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RESEARCH ARTICLE

DESIGN OF A VACUUM SEED PLATE BASED ON PHYSICAL AND MECHANICAL PROPERTIES OF MAIZE SEEDS

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Abstract

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A vacuum seed plate was designed, developed and evaluated based on physical and mechanical properties for three Egyptian maize seed varieties. The studied properties included seed moisture content, one thousand seed mass, maize seed linear dimensions, geometric mean diameter, the degree of sphericity, coefficient of friction and repose angle. According to the such measured properties, the seed plate dimensions were designed to be 230 mm for outside diameter, 190 mm for pitch circle diameter, 15.1 mm diameter of conical hole edges and 4.0 mm for a hole diameter. A precision vacuum planter was used to evaluate the performance of the developed vacuum seed plate under three different forward speeds 2.7 , 3.6 and 5.6 km/h (0.75, 1.0 and 1.47 m/s), three different hole diameters of 3.5, 4.0, 4.5 mm, the entry cone angle of the hole was 120^{o} and the vacuum pressure was 4 kPa. Results concluded that the vacuum seed plate can be operated successfully at the proper operating parameters of 3.6 km/h forward speed and with a hole diameter of 4.0 mm, At these proper operating parameters, the vacuum metering system having miss indices (0.0%) and multiple indices (5.0 %) with quality of feed index 95 % and 9.91 % precision in spacing (coefficient of variation) with a mean seed spacing of 180.5 mm. The purchase price of the imported vacuum seed plate increased about 83.0 % when compared with that for the developed vacuum seed plate.

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Introduction:-

Maize is considered one of the most important summer crops in Egypt, the average total annual consumption of maize in Egypt, with all its types, ranged between 16 and 17 million tons. Around 50% of the consumed quantity is locally produced, while the other 50% is provided through importation from other countries (FAO, 2018).

Identifying the physical and mechanical properties of maize seeds is very important to optimize the design parameters of vacuum seed plate. So, it is essential to determine and recognize the database of physical and mechanical properties of maize seeds because these properties play an important role in designing and developing of

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vacuum seed plate to determine the optimum design parameters affecting in vacuum seed plate in precision vacuum planter to suite many varieties of maize seeds. Hence, this study aimed to determine the optimum values of the basic physical and mechanical properties of maize seeds to utilize the obtained results to optimize the best design parameters in vacuum seed plate. The size, shape and physical dimensions of seeds were very essential for designing the hole diameter on the vacuum seed plate, it must control the seeding rate and meter the seeds to attain the optimum yield when planting most kinds of crops (Searle et al., 2008). Angle of repose was very essential for designing the seed box to insure the continuous flow of seeds (Tian et al., 2010) and (Matouk et al., 2004) developed the mathematical relationships relating the changes of the properties with the seed moisture content. The seed principal dimensions, mass of 1000 seeds and seed projection area are generally increased by increasing of seed moisture content. Also (Singh et al., 2005) observed that the seed plate with a 120^{o} hole conical angle gave the best performance at all speeds and vacuum pressures using cotton seeds. The metering system with disc speed of 0.42 m /s (1.5 km /h), and a vacuum pressure of 2 kPa produced better results with a feed index of 94.7%, a coefficient of variation in spacing of 8.6% and recorded a mean seed spacing of 251 mm. A study was conducted by (Barut and Özmerzi ,2004) to determine the effect of different operating parameters on seed holding in a single seed metering system using seed maize. The shapes of the holes, peripheral velocities, vacuum pressure, hole area on the seed plate and one thousand grain weights of seed were selected as the operating parameters. Among all the holes that the seed holding possessed, the circular holes were the best in contrast with the other shapes of hole. The negative pressure was 3.0 and 4.0 kPa at the highest ratio of holding in circular holes. Also (Karayel et al., 2004) developed a mathematical model using some physical properties of maize seeds. They found that the optimum vacuum pressure of a precision seeder were 4 kPa for maize.

The vacuum precision planters have the following advantages: More precise seed rates with lower rate of seed damage, better control and adjustment of upkeep and drift of seeds, broader spectrum of applicability, more strict to the seed size, and no seed grading, it is tolerant to seeds geometry for precision seeding (Wang, 2006). The most important component of a pneumatic planter is the vacuum seed metering system (Murray et al., 2006; Searle et al., 2008). Seed metering is considered as one of the major functions in any types of planters. In addition, for appropriate working of the seed metering system, some factors must be measured for various seeds such as shape, diameter, angle of opening and linear speed of the seed plate, and vacuum pressure inside the seed metering system. Doubling and missing in the row are unwanted since doubling affects yield and dry matter while missing causes a reduction in yield (Demmel et al., 2000).

Therefore, this study aims to design, develop and evaluate a locally unit of vacuum seed plate for planting Egyptian maize varieties based on physical and mechanical properties. It makes optimization design for structure parameters (hole diameter, distance of wide hole, number of holes, pitch circle diameter, outside diameter) of the vacuum seed plate which makes it optimum score of missing and multiple indices with optimum quality of feed index and precision in spacing (coefficient of variation).

Materials and Methods:-

Laboratory tests were carried out at the Agricultural Engineering Research Institute (AEnRI), Dokki-Giza, Egypt in 2020 to study the physical and mechanical properties for three Egyptian maize seed varieties of white maize single cross 132 (SC-132), yellow maize single cross 176 (SC-176) and yellow maize single cross 178 (SC-178) (Plate 1) were studied to design the seed vacuum plate.

Physical properties of maize seeds:

Seed moisture content:

The seed moisture content of samples were determined by drying about 15 g of three samples in an air convection oven at 103±2 ^{o}C for 50 min (ASAE Standard, 1999). The process was repeated three times to determine mean values for each studied maize varieties. An electric balance with a sensitivity of 0.001 g was used to determine the mass before and after drying seed samples.

One thousand seed mass:

Mass of one thousand seed was determined using an electronic balance with a sensitivity of 0.001 g. Three groups of samples were taken to determine one thousands seed mass. Each sample was contains 1000 seeds. The average of the three replicates was considered for each studied maize varieties.

Maize seed linear dimensions:

The physical dimensions of seeds were very essential for designing the hole diameter on the vacuum seed plate. In order to determine the dimensions at moisture level were randomly selected, and three principal dimensions, namely, minor diameter (thickness), intermediate diameter (width) and major diameter (length), were measured for each studied maize varieties using an electronic digital caliper (GUANGLU), which was accurate to 0.01 mm. Three samples were taken to determine the linear dimensions. Each sample was contains 100 seeds.

White maize single cross 132 Yellow maize single cross 176 Yellow maize single cross 178

Plate 1:- Investigated Egyptian maize varieties.

Geometric mean diameter:

The geometric mean diameter of maize seeds was very essential for designing the holes diameter on the vacuum seed plate. This was determined from the principal dimensions of seed by (Singh et. al, 2005) using the following equation:

$$D_g = (LWT)^{1/3} \quad (1)$$

Where:

D_g: geometric mean diameter (mm),
L: Length of seed (mm),
W: Width of seed (mm), and
T : Thickness of seed (mm).

The degree of sphericity:

The degree of sphericity (φ) was very essential for designing the hole shape on the vacuum seed plate. It was determined from the principal dimensions of maize seeds (Mohsenin, 1986).

$$\varphi = \frac{(LWT)^{\frac{1}{3}}}{L} \times 100 \quad (2)$$

Where:

φ: The degree of sphericity (%),
L: length of seed (mm),
W: width of seed (mm),and
T : Thickness of seed (mm).

Coefficient of friction:

The coefficient of friction for maize seed varieties measured using an instrument constructed in the workshop of Agric. Eng. Rec. Institute on three different material surfaces namely plywood sheet, galvanized iron sheet, and stainless steel 304 sheet. Fifteen samples of maize seeds from each varieties were taken to determine the dynamic coefficient of friction for maize seeds and the average was determined. Then, the following equation used to calculate the dynamic coefficient of friction.

$$\mu = \tan\varphi \quad (3)$$

Where:

μ: Friction coefficient, and
φ: Friction angle (deg).

Repose angle:
Repose angle was very essential for designing the seed box of the machine to insure continuous flow of seeds especially for maize seeds around vacuum seed plate . It was determined using a digital instrument construct in the laboratory of Agric. Eng. Rec. Institute. The average value of five replications for each studied maize varieties were reported.

Design and development of the vacuum seed plate:
Design parameters of the vacuum seed plate:
Shape of holes:
According to the degree of sphericity (φ) for maize varieties and based on Barut and Özmerzi (2004), the shape of holes for the vacuum seed plate was recommended as a circular hole for each studied maize varieties.

Angle of holes:
Based on Singh et al., (2005). They showed that most suitable conical angle of the seed plate was 120^o. To prevent the seed from entering for seed opening on seed plate (2β), it should be conical in shape that could be completely closed by a seed to avoid multiple seeds being picked up by the seed plate.

Diameter of holes:
The diameter of holes on the vacuum seed plate (do) was determined based on the less than 50% size of the geometric mean diameter for each studied maize varieties (Singh et al., 2005).

Calculating distance of wide hole (Do):
Based on (Sial and Persson ,1984)., (Afify et al., 2009) and for $2\beta=90^o$ or 120^o or 150^o; $Dg \cos \beta \leq do < Dg$ (Fig. 1). Based on results of geometric mean diameter (Dg) and the hole diameter of the vacuum seed plate (do) for each studied maize varieties. Therefore, calculating distance of wide hole (Do), considering $b = t–t_1= 1$ mm, the optimum diameter (do) and angle of holes on the vacuum seed plate(2β) was used for calculation from this Equations:

$$a = b \tan \beta = (t-t_1) \tan\beta \quad (4)$$

$$Do = 2a + do = 2b \times \tan\beta + do \quad (5)$$

$$Do = 2(t-t_1) \tan\beta + do \quad (6)$$

Where:

- Do: Distance of wide hole, mm
- Do: Hole diameter of the vacuum seed plate, mm
- A: Horizontal length of conical holes, mm
- b: Thickness of conical holes, mm
- t: Thickness of the vacuum seed plate, mm
- t_1: Thickness of holes, mm
- 2β: Entrance section cone angle, degree

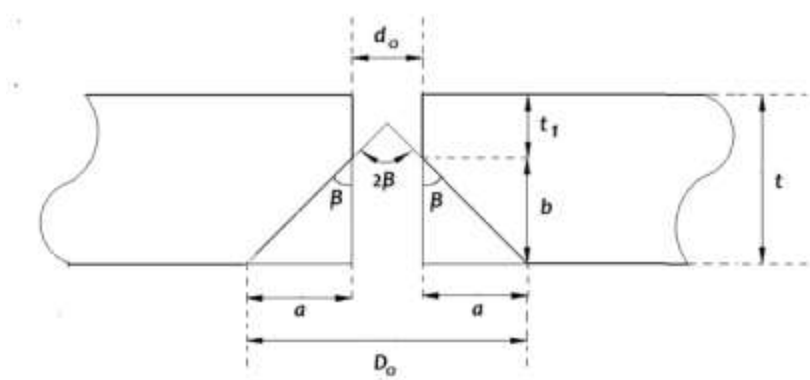

Fig.1:- Dimensions of holes on vacuum seed plate.

Number of holes:
The number of holes on the vacuum seed plate (N) for maize seed was determined from this equation:

$$N = \frac{C_w}{X_s \times n_r} \quad (7)$$

Where:

C_w : Circumference of drive wheel (cm),

X_s: Theoretical seeds spacing within row (cm) and

n_r: Ratio between teeth of drive wheel sprockets and seed plate gears

Pitch circle diameter:

The Pitch circle diameter(D_p, mm) on vacuum seed plate can be given from this equation:

$$D_p = \frac{N \times (D_0 + C_o)}{\pi} \quad (8)$$

Where:

D_o: Diameter of conical hole edges (outside diameter of the seed hole) on vacuum seed plate, mm

C_o: Clearance between holes on the vacuum seed plate, mm.

Outside diameter of the vacuum seed plate:

The outside diameter of the vacuum seed plate (D_s, mm) can be given from this equation:

$$D_s = D_p + D_0 + 2C_e \quad (9)$$

Where:

C_e: Clearance from edge of holes between to outside edge of the vacuum seed plate, mm

Experimental field test and evaluation:

Tests under field conditions were carried out using a precision vacuum planter under various levels of forward speeds 2.7, 3.6 and 5.3 km/h (0.75, 1.0 and 1.47 m/s) at 4.0 kPa negative pressure and three seed plates were fabricated from stainless steel 304 with different hole diameters of 3.5, 4.0 and 4.5 mm at the cone angle of holes (2β) on the seed plate was 120^o . The experimental soil was classified as a Clay having 53.32% clay, 17.63% silt and 29.05% sand. The land of experimental is located in Rice Mechanization Center, Meet El-Deeba, Kafer El-Sheikh Governorate, during season 2020. The design of experiment was laid out in a randomized completely block design, with three replications. An area of about 3888 m^2 was divided into 27 plots. Therefore, the area of each plot becomes 144 m^2 with 24.0 m length and 6.0 m width. The pneumatic type is vacuum and mad in Italy and it has 4 units and adjusted to deliver maize seeds at a theoretical seed spacing (nominal seed spacing) of 200 mm in row. They also adjusted to put the seeds with a 75 cm distance between rows and at 40 mm depth of planting. The precision vacuum planter was operated by a Massy Ferguson tractor model 290, 2WD, of about 75 hp. The tractor travel speed was selected according to the tractor gear box; then the actual travel speed during tests was measured three times for each nominal speed. . After the plants emerged (16^{th} days following seedling). The plant distances in row was measured. Twenty plants spacing were evaluated on the field to determine performance of the vacuum seed metering system and the parameters evaluated included mean seed spacing, miss index, multiple index, quality of feed index and precision in spacing (Singh, et al., 2005) as following:

Miss index:

The miss index I_{miss} is the percentage of spacing greater than 1.5 times the set planting distance S in mm.

$$I_{miss} = \frac{n_1}{N} \quad (10)$$

Where:

n_1: Number of spacing > 1.5 S; and N is total number of measured spacing.

Multiple index:

The multiple index I_{mult} is the percentage of spacing that are less than or equal to half of the set plant distance S in mm.

$$I_{mult} = \frac{n_2}{N} \quad (11)$$

Where:

n_2: is number of spacing ≤ 0.5 S.

Quality of feed index:
The quality of feed index I_{fq} is the percentage of spacing that are more than half but not more than 1.5 times the set planting distance S in mm. The quality of feed index is an alternate way of presenting the performance of misses and multiples.

$$I_{fq} = 100 - (I_{miss} + I_{mult}) \quad (12)$$

Precision in spacing:
The precision of seed spacing is a measure of the variability (coefficient of variation) in spacing X_{ref}, between seeds after accounting variability due to both multiple and miss

$$P_r = \frac{S_2}{X_{ref}} \times 100 \quad (13)$$

Where:
P_r: Precision in spacing (%), and
S_2: Standard deviation of the measured spacing more than half but not more than 1.5 times the theoretical spacing (X_{ref}) in region (2).

Results and Discution:-

Maize seed linear dimensions:
Maize seed linear dimensions (length, width and thickness) at moisture content of 12.5% w.b. were summarized in Table 1. The seed average length recorded 12.37, 12.05 and 11.26 mm for white maize single cross 132 (SC-132), yellow maize single cross 176 (SC-176) and yellow maize single cross 178 (SC-178) , respectively. The seed average width recorded 8.08, 8.14 and 8.98 mm for white maize (SC-132), yellow maize (SC-176) and yellow maize (SC-178), respectively. The seed average thickness recorded 4.89, 4.81 and 4.65 mm for white maize (SC-132), yellow maize (SC-176) and yellow maize (SC-178), respectively.

The geometric mean diameter:
The geometric mean diameter recorded 7.69, 7.60 and 7.60 mm (Equation 2) for white maize (SC-132), yellow maize (SC-176) and yellow maize (SC-178), respectively. The above mentioned dimensions was assigned for calculating the hole diameter of the vacuum seed plate using seed linear dimensions.

One thousand seed mass:
One thousand seed mass for the yellow maize (SC-178), yellow maize (SC-176) and white maize (SC-132) recorded values of 364, 341.27 and 339.5 g, respectively, as shown in Table 1.

Friction coefficient:
It is one of the important measurements used to define the proper angles and tendencies of different machine parts, which deals with the movement of grain and moving from one point to another. Friction coefficient was varied with roughness of grain surface and type of friction surface. For all studied maize varieties coefficient of friction increased with the increase of roughness degree of both grain and the tested surfaces. The friction coefficient for different studied varieties varied from 0.404 to 0.466. The steel and wood surfaces recorded the highest friction coefficient values which ranged from 0.324 to 0.466 (Equation 3). While the stainless steel surface recorded the lowest values which ranged from 0.249 to 0.268, as shown in Tables 1. Therefore, we used stainless steel 304 for manufacture vacuum seed plate. These results are in agreement with previous findings by (Ramesh et al., 2015).

Table 1:- Measured and calculated physical and mechanical properties.

Property	Unit	White maize (SC-132)	Yellow maize (SC-176)	Yellow maize (SC-178)
Length, L	mm	12.37	12.05	11.26
Width, W	mm	8.08	8.14	8.98
Thickness, T	mm	4.89	4.81	4.65
Geometric mean diameter, Dg	mm	7.69	7.60	7.60
Sphericity,ϕ	decimal	63.68	64.61	69.05
One thousand of seed mass	g	339.5	341.27	364
Coefficient of friction, steel	decimal	0.404	0.466	0.42
Coefficient of friction, wood	decimal	0.324	0.287	0.364

Coefficient of friction, stainless steel	decimal	0.249	0.268	0.268

Design and development of the vacuum seed plate:

Shape of holes:

Based on study in Table 1, it shows that, sphericity for white maize (SC-132), yellow maize (SC-176) and yellow maize (SC-178) were 63.68 %, 64.61 % and 69.05%, respectively. The lowest value of the sphericity was obtained for yellow maize (SC-176). However, the highest value of the Sphericity was obtained for yellow maize (SC-178) nearest from (70 %). These results confirm the hole shape on the vacuum seed plate is circular shape. These results are in agreement with previous findings by Barut and Özmerzi (2004) and Kl.ver (1991).

Diameter of holes:

The diameter of holes on the vacuum seed plate (do) was based on the less than 50% size of the geometric mean diameter (D_g). The geometric mean diameters were 7.69, 7.60 and 7.60 mm (Equation 1). Therefore, the diameters of holes on the vacuum seed plate were 3.84 mm, 3.80 mm and 3.80 mm for white maize (SC-132), yellow maize (SC-176) and yellow maize (SC-178), respectively. It shows that, the geometric mean diameter (D_g=7.6 mm for all studied seed maize). Therefore, the diameter of holes on the vacuum seed plate is similar for all seed vacuum plate and must be considered (do = 3.8 ≈ 4.0 mm).

Distance of wide hole:

Based on results of geometric mean diameter (D_g) for all varieties of maize seeds considering from Table 1 to calculate the hole diameter of the vacuum seed plate (do) and hole angle of vacuum seed plate (120^o). Therefore, the distance of wide hole (do = 15.15 ≈ 16 mm) (Equation 6).

Number of holes:

If seed spacing in row for maize seeds is considering 20 cm and when rotational speed of the ground wheel (n_s) equal rotational speed of vacuum seed plate (n_s). The diameter of the ground wheel (0.4 m) and according to (Equation 7) .Then the number of holes on the vacuum seed plate (N) for maize seeds was 13 holes**.**

Pitch circle diameter:

If the diameter of conical hole edges, clearance between holes and number of holes on vacuum seed plate were 15.1 mm, 30.8 mm and 13 holes, respectively. Then the Pitch circle diameter (D_p=190 mm). The pitch circle diameter was estimated from (Equation 8).

Outside diameter:

If the clearance from edge of holes between to outside edges (C_e =30.9) and according to (Equation 8) the outside diameter of the vacuum seed plate D_s = 230mm.

Design parameters and construction cost of the vacuum seed plate:

Fig. 2 indicated that the vacuum seed plate was manufactured from stainless steel 304 with outer diameter D_s = 230mm, circular hole shape, hole diameter (4.0 mm), diameter of conical opening edges (15.1 mm), number of holes (13), pitch circle diameter (190 mm), the clearance from edge of holes between to outside edges (C_e =30.9 mm). The construction cost of single vacuum seed plate was (6 $).

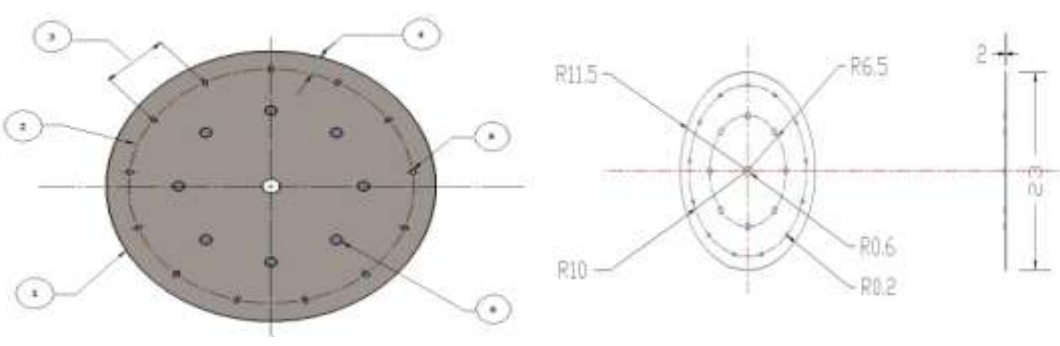

Fig. 2:- Schematic diagram dimensions of holes on vacuum seed plate.

1-Outsidediameter, 2-Pitch circle diameter, 3-Clearance between holes, 4-Clearance from edge of holes to outside edge, 5-Vacuum hole and 6- Mixing device

Effect of the forward speed on the different operating parameters at different levels of hole diameters for developed vacuum seed plate:

The seed miss index:

Fig. 3,a shows the effect of the forward speed on the seed miss index for the developed vacuum seed plate. It shows that, the seed miss index increased as the forward speeds increased at various levels of hole diameters. The lowest values of the seed miss indices were obtained at 2.7 km/h (0.75 m/s) and 3.6 km/h (1.0 m/s) followed by 5.3 km/h (1.47 m/s) forward speeds, respectively (Equation 10). This result due to that the vacuum seed plate at high disc speed does not get enough time to pick up maize seeds, which resulting in higher miss indices. This result is in agreement with the previous finding by Shaaban et al., (2007) and Karayel and Ozmerzi (2002).

The seed multiple index:

Fig.3,b shows the seed multiple index with the developed vacuum seed plate. It shows that, the seed multiple index decreased as the forward speeds increased at various levels of hole diameters The seed multiple indices decreased by 50 % as forward speed increased from 2.7 to 5.3 km/h. These results due to that the vacuum seed plate at low disc speed get enough time to pick up more than one seed, which resulting a higher in multiple indices. These results also are in agreement with previous finding by Barut and Ozmerzi (2004) and Singh et al (2005). Results of the seed multiple index with the forward speed indicates the lowest values were obtained at 3.6 km/h forward speed. However, there was none potential change in the seed multiple indices between 3.6 (1.0 m/s) and 5.3 (1.47 m/s) km/h forward speeds Fig.3,b. These results are in agreement with (Panning et al., 2000).

The quality of feed index:

Fig.3,c shows the effect of the forward speed on the quality of feed index for the developed vacuum seed plate. It shows that the highest values of the quality of feed index were obtained at 3.6 km/h (1.0 m/s) forward speed (Equation 13). These results may be attributed to that the increasing ratio in the seed miss index by increasing forward speed equal the decreasing ratio in the seed multiple index (Fig.3,a and b).

The precision in spacing:

The precision in spacing in relation to different levels of forward speeds for the developed vacuum seed plate are shown in Figure. 4. It indicates that, results of the precision in spacing with different forward speeds showed that the forward speed of 3.6 km/h (1.0 m/s) and hole diameter 4.0 mm gave the lowest values of the precision in spacing and the lowest values of the precision in spacing were obtained at 3.6 km/h followed by 5.3 and 2.7 km/h forward speeds, respectively (Equation 13). This is due to that the highest values of the quality of feed index were obtained at 3.6 km/h (1.0 m/s) forward speed. However, there are no changes in the quality of feed indices between 2.7 (0.75 m/s) and 5.3 (1.47 m/s) km/h forward speeds for the developed vacuum seed plate.

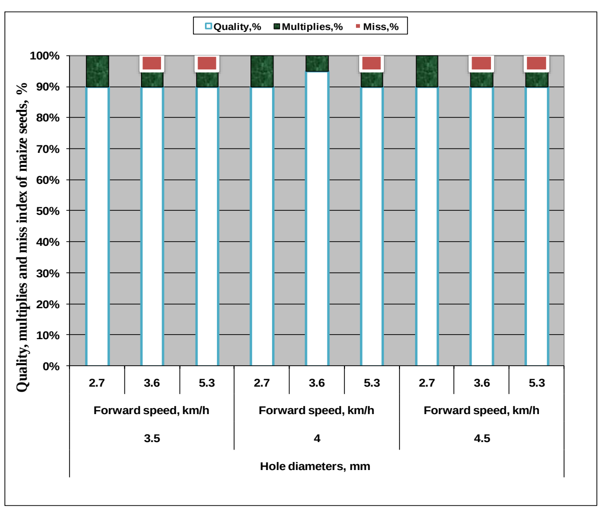

Fig. 3:- Effect of the forward speed on the seed miss index (a), seed multiple index (b) and quality of feed index (c) under different levels of hole diameters.

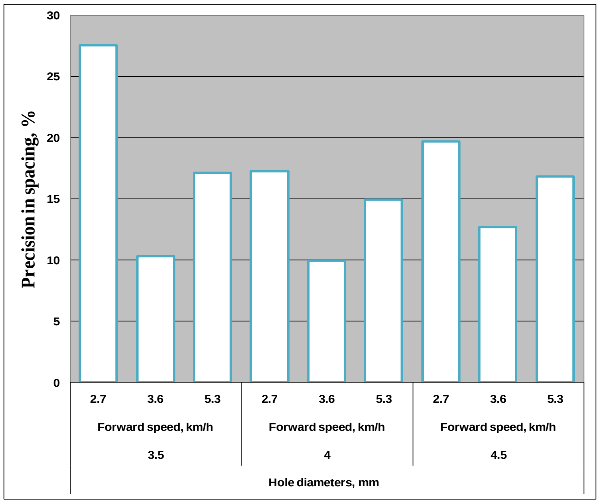

Fig. 4:- Effect of the forward speed on the precision in spacing under different levels of hole diameters.

Conclusion:-

The important results could be summarized as follow:

1. Measured design parameters of the vacuum seed plate were outside diameter 230 mm, pitch circle diameter 190 mm, diameter of conical hole edges 15.1 mm and with a hole diameter 4.0 mm with circular hole shape, 13 holes and the clearance from edge of holes between to outside edges (C_e =30.9 mm).
2. Performance of the developed vacuum seed plate was evaluated under three different forward speed 2.7 ,3.6 and 5.6 km/h (0.75, 1.0 and 1.47 m/s), three different hole diameter of 3.5, 4.0 and 4.5 mm, the entry cone angle (opening angle) of the hole was 120^o and the vacuum pressure was 4.0 kPa.
3. The developed vacuum seed plate could be used successfully based on physical and mechanical properties for maize seeds and must be used the same method of any crop seeds establishment in Egypt before using pneumatic vacuum planters which having the minimum missing and multiple indices with optimum quality of feed index and precision in spacing (coefficient of variation).
4. The construction cost of single vacuum seed plate was (6 $).

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