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Development and Performance Evaluation of a Summer Squash Seed Extracting Machine

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Abstract: A low-cost summer squash (*Cucurbita pepo* L.) seed extraction machine was locally designed, manufactured and evaluated. Seed extraction by the machine was conducted by first crushing the vegetables, then separating seeds from flesh, skin and other vegetable materials. The performance of the developed machine was evaluated based on seed loss, broken seeds, machine extraction efficiency and specific energy requirements. The evaluation was conducted at different operation conditions including different crushing drum speeds (ranging from 5.23 to 9.16 m/s), feed rates (ranging from 300 to 1200 kg/h) and wet-based (wb) vegetable moisture contents (MC) (ranging from 82.03 to 93.54%). Results revealed that the seed loss was proportional to the feed rate and inversely proportional to the MC. At all other variable levels, the minimum loss was found at a drum speed of 6.54 m/s. The broken seeds, however, were found to decrease with increasing feed rate and MC and increase with increasing drum speed. The maximum percentage of broken seeds was less than 1.3. For the extraction efficiency, it was found to be proportional to the MC and inversely proportional to the feed rate approaching its maximum value at a 6.54 m/s drum speed with all other variable levels. For all values of drum speed and feed rate, the specific energy required by the machine was found to be inversely proportional to the vegetable MC. At a specific MC, the specific energy was found to be proportional to drum speed and inversely proportional to feed rate. Increasing the feed rate from 300 to 1200 kg/h decreased the required energy from 83 to 38 kW.h/t. Operation cost analysis showed that the extraction cost by the machine was at 20.83 $/ton compared to 192 $/ton for manual seed extraction, hence, a saving of above 89% can be achieved using the developed machine.

Key words: Summer squash · Seed extraction · Operation conditions · Performance evaluation · Extraction cost

INTRODUCTION

Summer squash (*Cucurbita pepo* L.) is a very popular vegetable in Egypt, where the current cultivated area of this crop reached above 42000 ha [1]. Summer squash is cultivated for different reasons, one of them is to extract the seeds to be used and marketed as edible seeds, where an average seed yield of 1.1 t/ha can be obtained [1]. This agricultural product (summer squash seeds) is considered in Egypt to have a satisfying commercial value and a potential to be exported as a commercial commodity.

Seed from the summer squash can be extracted using either a dry or a wet method. In the dry method, the dried vegetable is cut from one side where the seeds can flow out. However, the vegetable in the wet method is cut longitudinally and seeds are scooped out. In the wet method, seed extraction can be either mechanical, by natural fermentation or chemical extraction [2].

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Efforts have been made by several researchers to mechanize the process of handling various agricultural products. However, a deep knowledge in the physical and mechanical properties of these products is important to be available in order to develop suitable processing machines [3]. Physical properties of twenty different fruits were determined and an equation was produced to calculate the surface area and the volume of a particular fruit given that the mass or the mean diameter of the fruit was known [4]. A study on the engineering characteristics of pumpkin seeds and hulls, such as dehulling load, surface roughness, transport velocity and densities was carried out [5]. Results showed that it was feasible to mechanically dehull the seeds by a system in which the sharp tips of the seeds impinge on a hard surface. Differences in seeds properties such as surface roughness, densities and transport velocities were used to separate kernels, hulls and any unhulled seeds. An attempt was made to determine the physical properties of guna seeds as a function of moisture content. As the moisture content increased from 4.7 to 39.3% dry-based (db), true and bulk densities decreased from 870 to 680 kg/m^3 and from 544 to 400 kg/m^3, respectively; however, the coefficient of static friction was found to increase from 0.41 to 0.98 over the surface of different materials [6].

The productivity of hand extraction can be as low as 29 fruits/h compared to manual extracting machine prototype and motorized machine, where the productivity was 458 fruits/h and 2390 fruits/h, respectively [3]. Therefore, several attempts have been made to mechanize seed extraction in order to lower the dependence on human labor in performing this operation. A mechanical seed extractor was developed and tested which reduced the extraction cost by 50% compared to manual extraction[7]. The performance of an axial-flow vegetable seed extracting machine was developed and evaluated, which was found to be suitable for wet seed extraction of most Indian vegetables [8]. The germination of seeds extracted with this machine was higher than that of manually extracted ones. The performance evaluation of a guna seed extractor showed that the fruit moisture content, material feed rate and machine speed had a significant effect on its performance indices [9]. A watermelon seed extraction machine exhibited its proper performance at a crushing drum speed of 4.7 m/s, clearance concave of 24 mm and with eight cleaning brushes rotating at a peripheral speed of 4.7 m/s [10]. At these operating conditions, the productivity reached up to 217.4 kg/hr, the cleaning efficiency was as high as 84.7%, the percentages of visible seed damage and seed loss were 0.398 and 3.83, respectively. A tomato seed extractor that utilized the squeezing action of a screw auger resulted in seed extraction efficiency of up to 98.8%. [11]. The efficiency of an extraction machine increased from 95.5% to 99.1% by increasing the chopping drum speed from 3.75 m/s to 5.7 m/s [12]. However, the seed loss was also increased by increasing the chopping drum speed.

Despite the fact that it is costly, low productive, slow and time consuming process, manual seed extraction is still the dominant procedure in Egypt. Mechanization of seed extraction can play a pivotal and essential role in eliminating or, at least, greatly decreasing the drawbacks associated with manual extraction. Unfortunately, seed extraction machinery that can be used for summer squash is not available in Egypt. Moreover, imported machines are expensive and inefficient as they were not designed to suit most Egyptian fruits, vegetables and seed properties. Therefore, the overall goal of this study was to develop and test the performance of a summer squash seed extracting machine. However, the specific objectives include the following:

- To design and locally fabricate a summer squash seed extraction machine that is able to perform vegetable cutting, seed separation from flesh and skin and skin releasing.
- To evaluate the extraction performance of the developed machine under different operation conditions.
- To compare the extraction costs using the developed machine with that of manual extraction method of summer squash seeds.

MATERIALS AND METHODS

Determination of Summer Squash Vegetable and Seed Properties: In order to study the physical and mechanical properties of summer squash (Fig. 1) vegetables and seeds that influenced its mechanical cutting and seed extraction, a sample of 100 vegetables selected randomly from different farms and zones at Kafr El-Sheikh Governorate, Egypt was used. The determined properties, shown in Table 1, were measured in a laboratory at the Rice Mechanization Center (RMC), Meet El-Dyba, Kafr El-Sheikh, according to the standard methods [13].

Fig. 1: A photographic view of summer squash vegetables.

Table 1: Main characteristics of the tested summer squash vegetable sample.

Characteristics	Average ± Sd
1. Dimensions:	
a) summer squash vegetable:	
-Length (mm)	250.2 ± 14.0
-Intermediate diameter (mm)	90.9 ± 4.8
b) summer squash seed:	
-Length (mm)	19.6 ± 2.1
-Width (mm)	9.4 ± 0.6
-Thickness (mm)	2.8 ± 0.5
2. Mass:	
-Mass of summer squash vegetable (g/vegetable)	1408 ± 99.74
-Mass of seed (g/vegetable)	187.55 ± 17.20
-Seed/vegetable ratio	0.134 ± 0.0173
3. Volume of vegetable (cm^3)	2600 ± 141.42
4. Density of vegetable (g/cm^3)	0.546 ± 0.01
5. Coefficient of friction against metal	0.856 ± 0.662

Fabrication of the Extraction Machine: The developed seed extraction machine was manufactured at a local workshop in Kafr El-Sheikh, while the preliminary tests and calibrations were conducted at the workshop of the RMC. A schematic diagram of the machine is depicted in Fig. 2. The machine was designed to perform seed extraction by first crushing the vegetable, separating seeds from flesh and other vegetable materials and then releasing the skin. A combination of impact and rubbing actions was proposed to accomplish the seed extraction process. Based on the proposed combination of action, the machine was designed to include the following major components:

A drop type hopper that was designed to deliver the vegetables by gravity through an orifice to a revolving drum. The trapezoidal shape hopper had a rectangular intake upper opening of 300 × 200 mm and an outlet base square opining of 200 × 200 mm.

A crushing drum with the dimensions of 250 mm in diameter and 600 mm in length was fabricated using 3 mm thick galvanized steel sheets. A steel drive shaft of 50 mm diameter mounted on two journal bearings at each end of the machine main frame was utilized to run the drum. The crushing drum was composed of three main components. The first component to receive the vegetables contained eight cutting knives mounted at an angle on the circumference of the drum at equal distances in a helical arrangement. These knives stroke the vegetables as they were displaced not only in the plane of the drum rotation, but also in its knife axial direction. Hence the crushed vegetable parts were forced to transport through a gap between a concave and the drum to a central location on the drum. The second component of the drum, placed at the central location, was designed to perform the separation process. Rubber cleaning brushes with the size of 250 × 20 mm and 25 mm thick were fitted in the central

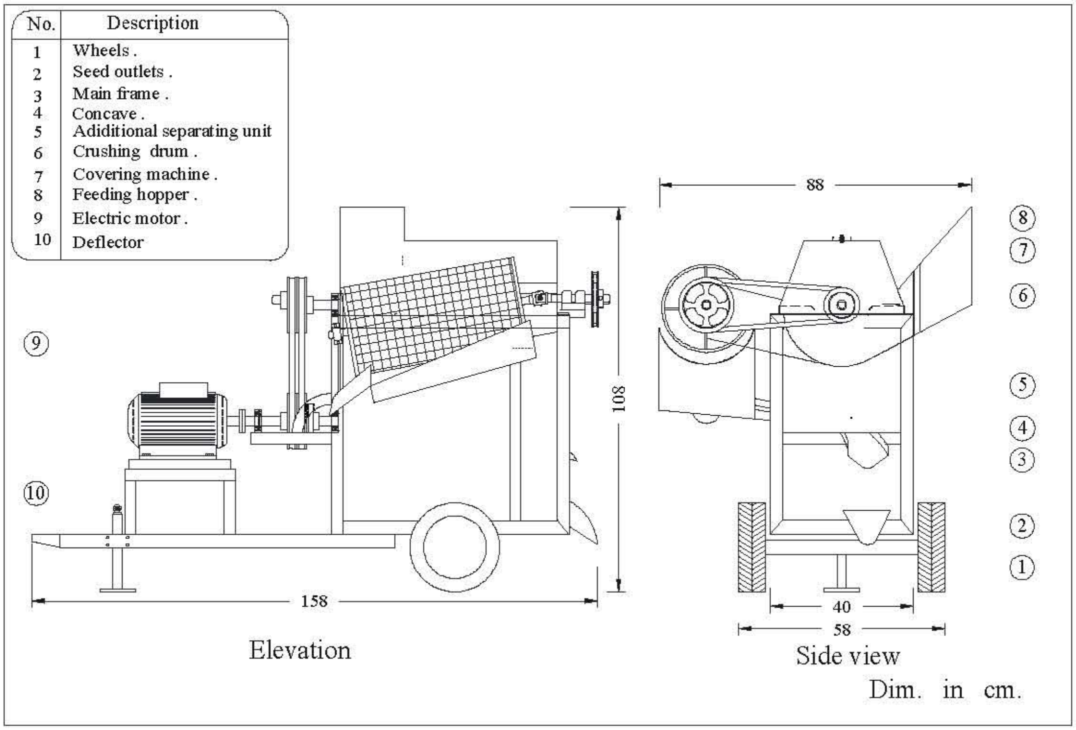

Fig. 2: Main assembly of the developed machine.

area of the drum in a helical arrangement. The repeated impact and rubbing actions of these brushes on the crushed mass caused most of the seeds (nearly 80%) to be separated from the vegetables. The extracted seeds fell through openings in a concave into a collecting transition channel down to the delivery chute, which was fabricated from a mild steel plate. The third component at the end of the crushing drum contained a number of blades arranged in a straight path on the drum. The purpose of this component was to receive the vegetable skin and pulp mixed with seeds that were not separated at the center portion of the drum. These materials were directed to the blades, which forced them to be routed through a screw to an additional separating drum.

A concave with the size of 700 × 600 mm made from a 3 mm thick steel sheet was fitted right below the crushing drum, where its surface area was covered by a mesh of 25 × 25 mm grids (holes). The holes were designed to allow only the seeds to pass through with all other materials restrained.

An additional separating drum with 250 mm in diameter and 550 mm in length was fabricated from a 3 mm thick steel sheet and designed to be open at both ends. This drum was mainly a cylindrical shape mesh with 25 × 25 mm grids (openings) and mounted where its axle was at a slight (and adjustable) angle of 10° with the horizontal to facilitate movement of the material through its interior. Separation of seeds from the crushed vegetables that were fed into this separation unit at one end of the drum was achieved by the tumbling action of this drum. Separated seeds were collected while pulp and flesh moved axially through the drum and exited at the opposite drum end.

An electric motor with three-phase rated at 7.4 kW and operating at 1400 rpm was utilized to power the extraction machine. Belt and pulley drive arrangement was set-up to transfer power from the motor to the machine.

A steel frame fabricated from 70 × 70 mm steel channels with 7 mm thickness was equipped with two rubber wheels and utilized as a main frame, where a seed collection pan was mounted. A tubular steel frame with a wall thickness of 3.2 mm was designed to serve as a skeleton, on which all other machine components were mounted. The technical specifications of the fabricated prototype are shown in Table 2.

Machine Performance Evaluation: The performance of the developed machine was investigated at four different feeding rates (300, 600, 900 and 1200 kg/hr), four different crushing drum speeds (400, 500, 600 and 700 rpm, converted to 5.23, 6.54, 7.85 and 9.16 m/s, respectively) and four values of wet-based (wb) calculated vegetable

Table 2: Main technical specifications of the developed machine.

Items	Specifications
Overall length (mm)	1580
Total Width (mm)	880
Total Height (mm)	1080
Weight (kg)	312
Source of power	Electric motor
Crushing cylinder length (mm)	600
Drum diameter (mm)	250
Crushing knives dimension (mm)	180 length × 60 height × 10.0 thickness
Hoper dimension (mm)-Upper- Base	300 × 300200 × 200
Separating drum length (mm)	550
Separating drum diameter (mm)	250

moisture content (MC) (82.08, 86.21, 89.73 and 93.45%). A concave clearance of 50 mm and a rotational speed of 70 rpm of the additional separating drum were kept constant at all machine tests. Different levels of summer squash MC were obtained by dividing a quantity of freshly harvested vegetables into four lots which were subjected to different storing periods, hence different MC values were obtained for the different lots. The first lot of fresh vegetables was directly used to be processed by the machine. However, the second, third and fourth lot were processed after 7, 11 and 15 days, respectively, of storing periods.

The criteria of the performance evaluation included broken seeds, seed losses, extraction efficiency and energy requirements. The percentage of broken seeds was calculated using the following formula:

$$\text{Broken seeds (\%)} = \frac{W_b}{W_t} \times 100 \qquad (1)$$

Where:

W_b is the weight of broken seeds (g),
W_t is the total weight of seeds in the sample (g).

However, determining the seed losses involved manually picking up of the seeds, for each treatment, that were mixed with peels and other vegetable materials and weighing collected seeds. The percentage of seed losses was then calculated using the following relationship:

$$\text{Seed losses (\%)} = \frac{W_1}{W_1 + W_2} \times 100 \qquad (2)$$

Where:
W_1 is the weight of seeds mixed with expelled peels and other materials (g),
W_2 is the weight of seeds from the separation system output opening (g).
The efficiency of the machine in seed extraction was calculated according to the following equation:

$$\text{Extraction efficiencey} = \frac{W_2}{W_3} \times 100 \qquad (3)$$

Where:
W_3 is the total weight of seeds contained in the vegetables (g).

In order to estimate the machine power requirements, an ammeter and a voltmeter were utilized to determine the current and the voltage, respectively, from the electric motor during each test treatment. The power consumption was then calculated using the following formula [14].

$$\text{Power consuption (W)} = \sqrt{3}.I.V.\cos\theta.\eta \qquad (4)$$

Where:
I is the electric current (A),
V is the voltage (v),
$\cos\theta$ is the power factor (0.71),
η is the mechanical efficiency of the electric motor (assumed to be 90%).

For each test treatment, the machine specific energy requirement was also calculated using the following formula:

$$\text{Specific energy requirement (kW.hr/t)} = \frac{P}{Pr} \qquad (5)$$

Where:
P is the consumed power (kW),
Pr is the machine productivity (t/hr).

RESULTS AND DISCUSSION

Percentage of Broken Seeds: Data of broken seeds affected by the different operation variables considered is shown in Fig. 3. At given drum speed and moisture content (MC) values, the percentage of broken seeds was observed to decrease with increasing feed rate. For example, an increase in the feed rate from 300 to 1200 kg/hr caused a drop in the percentage of broken seeds from 0.74 to 0.45 at a drum speed of 6.54 m/s and an MC of 89.73%.

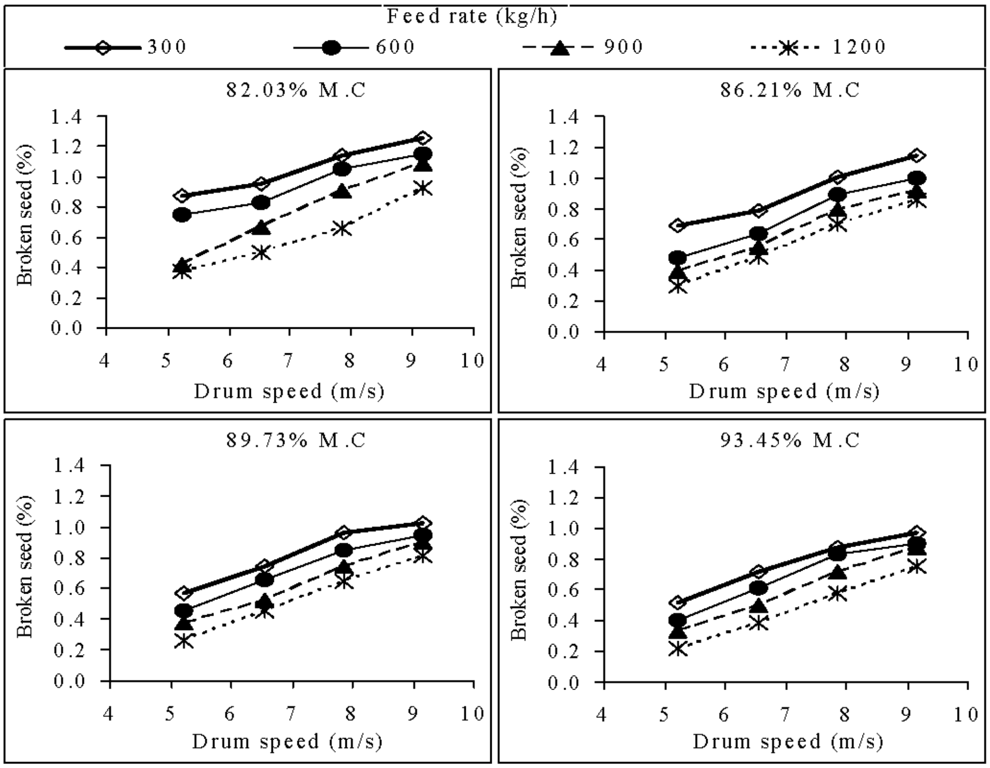

Fig. 3: Effect of the operation parameters on seed breakage.

That was attributed to decreasing impact forces among seeds. As the feed rate increased, more vegetables would be discharged to the clearance between the crushing drum and the concave, causing damping action and less crushing effect. On the other hand, increasing the crushing drum speed caused an increase in the percentage of broken seeds at all levels of MC and feed rate included in the study. At a feed rate of 300 kg/hr and an MC of 93.45%, an increase in the percentage of broken seeds from 0.52 to 0.98 was observed as the drum speed hiked from 5.23 to 9.16 m/s. It can be seen from Fig. 3 that the percentage of broken seeds was inversely proportional to the MC at all values of the other operation parameters. For instance, the percentage of broken seeds increased from 0.98% to 1.26% as the MC decreased from 93.45% to 82.03% at a feed rate of 300 kg/hr and a drum speed of 9.16 m/s. The percentage of broken seeds was found to be less than 1.3% at all values of the parameters considered.

Seed Losses: The general trend presented in Fig. 4 suggested that the seed loss was increasing with increasing feed rate at all variable levels. At a drum speed of 6.54 m/s and an MC of 89.73%, it was observed that the percentage of seed loss increased from 2.27% to 5.36% as the feed rate increased from 300 kg/hr to 1200 kg/hr. It can also be seen from Fig. 4 that the drum speed was an effective factor on the seed loss. At all levels of other variables, the minimum seed loss was found to be associated with a drum speed of 6.54 m/s. Increasing or decreasing the drum speed more or less than 6.54 m/s was observed to cause an increase in the seed loss. The decrease in seed losses as the drum speed increased from 5.23 m/s to 6.54 m/s was attributed to the greater impact energy induced on the peel. A drum speed beyond 6.54 m/s provided less time for the seeds to pass through the concave holes, leading to increased seed losses.

It can also be observed from Fig. 4 that the seed loss decreased with increasing values of MC at all values of other parameters. This was attributed to the fact that the vegetables became more brittle and susceptible to mechanical damage as their MC levels decreased. A maximum seed loss of 9.72% occurred at an MC value of 82.03%, a drum speed of 9.16 m/s and a feed rate of 1200 kg/hr. However, the minimum seed loss of 1.79% was achieved at the values of 93.45%, 6.54 m/s and 300 kg/hr for MC, drum speed and feed rate, respectively.

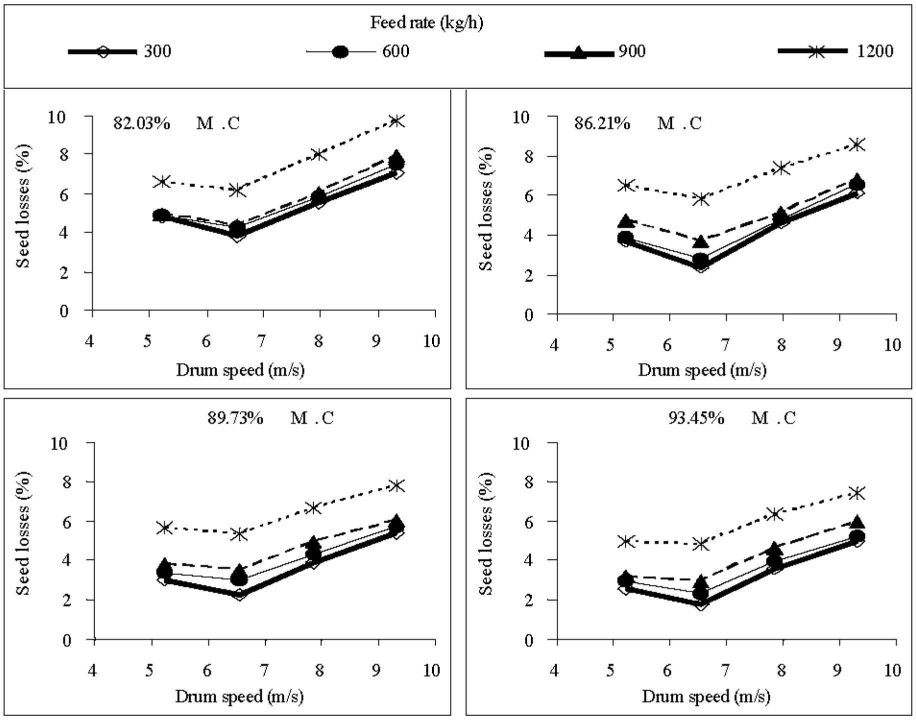

Fig. 4: Effect of operation parameters on seed loss

Seed Extraction Efficiency: The results of seed extraction efficiency versus feed rate and drum speed for the four different MC levels are demonstrated in Fig. 5. It can be observed that, at a given drum speed, the seed extraction efficiency increased with the decreased feed rate and increased vegetable moisture content. The seed extraction efficiency increased from 95.15 to 98.21% as the feed rate decreased from 1200 to 300 kg/hr at a drum speed of 6.54m/s and vegetable moisture content of 93.45%. At a feeding rate of 600 kg/hr and MC of 89.73%, the seed extraction efficiency decreased from 96.95 to 94.27% as the drum speed increased from 6.54 to 9.16 m/s. This was attributed to the fact that the seed losses were found to increase with higher drum speeds. On the other hand, higher MC levels produced lower seed loss percentages (Figs. 3&4), hence higher extraction efficiency (Fig. 5). The maximum value of seed extraction efficiency (98.2%) was recorded at an MC of 93.45%, drum speed of 6.54 m/s and feed rate of 300 kg/hr. However, the minimum value (90.28%) was obtained at a moisture content of 82.03%, a drum speed of 9.16 m/s and a feed rate of 1200 kg/hr.

Specific Energy Requirement: The average values of the specific energy at different MC levels as affected by feed rate and drum speed are plotted in Fig. 6. The general trend shown in Fig. 6 suggested that the required specific energy, at all levels of other parameters, decreased as the MC increased. It decreased from 83 to 67 kW.h/t as the MC increased from 82.03 to 89.73%. However, at a given MC value, the specific energy was found to be proportional and inversely proportional to the drum speed and the feed rate, respectively. As the drum speed increased from 5.23 to 9.16 m/s, the required specific energy rose from 67 to 82 kW.h/t at a feed rate of 300 kg/h and an MC of 89.73%. However, at the same MC value, the energy dropped from 67 to 33 kW.h/t as the feed rate increased from 300 to 1200 kg/h at a drum speed of 5.23 m/s. These findings were in agreement with the results reported earlier [10,15].

Extraction Cost Analysis: The extraction cost involved when using the developed extraction machine was calculated as follows:

Fixed Cost: The machine-related fixed costs included depreciation, interest, taxes, housing and insurance. Assuming a machine life expectancy of five years, an interest rate of 10% and a machine salvage rate of 10% of the machine price (cost) of $1250, the annual capital consumption (CC), which included the depreciation and the interest costs, was estimated at 25% of the machine cost [16]. Therefore, the annual CC for the developed

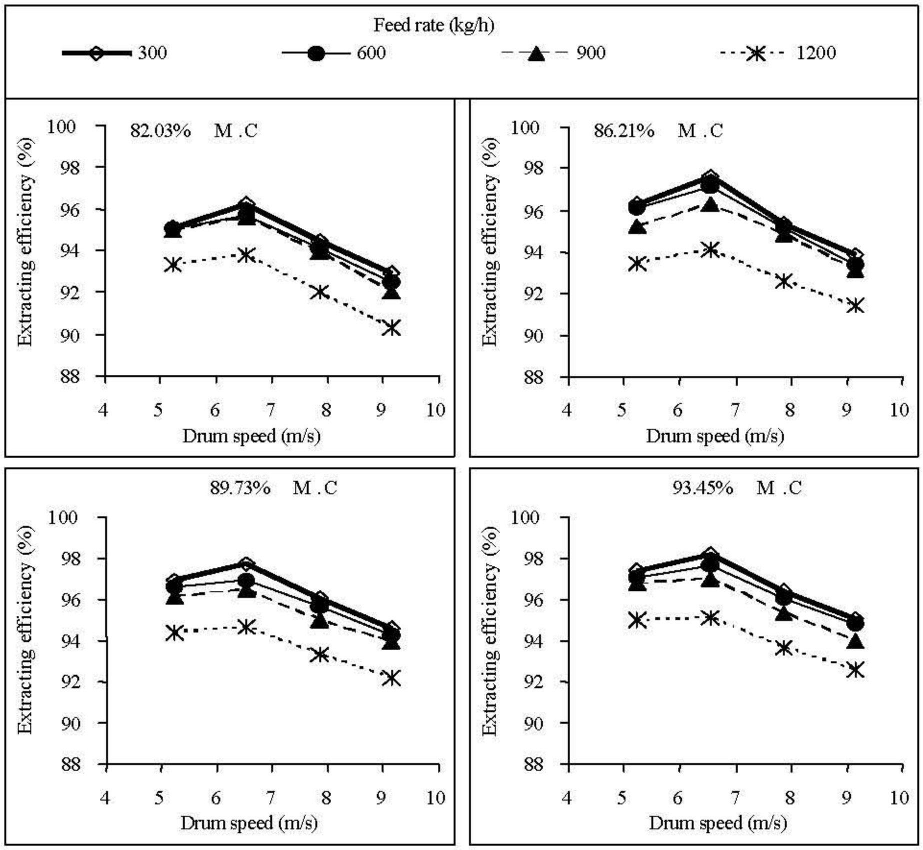

Fig. 5: Effect of operation parameters on seed extraction efficiency

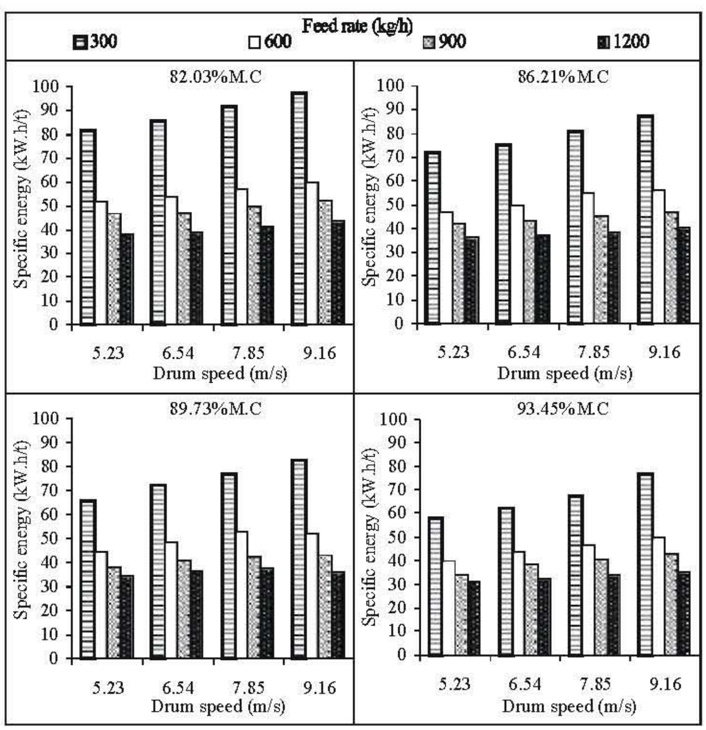

Fig. 6: Effect of operation parameters on the required specific energy.

machine was calculated at $312.5. With the assumption of 300 operating hours per year, the depreciation and interest costs were calculated at $1.04/h. The remaining three elements of the fixed costs (interest, taxes and housing) were, annually, assumed to be 2% of the machine cost [16], which was calculated at $25/y, hence $0.083/h. The fixed cost was determined as per the following equation:

$$\text{Fixed cost (\$/h)} = 1.04 + 0.083 = 1.123 \qquad (6)$$

Operation (Variable) Cost: The operation costs included the cost of labor, electric power, repair and maintenance. The labor cost was calculated based on the fact that two laborers were required to properly operate the machine. This cost was estimated at $8.8/day (8 hr/day), hence the labor cost was calculated at $1.1/hr. The electric power cost of the machine was determined to be $0.026/hr at the parameter values of 6.54 m/s, 900 kg/h and 93.45% for the crushing drum speed, the feed rate and the vegetable MC, respectively. These values of the parameters were selected for the purpose of conducting the operation cost analysis. However, the cost of repair and maintenance was estimated at 2% of the machine cost per 100 hours of operation, which was calculated at $0.25/hr [16]. Therefore, the operation (variable) cost was determined as follows:

$$\text{Operation cost (\$/hr)} = 1.1 + 0.026 + 0.25 = 1.376 \qquad (7)$$

The total machine cost was obtained using equations 6 and 7 as follows:

$$\text{Total machine cost (\$/hr)} = 1.123 + 1.376 = 2.5 \qquad (8)$$

$$\text{Extraction time (hr/t)} = \frac{1}{\text{Productivity}} = \frac{1}{0.12} = 8.33 \qquad (9)$$

The machine productivity was measured in the field when operated at the selected operating conditions. Hence, the extraction cost by the machine was obtained by multiplying the extraction time in eq. 9 by the total machine cost in eq. 8 as follows:

$$\text{Extraction cost (\$/t)} = 2.5 \times 8.33 = 20.83 \qquad (10)$$

On the other hand, manual extraction cost was determined. On the average, one hectare of summer squash was estimated, based on field experience reported by local farmers, to require 48 laborers to perform seed extraction within one working day, with an average cost of $4.4/laborer/day. However, the field productivity of summer squash seeds was assumed, on the average, to be 1.1 t/ha [1].

$$\text{Manual seed extrectioncost (\$/t)} = \frac{4.4 \text{ x } 48}{1.1} = 192 \qquad (11)$$

From equations 10 and 11, the extraction cost was found to increase from 20.83 $/t, when using the developed extraction machine, to 192 $/t when manual extraction was implemented. Therefore, the machine was able to cut the extraction cost by 89.15%, which was of course a very significant cost reduction that would greatly increase the efficiency of the seed extraction process.

CONCLUSION

A low cost ($1250) summer squash seed extraction machine was locally designed and manufactured. In addition, the performance of the developed machine was evaluated based on seed loss, broken seeds, extraction efficiency and required specific energy. The evaluation was conducted at four different feed rates (300, 600, 900 and 1200 kg/hr), four different drum speeds (5.23, 6.54, 7.85 and 9.16 m/s) and four levels of vegetable moisture content (MC) (82.08, 86.21, 89.73 and 93.45%). Cost implications using the machine was also investigated. Specific conclusions of the study include the following:

- The increase in feed rate, within the range of values included in this study, was found to increase seed losses. However, it caused a decrease in broken seeds, machine extraction efficiency and required specific energy.
- At all levels of MC and feed rates, the broken seed percentage was found to be proportional to the drum speed. However, the minimum seed loss and maximum machine efficiency were achieved at a drum speed of 6.54 m/s at all values of other parameters. Also, at all values of other parameters, the specific energy requirement was found to be proportional to the drum speed. Increasing the drum speed from 5.23 to 9.16 m/s increased the required specific energy from 67 to 82 kW.h/t at MC and feed rate values of 89.73% and 300 kg/h, respectively.
- At all values of other parameters, the vegetable MC was found to be inversely proportional to seed loss and broken seeds percentages. However, it was shown to be proportional to the machine extraction efficiency. The required specific energy was at its minimum values at the highest MC value of 93.45% considering all other parameter values.

- The percentage of broken seeds did not seem to be highly affected by the parameters within the range of MC included in the study. The highest percentage of broken seeds was less than 1.3 at all values of the operation parameters.
- The developed extraction machine was proven to be very cost effective. The extraction cost by the machine was calculated at 20.83 $/t compared to the cost of manual extraction of 192 $/t. Therefore, a saving of more than 89% in extraction cost can be achieved utilizing the developed machine.

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