Measuring picking force of sunflower seeds and prediction of reasonable range of air-jet parameters to remove sunflower seeds from the head

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Abstract: To design a new machine which removes the seeds of sunflowers based on air-jet impingement, picking force of five varieties of sunflower seeds was measured. Effects of the loading rate, sunflower head's diameter, the location of the seeds on the head and the number of the days after harvesting on picking force of seeds were studied. The tests were conducted one, two, three and four days after harvesting. Also theoretical air-jet impingement forces for four levels of nozzle diameter, four levels of jet temperature and eight levels of pressure of reservoir to which the jet were calculated. With the increase of the sunflower heads' diameter and the loading rate from 50 to 150 g/min, the values of the picking force increased. With the increase of the distance between the location of the seeds and the center of the head, the values of the picking force decreased. Comparison between the experimental results and the theoretical calculations indicated that removing the sunflower seeds using nozzles with 2 mm is not possible. Also when the supply pressure is less than 5 bar, nozzles with a 4 mm diameter cannot be used to remove the sunflower seeds from the heads. The results indicate that using a nozzle with a diameter of 6 to 8 mm and pressure of 6 to 8 bar seems to be suitable for separating the seeds from SH, though more studies are required.

Keywords: sunflower thresher, seed picking force, impingement jet method, jet force, agricultural engineering, Helianthus Annuus L

Citation: Mirzabe, A. H., and G. R. Chegini. 2015. Measuring picking force of sunflower seeds and prediction of reasonable range of air-jet parameters to remove sunflower seeds from the head. AgricEngInt: CIGR Journal, 17(3): 415-429.

1 Introduction

Sunflower (*Helianthus annuus* L.), (Schaffner, 1898)is one of the most important oil crops due to its high amount of unsaturated fatty acids and also absence of cholesterol (Razi and Assad, 1998; Darvishzadeh et al., 2010).Along with soybean, canola, and cotton, sunflower contributes considerably to the edible vegetable oil market. Sunflower oil has a light color, a bland flavor, a high smoke point, and contains a relatively high concentration of the polyunsaturated fatty acid, linoleic acid. This fact makes sunflower oil a premium cooking oil and one of the major vegetable oils used in the food manufacturing industry (Chandrasekaran and Shine, 2012).

Iran relies heavily on imports of edible oil to offset the low production levels of oil crops as they cannot meet the growing demands of oil factories. In Iran, sunflower is usually cultivated in small farmers. The area under sunflower production in Iran has been on increase; but in Iran and many developing countries there are many problems for sunflower planting such as: pest's damage, diseases damage, poor soil fertility, water stress (Nderituet al., 2008) and non-availability of suitable machinery for sunflower's sowing, harvest, post-harvest and oil extraction operations.

Due to non-availability of suitable machinery for sunflower's harvest and post-harvest operations in some

Received date: 2015-06-15 **Accepted date:** 2015-08-09

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regions of the world, farmers are following the manual and traditional methods (Mirzabe et al., 2012).Traditionally, the farmers rub the sunflower heads (SHs) over a brick, a stone, a piece of metal, wood or rubber or rub the sunflower heads on each other for its threshing. The efficiency of the traditional manual threshing is very low and depends upon the efficiency and experience of the workers.

Farmers in some areas thresh sunflower using rice (*Oryza sativa* L.), or soybean (*Glycine max* L.) thresher or a corn (*Zea mays* L.) sheller, due to non-availability of sunflower thresher machines. Sudajan et al. (2002) and Mirzabe et al. (2012) cited that these types of threshers are not efficient for threshing sunflower.

In some areas of the world (in many developing countries), due to low level of agricultural mechanization and traditional farming, low level of farmer's income, complexity of thresher mechanisms, many settings of thresher machine and also damage to seeds during operation with stationary thresher and combined harvester machines, farmers are not interested in the use of stationary thresher machines.

However, decreasing the power consumption, the complexity of sunflower thresher machines and reducing the number of the damaged seeds, as well as increasing its efficiency, are the main problems in many developing countries; so, in such countries, these machines should be redesigned or optimized or new methods should be used to remove the sunflower seeds from their heads.

Today, air-jet impingement and water-jet impingement have many applications in industry, food science and agriculture. Jet impingement is one of the efficient methods to remove the arils of pomegranate fruits and extract the citrus juice and juice sacs (Khazaei et al., 2008; Schmilovitch et al., 2011).This method can be used to extract sunflower seeds from their head.

No published literature could be seen on the effects of the air-jet impingement parameters on removing the sunflower seeds from the heads; but to design a new sunflower machine removing the sunflower seeds from the sunflower head (SH) based on jet impingement, physical and mechanical properties of the sunflower seeds and heads and air-jet impingement parameters must be known.

Little published literature is available on picking and cutting force of other seeds, grains or fruits of agricultural crops and published research on picking force of sunflower seeds (PFSS) from their heads could not be seen. If the PFSS is known, the range of the needed theoretical force of the jet to remove seeds from the head can be estimated.

The efficiency of the air-jet impingement, impingement force and the quality of removed materials are greatly influenced by air pressure, nozzle diameter, the number of passes, and the route of the nozzle over the surface (Khazaei et al., 2005, 2008). In addition to the mentioned parameters, temperature of the jet, distance between nozzle outlet and impingement surface, angle between jet and impingement surface and coarseness of the impingement surface can be of influence on the removing efficiency (Oka et al., 2007; Ozcelik et al., 2011).

The aim of the present research is to determine the PFSS from the SH and predict the required force for removing the sunflower seeds from the SH based using air-jet impingement; therefore, the effect of the loading rate, the size of SH, the location of the seed on the SH, and the effect of the number of the days after harvesting on PFSS were studied. Also, to design new sunflower machine removing the seeds from the SH based on air-jet impingement, the theoretical air-jet impingement force (AIF) was calculated. The effects of the nozzle diameter, jet temperature and jet pressure on AIF in the outlet of the nozzle were studied and the experimental measured picking forces and theoretical AIF were compared.

3 Material and methods

3.1 Theoretical considerations

In the air-jet method of removing the sunflower seeds, the seeds are subject to the external forces caused by the high-speed air-jet. The air-jet transfers momentum to the sunflower head and the sunflower seeds and generates a force on the head surface. Calculation of the momentum, and hence the force available from a given jet, requires knowledge of the initial velocity and the mass flow rate of the jet.

In the simplest case of a jet discharging fluid with a uniform initial velocity field U_0 into a medium moving at constant velocity U_0, the boundary layer thickness in the initial section of the jet is zero (see Figure 1). The boundary layer thickens away from the nozzle outlet as particles of the surrounding medium become entrained and are carried along with corresponding particles of the jet which are slowed down; whereas with increasing in the cross-section of the jet, it also gradually consumes the non-viscous core. This short region of the jet, in which the center line velocity remains constant, is called the initial region (Reed and Miles, 2004). The plane representing the limit of constant axial velocity is called the transitional cross-section. Beyond this point in the main region of the jet, the center line velocity of the jet U_m progressively reduces as the diameter of the jet continues to expand. In the main region of the jet, the pressure is almost constant and equals to the pressure in the environment space (Khazaeiet al., 2008).

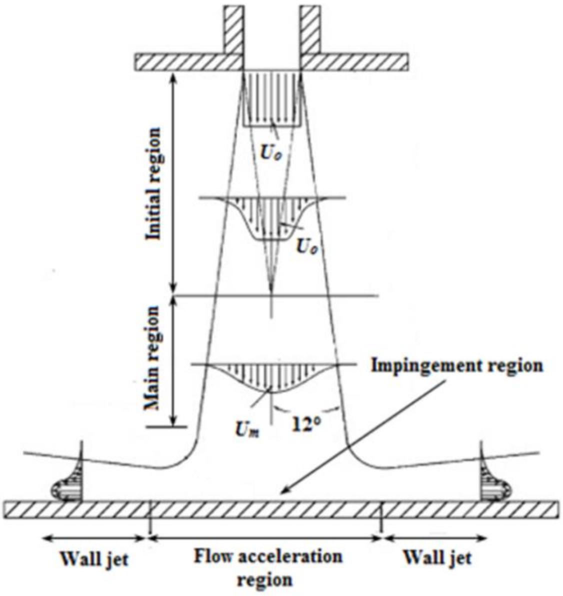

Figure 1 Formation of a gas jet on flat surface. U_m is center line velocity of the air-jet and U_0 is initial velocity of the air-jet

In critical flows, value of maximum AIF in outlet of nozzle is expanded, as shown in Equation 1 (Munoz, 2011; Sutton and Biblarz, 2011):

$$F = \dot{m}V_{cr} + (P - P_0)A \quad (1)$$

where: A is area of nozzle outlet; P is pressure at the nozzle outlet; P_0 is pressure of the atmosphere; V_{cr} is nozzle exit velocity and $\dot{m}$ is mass flow rate in nozzle outlet. In order to calculate the jet force, the value of m and the critical speed of sound must be known. For critical flows, the critical m for a perfect gas with constant specific heat was calculated using Equation 2 (Khazaei et al., 2008; Smith, 2010):

$$\dot{m} = \rho_s V_l \ A\left(\frac{2}{k+1}\right)^{\frac{k+1}{2(k-1)}} \quad (2)$$

where: ρ_s is supply air density; A is area of nozzle outlet; k is specific heat transfer and V_l is local speed of sound. Critical speed of the sound in general stats can be determined using Equation 3 and when the Mach number (Mach number is a dimension less quantity representing the ratio of speed of an object moving through a fluid and the local speed of sound. Where is the ratio of speed of air-jet impingement speed and the local speed of sound) equals to one, critical speed of the sound can be calculated using Equation 4 (Khazaei et al., 2008):

$$V_{cr} = V_l\left(\frac{1+k}{2}M_a\right)^{-\frac{1}{2}} \quad (3)$$

$$V_{cr} = V_l\left(\frac{1+k}{2}\right)^{-\frac{1}{2}} \quad (4)$$

In order to calculate m, the value of V_l and ρ_s must be known. Local speed of sound can be calculated using Equation 5 (Huber, 2007):

$$V_l = \sqrt{\frac{kRT_s}{M}} \quad (5)$$

where: T_s is relative temperature of the fluid; R is real gas constant; k is specific heat transfer and M is molar mass of the air. The density of moist air is evaluated using Equation 6 of state (Picard et al., 2008):

$$\rho_s = \frac{PM_a}{ZRT}\left[1 - x_v\left(1 - \frac{M_v}{M_a}\right)\right] \quad (6)$$

where: P is pressure; T is air temperature (thermodynamic temperature); x_v, mole fraction of water vapor, M_a is molar mass of dry air; M_v is molar mass of water; R is real gas constant and Z is the compressibility factor. If moisture of the air were ignored, Equation 5 will be modified as following Equation 7:

$$\rho_s = \frac{PM_a}{ZRT} \quad (7)$$

Molar mass of the dry air was calculated by Picard et al. (2008).Composition of dry air taken as reference for the air density evaluation is shown in Table 1 (Picard et al., 2008).It was necessary to calculate the amount of AIF in different temperatures with high accuracy in order to calculate the difference among different forces produced in different temperatures accurately. As mentioned before, in order to calculate the jet force, air's density should be computed and for computing density, molar mass has to be calculated. In literature, different amounts for the percentage of elements of dry air and also the molar mass have been mentioned. Table 1 shows these amounts retrieved from Picard et al. (2008).

Table 1 Composition and of dry air taken as reference for the air density evaluation (Picard et al., 2008)

Constituent	Molar mass of Constituent , M_i, 10^{-3} kg/mol)	Mole fraction (X_i)	Contribution , $M_i.X_i$, 10^{-3} kg/mol)
N_2	28.0134	0.780848	21.874207
O_2	31.9988	0.209390	6.700229
Ar	39.948	0.009332	0.372795
CO_2	44.01	0.000 40	0.017604
Ne	20.18	$18.2 \cdot 10^{-6}$	0.000367
He	4.0	$5.2 \cdot 10^{-6}$	0.000021
CH_2	16.0	$1.5 \cdot 10^{-6}$	0.000024
Kr	83.8	$1.1 \cdot 10^{-6}$	0.000092
H_2	2	$0.5 \cdot 10^{-6}$	0.000001
N_2O	44	$0.3 \cdot 10^{-6}$	0.000013
CO	28	$0.2 \cdot 10^{-6}$	0.000006
Xe	131	$0.1 \cdot 10^{-6}$	0.000013
$Molar\ mass\ of\ the\ dry\ air\ (M_a) = \sum(M_iX_i) = 28.96546 \cdot 10^{-3}$ kg/mol			

In order to calculate the levels of air density of reservoir to which the jet, value of the compressibility factor of the dry air must be known. Mendes and Pavlis (2004) mentioned that compressibility factor of the dry air in different pressures and different temperatures can be calculated using Equation 8:

$$Z = 1 - \frac{P}{T}\left[a_0 + a_1 t + a_2 t\right] \quad (8)$$

where: P is air pressure; T is air temperature in K; t is temperature in ^{o}C. Also a_0, a_1 and a_2 are constant factors: $a_0 = 1.58123 \times 10^{-6}\ \frac{K}{Pa}$, $a_1 = -2.93310 \times 10^{-8}\ \frac{1}{Pa}$, $a_2 = 1.10430 \times 10^{-10}\ \frac{1}{K.Pa}$

3.2 Sampling preparation

Five varieties of sunflowers, widely cultivated in Iran namely ˈMikhiˈ, ˈSonghoriˈ, ˈDorsefidˈ, ˈShamshiriˈ, and ˈSirenaˈ, were used in the present work. ˈMikhiˈ, ˈSonghoriˈ,ˈDorsefidˈ and ˈShamshiriˈ varieties are native of Iran.

ˈMikhiˈ, ˈSonghoriˈ and ˈSirenaˈ varieties were planted on June 17th, 2011 in local farms of Foodan located on Shahreza, Isfahan province, Iran. The sunflower heads were harvested manually (for harvesting, the SHs were grabbed by one hand and the other hand cut the head using a sickle) in late October 2011, after SHs were matured completely.

ˈDorsefidˈ, ˈShamshiriˈ, and ˈSirenaˈ varieties were planted on April 27th, 2012 in the research farms of the University of Tehran, located on Pakdasht, Tehran province, Iran (although ˈSirenaˈ was once planted in June 17th, 2011 in local farms of Foodan located on Shahreza, Isfahan province, Iran, it was cultivated again). The SHs were harvested manually in late September 2012, when SHs were completely matured.

The obtained results showed that the greatest amount of PFSS needed in previous plantations (in Food an and research farms of the University of Tehran) belonged to ˈSirenaˈ variety; so, in order to have more accurate results, this variety was cultivated again on June 23th, 2012 in local farms of Food an plain and the sunflowers were harvested manually in late October 2012.

From each variety, 100 sunflower heads with different sizes were selected randomly. In order to study the effect of the sunflower head size on PFSS, the head diameter of each sunflower was measured. SHs were divided into three different categories, based on their diameters. If the value of SH diameter ranged from 6 to 16 cm, it was named small SH; if the value of SH diameter ranged from 16 to 26 cm, it was named medium SH; if the value of SH diameter ranged from 26 to 36 cm, it was named big SH. Importantly, if the diameter equaled 16, it was considered small, whereas, a diameter of 26 was considered medium. For each variety 10 sunflower heads with diameters of 10 to 12, 20 to 22 and 30 to 32 cm were selected.

In order to conduct the experiments, the SHs were transferred to the laboratory. The transfer time for each SH was less than 15 min, 6 to 8 min on average. In order to study the effect of sunflower seeds location on PFSS, the selected SHs were divided to three regions, namely central region (CR), middle region (MR) and side region (SR), as shown in Figure 2. In order to study the effect of the number of the days after harvest on PFSS, sunflower heads were left outside to decrease moisture content; tests were done one, two, three and four days after harvesting.

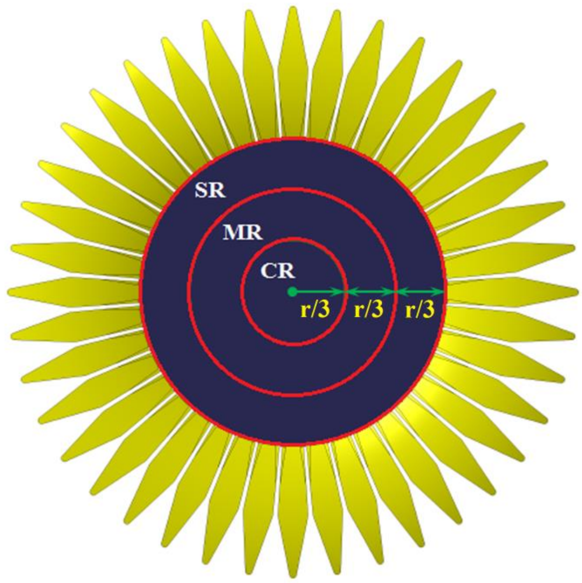

Figure 2 Three regions of sunflower head: 1) entral region (CR); 2) middle region (MR); 3) side region (SR). r= head radius

3.3 Experimental setup

As shown in Figure 3, a schematic diagram of the experimental set up was used to measure the PFSS. The apparatus made to measure the PFSS works as follows:

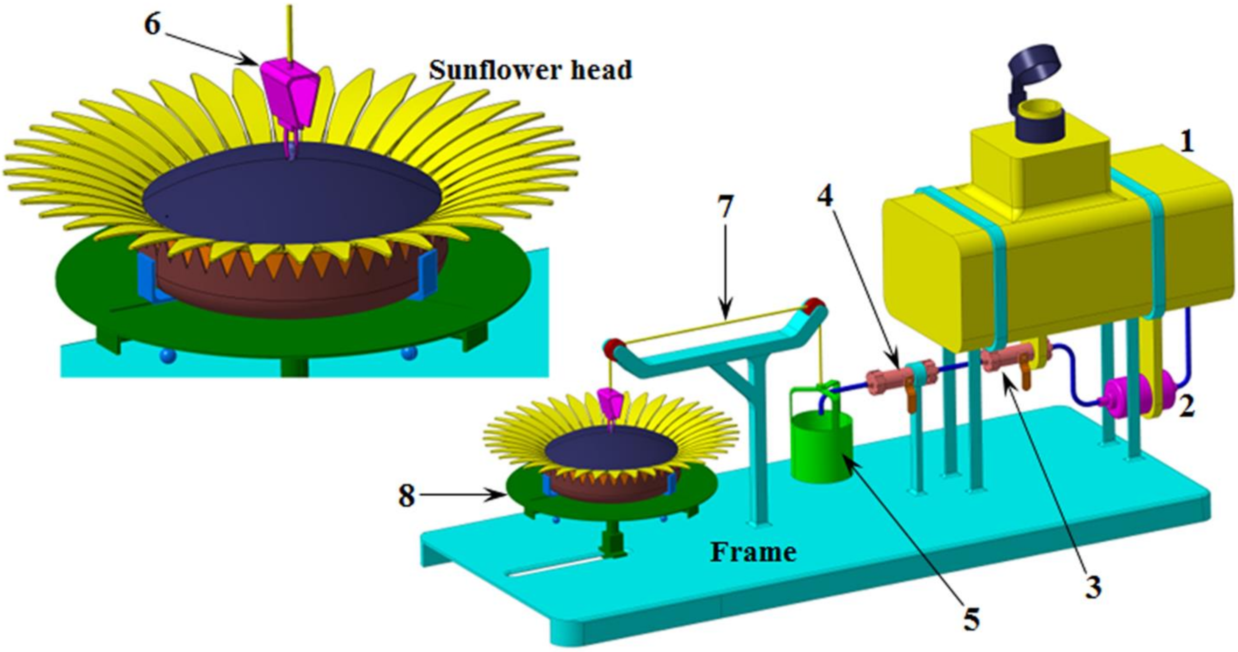

Figure 3 Experimental set up used to measure the picking force of sunflower seeds (PFSS). 1: reservoir, 2: water pump, 3: flow control valve, 4: off-on valve, 5: plastic beaker, 6: clamp, 7: string, 8: holder disc

The water is sucked out of the reservoir (1) using a water pump (2). The water pump was driven by an armature working with 3.5 v DC power. The water is pumped to the flow control valve (3). By regulating the flow rate of the flow control valve, the loading rate is regulated and water enters the off-on valve (4). Water comes out of off-on valve and enters a plastic beaker (5), which is connected to a clamp (6) with a string (7). The clamp holds the sunflower seed. The plastic beaker and the clamp were made so that their mass is equal. Holder disc (8) holds the sunflower head. In order to study the effect of seed position on picking force, a groove was made on the machine’s frame as a guide in which the disc could move. The water enters the beaker until the seed is picked. As soon as the seed is picked, the off-on valve stops the water flow. In order to measure PFSS, mass of the water in beaker was measured. Value of PFSS was equal to value of mass of water in the beaker. Mass of the water was measured using digital balance with an accuracy of 0.01 g (KERN, Japan, PLS 360-3). PFSS from the SHs was determined with 10 repetitions.

4 Results and discussions

4.1 Experimental results

The results of PFSS of ˈMikhiˈ variety are shown in Figure 4. Average values of moisture content for one, two, three and four days after harvesting was found to be 33.4, 28.5, 25.3 and 23.5% wet basis (w.b.), respectively. The results indicated that in all cases, with increasing the number of days after harvesting from one day to four days, values of PFSS decreased. The results showed that the values of PFSS on central region of medium SHs were greater than the values of PFSS on central region of small SHs. The values of PFSS on middle region of medium SHs were less than the values of PFSS on middle region of small SHs; but the difference between the values of PFSS of medium and small SHs were very small. Values of PFSS of medium SHs on central region were greater than the big and small SHs. The difference between values of PFSS on big SHs and medium SHs was greater than the difference between medium and small SHs. The results indicated that difference between values of PFSS on central and middle region was less than the difference between middle and side region. According to Figure 4, when the loading rate equals 150 g/min, values of PFSS were greater than when the loading rate equals 50 g/min.

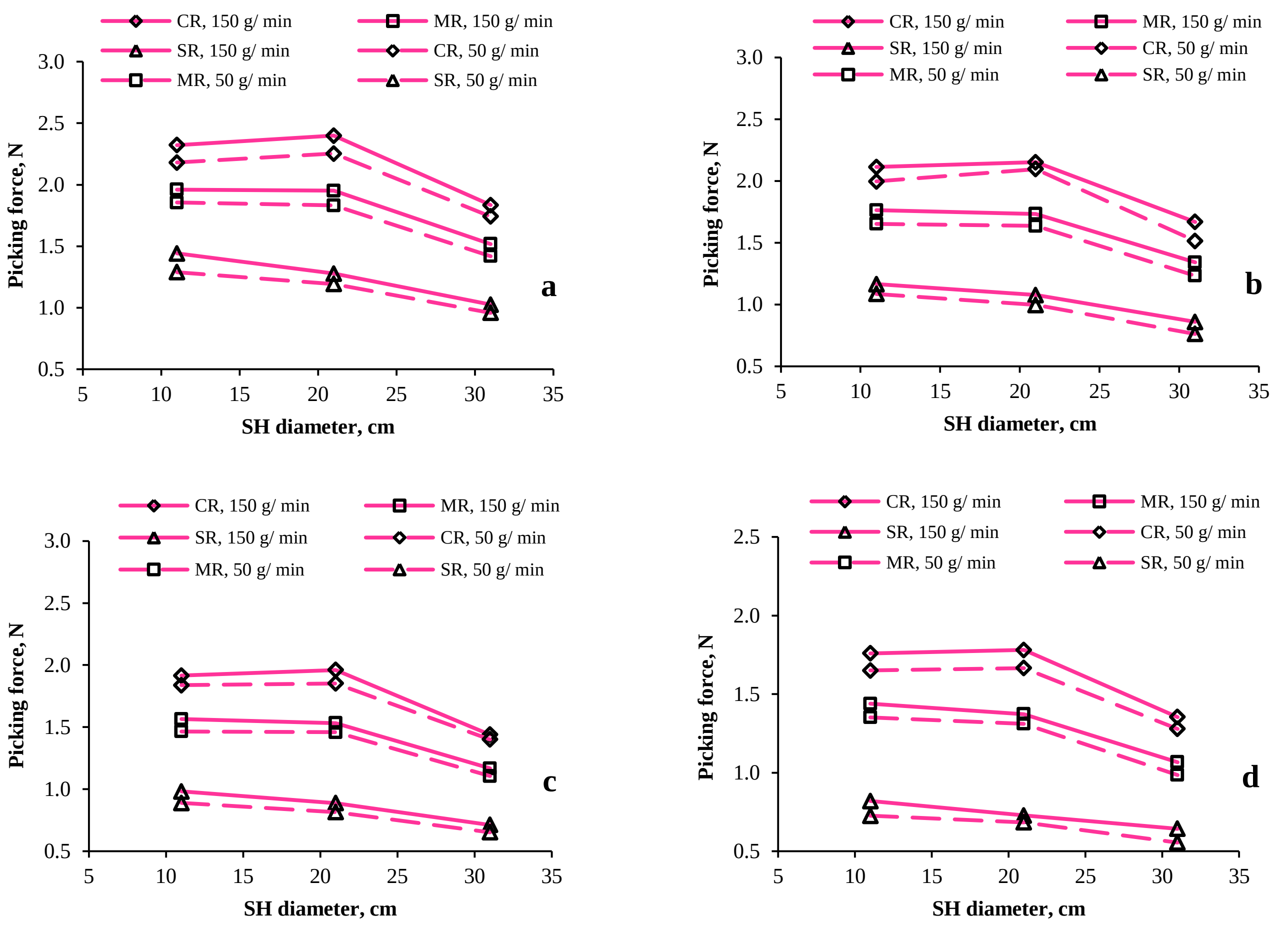

Figure 4 Effect of loading rate, seeds location, sunflower head diameter and number of days after harvesting on picking force of sunflower seeds of 'Mikhi' variety. CR: central region, MR: middle region, SR: side region. a, b, c and d are first, second, third and fourth day, respectively

For 'Songhori' variety, the average values of moisture content for one, two, three and four days after harvesting were found to be 31, 27.7, 24.6 and 22.1% (w.b.), respectively. According to Figure 5, with the increase of the number of days after harvesting from one to four, with the increase of SH diameter and with the increase of the loading rate, values of PFSS decreased. The difference between the values of PFSS on small SHs and medium SHs was less than the difference between medium and big SHs. Results indicated that the difference between the values of PFSS on central region and middle region was less than the difference between the middle and the side region for two and four days after harvesting; for one day and three days after harvesting, the difference between the values of PFSS on central region and middle region were greater than the difference between middle and side region.

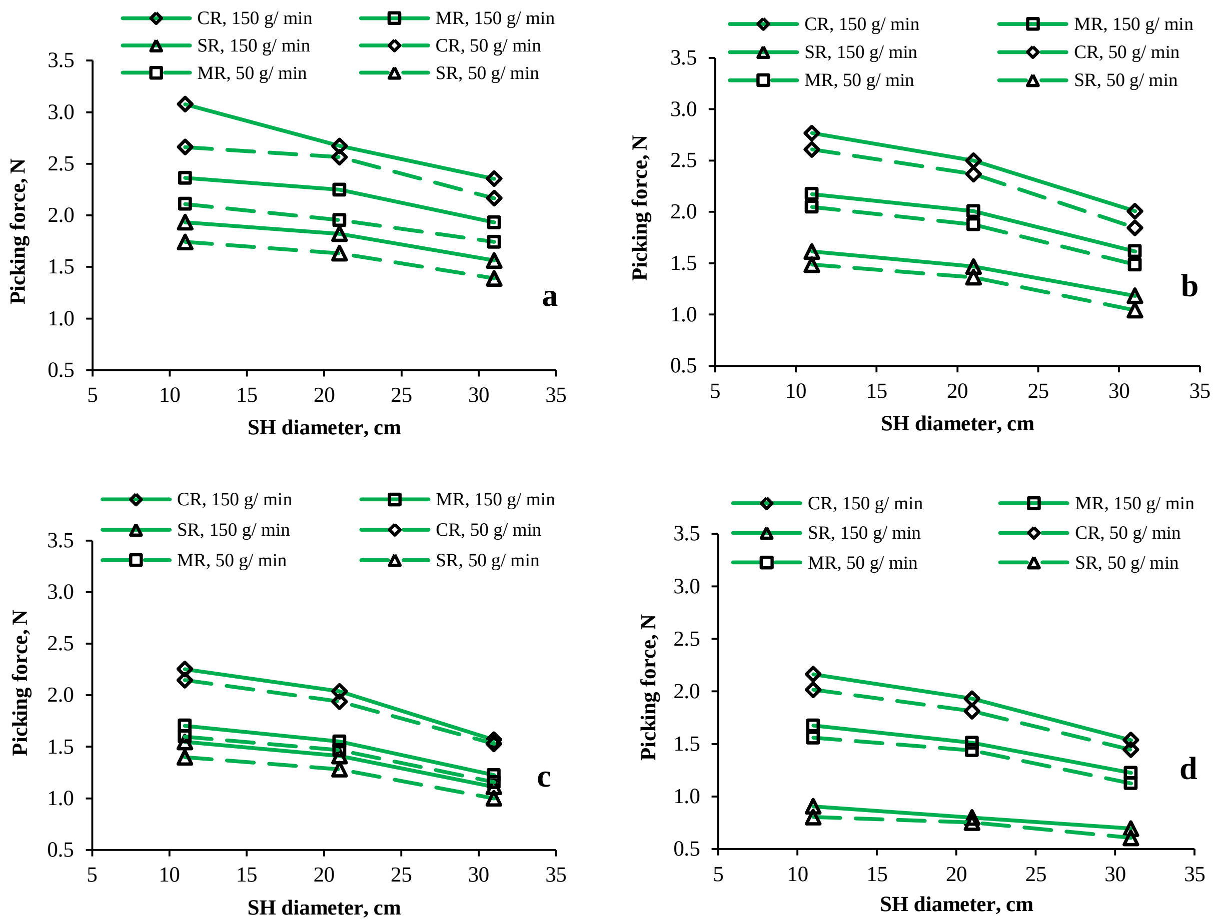

Figure 5 Effect of loading rate, seeds location, sunflower head diameter and number of days after harvesting on picking force of sunflower seeds of 'Songhori' variety. CR: central region, MR: middle region, SR: side region. a, b, c and d are first, second, third and fourth day, respectively

Results of PFSS of 'Dorsefid' variety are shown in Figure 6. Average values of moisture content for one, two, three and four days after harvesting was found to be 32.3, 27.5, 24.2 and 21.9 % (w.b.), respectively. The results indicated that in all cases, with the increase of the number of the days after harvesting from one to four, with the increase of SH diameter and with the increase of the loading rate, values of PFSS decreased. The difference between values of PFSS on big SHs and medium SHs was greater than the difference between medium and small SHs. The results indicated that the difference between values of PFSS on central region and middle region prove to be less than the difference between the middle and the side region. Also the difference between values of the PFSS of big and medium SHs and difference between values of the PFSS of medium and small SHs on side region were less than the difference between the values of the PFSS on central and middle regions.

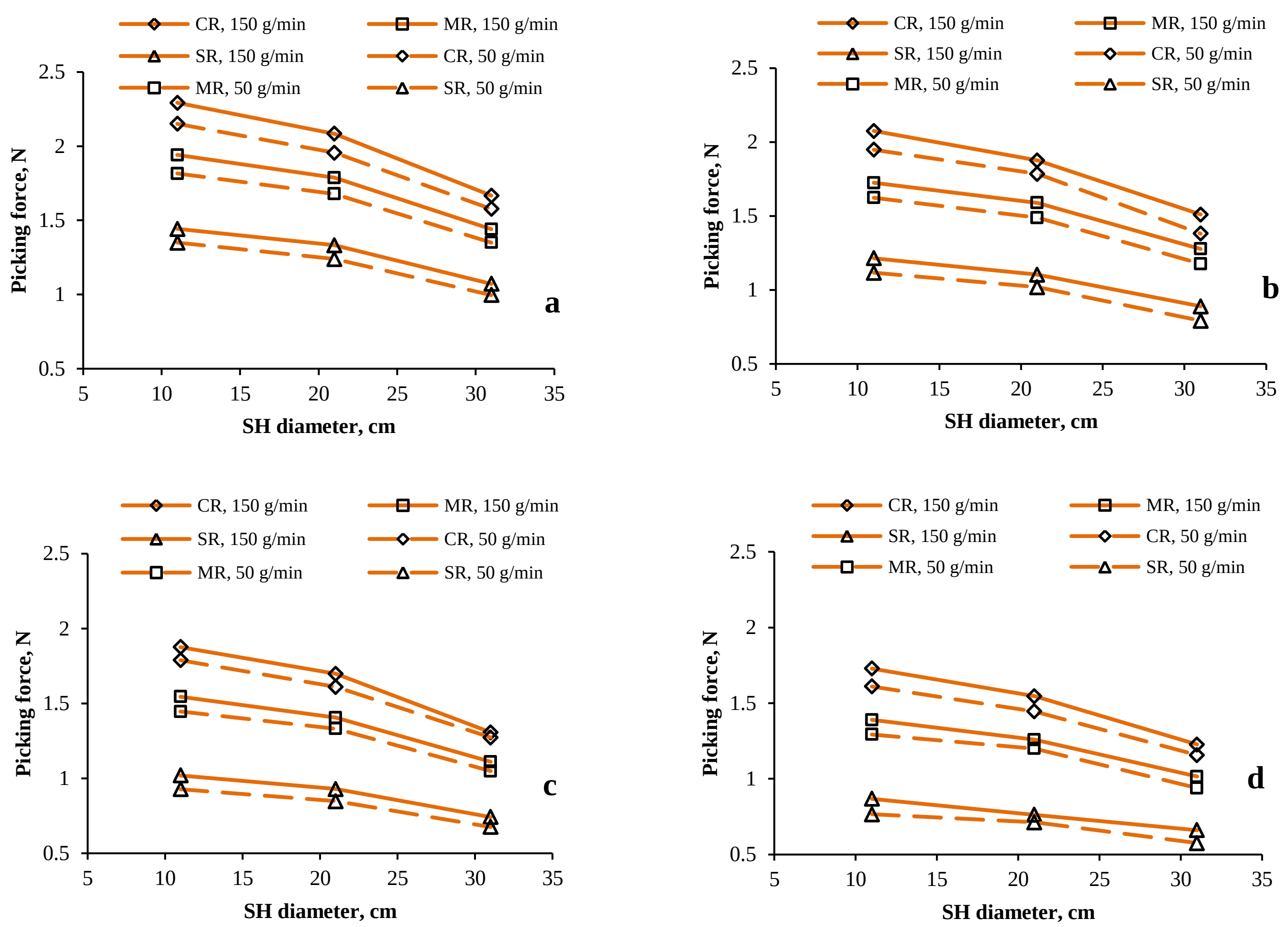

Figure 6 Effect of loading rate, seeds location, sunflower head diameter and number of days after harvesting on picking force of sunflower seeds of 'Dorsefid' variety. CR: central region, MR: middle region, SR: side region. a, b, c and d are first, second, third and fourth day, respectively

Average values of moisture content of 'Shamshiri' variety for one, two, three and four days after harvesting was found to be 33.2, 28.7, 25.9 and 23.4 % (w.b), respectively. The results showed that with the increase of the number of the days after harvesting from one to four, with the increase of SH diameter and with the increase of the loading rate values of PFSS decreased (see Figure 7). The differences between values of PFSS of small and medium SHs were small and less than the differences between medium and big SHs. Results indicated that the differences between the values of PFSS on middle and side regions were greater than the differences between central and middle regions. Also the difference between values of the PFSS of big and medium SHs and differences between the values of the PFSS of medium and small SHs on side region for two, three and four days after harvesting were less than the differences between the values of the PFSS on central and middle regions.

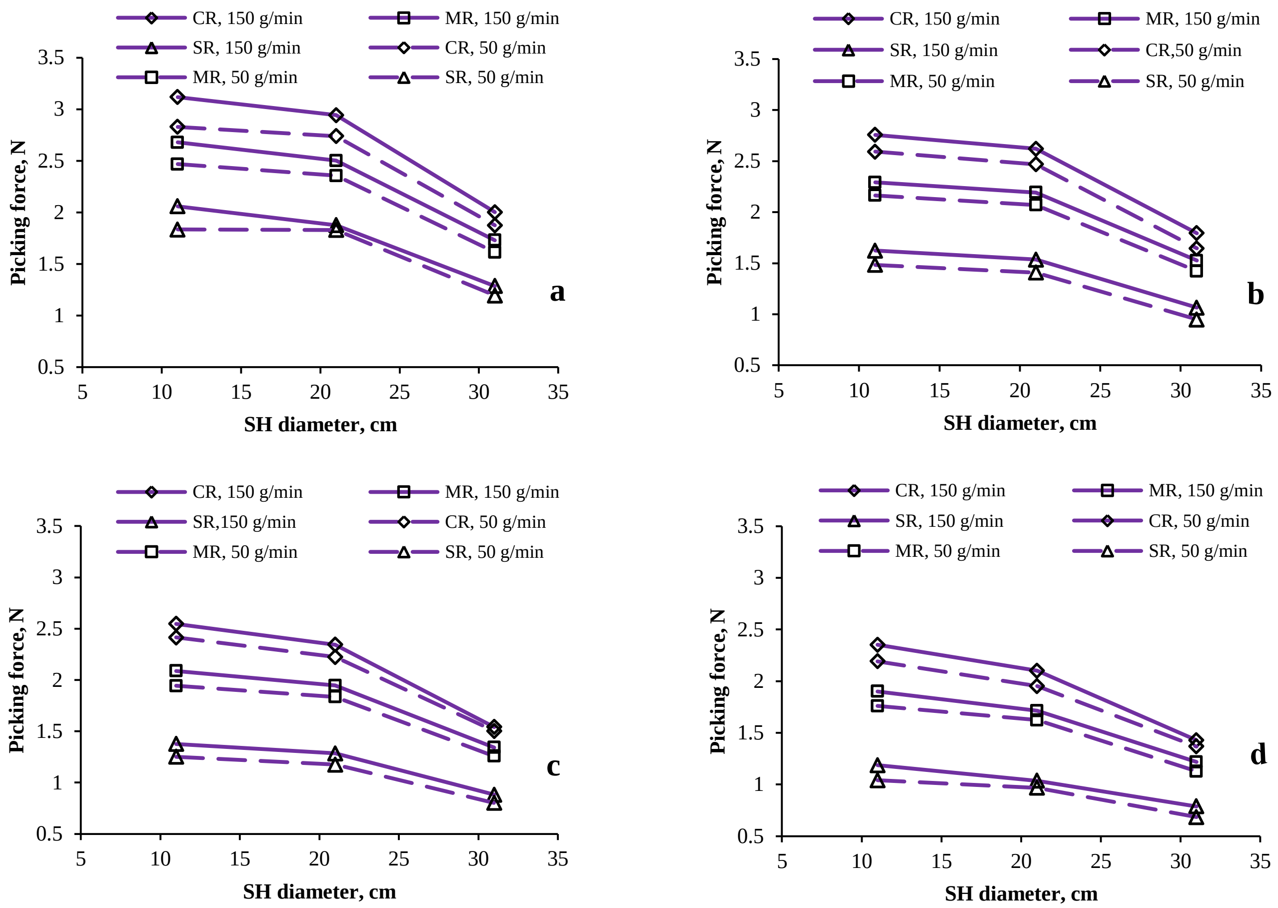

Figure 7 Effect of loading rate, seeds location, sunflower head diameter and number of days after harvesting on picking force of sunflower seeds of 'Shamshiri' variety. CR: central region, MR: middle region, SR: side region. a, b, c and d are first, second, third and fourth day, respectively

As mentioned before, 'Sirena' variety was cultivated in three periods of time. Comparison of PFSS values of 'Sirena', 'Mikhi' and 'Songhori' showed that Sirena's PFSS values was greater than 'Mikhi' and 'Songhori' in all conditions, so 'Sirena' was cultivated again, along with 'Shamshiri' and 'Dorsefid' varieties. Comparison of PFSS values of 'Sirena', 'Shamshiri' and 'Dorsefid' varieties showed that Sirena's PFSS values are greater than 'Shamshiri' and 'Dorsefid' varieties, too. In order to the focus on the 'Sirena' variety's results, 'Sirena' was cultivated again. Comparison of the results indicated that the PFSS values of 'Sirena' variety cultivated in April 27th, 2012 in the research farms of the University of Tehran is greater than the other two cultivations. Designation of the machine had to be based on critical conditions; therefore, only the results of cultivation of 'Sirena' April 27th, 2012 were reported.

The results of PFSS of 'Sirena' variety are shown in Figure 8. Average values of moisture content for one, two, three and four days after harvesting was found to be 35.2, 29.7, 26.6 and 23.9 % (w.b), respectively. The results showed that in all cases with the increase of the number of the days after harvesting from one day to four days, the values of PFSS decreased. The results also showed that with the increase of SH diameter, value of PFSS decreased. The differences between values of PFSS on small SHs and medium SHs were less than the differences between medium and big SHs. The results indicated that the difference between the values of PFSS on central region and middle regions was less than the difference between the middle and side regions. According to Figure 8, when the loading rate equals 150 g/min, values of the PFSS were greater than when the loading rate equals 50 g/min.

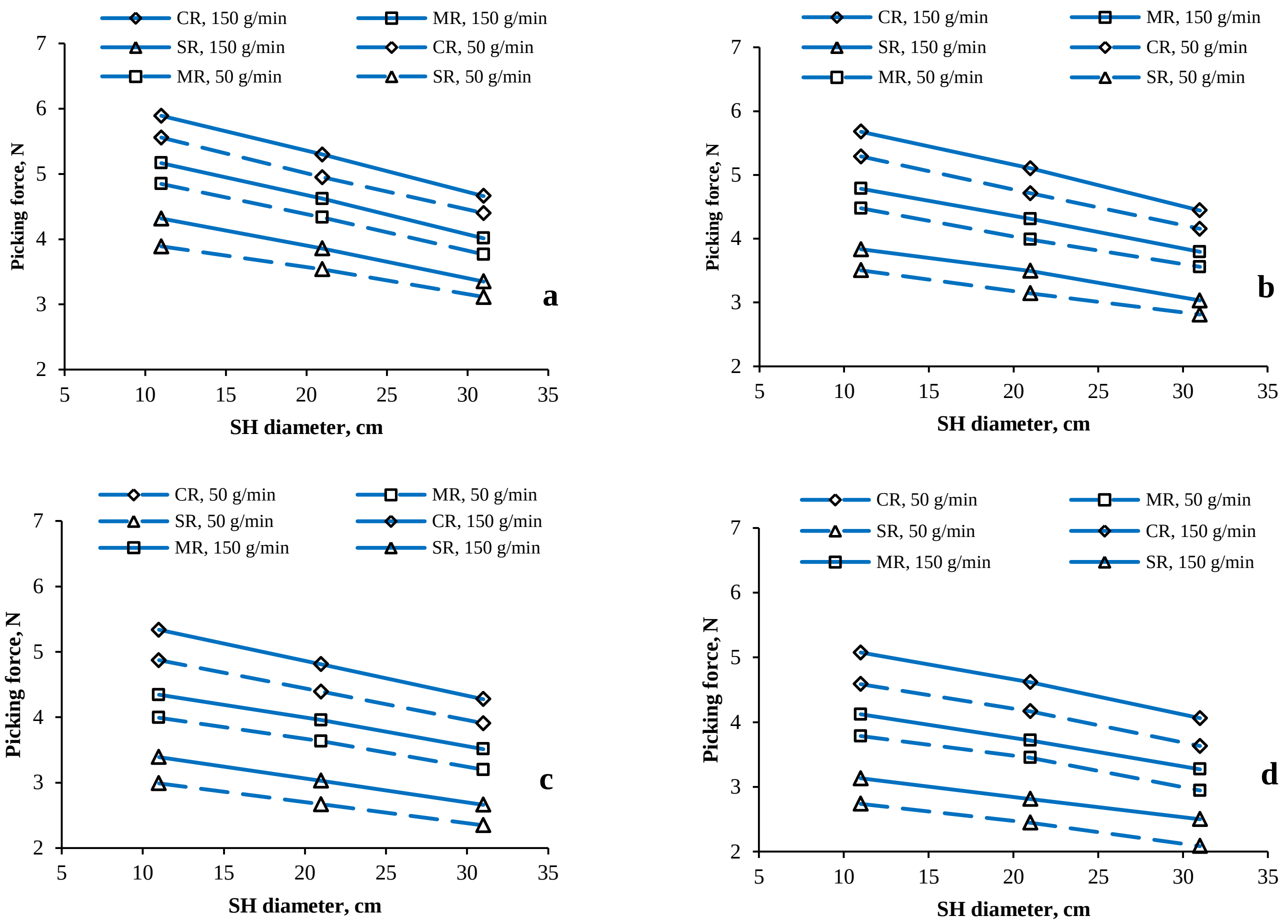

Figure 8 Effect of loading rate, seeds location, sunflower head diameter and number of days after harvesting on picking force of sunflower seeds of 'Sirena' variety. CR: central region, MR: middle region, SR: side region. a, b, c and d are first, second, third and fourth day, respectively

4.2 Theoretical results

Theoretical AIF for eight levels of reservoir pressure, four levels of jet temperature and four levels of nozzle diameter were calculated. Increasing AIF with increasing reservoir pressure for four levels of nozzle diameter (N_d), when the temperature equals 20 ℃, is shown in Figure 9.

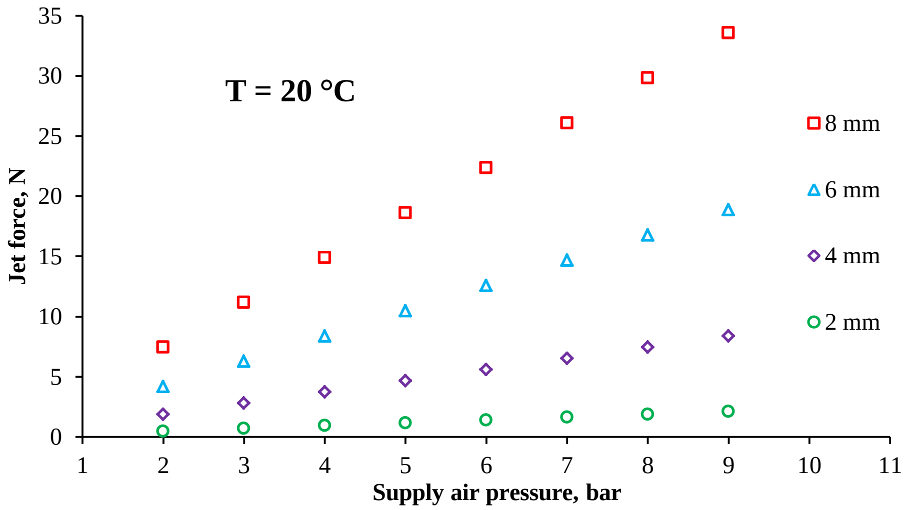

Figure 9 Increasing air-jet impingement force with increasing reservoir pressure at 20 ℃ of temperature

The obtained results based on calculations indicated that in all cases with increasing reservoir pressure and nozzle diameter, AIF increased; but when the jet temperature increased from 10 to 30 ℃, AIF decreased. Based on Table 2, although increase in the jet's temperature causes the decrease in AIF, this reduction is not considerable. Sunflower remover machine must have the ability to separate the seeds in different conditions. One of the factors which differ in different conditions is temperature. To show that the differences of temperature does not have a considerable influence on the force produced by jet, the difference between forces produced by air jet between 10 ℃ and 30 ℃ in different pressures and for nozzles with different diameters have been calculated.

Table 2 Difference between air-jet impingement force (in N) at two different temperatures, 10 ℃ and 30 ℃, calculated for four different levels of nozzle diameter (Nd) and 8 different levels of reservoir pressure

Reservoir pressure, bar	Difference jet force, N			
	Nd= **2 mm**	Nd= **4 mm**	Nd= **6 mm**	Nd= **8 mm**
2	0.00020	0.00082	0.00184	0.00328
3	0.00047	0.00187	0.00421	0.00749
4	0.00083	0.00332	0.00747	0.01327
5	0.00131	0.00522	0.01175	0.02089
6	0.00186	0.00745	0.01676	0.02979
7	0.00255	0.01020	0.02295	0.04079
8	0.00333	0.01331	0.02994	0.05323
9	0.00423	0.01692	0.03807	0.06767

4.3 Experimentaldiscussions

The results showed that when the loading rate equals 150 g/min, for big, medium and small SHs of 'Dorsefid', 'Shamshiri', 'Mikhi', 'Songhori' and 'Sirena' varieties, the average of the ratio of PFSS on middle region to central region (average of one day, two days, three days and four days after harvesting), ranged from 0.776 to 0.859. Maximum and minimum values of ratio of PFSS on middle region to side region for 'Shamshiri' and 'Songhori' varieties were obtained. When the loading rate equals 50 g/min, the corresponding values would be 0.775 and 0.847, respectively. Maximum and minimum values of ratio of PFSS on middle region to central region for 'Shamshiri' and 'Songhori' varieties were obtained.

The result showed that when the loading rate equals 150 g/min, for big, medium and small SHs of the all varieties, average of ratio of PFSS on side region to central region (average of oneday, two days, three days and four days after harvesting), ranged from 0.474 to 0.663. Maximum and minimum values of ratio of PFSS on middle region to side region for 'Sirena' and 'Mikhi' varieties were obtained. When the loading rate equals 50 g/min, the corresponding values would be 0.464 and 0.644, respectively. Maximum and minimum values of ratio of PFSSon side region to central region for 'Sirena' and 'Mikhi' varieties were obtained.

Physiological maturity of sunflower heads starts from the side region to the central region. So when the sunflower head matures, there are immature seeds in central region which are still absorbing nutrients from the plant; therefore, in most cases in the central region, maturity does not happen completely and so, PFSS in central region are greater than in the side and middle region. In all cases, the value of PFSS on middle region was greater than in the side region, while the value of the PFSS on central region was the greatest among all regions; because for each head, seeds located on the side region of the head had reached maturity before the seeds located on the middle region of the head. Also, seeds located on the middle region of the head reached maturity before the seeds located on the central region of the head.

With the increase of the maturity of seeds, the moisture content of head and seeds decreases and some physiological changes (*e.g.* increasing abscisic acid) happens. When the moisture content decreases and the physiological changes are made, tensile cutting force of xylems that contacts the seeds to head decreases; therefore, the PFSS decreases.

The results showed that for the big, medium and small SHs of ˈDorsefidˈ, ˈShamshiriˈ, ˈMikhiˈ, ˈSonghoriˈ and ˈSirenaˈ varieties, when the loading rate increased from 50 to 150 g/min, the value of the PFSS of the seeds in central, middle and side regions increased.

The effect of loading rate and moisture content on picking and cutting force of agricultural crops was also reported by previous researchers. Hemmatian et al. (2012) investigated the shearing properties of sugarcane (*Saccharumofficinarum* L.) stems at five moisture content levels, three shearing speed and at ten positions on the stem. The results of ANOVA analysis indicated that effect of the shearing speed was significant at 1% probability level. Shearing strength and specific shearing energy increased with an increase in shearing speed and so shearing strength and specific shearing energy decreased when the stem moisture content decreased.

Shahbazi and Galedar (2012) determined bending stress, Young's modulus, shearing stress, and shearing energy of safflower (*Carthamustinctorius* L.) stalk as a function of moisture content and stalk region. The results indicated that shearing strength and shearing energy increased with increasing in stem moisture content. Results of Hassan-Beygi et al. (2010) showed that with increasing tension rate the required tensile strength per unit, area of saffron stalk increased significantly.

The results indicated that for ˈDorsefidˈ, ˈShamshiriˈ, ˈMikhiˈ, ˈSonghoriˈ and ˈSirenaˈ, the values of PFSS decreased with the increase of the number of the days after harvesting from one day to four days. Also for ˈDorsefidˈ, ˈShamshiriˈ, ˈSonghoriˈ and ˈSirenaˈ, the value of PFSS decreased with the increase of the SHs diameter. Results of ˈMikhiˈ indicated that PFSS of medium SHs on central region was greater than the big and small SHs.

According to the obtained results, values of PFSS of ˈDorsefidˈ, ˈShamshiriˈ, ˈMikhiˈ and ˈSonghoriˈ varieties were lower than of ˈSirenaˈ. In some cases, the values of PFSS of ˈShamshiriˈ, ˈMikhiˈ, ˈSonghoriˈ and ˈSirenaˈ were greater than in ˈDorsefidˈ and in other cases values of PFSS of the ˈMikhiˈ variety were lower than in other varieties.

4.4 Theoreticaldiscussions

As it was mentioned before, theoretical AIF for eight levels of reservoir pressure, four levels of jet temperature and four levels of nozzle diameter were calculated. The obtained results indicated that with the increase of the reservoir pressure, AIF was increased; theoretically, it can be explained as follows: as the current in nozzle outlet is supersonic increase in the air reservoir pressure results in the increase in velocity of the air in nozzle outlet. Increase in air velocity in nozzle outlet results in increase in mass flow rate which results in increase in impingement jet force.

Results indicated that with the increase of the nozzle diameter, AIF also increased; theoretically, it can be explained as follows: and increase in the nozzle diameter causes an increase in the cross section of the nozzle outlet, which causes an increase in mass flow rate and therefore an increase in AIF in nozzle outlet. This implies an increase in AIF on impingement surface.

Also results indicated that in the same conditions (identical pressure, identical nozzle diameter, identical shape of nozzle outlet, identical air moisture etc.) with increasing jet temperature, AIF decreased. Theoretically, it can be described as follows: increase in air temperature increases the distance between the adjacent air molecules which results in a decrease in air's density. Decrease in the air density in nozzle outlet causes a decrease in mass flow rate in nozzle outlet. This decrease in mass flow rate, results in a decrease in AIF impingement.

4.5 Comparison between experimental and theoretical results

In order to design the new machine for removing sunflower seeds from SH based on the air-jet impingement, critical condition should be considered; this means that the sunflower remover machine should be designed based on maximum value of requirement force to pick the sunflower seeds from the sunflower heads. According to the obtained experimental results, in the same conditions, values of ˈSirenaˈ PFSS were higher than those of the other varieties; therefore the sunflower thresher machine should be designed based on ˈSirenaˈ values. The results showed that the maximum values of PFSS is needed in the first day after harvesting, when the loading rate equals 150 g/min, for the seeds located at the center of the heads. The maximum value of for SRF was obtained to be 5.89 N, which was for ˈSirenaˈ variety's SR on the first day after harvesting. Therefore in order to remove the sunflower seeds using air-jet impingement, the value of the AIF should be greater than the 5.89 N.

Comparison between experimental and theoretical results indicated that to separate the sunflower seeds from the head, nozzles with 2 mm diameter cannot be used; because for nozzles with 2 mm diameter in all cases (when increasing the temperature from 10℃ to 30℃, and reservoir pressure from 2 to 9 bar), AIF in the nozzle exit is less than 3 N. Also results indicated that when the reservoir pressure is less than 5 bar, separating the sunflower seeds from the head using nozzles with 4 mm diameter is not possible; because in such conditions AIF was less than 5.89 N.

5 Conclusions

It should be noted that with the increase of the distance between the nozzle outlet and SH surface, value of the AIF decreases; therefore, it can be predicted that removing sunflower seeds from the SH cannot be possible when the air-jet pressure is less than the 5 bar.

Consequently, the effect of the loading rate, the size of sunflower head, the location of seed on sunflower head, and the number of days after harvesting, on picking force of sunflower seeds from the sunflower head, for three sunflower varieties, were determined. Also in order to estimate the theoretical requirement force to pick the sunflower seeds from the sunflower heads, the effects of the nozzle diameter, reservoir pressure, and jet temperature on impingement jet temperature were examined. The results indicate that using a nozzle with a diameter of 6 to 8 mm and pressure of 6 to 8 bar seems to be suitable for separating the seeds from SH, though more studies are required.

Acknowledgements

The authors would like to thank the University of Tehran for providing technical support for this work. We would also like to sincerely thank Mr. Asghar Mirzabe, Mr. Farbod Mokhaberi and Ms. Zohre Torki for their technical help and supervision while writing the paper. The authors would also like to thank Mr. Mohammad Hassan Torabi and Mr. Ebrahim Sharifat for editing the language of the paper.

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