang and Sokhansanj (1993) and Visvanathan *et al.* (1996) for cherry laurel, soybean, pumpkin seeds, Chick pea seeds, Karingda seed, lentil seeds and Neem nuts, respectively. In addition to design of packing equipment, knowledge of porosity is essential for the study of air and heat flow (14) in dryers and separators of the flower parts. The following regression equations were found for porosity values of flower parts with respect to moisture content change:

$P_{Petal}= 0.0127M_C + 94.42$ ($R^2 = 0.79$) (10

$P_{Anther}= -0.0871M_C + 93.37$ ($R^2 = 0.98$) (11

$P_{Stigma}= 0.0748M_C + 83.10$ ($R^2 = 0.93$) (12

Static and Dynamic Coefficients of Friction

The moisture dependent values of the static and dynamic coefficients of friction that were measured for saffron flower on three surfaces including plywood, iron, and galvanized steel sheets are represented in Table 4. The value of static coefficient of friction for all the three parts of fresh flower (initial level of moisture content) could not be determined because of high adherence forces between the samples

Table 4. Static and dynamic coefficients of friction of saffron flower parts (± standard deviation).

		Static coefficient of friction (μ_s) Surface			Dynamic coefficient of friction (μ_d) Surface		
Flower parts	M_C (w.b.%)	Plywood	Iron	Galvanized steel sheet	Plywood	Iron	Galvanized steel sheet
Petal	10	0.98 (±0.09)	1 (±0.07)	1.10 (±0.05)	0.94 (±0.06)	0.91 (±0.04)	1.08 (±0.07)
	48	1.18 (±0.08)	1.49 (±0.13)	1.35 (±0.09)	0.99 (±0.07)	1.00 (±0.05)	1.11 (±0.07)
	65	1.43 (±0.10)	1.50 (±0.09)	1.45 (±1.10)	1.02 (±0.11)	0.98 (±0.04)	1.13 (±0.10)
	87.7	-	-	-	1.10 (±0.10)	1.04 (±0.07)	1.14 (±0.12)
Anther	11.8	0.91 (±0.05)	0.91 (±0.04)	0.80 (±0.03)	0.74 (±0.10)	0.45 (±0.06)	0.63 (±0.10)
	32	1.03 (±0.06)	1.04 (±0.09)	1.00 (±0.05)	0.76 (±0.06)	0.52 (±0.08)	0.84 (±0.11)
	60	1.08 (±0.09)	1.1 (±0.10)	1.10 (±0.09)	0.87 (±0.09)	0.58 (±0.03)	0.97 (±0.05)
	77.6	-	-	-	0.99 (±0.05)	0.65 (±0.07)	1.12 (±0.08)
Stigma	4	1.56 (±0.12)	1.42 (±0.10)	1.90 (±0.09)	0.76 (±0.11)	0.67 (±0.05)	0.72 (±0.13)
	24	1.66 (±0.10)	1.51 (±0.07)	1.93 (±0.13)	0.79 (±0.07)	0.69 (±0.04)	0.75 (±0.07)
	55	2.04 (±0.12)	1.66 (±0.12)	2.14 (±0.11)	0.82 (±0.06)	0.75 (±0.03)	0.86 (±0.06)
	78.2	-	-	-	0.96 (±0.05)	0.82 (±0.03)	1.13 (±0.06)

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and the investigated surfaces. Both measured static and dynamic coefficients of friction increased linearly with the increase of moisture content. The reason for this behavior may be attributed to the high cohesive force at higher levels of moisture contents compared to the initial conditions. A positive correlation of friction coefficients with moisture content have also been reported for hazelnut varieties (27), gram (6), rape seed (28) and neem nut (15). The lowest and highest values of the static coefficient of friction were obtained for the galvanized steel sheet. The minimum value of static coefficient of friction (0.8) was recorded for anther at the lowest level of its moisture content (11.8%). The stigma showed the highest static coefficient of friction (2.14) at 55% moisture content. The lowest and highest values of dynamic coefficient of friction belonged to the anther (0.45, 11.8% w.b.) on iron and the petal (1.14, 87.7% w.b.) on galvanized steel sheet, respectively. The obtained results of friction coefficients of saffron flower parts can be used in the design of various equipment including conveyors (12) and separators (1). The regression equations of the linear relationship between the values for moisture content and the coefficients of friction along with their R^2 values for the three different parts of saffron flower are shown in Table 5.

Terminal Velocity

The terminal velocity of the three parts of saffron flower increased linearly with the increase of moisture content as shown in Figure 3. All flower parts exhibited an aerodynamic instability during the experiments due to their asymmetrical and non-uniform shape (8). The terminal velocities ranged from 1.52 to 2.38 for the stigma and from 1.32 to 2.34 ms^{-1} for the anther when the moisture content increased from 4 to 79% and 7.4 to 60%, respectively. The obtained range of terminal velocity for the petal was lower than that of the other two parts of the flower. The reason may be attributed to both the horizontal lying and the maximum frontal area of the petal against air stream. The terminal velocity of the petal was recorded from 0.9 to 1.39 ms^{-1} for the increase in moisture content from 10 to 87.7%, respectively. Zewdu (2007) reported the terminal velocity of the straw for the teff grain as 3.08 to 3.69 ms^{-1}. The

Table 5. Regression equations related to static and dynamic coefficients of friction of saffron flower parts.

Flower parts	M_C (w.b.%)	Surfaces	Equation	R^2
Petal	10-87.7	Plywood	μ_s=0.0087 M_C + 0.8518	0.95
			μ_d=0.002 M_C + 0.9092	0.93
		Iron	μ_s=0.011 M_C + 0.9225	0.85
			μ_d=0.0015 M_C + 0.9057	0.88
		Galvanized steel sheet	μ_s=0.006 M_C + 1.0833	0.90
			μ_d=0.0009 M_C + 1.0771	0.97
Anther	11.8-77.6	Plywood	μ_s=0.0033 M_C + 0.8981	0.87
			μ_d=0.0038 M_C + 0.6751	0.91
		Iron	μ_s=0.0038 M_C + 0.886	0.90
			μ_d=0.0028 M_C + 04158	0.91
		Galvanized steel sheet	μ_s=0.006 M_C + 0.7598	0.91
			μ_d=0.007 M_C + 0.5725	0.96
Stigma	4-78.2	Plywood	μ_s=0.0097 M_C + 1.4917	0.95
			μ_d=0.0025 M_C + 0.7363	0.84
		Iron	μ_s=0.0046 M_C + 1.4048	0.99
			μ_d=0.002 M_C + 0.6626	0.95
		Galvanized steel sheet	μ_s=0.0049 M_C + 0.8546	0.92
			μ_d=0.0052 M_C + 0.665	0.85

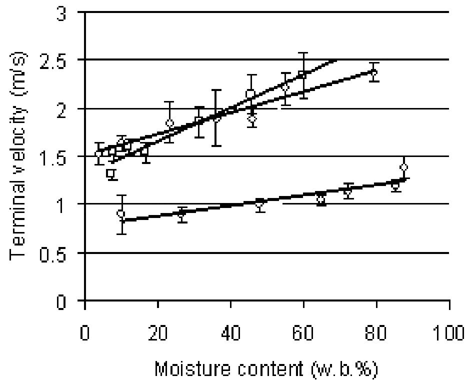

Figure 3: Effect of moisture content variation on the terminal velocity of saffron flower parts (□, anther; ○, petal; ◊, stigma), error bars represent standard deviations

terminal velocity reported for straw material of wheat is from 2.53 to 4.85 ms^{-1} (4). The data of terminal velocity of different parts of saffron flower may be used for the design and manufacturing of separators (1) and pneumatic transporters. The regression equations of the linear relationship between terminal velocity (v) of different parts of saffron flower and moisture content are shown below:

$$v_{Petal} = 0.0054M_C + 0.77\ (R^2 = 0.81) \quad (13$$
$$v_{Anther} = 0.0174M_C + 1.31\ (R^2 = 0.95) \quad (14$$
$$v_{Stigma} = 0.0109M_C + 1.51\ (R^2 = 0.94) \quad (15$$

Application of the Studied Properties

Manual separation of stigma from the other parts of saffron flower is the main current problem of its processing. Finding any difference between the values of the investigated properties of stigma and the other two parts of the flower could be useful in this regard. The obtained results showed that the design of a separator using either aerodynamic or frictional properties may be possible. The difference between the terminal velocity values of the stigma and the other two parts of saffron flower, particularly at the initial level of moisture content, was obvious. As depicted in Figure 4, the two trend lines that show the variation of terminal velocity for stigma and anther diverge from each other while the value of moisture content comes close to its initial level. This suggests that it may be possible to separate the stigma using the terminal velocity property, if the flower processing starts at the shortest period of time after harvesting. The proposed separator could be a vertical wind tunnel with one inlet for feeding flower parts and three outlets for the different separated parts (29). Comparison of the obtained results for the dynamic coefficient of friction also showed a difference between the stigma and the other two parts of the flower on the surface of a galvanized steel sheet at medium levels of moisture contents. Accordingly, conducting further research by using other materials may reveal larger, and useful, differences. However, an endless adjustable inclined belt of galvanized steel that rotates around two pulleys could be suggested as a mechanical separator. Feeding the flower parts from the top of the belt while it rotates upward in an adjusted angle can be easily led to separation of flower parts. The other studied properties can also be considered in the design of drying and packaging equipment.

CONCLUSION

Some useful engineering data about the main physical properties of saffron flower as a function of moisture content was obtained. In addition to the main dimensions that were identified at the initial level of moisture content, the average range of the total variation was about 0.001 to 0.009 gcm^{-3} for bulk density, 0.55 to 1.56 gcm^{-3} for true density, and 85.2 to 95.5% for porosity.

The study of frictional coefficients showed that the mechanical separation of the stigma from the other parts of saffron flower using dynamic coefficient on galvanized steel sheet is possible. Also, results of the terminal velocity measurements revealed that using this property could lead to the development of a mechanical method for stigma separation.

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Nomenclature

L_S	Length of stigma, mm
D_R	Root diameter of stigma, mm
D_T	Top diameter of stigma, mm
D_M	Middle diameter of stigma, mm
D_B	Bottom diameter of stigma, mm
L_A	Whole length of anther, mm
l_A	Length of anther without tail, mm
W_A	Width of anther, mm
T_A	Thickness of anther, mm
L_P	Length of petal, mm
M_C	Moisture content, %
W_P	Width of petal, mm
T_P	Thickness of petal, mm
m	Mass of the flower part, g
V	Volume of the flower part, cm^3
ρ_t	True density, gcm^{-3}
ρ_b	Bulk density, gcm^{-3}
p	Porosity, %
μ_s	Static coefficient of friction
μ_d	Dynamic coefficient of friction
v	Terminal velocity, ms^{-1}
α	Inclination angle of apparatus's surface for measuring static coefficient of friction

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خواص فیزیکی وابسته به رطوبت در گل زعفران

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چکیده

در این تحقیق خواص فیزیکی اجزای گل زعفران بمنظور فراهم نمودن اطلاعات لازم برای طراحی تجهیزات فرآوری آن مورد مطالعه قرار گرفت. خصوصیات مختلفی شامل ابعاد، وزن، چگالی های ظاهری و حقیقی، تخلخل، ضرایب اصطکاک استاتیک و دینامیک و سرعت حد در رطوبت های مختلف مورد تحقیق قرار گرفتند. دامنه متوسط تغییرات برای اجزای گل عبارت بودند از: ۰,۰۳ تا ۰,۱۶ گرم بر سانتیمتر مکعب برای چگالی ظاهری، ۰,۵۵ تا ۱,۵۶ گرم بر سانتیمتر مکعب برای چگالی حقیقی و ۸۵,۲ تا ۹۵,۵ درصد برای تخلخل. همچنین ضرایب اصطکاک اجزای گل بر روی سطوحی از جنس تخته سه لا، آهن و آهن گالوانیزه تعیین گردید. حداقل و حداکثر ضرایب اصطکاک استاتیک بترتیب برابر ۰,۸ برای پرچم و ۲,۱۴ برای کلاله هر دو بر روی ورق آهن گالوانیزه بدست آمدند. دامنه تغییرات ضریب اصطکاک دینامیکی نیز از ۰,۴۵ برای پرچم در روی آهن تا ۱,۱۴ برای گلبرگ بر روی ورق آهن گالوانیزه ثبت گردید. سرعت حد اجزای مختلف گل بین ۰,۹ تا ۲,۳۸ متر بر ثانیه تغییر داشت. نتایج بدست آمده نشان داد که طراحی دستگاه جداکننده اجزای گل بر مبنای اختلاف مقادیرضرایب اصطکاک و سرعت حد امکان پذیر است.

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