DETERMINATION OF THE MOISTURE-DEPENDENT PHYSICAL AND AERODYNAMIC PROPERTIES FOR FENUGREEK SEEDS TO PREDICT THE BEST CLEANING SYSTEM

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ABSTRACT

Some physical and aerodynamic properties of fenugreek seeds were measured as a function of moisture content. The data obtained during experiments showed that there were significant deviations in all of the measured parameters for fenugreek seeds. Increasing seeds moisture content from 13 to 27%(w.b) resulted in increasing the average length, width, thickness, geometric mean diameter, seed volume and thousand seed weight from 4.29 to 5.13 mm, 2.97 to 3.11 mm, 1.87 to 2 mm, 2.87 to 3.17 mm, 19.5 to 26.6 mm^3 and 15.6 to 19.2 g respectively, while sphericity and bulk density decreased from 67.4 to 61.9 % and from 800.6 to 722.2 kg/m^3 respectively. The static coefficients of friction on wire mesh screen, the terminal velocity and the projected area increased from 0.43 to 0.56, from 6.6 to 8.11 m/s and from 0.11 to 0.14 cm^2 respectively at the above mentioned moisture content range. A computer program was developed to calculate the number of cleaning stages according to the physical and aerodynamic properties of fenugreek seeds to maximize cleanliness, MOG rejected, separating efficiency and minimize seed loss.

Keywords: Aerodynamic properties, fenugreek seeds, density, terminal

1. INTRODUCTION

Fenugreek (Trigonella foenum-graceum L.) is an annual herb of leguminosea, is being used as spice crop in the entire world. It is used as medicine industry, cosmetic material and food flavor. Fenugreek is known as Greek hay which native to Southern Europe, the Mediterranean region and Western Asia but now is grown as a spice in most parts of the world. The Major fenugreek-producing countries are India, Iran, Egypt and China.

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The seeds and leaves have bitter taste and strong odor which have been used to reduce blood sugar and lower blood cholesterol. Physical and aerodynamic properties of fenugreek seeds are very important factors affecting cleaning, grading, handling and processing machines. El-Nakib and Abdel-Galil (2008) determined physical and mechanical properties of fenugreek seeds to develop and evaluate rotating screen separator for grading and cleaning fenugreek seeds. The separating efficiency increased by increasing the angular velocity of the horizontal cylindrical sieve (about 7% less than the critical velocity). The optimum parameters for separating fenugreek seeds under the specific conditions of this study were screen speed of 140 r.p.m, feed rate of 5 kg/h and screen slope of 0°. Hanna (2003) reported that after threshing medicinal and aromatic plants, the seeds usually consist of heterogeneous mix of stems, leaves, chaff, (MOG) and seeds of various size and quality. The traditional method for cleaning medicinal and aromatic seeds is by tossing the mixture of seeds and chaff through a current of air so that the light material other than grain (MOG) will be blown away from the heavier seeds. In this method the loss will be high about 30% and cleanliness will be low. Altuntas et al. (2005) evaluated some physical properties of fenugreek seeds as a function of moisture content to optimize the equipment design for harvesting, handling, storing and other processes of fenugreek seed. The average length, width, thickness, geometric mean diameter and unit mass of the seed ranged from 4.01 to 4.19mm, 2.35 to 2.61mm, 1.49 to 1.74mm, 2.40 to 2.66mm and 0.0157 to 0.0164g as moisture content increased from 8.9% to 20.1% (d.b). respectively. This research was carried out (1) To study the effect of seeds moisture content on the physical and aerodynamic properties of fenugreek seeds such as length, width, thickness, geometric mean diameter, projected area, sphericity, thousand seed weight, bulk density, seed volume, coefficient of friction and terminal velocity. (2) To develop a computer program for determining the number of cleaning stage for fenugreek seeds and to calculate Seed loss, MOG rejected, Cleanliness, Separating efficiency and Machine effectiveness after all cleaning stages.

2. MATERIAL AND METHODS

Fenugreek seeds used in these experiments were collected after manual harvesting and threshing in Tanta, Egypt at moisture content of 13 % (wb). The moisture content of the seeds was estimated by oven drying at

105 ± 1 °C for 24h (Suthar & Das, 1996). The desired moisture levels (16, 20 and 27%) were equipped by adding calculated amounts of water in samples and then putting in polyethylene bags. The samples were left in a refrigerator for 7day at 5 °C. The seed length, width and thickness were determined using a vernier caliper with accuracy of 0.1mm. Sample of 100 randomly selected seeds from each of the four moisture levels were used to determine the grain dimensions. The seed geometric mean diameter (Dg) in mm and sphericity(Sp) in percent were calculated using the following relationships given by (Ndirika and Oyeleke, 2005).

$$Dg = \sqrt[3]{L \times W \times T} \quad (1)$$

$$Sp = ((\sqrt[3]{L \times W \times T})/L) \times 100 \quad (2)$$

Where: L, W and T are length, width and thickness of the seed in mm respectively.

The volume of fenugreek seeds in mm^3 was determined from the following relationship given by özarslan (2002):

$$V = m/\rho_k \quad (3)$$

Where: V, m and ρ_k are seed volume in m^3, seed unit mass in Kg and the kernel density in Kg/m^3 respectively.

The thousand seed Weight was determined by an electronic balance with an accuracy of 0.001 g. Ten samples of 1000 seeds were counted by hand to determine the thousand kernel weight. The terminal velocity of fenugreek seeds was measured by using the terminal velocity apparatus as shown in Fig.(1). which consists of a 2 m vertical transparent plexi glass tube with diameter of 192.3 mm. The air was provided to the vertical tube to suspend the seed in an air stream by a suction blower fan powered by an electric motor. The mean air velocity in the transparent tube was determined by an electronic manometer at a measuring orifice.

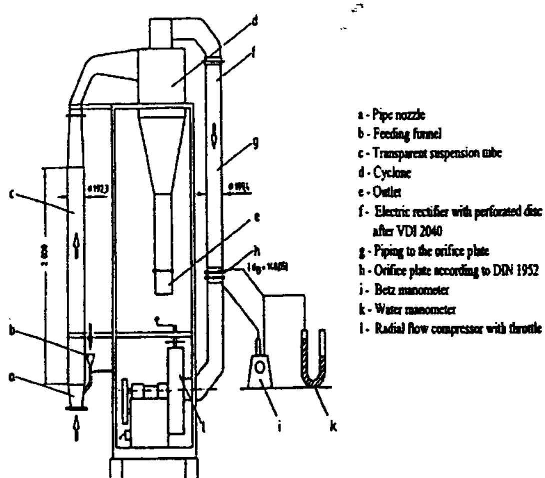


Fig. (1): Terminal velocity apparatus (El-Sayed et al; 2001).

The test was carried out by putting 100 g sample into the feeding funnel. The air velocity was increased by opening the fan throttle manually. Each air velocity was left two minutes until the particles appear through the transparent tube which was carried to outlet through the cyclone. The particles were collected to determine the separated seeds, (%) at each air velocity. The test was continued until no material remaining in the pipe nozzle (El-Sayed et al; 2001).

The bulk density of the seeds was determined by using bulk density cylinder. Ten samples were selected at each moisture content level to determine the bulk density. The seeds were weighted and packed into cylinder with known volume (Beck, 1991). The bulk density of the seeds was calculated as follows:

$$Bd = \frac{Sw}{Sv} \qquad (4)$$

Where: Bd, Sw and Sv are the bulk density in Kg/m^3, seed weight in Kg and seed volume in m^3

The coefficient of friction of the seeds on wire mesh screen was determined by using friction angle measuring device which consists of sliding surface and optical cell. Samples of 50 randomly selected seeds of each moisture content level were selected to determine the friction angle. A seed was placed between light source and receiver of an optical cell so that the receiver didn't receive any light and the sliding surface was automatically tended vertically until the kernel just start to slide. At this moment the receiver received light from the light source and the sliding surface was stopped at known angle (Beck, 1991).

The coefficient of friction of the material was determined as follows:

$$\mu = \tan \varnothing \qquad (5)$$

Where: μ and $\varnothing$ are the coefficient of friction and the angle between the sliding surface and the horizontal level in degrees

The projected area of the whole grains was determined by using (Image Processing and Pattern Recognition System). After calibrating the system a sample of 100 seeds was placed on the white surface under Kodak color camera which takes digital image. Software Image Editor analyzed the digital image to calculate surface area of the seed.

3. RESULTS AND DISCUSSION

The data obtained during the measurements showed that there were deviations in all of the measured parameters for fenugreek seeds, the most deviation was found for projected area at moisture content of 13% with coefficient of variation of 14.16% while the least deviation was the thousand seed weight at moisture content of 16% with coefficient of variation of 0.14% as shown in table 1.

1- Dimensions

Increasing seeds moisture content from 13 to 27% (w.b) resulted in increasing the average length, width, thickness and geometric mean diameter, mm from 4.29 to 5.13 mm, 2.97 to 3.11 mm, 1.87 to 2 mm and 2.87 to 3.17, mm respectively as shown in Fig. (2).The relationship between seeds moisture content and each of average length, width, thickness and geometric mean diameter can be represented by linear regression equations: $(13 \leq M.C. \leq 27\%)$

$L = 0.059M + 3.50$ $(R^2 = 0.99)$ (6) $W = 0.009M + 2.85$ $(R^2 = 0.98)$ (8)

$T = 0.008M + 1.76$ $(R^2 = 0.97)$ (7) $G = 0.020M + 2.61$ $(R^2 = 0.99)$ (9)

where: L, W, T, G and M are length, width, thickness, geometric mean diameter in mm and moisture content, % respectively.

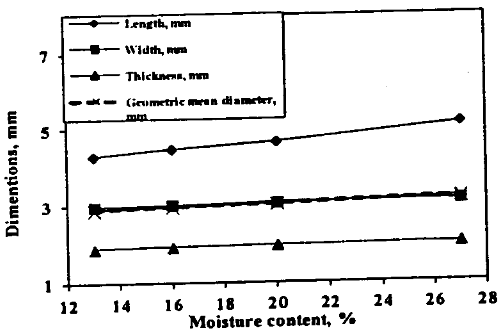


Fig. (2): Effect of moisture content on average length, width, thickness and geometric mean diameter.

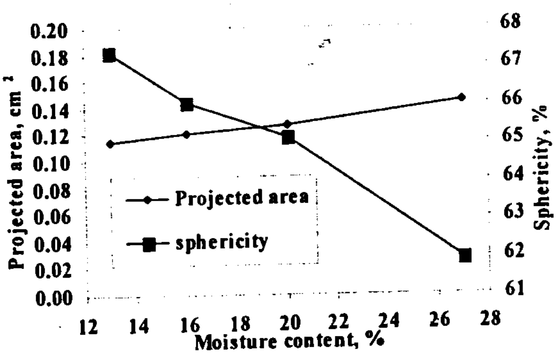


Fig. (3): Effect of moisture content on average Projected area and sphericity.

2- Projected area (Sa)

Increasing seeds moisture content from 13 to 27% (w.b) resulted in increasing the average projected area linearly from 0.114 to 0.144 cm^2 as shown in Fig. (3). The linear relationship can be represented by the regression equation:

$Sa = 0.0021M + 0.086$ $(R^2 = 0.98)$ $(13 \leq M.C. \leq 27\%)$ (10)

A mathematical equation was concluded from the measured seed length and width to estimate projected area of the seed:

$Sa = (0.9\ L\ .\ W)$ $(13 \leq M.C. \leq 27\%)$ (11)

where : Sa, L and W are surface area, length and width respectively.

3- Coefficient of friction (μ)

Increasing seeds moisture content from 13 to 27% (w.b) resulted in increasing the average coefficient of friction on wire mesh screen linearly from 0.43 to 0.56 as shown in Fig. (4). The relationship can be represented by linear regression equation:

$\mu = 0.009M + 0.301$ $(R^2 = 0.973)$ $(13 \leq M.C. \leq 27\%)$ (12)

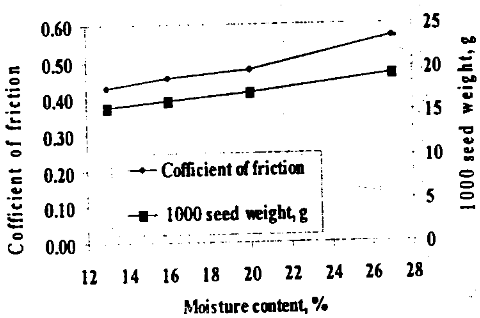


Fig. (4): Effect of moisture content on average coefficient of friction and 1000 seed weight.

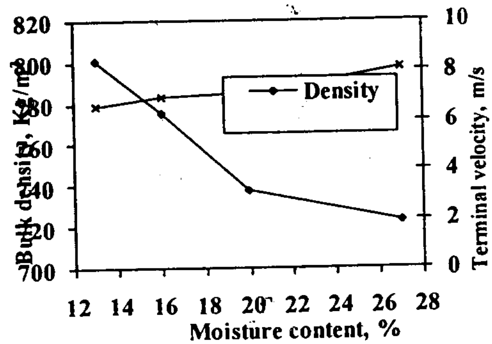


Fig. (5):Effect of moisture content on average bulk density and terminal velocity.

4- Thousand seed weight (TSW)

Increasing seeds moisture content from 13 to 27 % (wb) resulted in increasing the average thousand seed weight from 15.62 to 19.22, g as shown in Fig. (4). The relationship can be represented by linear regression equation:

$TSW = 0.253M + 12.32$ $(R^2 = 0.99)$ $(13 \leq M.C. \leq 27\%)$ (13)

5- Sphericity (S_p)

Increasing seeds moisture content from 13 to 27 % (wb) resulted in decreasing seeds sphericity from 67.4 to 61.9 % as shown in Fig. (3). The relationship can be represented by linear regression equation:

$S_p = -0.38M + 72.371$ $(R^2 = 0.98)$ $(13 \leq M.C. \leq 27\%)$ (14)

6- Bulk density (B_d)

Increasing seeds moisture content from 13 to 27% (w.b) resulted in decreasing the average bulk density linearly from 800.6 to 722.2 kg/m^3 as shown in Fig. (5). The relationship can be represented by linear regression equation:

$B_d = -5.58M + 865.26$ ($R^2 = 0.90$) ($13 \leq M.C. \leq 27\%$) (15)

7- Terminal velocity (T_v)

Increasing seeds moisture content from 13 to 27% (w.b) resulted in increasing the average terminal velocity linearly from 6.6 to 8.11 m/s as shown in Fig. (5). The relationship can be represented by linear regression equation: $T_v = 0.10M + 5.19$ ($R^2 = 0.96$) ($13 \leq M.C. \leq 27\%$) (16)

Table 1. Physical and aerodynamic properties of Fenugreek seeds (Trigonella foenum-graceum L.).

Parameter	Moisture content 13%					Moisture content 16%				
	Aver	SD	CV,%	Min	Max	Aver	SD	CV,%	Min	Max
Length, mm	4.29	0.48	11.26	3.4	5.5	4.65	0.36	7.82	4.11	4.9
Width, mm	2.97	0.24	7.96	2.5	3.5	3.05	0.24	7.9	2.9	3.4
Thickness, mm	1.87	0.16	8.64	1.5	2.2	1.94	0.17	8.53	1.8	2.05
Geo mean diam ,mm	2.87	0.18	6.3	2.47	3.29	3.02	0.17	5.73	2.91	3.12
Sphericity,%	67.41	5.13	7.62	58.12	78.96	64.82	4.6	7.1	62.8	67.9
Coefficient of friction	0.43	0.05	12.31	0.41	0.44	0.45	0.05	11.34	0.42	0.46
Projected area, cm^2	0.11	0.02	14.16	0.08	0.15	0.13	0.02	12.91	0.121	0.132
Terminal velocity, m/s	6.6	0.67	10.08	5.20	8.40	6.94	0.58	8.36	5.70	8.00
Thousand seed weight, g	15.68	0.03	0.21	15.20	16.50	16.36	0.02	0.14	16.10	16.66
Density kg/m^3	800.6	0.94	1.18	749	801	775.6	2.03	2.62	773.3	776.3
Volume,mm^3	19.59	0.98	5	19.1	20.14	21.09	2.05	9.73	20.1	22.21
Parameter	**Moisture content 20%**					**Moisture content 27%**				
	Aver	**SD**	**CV,%**	**Min**	**Max**	**Aver**	**SD**	**CV,%**	**Min**	**Max**
Length, mm	4.69	0.42	8.97	4	5.6	5.13	0.4	7.84	4.3	6
Width, mm	3.06	0.23	7.45	2.5	3.5	3.11	0.26	8.28	2.5	3.7
Thickness, mm	1.95	0.17	8.81	1.6	2.3	2	0.16	8.16	1.7	2.4
Geo mean diam ,mm	3.02	0.17	5.56	2.71	3.34	3.17	0.17	5.32	2.79	3.61
Sphericity, %	65.13	3.86	5.92	58.47	74.38	61.93	4.81	7.76	53.49	78.31
Coefficient of friction	0.48	0.05	10.36	0.47	0.49	0.57	0.08	13.83	0.55	0.58
Projected area, cm^2	0.13	0.02	12.43	0.094	0.157	0.14	0.02	12.15	0.098	0.205
Terminal velocity, m/s	7.11	0.69	9.71	5.70	8.30	8.11	0.81	9.93	7.00	10.00
Thousand seed weight, g	17.31	0.02	0.12	17.10	17.53	19.22	0.04	0.22	18.70	19.69
Density kg/m^3	737.8	1.53	2.07	719	760	722.2	1.36	1.88	702	733
Volume,mm^3	23.46	1.55	6.6	23.15	24.32	26.61	1.4	5.25	26.19	26.95

8- Volume (V)

Increasing seeds moisture content from 13 to 27% (w.b) resulted in increasing seed volume linearly from 19.59 to 26.61 mm^3 which can be represented by linear regression equation:

$$V = 0.505\ M + 13.09 \qquad (R^2 = 0.996) \qquad (13 \le M.C. \le 27\%) \qquad (17)$$

A mathematical equation was concluded from the measured seed length, width and thickness to estimate seed volume:

$$V = 0.92\ (L.W.T) \qquad (13 \le M.C. \le 27\%) \qquad (18)$$

where : V, L, W and T are seed volume in mm^3, length, width and thickness in mm respectively. According to the measured physical and aerodynamic properties of Fenugreek seeds at different moisture content the minimum values of seed dimensions, volume, thousand seed weight, terminal velocity and coefficient of friction were at moisture content of 13 % (wb) as shown in Table (1). Since it is easier to clean, grade and handle seeds at smallest volume, weight and air velocity. Besides, at minimum moisture content, seeds damage does not occur fast as in higher moisture contents. The frequency distribution curves for thickness of seeds and MOG were used to determine the best thickness to separate big MOG from the seed as shown in Fig.(7).

The frequency distribution curves for width of seeds and MOG were used to determine the best width to separate to separate small MOG from the seed as shown in Fig.(6). The best thickness and width were used to design upper screen shoe slotted perforation (2.5X20 mm) and lower

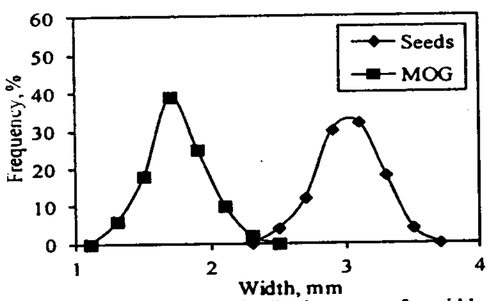


Fig. (6): Frequency distribution curves for width of seeds and MOG.

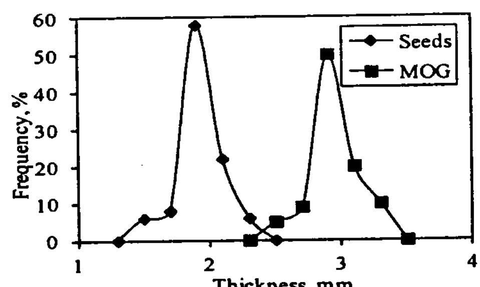


Fig. (7): Frequency distribution curves for thickness of seeds and MOG.

screen shoe round perforation (2.5mm diameter). The frequency distribution curves for terminal velocity of seeds, heavy MOG and light MOG were used to determine the best air velocities to separate heavy

MOG and light MOG from the seed as shown in Fig .(8). The best high speed air velocity was 8.4 m/s which used to separate seeds from heavy MOG. The best low speed air velocity was 5.2 m/s which used to separate light MOG from the seed.

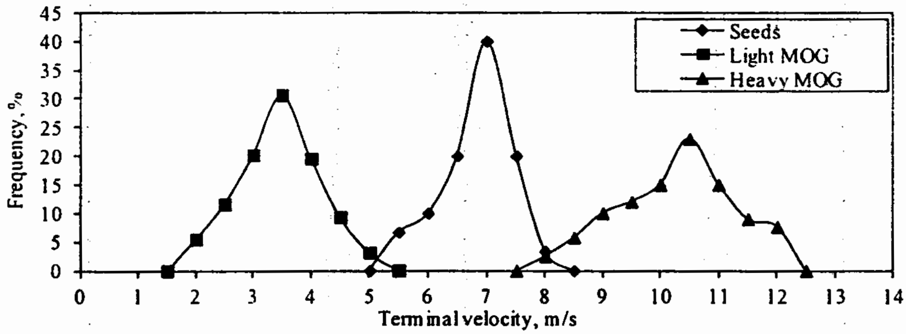


Fig. (8): Frequency distribution curves for terminal velocities of seeds, heavy MOG and light MOG.

9- The computer program:

A computer program was developed by C programming language which consists of two steps. The first step was developed to determine the number of cleaning stage for fenugreek seeds. The first cleaning stage consists of aerodynamic separation unit with high speed air velocity. The program compare between the separating efficiency after the first stage and the objected separating efficiency. If separating efficiency after the first stage is higher than the objected separating efficiency, so the first cleaning stage is enough to clean fenugreek seed. If a separating efficiency is lower than the objected separating efficiency, the seed need a second cleaning stage of aerodynamic separation with low speed air velocity. In the second stage the program makes a decision to determine if two stages are enough or extra third stage of slotted openings sieve is needed. In the third stage the program decides if three stages are enough or extra forth stage of round openings sieve is needed. In the forth stage the program decides if the seed need four stages or to repeat them one more time to reach the objected separating efficiency. 2- The second step to calculate Seed loss, MOG rejected, Cleanliness, Separating efficiency and Machine effectiveness after all cleaning stages

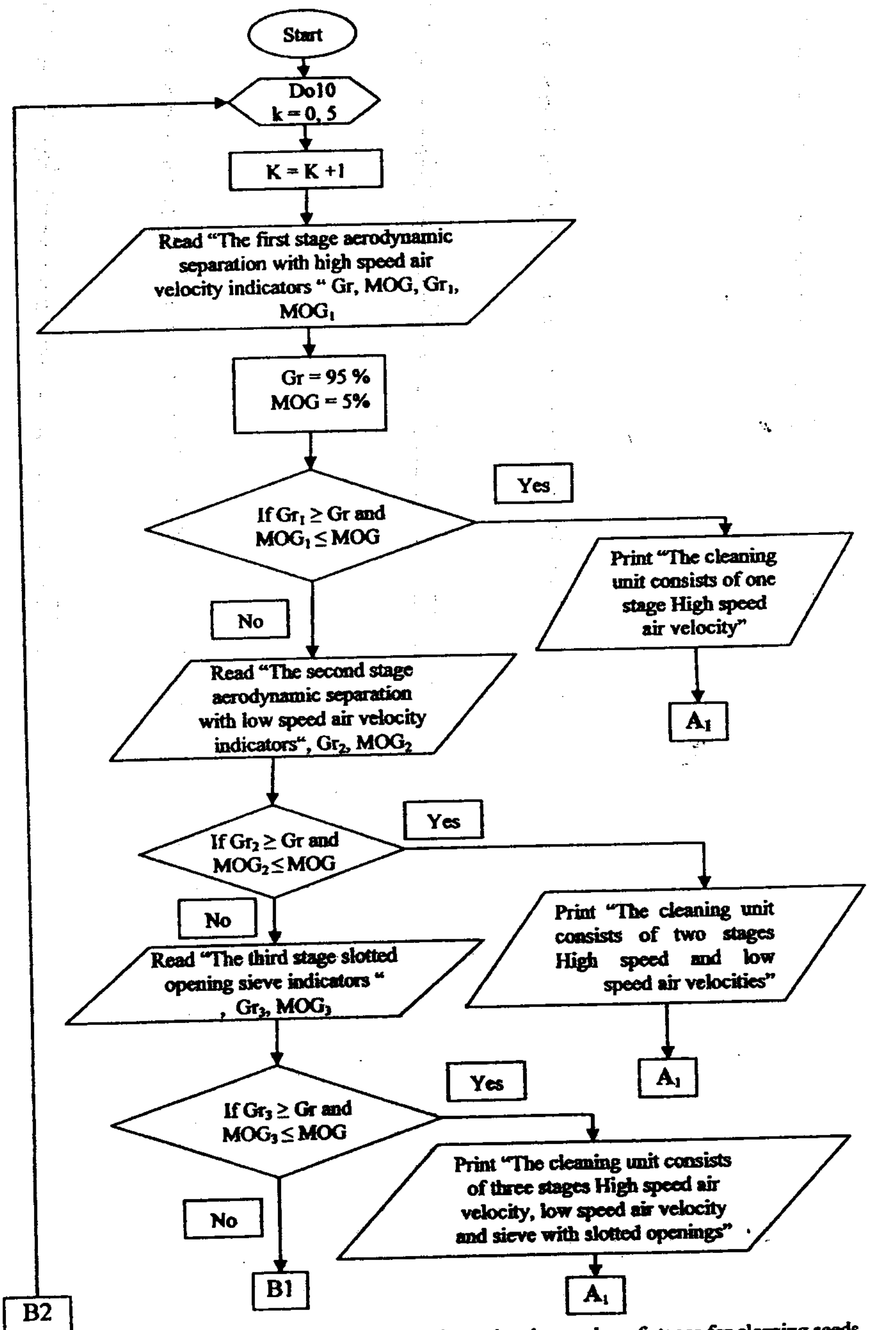
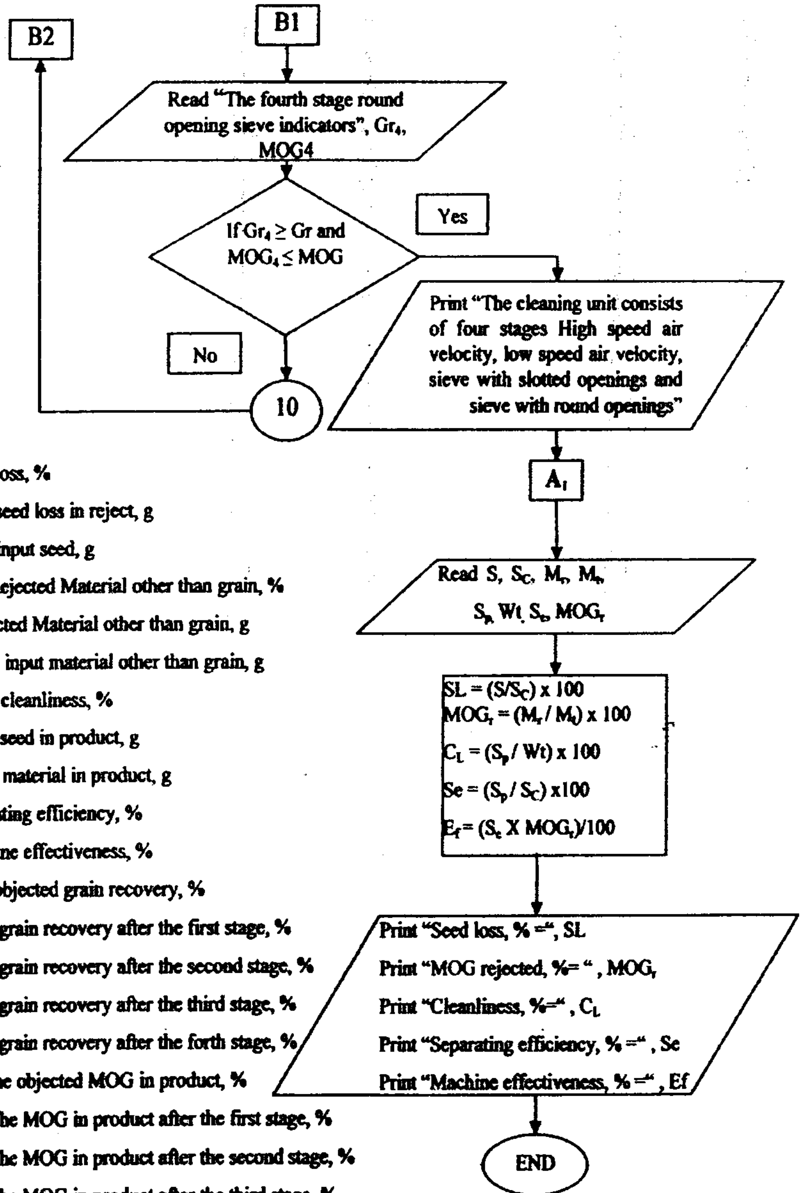


Fig. (9): The first step of program flowchart to determine the number of stages for cleaning seeds.



Where:

S_L = Seed loss, %

S = Total seed loss in reject, g

S_c = Total input seed, g

MOG_r = Rejected Material other than grain, %

M_r = Rejected Material other than grain, g

M_t = Total input material other than grain, g

C_L = Seed cleanliness, %

S_p = Clean seed in product, g

Wt = Total material in product, g

S_e = Separating efficiency, %

Ef = Machine effectiveness, %

Gr = The objected grain recovery, %

Gr_1 = The grain recovery after the first stage, %

Gr_2 = The grain recovery after the second stage, %

Gr_3 = The grain recovery after the third stage, %

Gr_4 = The grain recovery after the forth stage, %

MOG = The objected MOG in product, %

MOG_1 = The MOG in product after the first stage, %

MOG_2 = The MOG in product after the second stage, %

MOG_3 = The MOG in product after the third stage, %

MOG_4 = The MOG in product after the forth stage, %

Fig. (10): The second step of program flowchart to determine machine performance.

The suggested computer program can be used in case of applying a computer numerical control system (CNC) provided by a specific program containing coded alphanumeric data which control the functions and motion stages of the cleaning machine. The CNC system can measure seed and MOG percent after each cleaning stage of the four cleaning stages and convert them to input data required by the suggested program to decide through "if statement" whether the desired cleaning conditions are satisfied or not.

4. CONCLUSIONS

The measurements of physical and aerodynamic properties of fenugreek seeds showed that increasing seeds moisture content from 13 to 27% (w.b) resulted in increasing the average length, width, thickness, geometric mean diameter, seed volume, thousand seed weight, coefficients of friction on wire mesh screen, terminal velocity and projected area while resulted in decreasing sphericity and bulk density. The best moisture content for the seed was 13 % (wb), because the minimum values of seed dimensions, volume, thousand seed weight, terminal velocity and surface area were at this moisture content so that it is easier to clean, to grad and to handle the seed. A suggested computer program was developed to calculate the number of cleaning stages according to the measured physical and aerodynamic properties of fenugreek seeds to maximize cleanliness, MOG rejected, separating efficiency and minimize seed loss. The best cleaning system for fenugreek seeds consists of: 1- Aerodynamic separation unit with air velocity of 8.4 m/s to separate the seed from heavy MOG

2- Aerodynamic separation unit with air velocity of 5.2 m/s to separate light MOG from the seed 3- Sieve layer 1- upper screen shoe slotted perforation (2.5X20 mm) to separate big MOG 4- lower screen shoe round perforation (2.5mm diameter) to separate small MOG.

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الملخص العربي

دراسة تأثير المحتوي الرطوبي علي الخصائص الطبيعية و الأيروديناميكية لبذور الحلبة والتنبؤ بأفضل نظام لتنظيف البذور

د/ هيثم حسين يوسف محمد*

الحلبة عشب حولي يتبع العائلة البقولية موطنة الأصلي جنوب أوروبا و غرب أسيا و منطقة البحر المتوسط و هو نبات ذو اهمية كبري حيث يستخدم كتوابل و في الصناعات الدوائية و في صناعة مستحضرات التجميل

أجري هذا البحث من أجل ١- دراسة تأثير المحتوي الرطوبي علي الخصائص الطبيعية و الأيروديناميكية لبذور الحلبة كالطول و العرض و السمك و المتوسط الهندسي لقطر الحبة و مساحة السطح و الكروية و وزن الألف حبة و الكثافة الظاهرية، وحجم البذرة و ومعامل الاحتكاك والسرعة النهائية. ٢- تصميم برنامج كمبيوتر للتنبؤ بأفضل الة لتنظيف البذور من حيث عدد و انواع مراحل التنظيف و حساب معايير أداء الألة بعد عملية التنظيف. و قد تم استخدام بذور حلبة ذات محتوي رطوبي١٣% علي الأساس الرطب بعد الحصاد. تم تجهيز محتويات رطوبية جديدة ١٦ و ٢٠ و ٢٧ % للحصول علي اربع مستويات للمحتوي الرطوبي.

ادي زيادة المحتوي الرطوبي من ١٣الي ٢٧ % الي زيادة الطول من ٤.٢٩ الي ٥.١٣ مللي و زيادة العرض من ٢.٩٧ الي ٣.١١ مللي و زيادة السمك من ١.٨٧ الي ٢ مللي و المتوسط الهندسي للقطر من ٢.٨٧ الي ٣.١٧ مللي و زيادة حجم الحبة من ١٩.٥ الي ٢٦.٦ مللي^{٣} و زيادة وزن الألف حبة من ١٥.٦ الي ١٩.٢ جرام و زيادة معامل الأحتكاك للحبوب علي سطح مصنوع من السلك المعدني من ٠.٤٣ الي ٠.٥٦ و زيادة السرعة النهائية للحبوب من ٦.٦ الي ٨.١١ متر/ث و زيادة مساحة سطح الحبة من ١١ الي ١٤ مللي^{٢} بينما حدث انخفاض في كرو ية الحبوب من ٦٧.٤ الي٦١.٩ % و كذلك حدث انخفاض في الكثافة الظاهرية للحبوب من ٨٠٠.٦ الي ٧٢٢.٢ كجم/متر^{٣} . و قد اوضحت النتائج ان افضل محتوي رطوبي للحبوب عند ١٣% حيث تكون البذور اصغر في الأبعاد و اقل في الحجم و كذلك اقل في الوزن بالتالي تكون اسهل في التداول و في عمليات التنظيف المختلفة و كذلك لا يحدث تلف سريع للبذور كما في باقي المحتويات الرطوبية الأعلي.

تم تصميم برنامج كمبيوتر للتنبؤ بافضل الأنظمة المستخدمة في التنظيف و ذلك بعد قياس الخصائص الطبيعية و الأيروديناميكية للبذور و كانت اهم هذة الخصائص عرض البذور و سمك لبذور و السرعة النهائية للبذور.

و اتضح من التجارب أن افضل نظام لتنظيف بذور الحلبة يتكون من :

١- وحدة تنظيف هوائي سريع علي سرعة ٨.٤ متر/ ث لفصل الشوائب ثقيلة الوزن

٢- وحدة تنظيف هوائي بطيئ علي سرعة ٥.٢ متر/ ث لفصل الشوائب خفيفة الوزن

٣- وحدة للتنظيف علي اساس سمك البذرة تتكون من غربال ذو فتحات طولية (٢.٥*٢٠ مللي) بحيث تمر من خلالة البذور و تفصل علي سطحة الشوائب كبيرة الحجم

٤- وحدة للتنظيف علي اساس عرض البذرة تتكون من غربال ذو فتحات دائرية (قطر2.5مللي) بحيث تمر من خلالة الشوائب صغيرة الحجم و تفصل علي سطحة البذور النظيفة.

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