Physical properties and modeling for sunflower seeds

Amir Hossein Mirzabe, Javad Khazaei*, Gholam Reza Chegini

(*Department of Agrotechnology*, *University of Tehran*, *College of Abouraihan*, *Tehran*, *Iran*)

Abstract: For designing the dehulling, separating, threshing, sizing and planting machines for sunflower, physical and mechanical properties of sunflower seeds should be known. In this work some physical properties of three varieties of sunflower seeds, distance between the adjacent seeds on the sunflower head (SH), length, width, thickness, mass of the individual seeds, 1000- seeds mass, and changing these parameters with location of seeds on SH were measured. Then shape properties, including geometric mean diameter, sphericity, surface area, projected area and volume of the seeds were calculated. Variations of the shape properties of the seeds on the SH were studied. Statistical indices for dimensional and shape parameters were calculated. For Mikhi, Sirena, and Songhori varieties, true and bulk densities, porosity, angle of repose on wood and galvanized surfaces were calculated by using standard methods in the moisture of 9.15, 5.26 and 5.62% (w.b.), respectively. The distribution of distance between adjacent seeds on SH was modeled by using three continuous statistical distributions namely Normal, two-parameter Log-normal and two-parameter Weibull distribution. Size and mass of seeds were modeled with two-parameter Weibull distribution. The parameters of the probability density functions (PDF) were estimated, then evaluated, and the predictive performances of the models were compared. Log likelihood goodness of fit test was used to test how well different PDFs work for prediction of the distance between seeds on sunflower head, size and mass of seeds.

The results for three varieties showed that when the distance between locations of the seed from center of the sunflower head increased, size, shape properties and mass of seed, increased, too. The values of true and bulk density, porosity and angle of repose on wood and galvanized surfaces for Mikhi variety were 497.500 kg/m^3, 331.027 kg/m^3, 33.46% , 25.08° and 22.23°, for Sirena were 580.368 kg/m^3, 422.015 kg/m^3, 27.28%, 26.80° and 23.86°, and for Songhori were 471.746 kg/m^3, 319.346 kg/m^3, 32.30%, 24.39° and 21.70° respectively. Modeling result for the distance between adjacent seeds on SH showed that, Log-normal distribution model fits the empirical probability density well and two-parameter Weibull distribution had worst performance for prediction. Also modeling result for the distance between adjacent seeds on showed that whenever Skewness and Kurtosis had negative value, Weibull distribution was best fit. Statistical analyses for dimensional properties and mass showed that in most cases, both Skewness and Kurtosis had negative values. Therefor for modeling dimensional properties and mass, Weibull distribution was used.

Keywords: sunflower seed, normal modeling, two-parameter log-normal modeling, two-parameter Weibull distribution modeling, physical properties

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1 Introduction

Sunflower (*Helianthus annuus* L.) is one of the world's most important industrial crops. The area under this crop has increased more than 15 times during the last fifteen years indicating strong motivation of the farmers of the state for this crop (Goel et al., 2009). Due to non availability of suitable machinery for its harvest and post harvest operations, farmers are following the manually methods. During sunflower production using manually methods, the most time and labour-consuming operation is the threshing of sunflower by beating the sunflower heads with a stick, rubbing wear heads against a rough metal surface or power tiller treading (Sangpratum, 1996). The capacity figures for these threshing methods are very

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***Corresponding author: Javad Khazaei,** Email: jkhazaei@ut.ac.ir

low, and impurities are very high. Farmers in some areas thresh sunflower with a rice or soybean thresher or a corn sheller. However, the results obtained indicated that these types of threshers are not efficient for threshing sunflower (Sudajan et al., 2002). Therefore, there was a need to develop a sunflower thresher. For the design and development of such a thresher knowledge of its working parameters is required.

Sharma and Devnani (1979) determined the effect of cylinder tip speed and concave clearance of a rasp bar thresher on threshing of sunflower. The effects of the impact mode of threshing on the thresh ability of a sunflower were studied by Naravani and Panwar (1994). The threshing efficiency of 71% with 9.7% (w.b.) seed moisture content at an energy level of 20.6 N m was observed. A prototype threshing machine for sunflower seeds designed and developed using basic principles adopted for cereal threshers (Anil et al., 1998). Effect of type of drum, drum speed and feed rate on sunflower threshing was studied by Sudajan et al. (2002). Power requirement and performance factors of a sunflower thresher were investigated (Sudajan et al., 2003). Effect of concave hole size, concave clearance and drum speed on rasp-bar drum performance for threshing sunflower were studied by Sudajan et al. (2002).

In order to reduce the number of damaged seeds and decreasing the power consumption of thresher machines and also for increasing their efficiency, these machines should be designed or optimized according to the mechanical and physical properties of the sunflower heads and seeds. These properties are: seeds dimensions, seeds mass, diameter and thickness of the head. But the average of these properties is not of much importance. For this purpose, it is necessary to know the value of mass and grain size distribution in a sunflower head, and also the changes in these properties in different positions of the sunflower head.

While a lot of researches about physical and mechanical properties of other plants have been conducted, a little published literature is available about physical, mechanical and other properties of sunflower seeds on head. Formation mechanism for the spiral type patterns of the sunflower head were investigated by Berding et al. (1983). A growth-controlled model of the shape of a sunflower head were exhibited by Yeatts (2004). The effects of intercepted solar radiation on sunflower seed composition from different head positions were studied (Santalla et al., 2002).

For a single seed, dimensions, mass and other physical properties can be determined; however, values of these properties differ for each individual seed. Normally, we are not interested to know the properties of each individual seed, but description of the frequency distributions of the dimensions, mass and physical properties of the whole sets of the seeds is needed for designing agricultural machinery (Khazaei et al, 2008). There are many researches on modeling the properties of agricultural products based on statistical distributions. Suitability of the Normal, Log-normal and Weibull distributions for fitting diameter distributions of neem plantations in northern Ghana were investigated by Nanag (1998). Frequency distribution curves for dimensions and mass of cocoa beans were fitted to empirical data (Bart-Plange and Baryeh, 2003). Frequency distribution curves for length, width and thickness of Sumac fruits were studied (Musa O., H. Haydar, 2004). Diameter distribution of *Betula alba* L. stands in northwest Spain with the two-parameter Weibull distribution was modeled by Gorgoso et al. (2007). Log-normal, Normal and Weibull distributions for modeling the mass and size distributions of two varieties of sunflower (Daneriz and Dorsefid) seeds and kernels were used by Khazaei et al. (2008). The frequency distribution curves for the length, width, thickness and mass for sunflower seeds and kernels were studied (Jafari et al., 2011).

Indeed, if $P(x)$ is a density function (DF) for a characteristic of a seeds sample, then:

$$\int_a^b P(x)dx = \begin{pmatrix} \text{Fraction of the} \\ \text{seeds sample for} \\ \text{which} a \le x \le b \end{pmatrix} \tag{1}$$

In Equation (1), if $P(x)$ is interpreted as a probability density function (PDF), then the right hand of the equation will be equal to the probability that $a \le x \le b$. We also know that for any density function (Khazaei et al., 2008):

$$\int_{-\infty}^{+\infty} P(x)dx = 1 \quad (2)$$

Moreover, the cumulative distribution function (CDF) for the seeds characteristic is defined as:

$$P(t) = \int_{-\infty}^{t} P(x)dx \quad (3)$$

This gives either the proportion of the seeds with characteristic value less than t, or the probability of having a value less than t.

The objective of present work was measuring and calculating some physical properties, such as distance between adjacent seeds, length, width, thickness, mass, geometric mean diameter, sphericity, surface area, volume, projected area, true density, bulk density, porosity, and angle of repose of sunflower seeds. The other objective of present work was to model distance between adjacent seeds on the sunflower head using Normal, two-parameter Log-normal and two-parameter Weibull distribution, to model size and mass of the sunflower seeds using two-parameter Weibull distribution, to estimate and evaluate the parameters of the probability density functions, and to compare predictive performances of the models using log likelihood goodness of fit test.

2 Material and method

2.1 Sample preparation

The SHs (sunflower heads)used in this study were provided on 29 October 2011 from local farms of Mahyar located at Shahreza, Iran. The heads with different sizes were randomly selected out of three sunflower varieties of Mikhi, Sirena and Songhori, which are widely cultivated in Iran. The Mikhi and Songhori varieties are native of Iran. Twenty sunflower heads of each variety with different sizes and at the harvesting maturity stage were harvested manually, cautiously and randomly. The SHs were immediately transferred to the laboratory. The SHs were stored in at 5℃ until use.

The moisture content of the seeds was determined by oven and by using standard method (AOAC, 2002), and it was found to be 21.55, 18.43 and 30.6% (w.b.) for Mikhi, Sirena and Songhori varieties, respectively. 60 matured SH with different sizes of three varieties were selected. According to the Figure 1 each was divided to three regions. For each region, the distance between adjacent seeds was measured. Then the seeds from heads were extracted. Bulk samples were selected quite randomly from sunflower heads. The length, width, thickness, and mass of each individual seed were measured. For measuring bulk and true density and angle of repose for each variety, the extracted seeds from central, middle and side region were mixed completely, and then bulk samples were selected quite randomly.

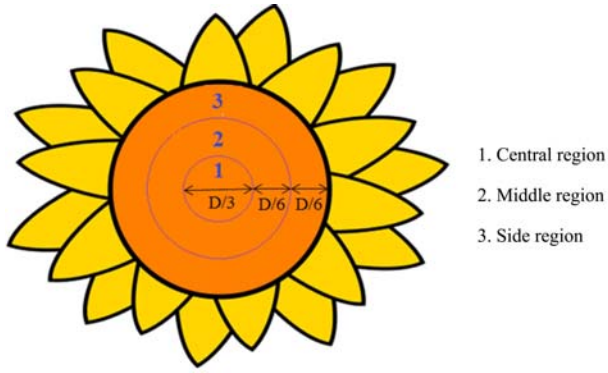

Figure 1 Three regions of SH

2.2 Physical properties of seeds on sunflower heads

2.2.1 Dimensional properties

According to the Figure 1, for each SHs (sunflower heads), the length (L), width (W) and thickness (T), and mass (m) of each individual seed on each of the three regions as well as the distance between two adjacent seeds (Figure 2) were measured. For each of the three SH regions of each variety, all the physical properties were measured for 200 seeds. A digital caliper with an accuracy of 0.01 mm for dimensional measurements was used.

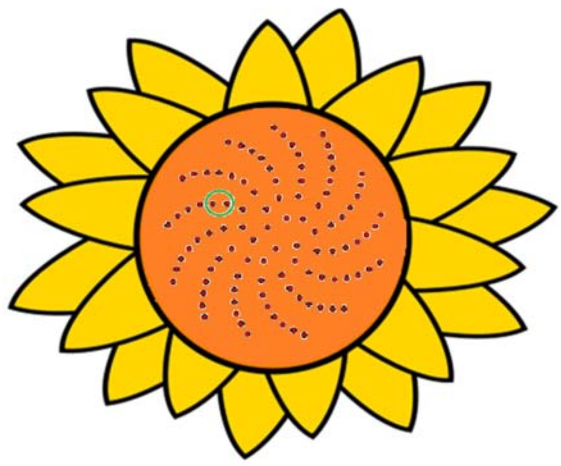

Figure 2 Distance between two adjacent seeds on SH

Then according to size of the seeds, geometric mean diameter (D_g) and sphericity (ϕ) of the seeds were determined using the following equations cited by Aydin (2003), Perez et al. (2007), and Milani et al. (2007):

$$D_g = \sqrt[3]{LWT} \tag{4}$$

$$\phi = \left(\frac{\sqrt[3]{LWT}}{L}\right) \times 100 \tag{5}$$

$$V = \left(\frac{\pi D_g^3}{6}\right) \tag{6}$$

Volume of the seeds (V) and the surface area (S) of the seeds were calculated from Equation (3) and (7) cited by Perez et al. (2007):

$$S = \pi D_g^2 \tag{7}$$

The projected area (A_p) was an important parameter for determining aerodynamic properties, such as terminal velocity, lift force, drag force and drag coefficient. This parameter was calculated based on Equation (8) cited by Gupta and Das (1997):

$$A_p = \left(\frac{\pi WL}{4}\right) \tag{8}$$

Statistical indices including maximum, minimum, average, standard deviation, Skewness and Kurtosis for measured (length, width, thickness and mass) and calculated (D_g, ϕ, V, S and A_P) data, were calculated. Microsoft Office Excel 2007 was used for calculating statistical indices.

2.2.2 Gravimetric properties

2.2.2.1 Mass properties

The mass of the single seeds was measured by a digital balance with an accuracy of 0.01 g. From bulk sample 300 seeds were selected quite randomly; then seeds were divided to three bins so that in each bin 100 seeds were placed. Bin weight was measured and multiplied by 10 to give mass of 1000 seeds.

2.2.2.2 Seeds density

For measuring the bulk density of the sunflower seed, a circular metallic container of 500 mL in volume and 150 mm in height was selected. The container was filled with the seeds. Then the contents of the container were weighed. The bulk density was calculated from the mass of the seeds and the volume of the container (Singh and Goswami, 1996; Sacilik et al., 2003).

For measuring true density water displacement method was used. Toluene (C7H8) was used instead of water because its absorption by seeds is lesser than water. Toluene density was 841 kg/m^3 (Vilche et al., 2003). The porosity of sunflower seed was calculated from bulk and true densities using the equation cited by Mohsenin (1970) as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_c}\right) \times 100 \tag{9}$$

where, ε was porosity; ρ_t was true density; ρ_c was bulk density.

2.2.3 Angle of repose

Static angle of repose was measured by the use of pouring method (Fraczek et al., 2007). The angle of repose was determined by using a topless and bottomless cylinder of 250 mm height and 150 mm diameter. The cylinder was placed at the galvanized and wood surface and was filled with sunflower seeds. The cylinder was raised slowly. The height of the cone was measured and the static angle of repose was calculated by the following equation cited by Razavi et al. (2007):

$$\theta_s = \arctan\frac{H}{R} \tag{10}$$

where, θ_s was angle of repose; H was height of the cone; R was radius of the cone.

For Mikhi, Sirena and Songhori varieties true densities, bulk densities, porosity, angle of repose on wood and galvanized surface were calculated in the moisture of 9.15, 5.26 and 5.62% (w.b.), respectively.

2.3 Modeling the density function

Three continuous statistical distributions, Normal, Log-normal and two-parameter Weibull distribution for modeling distance between the adjacent seeds were used. For modeling the size and mass of the seeds, just two-parameter Weibull distribution was used. The parameters of the probability density functions were estimated, then evaluated, and the predictive performances of the models were compared. Log likelihood goodness of fit test was used to test how well different PDFs work for prediction of size and mass distributions. For calculating the parameters of the probability density functions and Log likelihood, MATLAB R2007b was used.

The probability density functions ($f(x)$) and cumulative frequency functions ($F(x)$) for three distributions were shown in Table 1. According to the equations expressed in Table 1, for the Normal distributions, μ was mean or location parameter and σ was standard deviation or scale parameter. For the Log-normal distribution, ζ was the shape parameter, λ was the scale parameter and γ was the location parameter. Whenever γ was equal to zero, Log-normal distribution was called two-parameter distribution. Otherwise it was called three-parameter distribution. Whenever γ was equal to zero and λ was equal to one, the Log-normal distribution was called standard Log-normal distribution. In this study, two-parameter Log-normal distribution was used.

Table 1 Probability distribution function and cumulative distribution function of Normal, Log-normal and Weibull distribution

Distribution name	Probability distribution function	Cumulative distribution function
Normal	$f(x)=\left(\frac{1}{\sigma\sqrt{2\pi}}\right)\exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right)$	$F(x)=\frac{x-\mu}{\sigma}$, $\phi(x)=\frac{1}{\sqrt{2\pi}}\int_0^x e^{-t^2/2}dt$
Log−normal	$f(x)=\left[\frac{1}{(x-\gamma)\zeta\sqrt{2\pi}}\right]\exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\lambda}{\zeta}\right)^2\right)$	$F(x)=\phi\frac{\ln(x-\gamma)-\lambda}{\sigma}$, $\phi(x)=\frac{1}{\sqrt{2\pi}}\int_0^x e^{-t^2/2}dt$
Weibull	$f(x)=\frac{£}{\beta}\left(\frac{x-\alpha}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x-\alpha}{\beta}\right)^{£}\right)$	$F(x)=1-\exp\left(-\left(\frac{x-\alpha}{\beta}\right)^{£}\right)$

According to the equations expressed in Table 1, for Weibull distribution, α was location parameter, β was scale parameter and £ was shape parameter. If α was equal to zero, the Weibull distribution was called two-parameter distribution; otherwise it was called three-parameter distribution. In this paper, for modeling the data, two-parameter Weibull distribution was used.

For evaluating distributions there are some methods. One of the methods is Kolomogrov-Smirnov. Kolmogorov-Smirnov is one of the goodness of fit test using to test how well different prediction (Rohatgi, 2003). The test is based on the vertical deviation between the observed cumulative density function and estimated cumulative density function under Equation (11). In this equation, small values of the test statistics K_s indicate a better fit.

$$K_s = \max(S(x) - F(x)) \tag{11}$$

were, *S(x)* was the cumulative frequency distribution observed;

Log likelihood is other method for comparison fits. Likelihood ratio test is a statistical test used to compare the fits. The test statistic (often denoted by *D*) is twice the difference in these log-likelihoods:

$$D = -2\frac{L_n}{L_a} \tag{12}$$

where, L_n was the likelihood for null model; L_a was the likelihood for alternative model.

Chi−squar is other method for comparison fits. Function of Chi-squar test is expressed in Equation (10), where is the observed frequency for bin *i* and is the expected frequency for bin *i* (Khazaei et al., 2008):

$$x^2 = \sum_{i=1}^{n}\frac{(O_i - E_i)^2}{E_i} \tag{13}$$

where, x^2 was Chi−squar; O_i was the observed frequency for bin *i*; E_i was the expected frequency for bin *i*; n-p-1 was degrees of freedom (*p* is the number of parameters estimated by sample data). Despite some methods for evaluating distributions, log likelihood method was used.

3 Result and discussion

3.1 Size, shape and mass

Distance between adjacent seeds for central, middle and side region of Mikhi variety ranged from 1.27 mm to 5.84 mm, 3.23 mm to 6.30 mm and 4.13 mm to 6.88 mm, respectively. The corresponding value for Sirena variety ranged from 1.54 mm to 5.53 mm, 3.30 mm to 5.91 mm and 4.12 mm to 6.55 mm respectively. The corresponding value for Soghori variety ranged from 2.00 mm to 4.83 mm, 2.99 mm to 5.85 mm and 4.05 mm to 6.84 mm, respectively. Table 2 showed statistical indices for the distance between adjacent seeds for three varieties of sunflower. When the distance between locations of the seed from center of the sunflower head increased, distance between adjacent seeds increased, too. Since when the distance between location of the seed and center of the sunflower head increased, width and thickness of the seeds increased as well.

Table 2 Statistical indices for distance between adjacent seeds on sunflower head

Variety	Location	Mean/mm	Max/mm	Min/mm	Std	Skewness	Kurtosis
Mikhi	Central region	3.5147	1.27	5.84	0.9018	-0.3234	-0.3600
	Middle region	4.8054	3.23	6.30	0.6214	0.0935	-0.4655
	Side region	5.4367	4.13	6.88	0.5400	0.0850	-0.1902
Sirena	Central region	3.7133	1.54	5.53	0.8721	-0.2851	-0.4917
	Middle region	4.6455	3.30	5.91	0.4859	-0.1398	0.2481
	Side region	5.2721	4.12	6.55	0.5187	0.0615	-0.3766
Songhori	Central region	3.6193	2.00	4.83	0.6548	-0.4368	-0.5164
	Middle region	4.4978	2.99	5.85	0.5737	-0.5428	-0.1304
	Side region	5.1495	4.05	6.84	0.5935	0.4423	-0.4389

During measurements of length, width, thickness and mass of seeds from different sunflower head, it was concluded that the dimensions of seed increased with increasing head size. Length, width, thickness, mass and one thousand seeds mass of Mikhi variety ranged from 12.77 mm to 19.87 mm, 4.37 mm to 9.91 mm, 1.95 mm to 5.70 mm and 0.01g to 0.23 g respectively. Statistical indices for size and shape properties and mass of the seeds for Mikhi variety were showed in Table 3. Table 3 showed that for the Mikhi variety, in 20 of 27 cases, both skewness and kurtosis values were negative.

Table 3 Statistical indices of size, shape properties and mass of the seeds of Mikhi variety.

Location	Parameter	Max	Min	Mean	Std	Skewness	Kurtosis
Central region	L/mm	19.26	12.77	15.8404	1.3053	0.2046	-0.2781
	W/ mm	8.44	4.37	6.7158	0.9204	0.5399	-0.3988
	T/ mm	4.94	1.95	3.2443	0.6395	-0.1969	-0.4784
	M/g	0.16	0.01	0.0895	0.0382	-0.2977	-0.5113
	D_g / mm	8.43	4.98	7.1116	0.7802	-0.7635	-0.0644
	ϕ/ %	52.35	36.09	44.8992	3.5469	-0.1905	-0.8417
	S/ mm^2	223.48	78.03	160.7842	33.4892	-0.5337	-0.3495
	V/ mm^3	314.16	64.82	194.8962	58.0519	-0.3074	-0.5128
	A_p / mm^2	112.42	44.58	83.97	15.27	-0.5290	-0.3477
Middle region	L/mm	19.66	14.44	17.0112	1.2526	-0.1333	-0.8312
	W/ mm	9.92	6.15	7.9434	0.8300	0.1801	-1.1034
	T/ mm	5.41	2.94	4.1538	0.5530	0.0201	-0.6439
	M/g	0.20	0.02	0.1254	0.0368	-0.7825	0.4152
	D_g / mm	9.48	6.75	8.2258	0.6230	-0.2701	-0.4957
	ϕ/ %	56.14	46.11	48.5204	4.1113	-0.0166	-1.3365
	S/ mm^2	282.51	143.07	213.7792	31.9045	-0.1079	-0.5850
	V/ mm^3	446.51	160.92	296.3769	65.4496	0.0498	-0.6128
	A_p / mm^2	132.91	74.93	105.98	12.11	-0.3206	-0.4727
Side region	L/mm	19.87	14.72	17.2125	1.5227	-0.2119	-0.6641
	W/ mm	9.91	6.54	8.1380	0.8838	0.0401	-1.1171
	T/ mm	5.70	3.16	4.5369	0.5332	-0.5232	-0.3278
	M/g	0.23	0.05	0.152	0.0397	-0.5337	-0.5168
	D_g / mm	9.79	6.98	8.5756	0.6339	-0.4931	-0.4647
	ϕ/ %	56.51	46.88	49.9098	3.3781	-0.0611	-0.8623
	S/ mm^2	301.17	153.02	232.2874	33.5705	-0.3483	-0.5844
	V/ mm^3	491.47	178	335.5284	71.1734	-0.2043	-0.6521
	A_p / mm^2	151.38	79.23	109.99	13.8253	-0.0455	-0.6297

Length, width, thickness, mass and one thousand seeds mass of Sirena variety ranged from 10.33 mm to 14.12 mm, 3.27 mm to 7.77 mm, 1.59 mm to 5.84 mm and 0.01g to 0.14 g respectively. The corresponding value for Songhori variety was found to be 15.92 mm to 24.31 mm, 5.58 mm to 9.75 mm, 1.76 mm to 5.99 mm and 0.01g to 0.27 g respectively. Statistical indices for size, shape properties and mass for Sirena and Songhori varieties were showed in Tables 4 and Table 5 respectively. Table 4 showed that for the Sirena variety, in 10 of 27 cases, both skewness and kurtosis values were negative. In 3 of 27 cases, both skewness and kurtosis value were positive. Table 5 showed that for the Songhori variety, in 14 of 27 cases, both skewness and kurtosis values are negative.

The results of the three varieties showed that when the distance between the location of seed from the center of sunflower head increased, length, width, thickness, mass, geometric mean diameter, sphericity, volume, surface area, and projected area increased. For Songhori variety, value of the length and width of the seeds, in each region was greater than the corresponding values of other varieties. For Sirena variety, value of the length and width of the seeds, in each region was lesser than the corresponding values of other varieties.

The results showed that when the distance between the locations of seed from the center of sunflower head increased, width and thickness increased. The distance between locations of the seed from center of the sunflower head increased, distance between adjacent seeds increased, too. Distance between adjacent seeds, with increasing distance from the center point of sunflower head, increased, because with increasing distance from the center point of sunflower head, width and thickness of the seeds, increased.

Table 4 Statistical indices of size, shape properties and mass of the seeds of Sirena variety.

Location	Parameter	Max	Min	Mean	Std	Skewness	Kurtosis
Central region	L/mm	13.48	10.33	11.7321	0.6221	0.5666	0.2040
	W/ mm	7.1	3.27	5.3892	0.9872	-0.6908	-0.5943
	T/ mm	5.06	1.59	3.3883	0.7993	-0.2568	-0.5154
	M/g	0.09	0.01	0.0506	0.0199	0.0293	-0.5775
	D_g/ mm	7.65	3.94	5.9541	0.8951	-0.5404	-0.5879
	Φ/ %	62.91	34.28	50.6011	6.1333	-0.6880	-0.4747
	S/ mm^2	183.66	48.85	113.8759	32.2487	-0.2719	-0.6588
	V/ mm^3	234.05	32.11	117.7762	47.3679	0.0137	-0.5432
	A_p/ mm^2	69.82	27.38	49.94	10.7334	-0.4722	-0.6224
Middle region	L/mm	13.76	10.90	12.2714	0.6524	0.0314	-0.9621
	W/ mm	7.32	4.11	6.3286	0.615	-0.5764	0.2990
	T/ mm	5.11	1.97	4.0461	0.6547	-0.7040	0.3877
	M/g	0.12	0.02	0.0711	0.0204	-0.2763	-0.1918
	D_g/ mm	7.82	4.93	6.7818	0.6359	-0.6257	0.0133
	Φ/ %	63.05	41.96	55.2051	3.5158	-0.9286	1.3632
	S/ mm^2	192.29	76.36	145.7516	26.3571	-0.4013	-0.4224
	V/ mm^3	250.74	62.75	167.5179	8.3435	-0.2041	-0.6977
	A_p/ mm^2	76.98	37.41	61.19	8.3435	-0.1323	-0.6634
Side region	L/mm	14.12	11.12	12.7068	0.5639	-0.2532	0.0263
	W/ mm	7.77	5.97	6.9264	0.3002	-0.1540	0.7991
	T/ mm	5.84	3.65	4.8566	0.3586	-0.4897	0.8972
	M/g	0.14	0.03	0.0961	0.0203	-0.3287	0.3791
	D_g/ mm	8.51	6.41	7.5288	0.3421	-0.2645	0.8248
	Φ/ %	64.05	52.69	59.2756	1.8373	-0.4727	0.7162
	S/ mm^2	227.38	129.22	178.4334	16.0976	-0.0796	0.6876
	V/ mm^3	322.42	138.13	224.8099	30.2587	0.1002	0.6456
	A_p/ mm^2	86.05	54.67	69.20	5.4632	0.0558	0.3427

Table 5 Statistical indices of size, shape properties and mass of the seeds of Songhori variety

Location	Parameter	Max	Min	Mean	Std	Skewness	Kurtosis
Central region	L/mm	20.44	15.92	18.3939	1.208	-0.1815	-0.6442
	W/ mm	8.40	5.58	7.0755	0.6866	-0.1508	-0.8820
	T/ mm	4.86	1.76	3.1979	0.7482	-0.0626	-0.7920
	M/g	0.18	0.01	0.1142	0.045	-0.8226	-0.5096
	D_g / mm	8.74	5.97	7.4122	33.0481	-0.0335	-0.8723
	ϕ / %	52.83	30.45	40.4477	4.6906	0.0046	-0.3882
	S/ mm^2	239.77	112.11	174.1702	33.0481	0.1277	-0.8623
	V/ mm^3	349.13	111.63	219.0486	61.7691	0.2858	-0.7966
	A_p / mm^2	123.21	75.73	102.19	11.2286	-0.1444	-0.8479
Middle region	L/mm	21.98	16.35	18.8253	1.3613	0.1608	-0.6945
	W/ mm	9.03	5.70	7.9880	0.6587	-0.9786	1.0039
	T/ mm	5.45	2.15	3.8803	0.6662	-0.4152	0.4356
	M/g	22	4	16.2512	0.0345	-1.2499	1.7163
	D_g / mm	9.39	6.34	8.3211	0.6496	-1.2398	1.3607
	ϕ / %	53.98	32.80	44.3642	4.0516	-0.4947	0.5849
	S/ mm^2	276.87	126.45	218.8407	32.3826	-1.0214	0.8127
	V/ mm^3	433.20	133.71	306.9839	64.8695	-0.8116	0.3732
	A_p / mm^2	153.8	82.18	118.25	14.1904	-0.2585	-0.4076
Side region	L/mm	24.31	16.71	19.5913	1.7397	0.8139	-0.0383
	W/ mm	9.75	6.42	8.3605	0.6540	-0.3200	-0.2186
	T/ mm	5.99	3.26	4.7097	0.6465	-0.2656	-0.6011
	M/g	27	6	18.3216	0.0461	-0.4570	-0.4398
	D_g / mm	10.83	7.51	9.1513	0.7482	-0.2513	-0.5068
	ϕ / %	53.51	39.53	46.1883	2.8852	-0.1912	-0.4119
	S/ mm^2	368.41	177.45	264.8409	42.6353	-0.0751	-0.5505
	V/ mm^3	664.93	222.27	409.2259	97.4265	-0.1001	-0.5216
	A_p / mm^2	175.12	94.19	129.03	18.2955	0.2986	-0.5086

For all varieties, value of the mean of the distance between the seeds, width and thickness of the seeds in the middle region were more than central region. Also values of the mean of the distance between the seeds, width and thickness of the seeds in the side region were more than middle region. For three varieties, difference of the mean of distance between the adjacent seeds and width of the seeds of middle region and central region, were more than the corresponding values of the side region and middle region. For Mikhi variety, difference between the mean of thickness of the seeds of middle region and central region, were more than the corresponding values of the side region and middle region. However, for Sirena and Songhori varieties, difference between the means of thickness of the seeds of middle region and central region, were less than the corresponding values of the side region and middle region. Therefore, effect of the width increasing on the increasing distance between the adjacent seeds, was more than the thickness increasing.

1000 seeds mass of Mikhi variety in central, middle and side regions were 90.65, 125.8 and 150.56 g respectively. The corresponding value for Sirena and Songhori varieties were 49.63, 70.07 and 94.87 g and 113.73, 162.75 and 181.81 g respectively. Results of mass measurement for Mikhi variety indicated that the seed would be hollow if its mass was less than 0.06, 0.07 and 0.08 g in central, middle and side region respectively. Therefore, 17%, 8% and 4% of seeds in central, middle and side region were hollow. For Sirena variety, the seed was hollow if the mass of the seed was less than 0.03, 0.04 and 0.05 g in the central, middle and side region respectively. Therefore, 13.5%, 5% and 2% of seeds in the central, middle and side region were hollow. The corresponding values for Songhori variety were 0.06, 0.07 and 0.08 g. Therefore, for Songhori variety, 18%, 4% and 2% of seeds in central, middle and side region were hollow.

For three regions of Mikhi variety, probability density distribution of seeds mass was shown in Figure 3; also the percentage of the hollow seeds for each region can be understood by looking at the Figure 3. This figure showed that there was a large overlap between the PDF of mass of the seeds in middle region and mass of seeds in other region. What is shown in Figure 3 and results of Table 3 were consistent.

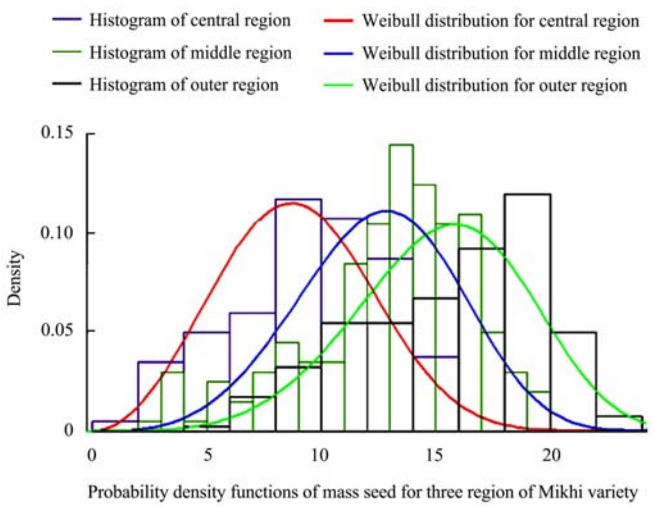

Figure 3 Probability density functions of mass seed for three region of Mikhi variety using two-parameter Weibull distribution.

3.2 Bulk density, true density, porosity and angle of repose

The value of bulk density for Mikhi, Sirena and Songhori varieties of sunflower seeds were measured by using standard method and the results were 331.027 kg/m^3, 422.015 kg/m^3 and 319.346 kg/m^3 respectively. The value of true density for Mikhi, Sirena and Songhori varieties using water displacement method were 497.5 kg/m^3, 580.368 kg/m^3 and 471.746 kg/m^3, respectively.

The true density of sunflower seeds of Shamshiri variety increased from 444.39 to 521.78 kg/m^3 when the moisture content increased from 5% to 20% (w.b.). This increase may be due to the increase in volume because of absorption of moisture. The bulk density decreased slightly with increase of moisture content (Jafari et al., 2011).

A comparison between the results of the works of Jafari et al.(2011) and this work showed that in the same moisture content the true density of Shamshiri variety was less than the other varieties' true density and the true density of Sirena variety was more than the other varieties.

Porosity was one of the physical properties and was dependent to the shape of the seeds. The value of the porosity of sunflower seeds for Mikhi, Sirena and Songhori varieties using Equation (6) was 33.46%, 27.28% and 32.30% respectively. The porosity of Morden variety of sunflower seeds was calculated by Gupta and Das (1997). For Modren variety in the moisture ranged from 4% to 20% (d.b.), porosity increased from 34. 3% to 43.3%. Jafari et al. (2011) cited that the Shamshiri variety in the moisture ranged from 1.8% to 20.3% (w. b.), porosity increased from 39.09% to 47.18%. Comparison between the results of the works of Jafari et al. (2011), Gupta and Das (1997) and this work showed that in the same moisture content, the porosity of Shamshiri variety was more than the other varieties' porosity and the porosity of Sirena variety was less than the other varieties' porosity.

The value of angle repose on wood surface for Mikhi, Sirena and Songhori variety were measured and the results were 25.08°, 26.80° and 24.39° respectively. The corresponding values on a galvanized surface were 22.23°, 23.86° and 24.39°. For each variety, the value of angle of repose on a wood surface was more than the value of angle of repose on a galvanized surface, because the value of friction of seeds on wood surface was more than the value of friction of seeds on galvanized surface. The angle of repose of Morden variety of sunflower seed and kernel increased from 33° to 41° for seed and from 26° to 38° for kernel in the moisture range of 3.6% to 20.2% (d. b) (Gupta and Das, 1997). Jafari et al. (2011) cited that the angle of repose of Shamshiri variety of sunflower seed increased from 15.69° to 38.83° at moisture range of 8% to 20% (w.b.). A comparison between the results of the works of Jafari et al. (2011), Gupta and Das (1997) and this work showed that in the same moisture content the angle of repose of Shamshiri variety was more than the other varieties' angle of repose.

3.3 Modeling results

The distance between the adjacent seeds distribution of three varieties of sunflower were modeled by using Normal, Log-normal, Weibull and probability density functions and cumulative frequency distribution. For examples of predicted size and mass distributions were illustrated in Figure 4. When the graphics were reviewed, it can easily be seen that Weibull distribution gave the best fitness and Log-normal distribution had bad performance.

Results for modeling of distance between adjacent seeds of Mikhi, Sirena and Songhori varieties of sunflower were shown in Table 6. These results indicated that whenever Skewness and Kurtosis had negative value, Weibull distribution was best fit. Whenever Skewness had positive value and Kurtosis has negative value, normal distribution was the best fit and Weibull distribution had the worst performance.

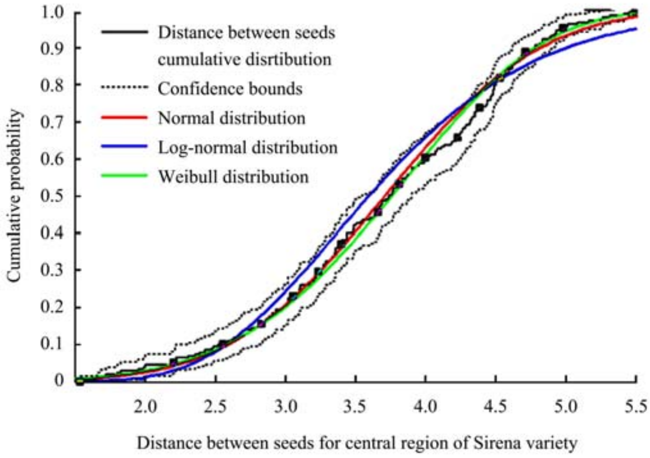

Figure 4 Modeling distance between adjacent seeds for central region of Sirena variety with Normal, Log-normal and Weibull cumulative distributions

Table 6 Calculated parameter values of the different probability density functions for distance between adjacent seeds on sunflower head.

Variety	Location	Distribution	σ^2	μ	Distribution parameters		LLH	Rank
Mikhi	Central region	Normal	0.8132	3.5147	$\alpha = 3.5147$	$\beta = 0.9018$	−262.613	2
		Lognormal	1.1091	3.5294	$L\alpha = 1.2185$	$L\beta = 0.2920$	−280.821	3
		Weibull	0.7726	3.5192	$\beta = 3.8540$	$\gamma = 4.5467$	−259.602	1
	Middle region	Normal	0.3861	4.8054	$\alpha = 4.8054$	$\beta = 0.6214$	−188.119	1
		Lognormal	0.3987	4.8061	$L\alpha = 1.5613$	$L\beta = 0.1308$	−188.768	2
		Weibull	0.4625	4.7951	$\beta = 5.0800$	$\gamma = 8.3947$	−194.179	3
	Side region	Normal	0.3024	5.4367	$\alpha = 5.4367$	$\beta = 0.5500$	−163.706	1
		Lognormal	0.3087	5.4370	$L\alpha = 1.6880$	$L\beta = 0.1019$	−164.206	2
		Weibull	0.3877	5.4207	$\beta = 5.6863$	$\gamma = 10.5015$	−172.372	3
Sirena	Central region	Normal	0.7606	3.7133	$\alpha = 3.7133$	$\beta = 0.8721$	−255.919	2
		Lognormal	0.9710	3.7232	$L\alpha = 1.2807$	$L\beta = 0.2602$	−270.175	3
		Weibull	0.7320	3.7185	$\beta = 4.0511$	$\gamma = 4.9754$	−252.912	1
	Middle region	Normal	0.2361	4.6455	$\alpha = 4.6455$	$\beta = 0.4859$	−138.931	1
		Lognormal	0.2485	4.6461	$L\alpha = 1.5303$	$L\beta = 0.1070$	−142.332	2
		Weibull	0.2900	4.6325	$\beta = 4.8619$	$\gamma = 10.3704$	−144.308	3
	Side region	Normal	0.2690	5.2721	$\alpha = 5.2721$	$\beta = 0.5187$	−152.003	1
		Lognormal	0.2744	5.2724	$L\alpha = 1.6576$	$L\beta = 0.0991$	−152.003	2
		Weibull	0.3400	5.2586	$\beta = 5.5079$	$\gamma = 10.9011$	−159.727	3
Songhori	Central region	Normal	0.4288	3.6193	$\alpha = 3.6193$	$\beta = 0.6548$	−198.618	2
		Lognormal	0.5090	3.6233	$L\alpha = 1.2684$	$L\beta = 0.1950$	−210.051	3
		Weibull	0.4070	3.6252	$\beta = 3.8856$	$\gamma = 6.6590$	−192.908	1
	Middle region	Normal	0.3291	4.4978	$\alpha = 4.4978$	$\beta = 0.5737$	−172.147	2
		Lognormal	0.3702	4.4996	$L\alpha = 1.4949$	$L\beta = 0.1346$	−181.192	3
		Weibull	0.3275	4.4983	$\beta = 4.7405$	$\gamma = 9.4241$	−165.720	1
	Side region	Normal	0.3522	5.1495	$\alpha = 5.1495$	$\beta = 0.5935$	−175.036	2
		Lognormal	0.3454	5.1495	$L\alpha = 1.6324$	$L\beta = 0.1137$	−175.036	1
		Weibull	0.4783	5.1291	$\beta = 5.4202$	$\gamma = 5.8595$	−192.442	3

Log-normal, Normal and Weibull distributions for modeling the mass and size distributions of Daneriz and Dorsefid varieties of sunflower seeds and kernels were used by Khazaei et al. (2006). They cited that when skewness had a positive value, lognormal distribution was the best and normal distribution was the worst function for predicting data. When Skewness had a small and negative value, Normal distribution has the best prediction and Weibull distribution has the worst prediction.

Tables 3, 4 and 5 showed that for the three varieties, in 16 of 36 cases, both Skewness and Kurtosis values were negative. In 8 of 36 cases, the Skewness value was positive, while the Kurtosis value was negative. For modeling dimensional properties and mass, Weibull distribution was used. Because the modeling results of distance between adjacent seeds were indicated whenever both Skewness and Kurtosis had negative values, Weibull distribution had best performance. Table 7 showed calculated parameter of Weibull distribution for size and mass of the seeds for Mikhi, Sirena and Songhori varieties.

Table 7 Value of the Weibull probability density functions parameters for three dimension and mass of the sunflower seeds

Variety	Location	Parameter	μ	σ^2	β	γ	LLH
Mikhi	Central region	L	15.7916	2.3272	16.4994	12.6024	−348.650
		W	6.7251	0.8037	7.1029	8.9681	−258.711
		T	3.4242	0.4209	3.6860	6.1476	−192.712
		M	8.9403	10.8975	10.0195	2.9475	−527.935
	Middle region	L	16.9902	1.8441	17.5812	15.3627	−330.600
		W	7.9275	0.8407	8.3183	10.4262	−253.005
		T	4.1427	0.3563	4.3923	8.2541	−169.726
		M	12.5032	12.077	13.7862	4.0414	−542.810
	Side region	L	17.7420	1.5580	16.9818	12.6024	−312.839
		W	8.1315	0.9029	8.5363	10.1332	−262.209
		T	4.5407	0.2988	4.7730	9.9924	−157.645
		M	15.2489	14.0098	16.6812	4.6347	−553.698
Sirena	Central region	L	11.6836	0.6467	12.0356	17.9434	−212.261
		W	5.4056	0.8258	5.7788	6.9958	−269.106
		T	3.3868	0.6236	3.6928	4.9036	−236.203
		M	5.0504	3.8830	5.6739	2.7715	−419.757
	Middle region	L	12.2481	0.5540	12.5751	20.4109	−206.877
		W	6.3259	0.3849	6.5932	12.4045	−180.431
		T	4.0458	0.3972	4.3071	7.5931	−191.347
		M	7.1024	4.0124	7.8384	3.9767	−424.830
	Side region	L	12.6866	0.4139	12.9707	24.5891	−173.710
		W	6.9082	0.1321	7.0685	23.6748	−54.6067
		T	4.8470	0.1529	5.0171	15.212	−78.578
		M	9.6021	4.1641	10.4089	5.4266	−423.704
Songhori	Central region	L	18.3719	1.2572	18.8645	20.3202	−289.901
		W	7.0772	0.5250	7.3886	11.8569	−208.530
		T	3.2087	0.5732	3.5013	4.8402	−225.749
		M	11.3777	18.4171	12.7636	2.8783	−588.770
	Middle region	L	18.7802	2.4697	19.4228	14.6453	−345.925
		W	7.9929	0.3884	8.2644	15.7651	−183.647
		T	3.8765	0.4567	4.1527	6.7271	−199.509
		M	16.2903	9.2823	17.5224	6.2351	−517.535
	Side region	L	19.5001	4.7596	20.4324	10.7985	−416.529
		W	8.3525	0.4881	8.6560	14.6524	−197.685
		T	4.7060	0.4392	4.9838	8.4592	−194.325
		M	18.3603	19.3345	20.0533	4.7617	−583.862

According to Table 7, for Mikhi variety, Weibull distribution had best prediction in side region for length and thickness. For width, the middle region showed the best performance. For mass the central region showed the best performance. For Sirena variety Weibull distribution had best performance in side region for length, width and thickness. For mass, the central region showed the best performance. For Songhori variety Weibull distribution had best performance in side region for thickness. For width and mass, the best prediction was performed in middle region. For length, best performance was got in central region.

4 Conclusion

Finally, some physical properties of three varieties of sunflower seeds including: distance between seeds on sunflower head, length, width, thickness, mass, geometric mean diameter, sphericity, surface area, projected area, volume and variations of these parameters in regard to seed location were calculated. Then the distance between adjacent seeds and dimensional properties and mass were modeled. The results indicated that whenever Skewness and Kurtosis had negative value, Weibull distribution was best fit. Whenever Skewness had positive value and Kurtosis had negative value, Normal distribution was the best fit and Weibull distribution had the worst performance. Also, true and bulk density, porosity and angle of repose were considered. The results indicated that, the value of angle of repose on a wood surface was more than the value of angle of repose on a galvanized surface because the value of friction of seeds on wood surface was more than the value of friction of seeds on galvanized surface.

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