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Physical characterization of sunflower seeds dehydrated by using electromagnetic induction and low-pressure system

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ABSTRACT

Drying is a widely used food preservation process in which water removal minimizes much of the moisture that causes deterioration reactions that impact the bioproduct quality. The objects of studying are high oleic sunflower seeds which are recognized as a worldwide source of edible oil; consequently, they have significant importance on health and food security. This work presents part of the results of a systematic study to compare the affectations on the several physical parameters of sunflower seeds and kernels with the Thermo-Solar Dehydration method (TSD) compared to Dehydration with Electromagnetic Induction at Low Pressures (DEMI-LP), finding that the in the last one the time to reach the 8% of the total moisture content was 2.5 times shorter, interesting physical effects and an increment of 5% in the volumetric expansion coefficient, reflected in a reduction of the cut resistance (Dehull) of 0.5*KgF* significant advantages for the food drying industry.

1. Introduction

According to the Department of Agriculture and Food (FAO) of the of United Nations (UN) during the projection period 2016–2025, world agricultural production of cereals and oilseeds for the production of vegetable oil (including sunflower seed) will be expanded, if natural conditions favor it. Additionally, an annual growth of 1.5% is expected due to the growing demand for biofuels from vegetable oils as a result of the continuous compliance with mandatory regulations for the use of biodiesel (OCDE-FAO, 2016).

In 2016, the world production of *Helianthus annuus*, whose common name is sunflower, was 45.75 *million Tons*. The major producing countries were Ukraine 30.6%, Russia 24.0%, Argentina 7.4%, and China 6.2%. Mexico only contributed with 0.28% of production, and the area destined for this crop has had a considerable increase going from 54 *ha* in 2000 to 7,216.72 *ha* in 2018 (Krautgartner, Lefebvre, Rehder, Boshnakova, & EU, 2018).

The sunflower (*Helianthus annuus*) is one of the world's leading oilseed crops, second only to soybean for the total high oleic oil production (Pighinelli, Ferrari, Miguel, & Park, 2011). Here lies its importance and its physical characteristic that allows the design and development of specialized equipment with the capacity for drying, handling, separating, dehulling, and storing systems (Acevedo Picon, Jaime, & Gelvez Figueredo, 2007).

The specific physical properties after dehydration of sunflower seeds which would be useful for the design of the dehulling process depend on surfaces, sphericity, and storage systems (Gupta, Arora, & Sharma, 2006; Gupta & Das, 1997; Pérez, Baümler, Crapiste, & Carelli, 2019; Perez, Crapiste, & Carelli, 2007). A variety of physical properties of the sunflower species that originated in Mesoamerica (Alvarado,

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Nomenclature

L	Length of seed, *mm*
l	Length of kernel, *mm*
T	Thickness of seed, *mm*
t	Thickness of the kernel, *mm*
W	Width of seed, *mm*
w	Width of kernel, *mm*
D_E	Equivalent diameter, *mm*
D_e	Equivalent diameter, *mm*
S	Surface area of seed, mm^2
s	Surface area of kernel, mm^2
V	Volume of seed, mm^3
v	Volume of kernel, mm^3
M	Unit mass of seed, *G*
m	Unit mass of kernel, *G*
M_C	Moisture content dry basis, *% d.b.*
ρ_b	Bulk density, kg/m^3
ρ_t	True density, kg/m^3
Ψ	Volumetric expansion coefficient, –
φ_S	Sphericity of seed, –
φ_K	Sphericity of kernel, –
$O_{\%}$	Occupancy factor, %
K_{DIP}	Constant of an occupational fraction, %

Tarighat, Bye, Lentz, & Pohl, 2008) has been reported to be influenced by the moisture content.

The sunflower (*Helianthus annuus*) is an erect annual species with yellow flowers that belongs to the Compositae family (Asteraceae). In some regions of Mexico, this species grows wild and is in the process of naturalization, widespread in the semi-arid lands of Zacatecas provinces. It becomes overlapping about 50% of the sunflower crop area; this wild sunflower is resistant to diseases, insect pests, and drought (Perez et al., 2007). Single grain volume and 100 *grain mass* were found to increase the individual physical properties of sunflower seeds substantially with dehydration time and moisture, although moisture content has been reported to influence several physical properties of the seeds of the *Helianthus annuus* (Krautgartner et al., 2018; Pérez et al., 2019).

Natural dehydration, which consists of direct exposure of products to the sunlight energy and environmental conditions, may cause a delay in the harvest application for at least 30 *days*, increasing along this time the probability of present losses by many other inherent problems of production such as climate and pests (FAO, 2019). The domestic thermosolar tunnel dehydrators present the issue of the appearance of rodents, significantly affecting the harvest (García, Mejía, Mejía, & Valencia, 2012; J.V, A, F, & J.L, 1984; Karam, Petit, Zimmer, Baudelaire Djantou, & Scher, 2016) An anticipated and efficient drying would increase the profits of the producers and of all those involved in the final production consumer chain, hence the need to innovate in this process (Swaminathan, 2017).

The Induction heating technique has not been found in the literature references for dehydration applications finding some other methods like Infrared Drying (IRD) (Kumar, Karim, & Joardder, 2014; L. Xie et al., 2017), Desiccant Drying (DD), Reactance Window Drying (RWD), supercritical Carbon Dioxide Drying ($scCO_2D$), Superheated Steam Drying (SSD), Heat Pump Drying (HPD), Radio Frequency Drying (RFD), controlled sudden decompression to vacuum (Dénte Instantanée Controlee) (DIC), Ultrasonic Drying (UD), and others based on electric technologies, for example, Electric Resistance Drying (ERD) or Electrohydrodynamic Drying (ED) (Karam et al., 2016).

Heating by electromagnetic induction is a fast, efficient, precise, repeatable, and non-contact method to increase temperature uniformly in most metals. The method is used in processes with temperatures ranging from 50 °C to 3000 °C (Jakubovi, Gašparec, Kopas, & Sága, 2016; Senhaji, 2017),which can be used in brief heating processes that are activated less than half a second and in others that are ongoing for months (Shokouhmand & Ghaffari, 2012). The technique for increasing the temperature by electromagnetic induction is used in several fields ranging from cooking to metal melting, heat treatments, and welding (Jakubovi et al., 2016)

The aim of this research is to determine and compare the physical affectation of dehydrate sunflower seed by two assisted methods: Thermo-Solar (TSD) Vs. a novel system by using electromagnetic induction and low-pressures (DEMI-LP), the data here reported could be useful for food drying industry and for the chain value of oilseeds and biofuels.

2. Materials and methods

2.1. Biological material

For this study, the early duration of the hi-oleic variety of sunflowers (*Helianthus annuus*) maturing within 125 *days* and widely grown in Mexico was selected. Freshly harvested samples of sunflower seeds, the product of the first generation of Pioneer® P64H41® precocious hybrid, have an average plant height of 111 cm, 60 *days* at flowering and 95 *days* at physiological maturity.

The sunflower seeds were collected approximately 40 *km* in the northwest of the capital of the state of Zacatecas with approximate geographic coordinates of 22.98 ° *latitude* and 102.28 ° *length* in the October–November 2017 harvest season when the plants present all the visual characteristics of physiological maturity. Ten bulk samples, each of the samples consisting of 1 *kg* of seeds, were procured from the DryLab-AORTech laboratories. The seeds were cleaned manually of foreign matter and of broken or immature seeds. The initial moisture content of the seeds was 14.95 % *d. b.*

2.2. Moisture content (Mc)

Samples were randomly selected according to the IUPAC method ((Pérez et al., 2019; Xie, Gong, & Yu, 2018; Zarein, Samadi, & Ghobadian, 2015). The sunflower seeds were set in an isolated chamber at a 50 ° *C* constant temperature for 24*h* to determine the percentage of water loss by evaporation and dry matter in the samples to determine the moisture content (%*d. b.*). In addition to this, commercial equipment was used, Moisture Check PLUS SW of John Deere® and Moisture Meter SL of Stein lite®. All data were used to correct calibration of new equipment development ThermoHum 2.0 in developing prosses by AORTech®.

2.3. Dehydration methods

The selection of the dehydration method is very important since when determining the nutritional properties of the final product, several factors such as the initial and final humidity, the drying time, and the most important of all, the temperature and its range of variation, in the case of dehydrating seeds several authors agree that regardless of the selected method that the ideal temperature of dehydration is just below 70 °C, (Panwar, Kaushik, & Kothari, 2014; Singh, Shrivastava, & Kumar, 2018; Toldrá, 2006), since above this temperature the proteins contained in the product in its natural state they begin to become denatured and therefore their nutritional content is degraded.

2.3.1. Thermo-solar method

The sunflower seed samples (2 kg) were processed for 4 *hours* inside the drying tunnel of the Thermo-Solar dehydration plant located in the municipality of Morelos Zacatecas, with 14.95 % *d. b.* of moisture which is almost 7% above the ideal percentage for storage and postharvest handling of the grain, 8 % *d. b.* (Acevedo Picon et al., 2007; Gupta & Das, 1997; Nithya, Renugadevi, Bhaskaran, & Johnjoel, 2017; Perez et al., 2007). For this dehydration process, the seed was exposed to a hot air flow ($1 \pm 0.21 \frac{m}{s}$) in the center of a closed chamber ($2.4 \times 2.6 \times 12.2$) m reaching temperatures between 66.39 °*C* and 44.09 °C. The seed samples were wholly characterized previously during (1 kg, elapsed 0.75 h) and after 4 *hours* of the dehydration process (1 kg) with the finality of researching a dependence of the physical parameters and properties.

2.3.2. Dehydration by electromagnetic induction and low-pressures (DEMI-LP)

The samples of sun flower seeds were dehydrated by periods of 0.5*h*, 1*h* and 1.5*h* (1*Kg* each), determinated by previous experimentation of mass losses (Water/Moisture), then the all other characterizations (Physical and Bio-Chemicals*) were carried out.

The equipment used for dehydration of sunflower seeds in this research is the patent process MX/a/2017/009811, (Ortiz Hernández et al., 2017), (Fig. 1). Schematic diagram of the DEMI-LP, and the operation of the system consists of increasing the temperature of a hermetic metallic rotative container (a) constructed of food-grade stainless steel in thermal contact with a martensitic stainless-steel jacket that allows the affectation of an high frequency electromagnetic fields (90 − 96 *KHz*) caused by electric flux in the copper conductor (b) around the metallic cylinder, and therefore, induces in it a temperature increase contactless due mainly to the Joule effect caused by the high electromagnetic resonance crystalline internal structure, reaching a homogenous temperature of 65 °C in approximately in 120 *seconds*, and maintained all the time of the process, the internal pressure of the container was adjusted around −20 *inHg* in 180 *seconds* with air extraction (c) using a 3.5 *HP* compressor, creating a negative pressure condition with respect to the external atmospheric pressure.

The simultaneous variation of both parameters (Pressure and Temperature) facilitates a drastic liquid-vapor water change of state allowing evaporation. Then the saturated steam is extracted with the same mechanism that generates the vacuum.

2.4. Physical properties

2.4.1. Mass (m)

To evaluate the seed mass, three groups of 100 *seeds* of each sample were randomly selected from the bulk and weighed on an electronic balance with 0.001 g accuracy, then the seeds were dehulled and the weights were averaged, this way determined the whole seeds that were the percentage of hull and kernel.

2.4.2. Dimensional Parameters: Length (L, l), width (W, w) and thickness (T, t)

Lots of 100 seeds were randomly drawn from the seed pool were measured and averaged to determine their size and shape. For each seed, three principal seed dimensions (*L*, *W* and *T*) all in *mm*, using a micrometer with 0.001 *mm* of accuracy, kernel dimensions (*l*, *w* and *t*) were determinated in the same way, but this time the seeds were dehulled.

2.4.3. Geometric parameters: Equivalent diameter (D_E), surface (S), volume (V) and sphericity (φ)

By analogy to a sphere, the equivalent diameter (*De*) in mm and sphericity (φ) were determined respectively using (Figueiredo, Baümler, Riccobene, & Nolasco, 2011):

$$D_E = (LWT)^{\frac{1}{3}} \tag{1}$$

$$\varphi = \frac{D_E}{L} \tag{2}$$

The seed surface area (*S*) in mm^2 was calculated in accord with (Perez et al., 2007). The geometric mean diameter can be determined with (Eq. (3)):

$$S = \pi D_E^{\,2} \tag{3}$$

The seed volume V_g in mm^3 was determined from the relationship Eq. (4).

Another form to calculate the volume of grain is by comparing it with a symmetric sphere, substituting the equivalent diameter $\left(\frac{D_e}{2}\right)$ with the radius (*r*) in Eq. (4) and reducing it to obtain Eq. (5).

$$V_{sphere} = \frac{4}{3}\pi r^3 \tag{4}$$

$$V_g = \frac{\pi D_e^{\,3}}{6} \tag{5}$$

The Volumetric Expansion Coefficient (Ψ) was calculated using the following relationship:

$$\Psi = \frac{V_g}{V_g^0} \tag{6}$$

where V_0 g is the volume of the dry seed. The dry seed weight was determined after drying it for 24 h at 50 °C.

The volume of the whole seeds was calculated according to Eq. (1), and the dimensions were determined in a 100 *seeds* randomly selected product of each type of dehydration. For each individual seed, the three principal dimensions, namely length (L and l), width (W and w) and thickness (T and t), were measured using a digital Vernier with 0.01 mm of accuracy.

2.4.4. Bulk density (ρ_b)

The bulk density considered as the ratio of the mass seed sample to its total volume was determined by using a 1 dm^3 cubical recipe filled with the grain samples, striking the top level and then weighing the contents 3 times for each sample and averaging the results by applying Eq. (6).

$$\rho_b = \frac{m}{1dm^3} \tag{7}$$

2.4.5. True density (ρ_t)

According with Cleva et al., 2017, (Carcasi, Alberto, & Pereira, 2015; Cleva et al., 2017), K_{DIP} by representing the percentage occupied by the seed, it is possible to get an approximate calculation by using the Digital Image Processing determined in the frequencies histogram in the monochromatic images and comparing the quantity of blank and occupied pixels. This factor is calculated in each face of the regular parallelepiped involving the whole seed in 3D: L, W, and T.

Fig. 2 shows the regular parallelepiped involving sunflower seeds used to calculate the occupational percentage considering that ($L > T > W$), then:

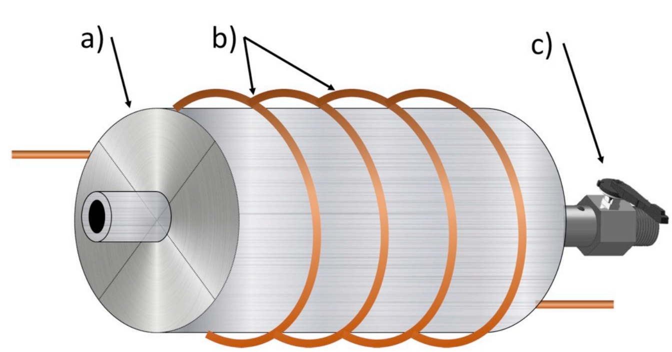

Fig. 1. Schematic diagram of the DEMI-LP,
a) Stainless hermetic container, b) Copper inductor and c) Vacuum control valve.

$$V_T = L * T * W \quad (8)$$

The total volume (Vg) is lower than total volume (V_T); both variables are closely related by using a constant of an occupational fraction, each with an orthogonal view of the whole seed (Fig. 3).

$$V_g = k_{DIP}(L * T * W) \quad (9)$$

The constant (k_{DIP}) was calculated as a factor of $O\%$ (Occupancy factor) which was calculated using the histogram of frequencies of a monochromatic picture of orthogonal views of 100 *grains* randomly selected of each sample. (See Fig. 4.)

$$k_{DIP} = \sqrt[3]{(O\%_L * O\%_T * O\%_W)} \quad (10)$$

2.4.6. Porosity (ε)

The porosity value, defined as the fraction of space in the bulk grain which is not occupied by the grain, was calculated from the following relationship (Eq. (10)).

$$\varepsilon = \left(1 - \frac{\rho_t}{\rho_b}\right) \times 100 \quad (11)$$

2.5. Cut resistance (C_R)

To determine the cut resistance, 100 *seeds* of each kind of samples were randomly selected and sliced by using the Warner Bratzler Blade a) (Johnson, Ribeiro, & Beckett, 2013) mounted in a piece of electromechanical equipment denominated KRN 3.0 developed by AORTech® Labs in the process of intellectual property protection MX/u/2018/000512 (Fig. 5) (Herrera Velázquez et al., 2018).

2.6. Surface morphology

For this study, the early duration of the hi-oleic variety of sunflowers (*Helianthus annuus*) maturing within 125 *days* and widely grown in Mexico was selected. The seeds were cleaned manually of foreign matter and of broken or immature seeds. The initial M_c of the seeds was 14.95 % *d. b.*

The surface morphology of the sunflower seed was performed on a Hitachi 5500 field emission Scanning Transmission Electron Microscope (STEM) operating at 30 *kV*, equipped with the bright field (BF) and annular dark field (ADF) detectors and an energy-dispersive X-ray (EDS) analyzer using magnification ranges between 50 and 200 μm.

3. Results

3.1. Mass (m)

As the process of dehydration of the sunflower seed was in progress, the sample mass presented a continuous decrease depending on the time elapsed. In Fig. 6, the measured values of the bulk as a function of the dehydration time were plotted. In addition to the seed mass, the evolution of the kernel and hull masses was included. The value expressed for the masses corresponds to the average value of 100 *seeds*, each value measured separately and subsequently averaged in the same way. For the error bars, the standard deviation was considered.

The results are expressed as the means of n determinations with 95% confidence intervals Table 1 summarizes the mean of measurements of mass in seed kernels and hulls of 100 sunflower seeds. The dependence of the mass with the time of dehydration is not to be a linear dependence, especially in a dehydration process in which the pressure is reduced at the same time while the sample is heated as in the present case. In all cases shown in Fig. 6, the masses of the plotted data can be adjusted to a decreasing exponential function (Eq. (11)). The values of the adjustment parameters are shown in Table 2, the coefficients of exponential equations adjusted to experimental data of dehydration.

$$f(x) = A_1 * e^{-\left(\frac{k}{t_1}\right)} - y_0 \quad (12)$$

3.2. Moisture content (M_c)

The result of comparing the measurements of moisture in the samples versus time of dehydration, using a conventional process by blowing hot air (TDS) and this new process of dehydration using electromagnetic induction heating under conditions of reduced pressure (DEMI-LP). As it can be observed in Fig. 7, both graphs, the moisture percentage shows a decreasing exponential dependency as a function of the dehydration time, independently of the method used to carry out the process. Nevertheless, there is a noticeable difference in the time needed to obtain similar results in each method. For example, to achieve a moisture percentage of 8% in each method A) DEMI-LP, 0.789 *h* (47 *min*) and B) TSD, it is necessary 2*h* (120 *min*) of continuous dehydration.

3.3. Dimensional parameters (L, l, W, w, T, t)

Average of linear dimensions are shown in Table 3, the coefficients of exponential equations adjusted to experimental data of dehydration are shown in Table 4- Coefficients of exponential equations adjusted to experimental data of dehydration.

3.4. Volumetric expansion coefficient (Ψ)

To determine the volumetric modification in a sunflower seed caused by moisture loss, the volumetric percentage was determined. Table 5 shows the results with the coefficients of expansion calculated by the relationship between the initial geometrical dimensions and final measurements of the same parameters.

3.5. Geometric parameters: Equivalent diameter (D_E), surface (S), volume (V) and sphericity (φ)

The sphericity and kernel of the sunflower seed were much lower than those reported for soybean and pigeonpea seeds. The equivalent diameter of the sunflower seed (Eq. 12) was higher than those reported for pigeonpea, longmelon and muskmelon seeds, and it was found close to watermelon, soybean and safflower seeds. On the other hand, it was considerably lower than those reported for oilbean and pumpkin seeds. (See Tables 6 and 7) (Gupta & Das, 1997).

3.6. Bulk density (ρ_b), true density (ρ_t) and porosity (ε)

The bulk density of seeds was measured in the *Mc* range between 3.81 and a 14.95 % *d. b.* The seed value was less than that of the kernels at any given moisture level. This difference may be attributed to the hull or the seed coat which is bulkier than the kernel such that it causes

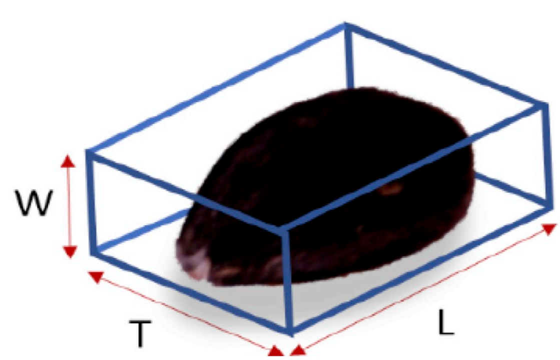

Fig. 2. Isometric model 3D of *Helianthus annuus* seed.

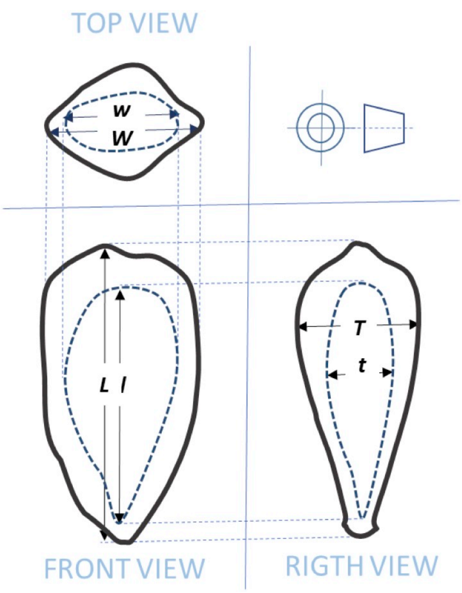

Fig. 3. Orthogonal views of dimensions of *Helianthus annuus* seed and kernel. L, l, length; W, w. width; T, t, thickness.

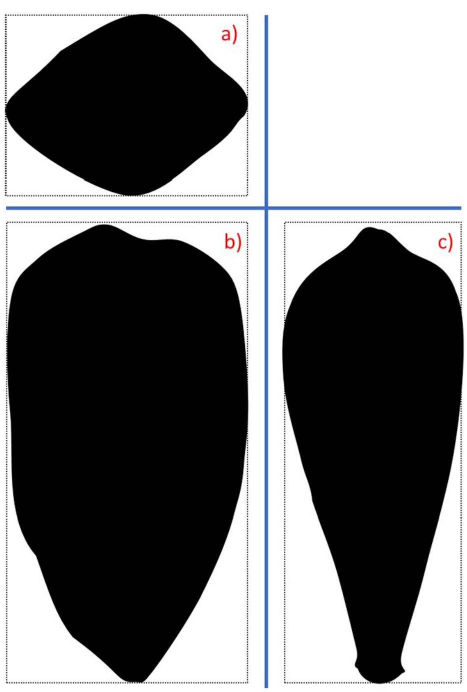

Fig. 4. Monochromatic views of dimensions of *Helianthus annuus* seed.

a considerable reduction in the total mass per volume unit occupied by the seed. The bulk density decreased with the increase in moisture content for the seed, whereas it increased with the moisture content for the core. Thus, it appears that the increase in volume was proportional to the rise in mass of the bulk seed. In Fig. 8, the correlations between the dehydration time and the bulk density of whole seed are as follows.

The true seed density was found to vary from 45.05 to 36.43 in seeds and from 102.11 to 84.74 in $\frac{g}{dm^3}$ when the *Mc* level decreases for about 14.96 to 3.81 % *d. b.*

The variations in true density with moisture content of seeds are represented in Table 8 as the seeds and kernels have a decreasing exponential dependence with moisture, similar to other grains such as corn, hard red winter wheat, pigeonpea, gram, soybean, pumpkin and safflower seeds. The true density of sunflower seeds was found to be less

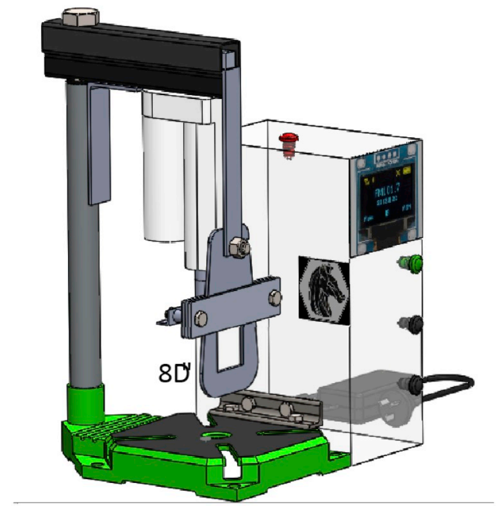

Fig. 5. KRN 3.0, a) Warner-Blatzer Blade.

Table 1
Mass of 100 pieces of sunflower seed, whole, kernel and hull.

Sample	Seed (g)	Kernel (g)	Hull (g)
Control	7.78 ± 0.13	5.02 ± 0.10	2.46 ± 0.12
0.5 h DEMI-LP	7.43 ± 0.07	4.82 ± 0.05	2.34 ± 0.03
1.0 h DEMI-LP	7.11 ± 0.14	4.64 ± 0.12	2.24 ± 0.08
1.5 h DEMI-LP	6.92 ± 0.06	4.54 ± 0.04	2.17 ± 0.02
4 h TSD	6.80 ± 0.07	4.47 ± 0.05	2.13 ± 0.03

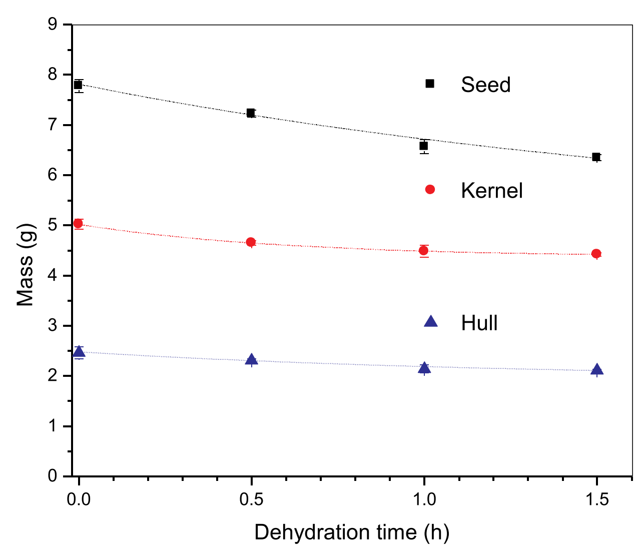

Fig. 6. Effect of time of dehydration DEMI-LP against mass in whole seed, kernel and hull, adjusted to decrescent exponential.

Table 2
Value of the variables in the negative exponential adjustment to the data of whole seed, kernel and shell.

Variable	Seed	Kernel	Hull
R2	0.994	0.993	0.999
y0	1.916 ± 0.057	4.196 ± 0.195	1.916 ± 0.057
A1	0.545 ± 0.056	0.824 ± 0.189	0.544 ± 0.056
t1	1.955 ± 0.296	1.675 ± 0.600	1.955 ± 0.296

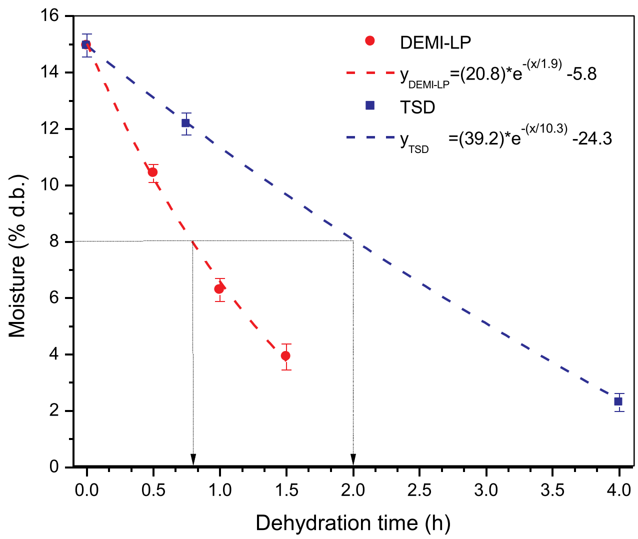

Fig. 7. Moisture percentage dry basis in function of dehydration time, a) DEMI-LP and b) TSD.

than that 0.4 times in all cases. It was also observed that the bulk density of hull $\left(284.5\,\frac{g}{dm^3}\right)$, measured at a moisture content of 14.96 % *d. b.*, was much lower than that of the seed and kernel, whereas the true density 102.11 and 45.05 $\left(\frac{g}{dm^3}\right)$ was substantially lower.

The porosity for sunflower seeds was evaluated using Eq. (3). The porosity increased from 34.3 to 43.3% in whole seeds and from 45.4 to 50.2% for seeds and kernels respectively when the moisture content changed from 14.95 to 3.92 % *d. b.* (Fig. 7). The relationships between the porosity and moisture content are given in Eq. (11). A comparison of the sunflower porosity before and after both methods of drying show 9% increment.

3.7. Surface morphology

The micrographs in Fig. 9 of *Helianthus annuus* whole seeds showed variations in the thickness of fiber layers: a) samples dehydrated by the Thermo-Solar system, b) Control (no dehydrated), c) 30 *min* in DEMI-LP, and d) 1 *h* in DEMI-LP up to down 50, 100 and 200 *μm*. In micrographs A) and B) in yellow circles, spheres about 2 − 6 *μm* that look like fungal spores (Aspergillus spp) were found in control samples and seeds treated with the TSD method.

Although in a much smaller quantity similar to Nyjer seeds (Gizachew, Hsu, Szonyi, & Ting, 2019), both samples dehydrated with the DEMI-LP method did not show the spores in c) and d), and the basal cells were more exposed than in pictures a) and b). Similar images of wild sunflower seeds were reported in 2007 by Perez, (Perez et al., 2007).

Table 4
Coefficients of exponential equations adjusted to experimental data of dehydration.

Variable	TSD	DEMI-LP
R^2	0.999	0.992
y_0	20.890 ± 1.000	20.830 ± 5.839
A_1	−5.904 ± 1.940	−5.805 ± 6.001
t_1	50.115 ± 0.784	1.927 ± 0.788

Table 5
Percentage of volumetric expansion (*Ψ*) in function of time and type of dehydration method.

Dimension		0.5 h DEMI-LP	1.0 h DEMI-LP	1.5 h DEMI-LP	4.0 h TSD
Seed	L	0.8	1.5	1.6	−0.4
	W	1.5	3.1	3.2	−0.1
	T	2.4	4.8	5.0	−0.5
Kernel	l	2.0	4.0	4.2	−0.3
	w	1.4	2.7	2.7	−0.4
	t	−0.5	2.0	1.9	−4.4

Table 6
Geometric parameters of sunflower seeds.

Sample	D_E (mm)	D_e (mm)	S (mm^2)	s (mm^2)	V (mm^3)	v (mm^3)	φ_S	φ_k
Control	6.91	4.54	150.01	64.75	172.66	49.16	0.53	0.47
0.5 h DEMI-LP	7.02	4.59	154.82	66.19	180.87	50.59	0.53	0.47
1.0 h DEMI-LP	7.13	4.68	159.71	68.81	189.43	53.57	0.54	0.47
1.5 h DEMI-LP	7.13	4.68	159.71	68.81	189.93	53.57	0.54	0.47
4.0 h TSD	6.88	4.47	148.71	62.77	170.87	46.63	0.53	0.46

Table 7
True density of sunflower seeds and kernel.

Sample	Seed	Kernel
	(g/dm^3)	(g/dm^3)
Control	45.05	102.11
0.5 h DEMI-LP	41.07	95.27
1.0 h DEMI-LP	37.53	86.61
1.5 h DEMI-LP	36.43	84.74
4.0 h TSD	39.79	95.86

3.8. Cut resistance (C_R)

The cut resistance values were obtained from the average of measuring the necessary strength to cut 100 randomly selected seeds and kernels three times from each lot of samples, and the results are shown in Fig. 10. The plotted data were adjusted with a decreasing exponential reaching a 96.75% in concordance. Figueiredo et al. reports similar results, but the characterization shows data of an ability to dehull sunflower seeds. (Figueiredo et al., 2011).

Table 3
Geometrical measurement of sunflower seeds and kernel.

Dimension		Control (*mm*)	0.5 h DEMI-LP (*mm*)	1.0 h DEMI-LP (*mm*)	1.5 h DEMI-LP (*mm*)	4.0 h TSD (*mm*)
Seed	L	13.07 ± 0.51	13.17 ± 0.50	13.28 ± 0.48	13.28 ± 0.88	13.02 ± 0.37
	W	6.24 ± 0.44	6.33 ± 0.36	6.43 ± 0.36	6.44 ± 0.60	6.23 ± 0.28
	T	4.05 ± 0.44	4.14 ± 0.36	4.24 ± 0.40	4.25 ± 0.81	4.03 ± 0.27
Kernel	l	9.66 ± 0.57	9.85 ± 0.44	10.05 ± 0.36	10.06 ± 1.03	9.63 ± 0.34
	w	4.27 ± 0.36	4.33 ± 0.27	4.39 ± 0.20	4.39 ± 0.85	4.25 ± 0.23
	t	2.28 ± 0.29	2.27 ± 0.33	2.32 ± 0.22	2.32 ± 0.52	2.18 ± 0.24

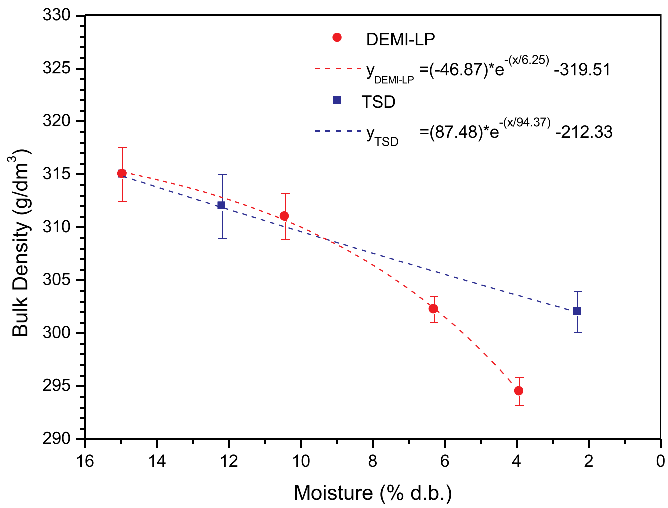

Fig. 8. Bulk Density of sunflower seeds at different Moisture in DEMI-LP and TSD, (Mass of $1 dm^3$).

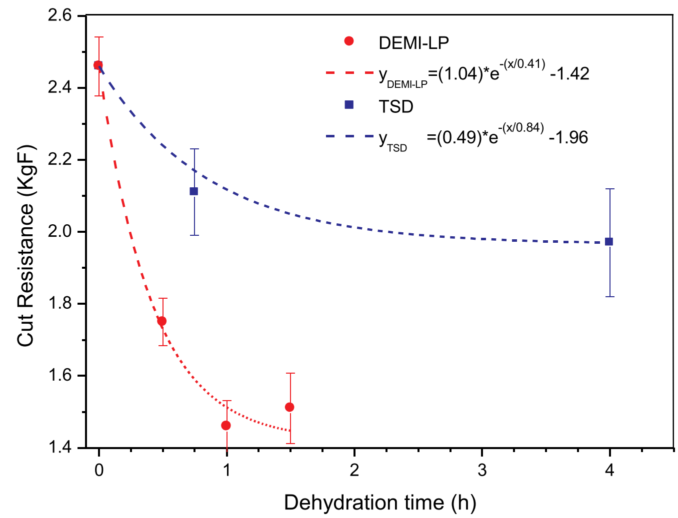

Fig. 10. Relationship between cut resistance ($\frac{1}{2}L$ by the Warner Bratzler Method) and time of dehydration DEMI-LP and TSD.

Table 8
True density (ρ_t) and pordosity (ε).

Sample	ρ_t (g/dm^3)	ε (%)
Control	45.05	84.16
0.5 h DEMI-LP	41.07	86.12
1.0 h DEMI-LP	37.53	87.59
1.5 h DEMI-LP	36.43	88.28
4.0 h TSD	39.80	87.49

4. Discussion and conclusions

The physical effect of the dehydration of sun flower seeds was determined to compare two different drying systems. Several physical and geometrical parameters like porosity, volume of individual seeds, equivalent diameter, and sphericity increased with the decrease of the moisture content in the seed, the most significant changes produced by the dehydration are described below.

The mass of kernel represents 65.19 ± 0.45% of the total mas of the sun flower seeds and the 31.46 ± 0.10% are hull, the average mass of 100 pieces are 7.20 ± 0.35 g, about geometrical relations kernel dimensions are 75.69% of (L), 68.23% of (W), 54.75% of (T). The average physical dimensions show a considerable increase in all directions, especially in the thickness (T) of whole seeds that was the volumetric expansion coefficient (Ψ) 5% with the DEMI-LP system and compared with a volumetric expansion coefficient of same magnitude (T), It was −0.5% in TSD.

Additionally, the obtained data in cut resistance probe, show that the average of strength to broke the seeds decreased considerably from 2.46 KgF of control sample to 1.46 KgF in DEMI-LP, 0.51 KgF less than the average of results of TSD 1.97 KgF, The cut resistance can be

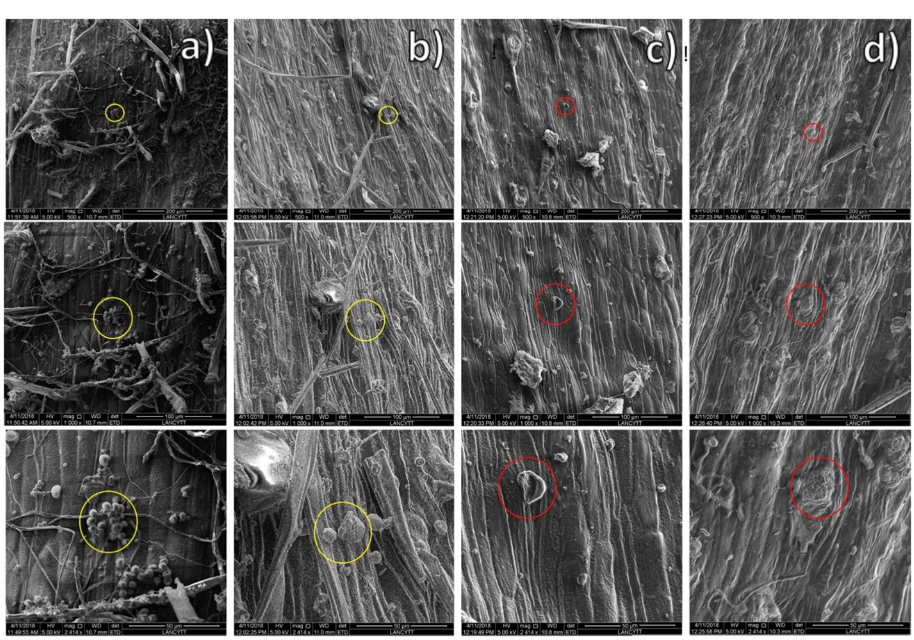

Fig. 9. Outer surface Scanning Electronic Micrographs of sunflower seeds. The scanning area corresponds from top to bottom, 580 × 500, 290 × 250 and 120 × 100 nm. The applied dehydration methodology was
a) Control, b) 4 h in TSD, c) 0.5 h and d) 1 h in DEMI-LP.

interpreted as the facility to dehull seeds.

An exponential decay dependence of moisture content with the percentage of true and bulk density were found in the function of length, width, and thickness of the sunflower seed. These parameters have affected the dimensions of the seeds during the dehydration process and were kept at the end of it.

The obtained micrographs of the samples showing how the fibers treated with the DEMI-LP process looked wider than the control seeds. Surface micrographs also showed spheres of about 2 − 6 μm in size, possibly related to fungal spores, whose presences can affect the quality and shelf life of the control samples and dried seeds by the conventional TSD process. Conversely, samples dried by our proposed method DEMI-LP did not show traces of fungal spores and other Bio-Chemicals effects of this kind of dehydration will be reported in future publications and more results that prove of is safe for human operation and products consumption because the frequency of the electromagnetic radiation used is under 100 kHz (Comisión Federal de Telecomunicaciones, 2012).

The results can be explained by the expansion of the seeds when the steam is going out of the fibers caused by a fast increment of temperature and a sudden reduction of internal pressure. Both of these conditions affected the grains at the time of dehydration. Moreover, the volumetric expansion by the DEMI-LP was kept until the pressure and temperature of the specimens reached the equilibrium with atmospheric pressure and room temperature. An increment in the thickness of the fibers was also corroborated, which is proportional to the time of dehydration.

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