Design, construction and evaluation of preliminarily machine for removing sunflower seeds from the head using air-jet impingement

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Abstract: To design a sunflower machine for removing seeds from sunflower head (SH) based on air-jet impingement, preliminarily model of such machine was designed, constructed and evaluated. Effects of the seed location, angle of impingement, distance between nozzle outlet and sunflower head, and rotational velocity of sunflower head on percentage of extracted seeds were examined. In order to examine the effects of air-jet parameters on percentage of removed seeds in different locations of seed on sunflower head, sunflower heads were divided into three regions, namely central region, middle region and side region. Results indicated that in all three regions, with increasing rotational velocity from 10 to 30 rev/min, percentages of removed seeds from the SH decreased. Results also indicated that in all three regions, with increasing distance between nozzle outlet and SH surface from 10 to 20 mm and decreasing distance between nozzle outlet and SH surface from 40 to 20 mm, percentage of removed seeds from the SH by air-jet increased. Results indicated that in side region, with decreasing angle of impingement from 90% to 30%, of removed seeds from the SH by air-jet increased and in middle and central regions, with increasing angle of impingement from 30º to 60º and decreasing angle of impingement from 90º to 60º, percentages of removed seeds from the SH by air-jet increased. Also in all tests, no seed damaged due to air-jet impinging was observed.

Keywords: preliminarily model; angle of impingement; nozzle; rotational velocity; sunflower head; seed location

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1 Introduction

Sunflower (*Helianthus annuus* L.) is one of the most important oil crops and is ranked 5th in oil production in the world (FAO, 2009). Sunflower originated in North America (most originated in the Fertile Crescent, Asia or South or Central America). Sunflower was probably first introduced to Europe through Spain, and spread through Europe as a curiosity until it reached Russia where it was readily adapted. Selection for high oil in Russia began in 1860 and was largely responsible for increasing oil content from 28% to almost 50%. Production of sunflowers subsequently rose dramatically in the Great Plains states as marketers found new niches for the seeds as an oil crop, a birdseed crop, and as a human snack food.

Agricultural sunflowers are divided into two types: food consumption of sunflower kernel and oil extraction. Although food consumption of kernels is one of the major reasons of cultivation of sunflower, the main reason of its cultivation is oil extraction from sunflower seeds. For both purposes, in the process of harvesting sunflowers, the seeds should remove from sunflower head (SH). Nowadays, the removing of seeds from sunflower heads (SHs) is done using traditional manual or mechanized methods.

Traditionally, the farmers rub the sunflower heads over a brick/stone/piece of metal, wood, rubber or rub the sunflower heads to each other for their threshing. The efficiency of the traditional manual methods is very low and depends upon the efficiency and experience of the labors (Goel et al., 2009; Mirzabe et al., 2012).

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Mechanized methods are mostly mechanical. The mechanical methods of removing sunflower seeds from the SHs are based on beating, friction and simultaneous beating and friction. The machines of removing sunflower seeds from the head are classified as 1) combined harvester machines 2) stationary thresher machines.

To solve the problems of mechanical method of removing seeds from sunflower heads, a new method was invented based on the use of air-jets impingement. In this method, impingement of high speed outgoing air flow from the nozzle to sunflower's surface causes the seeds to remove from the sunflower head.

Today air and water-jets impingement have many applications in industry, food sciences and machinery. Industrial applications such as cooling of plastic and glass sheets, electronic chip cooling, cryogenic tissue freezing, cooling of photovoltaic cells, de-icing of aircraft wings, compact heat exchangers in automotive and aeronautical applications, cooling in grinding process and combustor liners, cooling of gas turbine blades and etc.

Jet impingement ovens have been used for many years in food processing and have been the standard for meat and pizza cooking. Dehydration is one of the oldest methods of food preservation and it represents a very important aspect of food processing. Results of baking and drying foods using impingement jets showed that time of drying and baking, drying rate, cooking efficiency and power consumption were significantly affected by impingement jet parameters (Huber and Viskanta, 1994; Wählby et al., 2000; Braud et al., 2001; Caixeta et al., 2002; Xue and Walker, 2003; Sarkar et al., 2004; Sumnu et al., 2007; Banooni et al., 2009; Xiao et al., 2010a; Xiao et al., 2010b).

There is little published literature on application of the air-jet impingement to remove arils of pomegranate fruits (Sarige et al., 1985; Khazaei et al., 2008a; Schmilovitch et al., 2011). Also there is little published literature on application of the air-jet and water-jet impingement to extract the citrus juice and juice sacs (Hayashi et al., 1981; Ando et al., 1988; Nahir and Ronen, 1992; Khazaei et al., 2008b). Results of literature indicated that air-jet and water-jet impingement methods are efficient methods to remove the arils of pomegranate fruits and extract the citrus juice and juice sacs.

Literature review indicates that there is no published literature on effects of the air-jet impingement parameters on removing sunflower seeds from the head; therefore, the aims of present study were to design, construct and evaluate preliminarily model of remover machine for removing sunflower seeds from the head based on air-jet impingement. Effects of sunflower seeds location on head, distance between nozzle outlet and sunflower head, angle of impingement (angle between jet and sunflower head surface) and rotational velocity of sunflower head on percentage of removed seeds were examined.

2 Materials and methods

2.1 Sampling preparation

One variety of sunflowers, namely Sirena, widely cultivated in Iran, was used in the present work. The variety was planted on April 27th, 2012 in research farms of university of Tehran, located on Pakdasht, Tehran province, Iran. The sunflowers were harvested manually in late September, after they were matured completely.

To study effects of air-jet parameters on percentage of removed seeds from the sunflower head (SH) in different locations of seed on SH, sunflower heads (SHs) were divided to three regions namely central region (CR), middle region (MR) and side region (SR). Regions are shown in Figure 1.

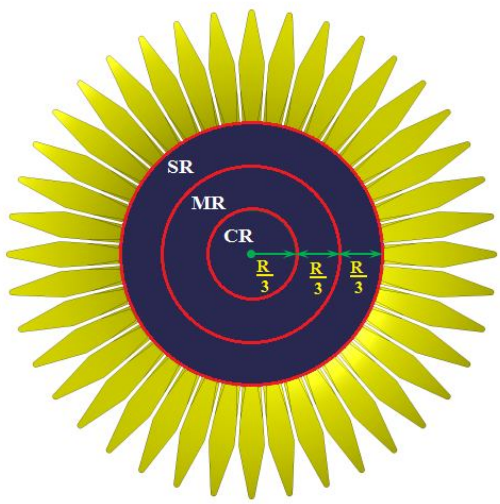


Figure 1 Three regions of SH. 1. Central region (CR) 2. Middle region (MR) 3. Side region (SR)

2.2 Experimental setup

A schematic diagram of the preliminarily model of machine used to evaluate the effects of operating parameters (nozzle diameter, angle of impingement, distance between nozzle outlet and SH surface and rotational velocity of the sunflower head) of air-jet impingement on removing sunflower seeds is shown in Figure 2.

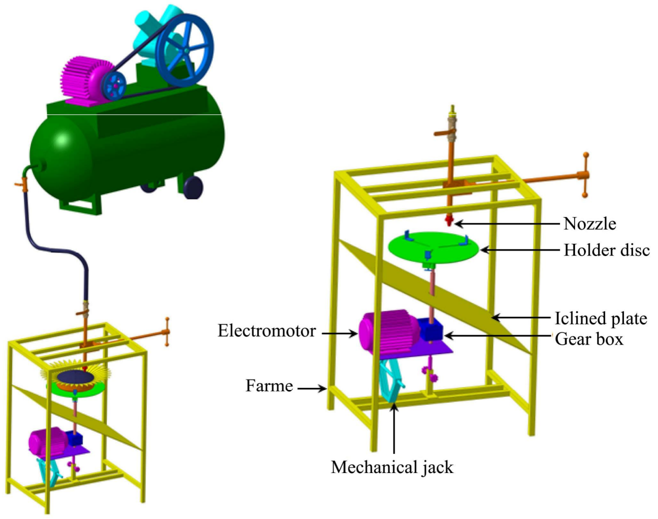
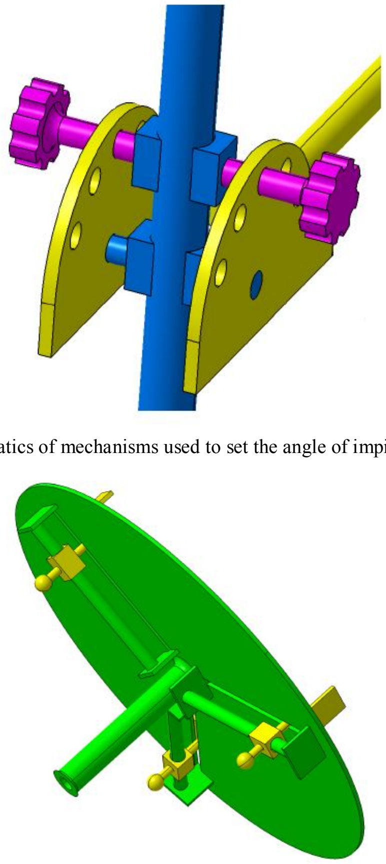


Figure 2 Schematics of preliminarily model of remover machine of sunflower seeds from the SH

The main part of the machine consists of frame, electromotor, worm gear box, holder disc, mechanism of changing angle of impingement, mechanism of changing horizontal position of the nozzle, mechanism of changing distance between nozzle outlet and SH surface (mechanical jack), switching valve, inclined metallic plate and transparent polycarbonate talc. This machine works as follows:

To provide the power required for rotating the sunflower head, electrical motor (Hummer, MS632-4, Iran) was used. To reduce the rotational velocity of the electro motor and change the rotational direction, worm gear box (Taizhou Jiaoxing Transmission Equipment Co., Ltd, RV30, China) was used. In order to hold the sunflower heads during tests and transfer the rotation from the gear box to the SH, sunflower heads were put on holder disc. The holder disc was constructed somehow to be capable of holding sunflower head with the diameter of 6 to 36 cm (Figure 3). To set the rotational velocity of the holder disc (sunflower head) Inverter (LS industrial systems, SV 015ic5-1F, China) was used.



a. Schematics of mechanisms used to set the angle of impingement

b. Schematics of mechanisms used to maintain the sunflower head during the tests

Figure 3 Schematics of designed and constructed mechanisms in order to change the angle of impingement and maintain the sunflower head during the tests

Distance between the sunflower heads and nozzle outlet was set using mechanical jack. In order to examine the effects of air-jet parameters on extracted regions in different locations of seed on SH, bolt of changing horizontal position of the nozzle was used. Angle of impingement (angle between sunflower head surface and air-jet impingement) was set using changing angle mechanisms which are zoom in Figure 3.

The pressure of the air was increased in piston compressor; the high pressure flow of the air was transferred to machine using pneumatic hoses. In order to connect and disconnect the air flow, switching valve was used. To avoid seed from getting thrown out from the machine, the transparent polycarbonate talc was used. The seeds, after removing from the SH, fall down on inclined plate; then the seeds were transferred out of the machine.

2.3 Data analysis

The effects of seeds location on SH (on SR, MR and CR), angle of impingement (at 30º, 60º and 90º), distance between nozzle outlet and SH surface (at 10, 20, 30 and 40 mm) and rotational velocity of the sunflower head (at 10, 15, 20 and 30 rev/min) on the percentage of the removed seeds from the SH were studied, when the air pressure was equal to 7 bar. Pressure is an important and effective factor on removing seeds from SHs in the air-jet impingement method; however, in this article, to avoid complexity resulted from existence of too many variables, pressure was considered to be equal to 7 bar. This number was selected after preliminary experiments. In those experiments, pressure fluctuated from 4 to 9 bar and 7 bar was selected for it showed the best results.

To examine the effects of the air-jet parameters on removing of seeds from the SH, removed seeds due to the impingement air-jet in one rotation of SH were collected after each test; weight of the extracted seeds were measured; then the remaining seeds on the head were extracted manually; total weight of sunflower head seeds (weight of the whole seeds, extracted seeds and not extracted seeds) were measured using a digital balance (Kern, EMB600-2, Philippines) with an accuracy of 0.01 g. Ratio of the weight of extracted seeds to weight of the whole seeds (percentage of extracted seeds) of the SH was calculated.

3 Results

3.1 Side region (SR)

Maximum percentage of removed seeds from SH was obtained when the angle of impingement, distance between nozzle outlet and SH surface and rotational velocity of SH were equal to 30º, 20 mm and 10 rev/min, respectively. Minimum percentage of removed seeds from SH was obtained when the angle of impingement, distance between nozzle outlet and SH surface and rotational velocity of SH were equal to 90º, 40 mm and 30 rev/min, respectively. Maximum and minimum values of percentage of removed seeds from SH were equal to 51.32% and 28.67%, respectively.

For example, the effect of the distance between nozzle outlet and SH surface and angle of impingement on percentage of removed seeds from the SH, when rotational velocity was equal to 10 rev/min are shown in Figure 4. Results indicated that in all cases (when rotational velocity were equal to 10, 15, 20 and 30 rev/min), with increasing distance between nozzle outlet and SH surface from 10 to 20 mm, decreasing distance between nozzle outlet and SH surface from 40 to 20 mm and decreasing angle of impingement from 90º to 30º, percentage of removed seeds from SH increased. Results indicated that with increasing angle of impingement from 30º to 60º, difference between percentages of removed seeds was great, but with increasing angle of impingement from 60º to 90º, difference between percentages of removed seeds was little.

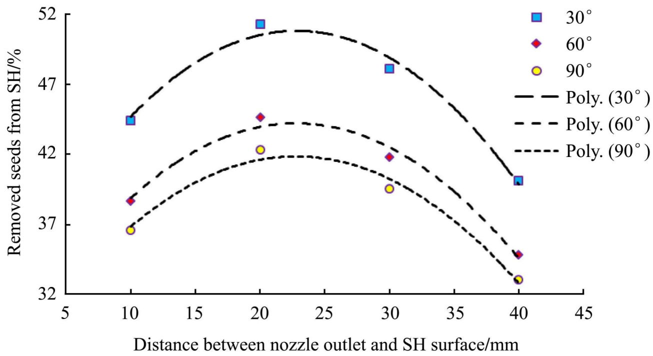


Figure 4 Effect of the distance between nozzle outlet and SH surface and angle of impingement on percentage of removed seeds from SH in SR (rotational velocity equals to 10 rev/min)

Correlation between percentages of removed seeds from the SH (PRS) and distance between nozzle outlet and SH surface (D) when the rotational velocity and angles of impingement were equal to 10 rev/min and 30º, 60º and 90º, could be represented by the following equations, respectively:

$$PRS_{30}=-0.0372D^2+1.6999D+31.4180, R^2=0.9800 \quad (1)$$

$$PRS_{60}=-0.0325D^2+1.4806D+27.3500, R^2=0.9793 \quad (2)$$

$$PRS_{90}=-0.0307D^2+1.3978D+25.9380, R^2=0.9763 \quad (3)$$

For example effect of the rotational velocity of SH surface and angle of impingement on percentage of removed seeds from the SH, when distance between nozzle outlet and SH surface was equal to 20 mm, is shown in Figure 5. Results indicated that in all cases (when distance between nozzle outlet and SH surface were equal to 10, 20, 30 and 40 mm), with increasing

rotational velocity of SH from 10 to 30 rev/min and decreasing angle of impingement from 90º to 30º, percentage of removed seeds from SH increased. Results indicated that with increasing angle of impingement from 30º to 60º, difference between percentages of removed seeds was great, but with increasing angle of impingement from 60º to 90º, difference between percentages of removed seeds was little.

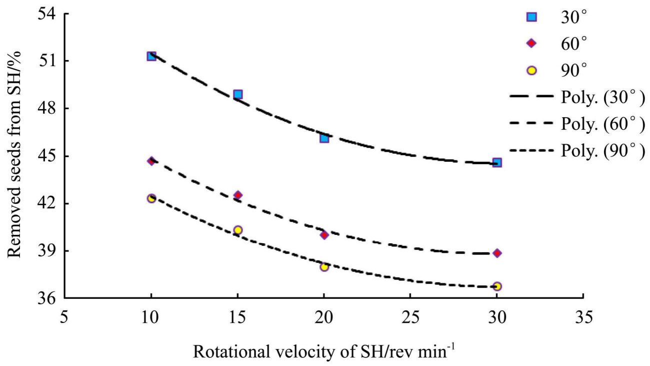


Figure 5 Effect of the rotational velocity of SH and angle of impingement on percentage of removed seeds from SH in SR (distance between nozzle outlet and SH surface equals to 20 mm)

Correlation between percentages of removed seeds from the SH (PRS) and rotational velocity (RV), when the distance between nozzle outlet and SH surface, and angle of impingement were equal to 20 mm and 30º, 60º and 90º, could be represented by the following equations, respectively:

$$PRS_{30}=0.0160RV^2-0.9881RV+59.7290,\ R^2=0.9920 \quad (4)$$

$$PRS_{60}=0.0148RV^2-0.8925RV+52.2440,\ R^2=0.9896 \quad (5)$$

$$PRS_{90}=0.0138RV^2-0.8390RV+49.4720,\ R^2=0.9901 \quad (6)$$

3.2 Middle region (MR)

Maximum percentage of removed seeds from SH was obtained when the angle of impingement, distance between nozzle outlet and SH surface and rotational velocity of SH were equal to 60º, 20 mm and 10 rev/min, respectively. Minimum percentage of removed seeds from SH was obtained when the angle of impingement, distance between nozzle outlet and SH surface and rotational velocity of SH were equal to 90º, 40 mm and 30 rev/min, respectively. Maximum and minimum values of percentage of removed seeds from SH were equal to 37.53% and 20.56%, respectively.

For example, in Figure 6, effect of the distance between nozzle outlet and SH surface and angle of impingement on percentage of removed seeds from the SH, when rotational velocity was equal to 10 rev/min is shown. Obtained results indicated that in all cases (when rotational velocity was equal to 10, 15, 20 and 30 rev/min), with increasing distance between nozzle outlet and SH surface from 10 to 20 mm, decreasing distance between nozzle outlet and SH surface from 40 to 20 mm, decreasing angle of impingement from 90º to 60º and increasing angle of impingement from 30º to 60º, percentage of removed seeds from SH increased. Results indicated that with decreasing angle of impingement from 90º to 60º, difference between percentages of removed seeds was greater than difference between percentages of removed seeds when angle of impingement increased from 30º to 60º.

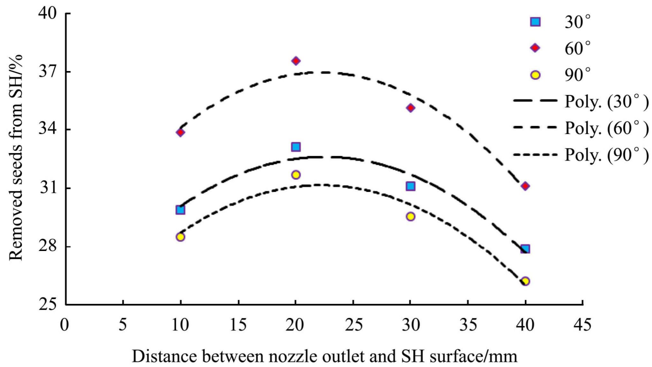


Figure 6 Effect of the distance between nozzle outlet and SH surface and angle of impingement on percentage of removed seeds from SH in MR (rotational velocity equals to 10 rev/min)

In MR, correlation between percentages of removed seeds from the SH (PRS) and distance between nozzle outlet and SH surface (D) when the rotational velocity and angle of impingement were equal to 10 rev/min and 30º, 60º and 90º, could be represented by the following equations, respectively:

$$PRS_{30}=-0.0161D^2+0.7254D+24.4300,\ R^2=0.9421 \quad (7)$$

$$PRS_{60}=-0.0163D^2+0.7234D+23.1080,\ R^2=0.9461 \quad (8)$$

$$PRS_{90}=-0.0307D^2+1.3978D+25.9380,\ R^2=0.9763 \quad (9)$$

For example, the effect of the rotational velocity of SH surface and angle of impingement on percentage of removed seeds from the SH, when distance between nozzle outlet and SH surface was equal to 20 mm is shown in Figure 7. Results indicated that in all cases (when distance between nozzle outlet and SH surface

were equal to 10, 20, 30 and 40 mm), with increasing rotational velocity of SH from 10 to 30 rev/min and decreasing angle of impingement from 90º to 30º, percentage of removed seeds from SH increased. Results indicated that with increasing angle of impingement from 30º to 60º, difference between percentages of removed seeds was great, but with increasing angle of impingement from 60º to 90º, difference between percentages of removed seeds was little.

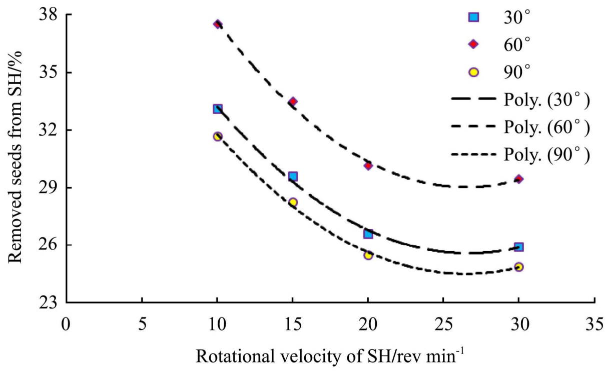


Figure 7 Effect of the rotational velocity of SH and angle of impingement on percentage of removed seeds from SH in MR (distance between nozzle outlet and SH surface equals to 20 mm)

In MR, correlation between percentages of removed seeds from the SH (PRS) and rotational velocity (RV) when the distance between nozzle outlet and SH surface, and angles of impingement were equal to 20 mm and 30º, 60º and 90º, could be represented by the following equations, respectively:

$$PRS_{30}=0.0275RV^2-1.4660RV+45.1160,\ R^2=0.9967 \quad (10)$$

$$PRS_{60}=0.0316RV^2-1.6748RV+51.2180,\ R^2=0.9970 \quad (11)$$

$$PRS_{90}=0.0268RV^2-1.4179RV+43.2660,\ R^2=0.9970 \quad (12)$$

3.3 Central region (MR)

The same as MR, when the angle of impingement, distance between nozzle outlet and SH surface and rotational velocity of SH were equal to 60º, 20 mm and 10 rev/min, respectively, maximum percentage of removed seeds from SH was obtained. Also the same as MR, when the angle of impingement, distance between nozzle outlet and SH surface and rotational velocity of SH were equal to 90º, 40 mm and 30 rev/min, respectively, minimum percentage of removed seeds from SH was obtained. Maximum and minimum values of percentage of removed seeds from SH were equal to 8.45% and 4.47 %, respectively.

For example, the effect of the distance between nozzle outlet and SH surface and angle of impingement on percentage of removed seeds from the SH, when rotational velocity was equal to 10 rev/min is shown in Figure 8. Obtained results indicated that same as MR, in all cases (when rotational velocity were equal to 10, 15, 20 and 30 rev/min), with increasing distance between nozzle outlet and SH surface from 10 to 20 mm, decreasing distance between nozzle outlet and SH surface from 40 to 20 mm, decreasing angle of impingement from 90º to 60º and increasing angle of impingement from 30º to 60º, percentage of removed seeds from SH increased. Results indicated that with decreasing angle of impingement from 90º to 60º, difference between percentages of removed seeds was greater than difference between percentages of removed seeds when angle of impingement increased from 30º to 60º.

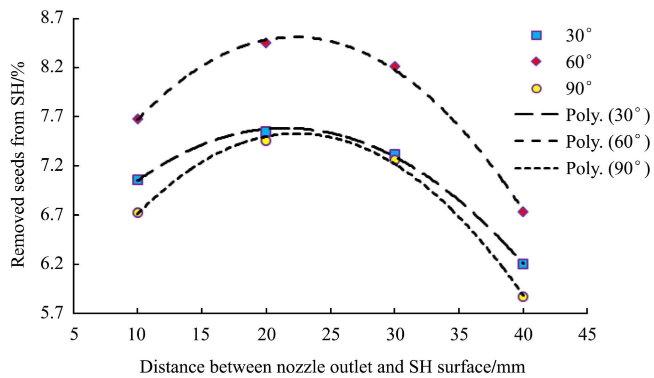


Figure 8 Effect of the distance between nozzle outlet and SH surface and angle of impingement on percentage of removed seeds from SH in CR (rotational velocity equals to 10 rev/min)

In CR, correlation between percentages of removed seeds from the SH (PRS) and distance between nozzle outlet and SH surface (D), when the rotational velocity and angles of impingement were equal to 10 rev/min and 30º, 60º and 90º, could be represented by the following equations, respectively:

$$PRS_{30}=-0.0040D^2+0.1731D+5.7225,\ R^2=0.9986 \quad (13)$$

$$PRS_{60}=-0.0056D^2+0.2494D+5.7350,\ R^2=0.9986 \quad (14)$$

$$PRS_{90}=-0.0053D^2+0.2372D+4.8750,\ R^2=0.9978 \quad (15)$$

For example, effect of the rotational velocity of SH surface and angle of impingement on percentage of removed seeds from the SH, when distance between nozzle outlet and SH surface was equal to 20 mm is

shown in Figure 9. Results indicated that in all cases (when distance between nozzle outlet and SH surface were equal to 10, 20, 30 and 40 mm), with increasing rotational velocity of SH from 10 to 30 rev/min and decreasing angle of impingement from 90º to 30º, percentage of removed seeds from SH increased. Results indicated that with increasing angle of impingement from 30º to 60º, difference between percentages of removed seeds was great, but with increasing angle of impingement from 60º to 90º, difference between percentages of removed seeds was little. In CR in all cases, when the angles of impingement were equal to 30º and 90º, differences between percentages removed seeds were very little.

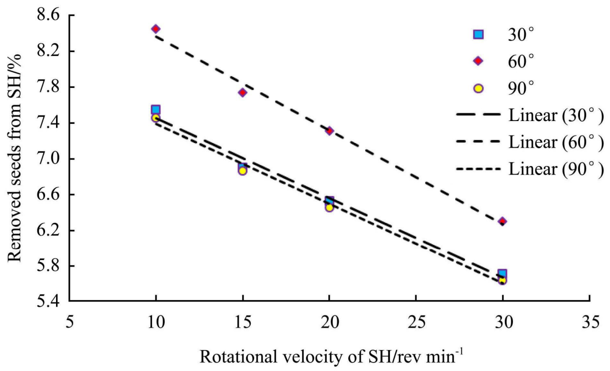


Figure 9 Effect of the rotational velocity of SH and angle of impingement on percentage of removed seeds from SH in CR (distance between nozzle outlet and SH surface equals to 20 mm)

In CR, correlation between percentages of removed seeds from the SH (PRS) and rotational velocity (RV) when the distance between nozzle outlet and SH surface, and angles of impingement were equal to 20 mm and 30º, 60º and 90º, could be represented by the following equations, respectively:

4 Discussion

4.1 Experimental results

The experimental results indicated that in the same condition (identical pressure, identical nozzle diameter, identical angle of impingement, identical distance between nozzle outlet and SH surface and identical rotational velocity of the SH) value of the percentage of the removed seeds from the SH on SR and CR were the most and the lowest, respectively; because for each head, seeds located on the side region of the head reach maturity before the seeds located on the middle region of the head. Also, seeds that are located on the middle region of the head reach maturity before the seeds located on the central region of the head (Mirzabe et al., 2013).

Physiological maturity of sunflower heads starts from the side region to the central region. So when the sunflower head matured, there are immature seeds in central region still absorbing nutrition from the plant; therefore, in most cases in the central region, maturity does not happen completely and so, picking force of the seeds in central region is more than the side and middle region and value of picking force on middle region is more than the side region (Mirzabe et al., 2013).

A comparison between three region of sunflower head namely side region, middle region and central region indicated that:

1) In all three regions, with increasing rotational velocity, percentage of removed seeds from the SH (PRS) by air-jet decreases.

2) In all three regions, with increasing distance between nozzle outlet and SH surface from 10 to 20 mm and decreasing distance between nozzle outlet and SH surface from 40 to 20 mm, percentage of removed seeds from the SH (PRS) by air-jet increases.

3) In all three regions, distance between nozzle outlet and SH surface and rotational velocity of SH had the quadratic relationship with percentage of removed seeds from the SH (PRS) by air-jet.

4) In side region, with decreasing angle of impingement from 90º to 30º, percentage of removed seeds from the SH (PRS) by air-jet increases.

5) In middle and central regions, with increasing angle of impingement from 30º to 60º and decreasing angle of impingement from 90º to 60º, percentage of removed seeds from the SH (PRS) by air-jet increases.

6) In all cases, no seed damaged due to air-jet impinging was observed.

4.2 Comparison between experimental results and theory

Based on the theory, with increasing distance between nozzle outlet and SH surface, area of the coverage by jet will increase, but the experimental results showed that percentage of the removed seeds with increasing distance

between nozzle outlet and SH surface increased, then decreased. In fact, when the distance from the nozzle outlet increased, area of the coverage by air-jet increased, but jet force decreased; therefore, it cannot be said that the area of the extracted region will increase with increasing distance from nozzle outlet, because the jet force will decrease.

Based on the theory, with increasing angle of impingement (from 30º to 90º), area of the covered region by the jet will decrease. In the side region, the experimental results confirmed the theory; but in the middle and central regions, with increasing angle of impingement, the extracted region increased, then decreased. Arrangement of the seeds on the heads and distance between adjacent seeds can be an influential factor on suitable angle of impingement. Mirzabe et al. (2012) cited that with increasing distance between locations of seeds and center of SH, distance between adjacent seeds increases.

Based on the theory, with increasing rotational velocity of SH, focus of jet on coverage by jet will decrease; therefore, percentage of removed seeds will decrease. Experimental results indicated that in all three regions, with increasing rotational velocity, percentage of removed seeds from the SH by air-jet increases.

5 Conclusions

Effects of some of the most important parameters of air-jet impingement parameters including angle of impingement, distance between nozzle outlet and SH surfaces and rotational velocity of the SH, on removing sunflower seeds from the three different locations of the SH were examined.

Results indicated that in the same condition, value of the percentage of the removed seeds on SR and CR were the most and the lowest, respectively. In all three regions, with increasing distance between nozzle outlet and SH surface from 10 to 20 mm, decreasing distance between nozzle outlet and SH surface from 40 to 20 mm and decreasing rotational velocity, the percentage of the removed seeds increased. Also, obtained results indicated that on side, middle and central regions, removing seeds from the heads using 30º, 60º and 90ºangle of impingement is suggested, respectively.

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