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Full length article

Developing and manufacturing a machine for cutting and shredding agricultural residues

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ABSTRACT

Crop residues have become a heavy burden on the Egyptian farmer. The problem could increase the desire to eliminate the crop residual to equip the land for the next crop. To eliminate the insects that result from the stored crop residuals, the difficulty of removing and storing the residues outside the farm and the unavailability of manual labor. This is done by using a machine consisting of a cutting unit and a chopping unit. The cutting unit is tested alone, then the chopping unit alone and the two units are tested together by studying the following variables: feed speed (920, 1100, and 1300 rpm) (8.8, 10.5, and 12.4 m/s) respectively, cutting speed (1600, 1800, 2000, and 2200 rpm) (18.5, 20.7, 23, and 25.3 m/s) respectively, chopping speed (1500, 1750, 2000, and 2800 rpm (18.8, 22, 25.1, 35.1 m/s) respectively, two sieves (3 and 4 mm).The machine is evaluated through: cutting productivity for the cutting unit, chopping productivity for the chopping unit, Cutting efficiency, and Power Consumed. The most important obtained results may be summarized as follows: the maxims of cutting productivity were 65 kg / h at a cutting speed of 2200 rpm (25.3 m/s) with a feeding speed of 1300 rpm (12.4 m/s), the results obtained when using the cutting speed were 1800 rpm (20.7 m/s), at the feed speed of 1100 rpm (10.5 m/s), and at the chopping speed of 1750 rpm (22 m/s), and with a sieve (3 mm). The best chopping efficiency was (98%), and the results obtained when using, at the chopping speed of 1500 rpm (18.8 m/s) and at the feed speed of 920 rpm (8.8 m/s) and with a sieve (3 mm). The less machine power consumption was (257 W).

1. Introduction

Crop residues have become a heavy burden on the Egyptian farmer, making them a breeding ground for diseases to spread and spread to the new crop, prompting farmers to get rid of them by burning them, which in turn led to serious environmental and health disasters for humans. Agricultural waste represents about 40 million tons, and waste taken from cotton, rice, corn, peanuts, potatoes and sweet potatoes represents about 30% to 50%. Burning residues is considered a waste of some elements of available wealth that can be converted, through some simple practical methods, into useful materials with economic return. Peanut Straw waste amounts to about (16%) of agricultural residues. Peanuts are considered one of the most important oil crops after cotton. The total cultivated area is about 165,793 Fadden, and the residues from peanuts are 252,337 Tons (Annual bulletin for statistics of crop areas and plant production, 2022). Agricultural residues are the most abundant biomass and forage resources. Chopping is a precondition for both uses, and reducing the shearing force has been considered one of the most effective ways to save energy. A smaller force can also permit more compact mechanical parts of chopping devices. In several cases, power consumption may be large, even when the shearing force is small, if the corresponding cutting velocity is high. Consequently, Minimizing cutting force and power consumption simultaneously (Vu et al., 2020). Currently, most crop residue

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is left in the field after harvesting and is underused for energy production. However, crop residues have an essential role in sustaining and improving the chemical, physical, and biological properties and soil processes, contributing to the suitable functioning of soil, plant growth, and other environmental services (Stavi et al., 2016). Reported that the cutting-length percentage of the residual crop for small-size categories less than 8 cm. increased by increasing cutting drum speed. Meanwhile, the cutting-length percentage of residual crops for large-size categories longer than 8 cm. decreased. He found that increasing the cutting drum speed from 750 to 1260 rpm increases the small-size categories less than 8 cm. from 47 to 69% and decreases large-size categories longer than 8 cm. from 53 to 31%. Abo-Elasaad (2016) mentioned that one of the alternatives is to utilize rice straw as a pre-material to make compost. The results indicated that the rice straw should be cut into small sizes of 5 - 10 cm. It was found that the average diameter, length, moisture content and bulk density of rice straw are 0.4 cm, 70.8 cm, 34.6 % wet basis and 160.6 kg/m^3 (AL-Gezawe et al., 2016). Developed to develop a crop residue management machine that can chop paddy residues and mix those with the soil of the combined harvested paddy field. For this purpose, two important units are attached to the developed machine: the chopping and incorporation units. The tractor operates this machine as the main source, with a power range of about 55.95 kW. The four independent parameters selected for the study were rotary speed (R1 = 900 & R2 = 1100 rpm), forward speed (F1 = 2.1 & F2 = 3.0 Kmph), horizontal adjustment (H1 = 550 & H2 = 650 mm), and vertical adjustment (V1 = 100 & V2 = 200 mm) between the straw chopper shaft and rotator shaft and its effect was found on incorporation efficiency, shredding efficiency, and trash size reduction of chopped paddy residues (Ramulu. et., 2023).

The purpose of the research used the following:

Manufacture and develop a small local chopping machine to prepare crop residues to be useful in different fields.

2. Materials and methods

The main idea of this study was to develop and manufacture a machine suitable for smallholders that could chop crop residues. This machine was fabricated in the Mabrouk factory. The main experiments were conducted in the Agricultural Engineering Institute workshop in Dokki, Giza, Egypt. The machine was local and suitable for cutting and chopping peanut straw. It was fabricated from local materials (low-cost) to overcome the problems of high-cost requirements.

2.1. Materials

2.1.1. Peanut Straw Specification

2.1.1.1. Physical Properties of Peanut Straw

30 random samples of peanut straws were taken to study their physical properties in length, mass, specific density, diameters, and moisture content.

2.2. The machine of design and development

The overall dimensions of the machine were 1919 mm Length 540 mm width, and 1273 mm height. It consisted of the main parts:

(1) Main Frame. (2) Feeding Unit. (3) Cutting Unit. (4) Chopping Unit. (5) Power Transmission.

The detailed engineering drawing of the machine and the three-dimensional illustration of the machine, as shown in Figs. 1 and 2.

(1) Main Frame

The main frame was manufactured from Angle steel ($\angle 40 \times 40 \times 4\ mm$), and the overall dimensions of the main frame were 1215 mm length, 540 mm Width, and 812 mm height. Another components of the machine were joined on the main frame.

(2) Feeding Unit: Consisting of:

- **Feeding Tray:** The feeding tray is fabricated from sheet metal 700 mm, long. It has two wide, a front wide of 400 mm, and an end wide of 215 mm.
- **Feeding Unite System:** The feeding unit consists of an upper drum and a lower roll. The feeding drum was fabricated from two flash steels with a diameter of 180 mm, mounted on a steel shaft drum (20 mm diameter) with a distance between them of 192 mm.

(3) Cutting Unit: The cutting unit mainly consists of:

- **Cutting drum:** It consisted of two flanges (35 mm. diameter, and 4 mm thickness). The distance between the two flanges was 192 mm, and each flange was 22 mm diameter.
- **Four knives:** It is distributed and installed on the outer perimeter of the flanges.
- **Drum shaft:** It was a steel shaft of 35 mm in diameter and 22 mm in length.

(4) Chopping Unit: The chopping unit was dependent on the theory of impact force and mainly consisted of:

- **Knives:** Four knives that are grouped perpendicularly and mutually distributed together. A central hole of 180 mm passes through the four knives. The knives were fabricated from sheet metal 3 mm.
- **Sieve:** Two round sieves (250 mm diameter) were fabricated from sheet metal 1 mm and holes are 3 and another 4 mm. The sieve was installed inside the chopping unit around four impact knives.

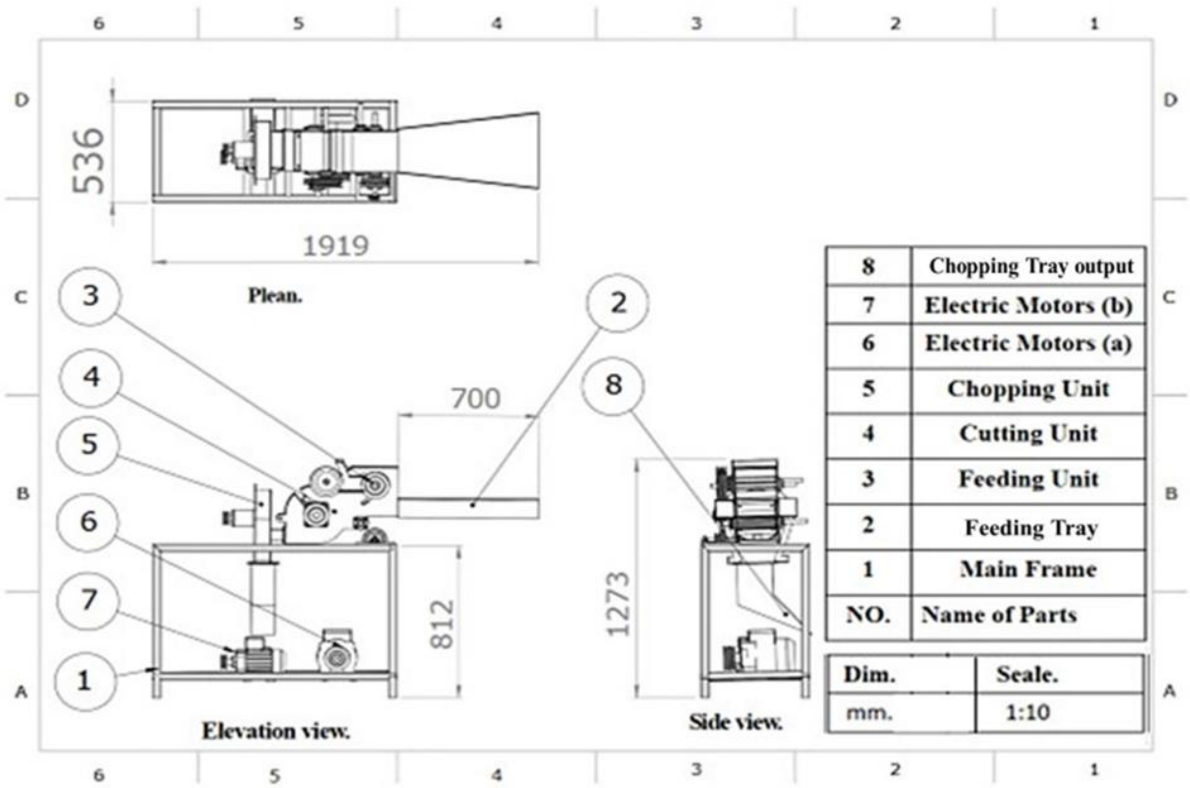

Fig. 1. Schematic of machine.

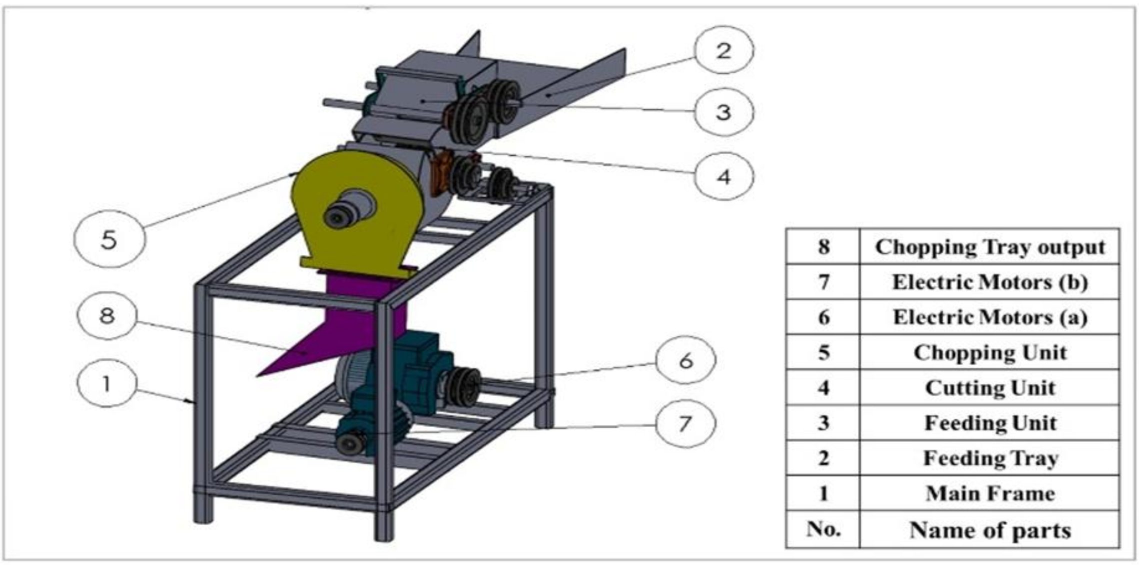

Fig. 2. 3D illustration of machine.

- **Main Shaft:** The drum shaft is fixed at one end to the chopping chamber via a square bearing seat, and the other end is mounted on a set of knives.

(5) Power Transmission

It used a three-phase electric motor, 4 HP. The double groove pulley (the inner diameter 7 cm, and outer diameter 6 cm) was mounted on the main shaft of the engine. V belted type (B) was used to transmit the rotation speed from the motor pulley to the cut drum.

Evaluation of double option machine (cutting and chopping) performance taking into consideration the following indicators and measurements:

- Duration time of each experiment.
- Softness degree of the product.

- Different Feeding speeds.
- Different Cutting speeds.
- Different Chopping speeds.
- Power consumption.

2.3. Methods

Trials of the cutting and chopping machine using peanut straw are carried out in three different stages :

1. The first stage is cutting only using different speeds with different feeding speeds.
2. The second stage is only chopping at different speeds with feeding speeds with two sieves (3mm and 4mm).
3. The third and final stage is the merging stage (cutting and chopping together) with different speeds for cutting and chopping and different speeds for feeding with two sieves (3 mm, 4 mm).

2.3.1. Moisture Content of Peanut Straw

The experiment was carried out to evaluate the cutting machines performance and optimize the operating parameters during the cutting and chopping processes. The humidity was measured using the Hay Moisture Testers device, which took ten samples from the peanut straw to measure the moisture percentage. The result was 15%. The peanut residuals (thrones) were spread out on linoleum (3 days) to expose them to the air.

After that, the percentage of humidity was measured in the same way as before, which was 12%.

He took a sample to use in the machine, but the machine did not work with the humidity mentioned, so the thrones were left exposed to the air again for another two days.

The humidity was measured again until it reached 10%, and a sample was taken to test it in the machine. The machine was operated successfully.

To increase confirmation of the humidity percentage, a convection oven was used, where three samples were taken from the peanut stalks, and they were placed in a thermal bag. The three samples were placed in the oven and the results were very similar to the first result.

2.3.2. Experimental Procedures

The following engineering variables were studied:

- **Feeding speed (m/s):** Three speeds for the down feeding drum were experimented at 920, 1100, and 1300 rpm (8.8, 10.5, and 12.4 m/s respectively).
- **Cutting Speed:** Four cutting drum speeds were experimented at 1600, 1800, 2000, and 2200 rpm (18.5, 20.7, 23, and 25.3 m/s. respectively).
- **Chopping Speed:** Four hammering drum speeds were experimented 1500, 1750, 2000, and 2800 rpm (18.8, 22, 25.1, and 35.1 m/s).
- **Sieving Mesh:** Tow screen meshes were tested (3 and 4 mm).
- **Source of Power:** Two electric motors using 4 and 1.5 H.

The moisture content of raw material was 10% content. All experiments were run on Peanut Straw.

- **Experimental Procedures**

These measurements were carried out to determine the machine productivity (kg/h), cutting efficiency (%), and power consumed (W)

- **Moisture Content**

Random samples of raw materials were taken sample dried in the oven at 70 c^0 for 24 hours to obtain data on raw materials moisture content. Using the following equation:

$$M_c = \frac{m_t - m_r}{m_t} \times 100\ \%$$

where:

M_c = moisture content, (%),
M_t = sample mass (kg),
M_r = sample mass after drying (kg).

- **The Specific Density of Peanut Straw**

Three random samples of peanut straw were taken to calculate the external density. The result after taking the average of the three samples was 5.4 g/cm^3. The law used to extract the external density was:

$$\rho = \frac{M}{V}$$

where:

ρ = Specific Density of peanut straw, g/cm^3
M = sample mass (g),
V = sample size, cm^3

- **Calculate the theoretical length of the cut**

It can be calculated using the following equation (Srivastava et al., 1995):

$$Lc = (60000\ Vf / \lambda k\ nc)$$

where:

Lc = Theoretical length of cut (mm).
V = Feed velocity (m/s) peripheral speed of feed rolls).
λk = Number of knives on the cutter head.
Nc = The rotational speed of the cutter head (rev/min).

For direct-cut forages, actual average lengths of cut are generally about 50% longer than the theoretical length

- **Determination of Productivity (Kg/h)**

The time of running the experiment was measured using the stopwatch. The malls of output in a certain time were determined by Ander to estimate the productivity (Kg/h). The following equation determines machine productivity:

$$M_p = \frac{W_s}{T} \quad \text{kg/h.}$$

where:

M_p = cutting productivity, (kg/h,)
W_s = machine Raw materials outlet, (kg)
T = time consumed to cut samples, (H).

- **Cutting Efficiency (%)**

The cutting efficiency was obtained as a percentage between the total weight of the sample and the weight that was cut and the result of the different sieves that were taken because of the sample inside the laboratory. The results of the sieves were similar, so the average sieves were as follows: in the mechanical analysis of materials from peanut residues with holes for cutting less than 1 mm - 3.35 mm, 3.35 - 13.2 mm, 13.2 - 50 mm. The cutting efficiency was estimated using the following equation:

$$\eta_{cut} = \frac{w_a}{w_b} \times 100$$

where:

η_{cut} = Cutting Efficiency (%).
w_b = Total sample weight (kg).
w_a = Sample weight after cutting (kg).

- **Chopping Efficiency (%)**

The chopping efficiency was obtained as a percentage between the total weight of the sample and the weight that was chopped and the result of the different sieves that were taken because of the sample inside the laboratory. The results of the sieves were similar, so the average sieves were as follows: in the mechanical analysis of materials from peanut residues with holes for chopping less than 1 mm – 1.4 mm, 1.4 - 3 mm, 1.4 - 4 mm, 3mm, and 4mm. The chopping efficiency was estimated using the following equation:

$$\eta_{cut} = \frac{w_a}{w_b} \times 100$$

where:

η_{cut} = Chopping Efficiency (%).
w_b = Total sample weight (kg).
w_a = Sample weight after chopping (kg).

- **Power Consumption (W)**
- **Electrical Power (W)**

The capacity to do work is termed Energy. The Energy expended to do work in unit time is termed as Power. It is represented as P. In any electrical circuit, Voltage, and current, it is articulated as:

$$P = V \times I$$

where:

P = The electric power per watts (W).
V = Is Electric Potential or per Voltage (V).
I = Is electric current per Amper (A).

3. Results and discussions

3.1. Physical Properties of Peanut Straw

The machine presented in this study is designed according to local conditions and physical properties of Peanut Straws. The average values for the lengths and diameters of a random sample of peanut straw were calculated. Also, the weight of the Peanut Straw was determined as weight per m² and calculated per Fed. An average of five random replicates from peanut straw weight per meter square was 1.44 Kg / m². Accordingly, the Peanut Straw quantity averaged 6.048 tons/ feddan. Three random samples of Peanut Straw were taken to calculate the external density. The result after taking the average of the three samples was 5.4 g/cm³. All these results as shown in Table 1.

Table 1

Physical properties of Peanut Straw.

Characteristics	Average Peanut Straw
length (cm)	25 cm
diameter (mm)	8 mm.
Weight per m^2 (Kg/m^2)	1.44 Kg/m^2
Specific Density g/cm^3	5.4 g/cm^3
Moisture Content of the Sample	9.7 %

3.2. Effect of feeding speeds and cutting speeds on theoretical cutting length.

The cutting length of the peanut straw was calculated using the mathematical equation for calculating the theoretical length. The best result was 22 mm at a feed speed of (8.8 m/s) and a cutting speed of (25.3 m/s). As shown in Table 2 and Fig. 3.

Table 2

Effect of feeding speed and cutting speed on theoretical cutting length.

Feeding Speed (m/s)	8.8 m/s	10.5 m/s	12.4 m/s
Cutting Speed (m/s)	Theoretical Cutting Length		
18.5 m/s	29	35	41
20.7 m/s	27	32	37
23 m/s	24	29	34
25.3 m/s	22	26	31

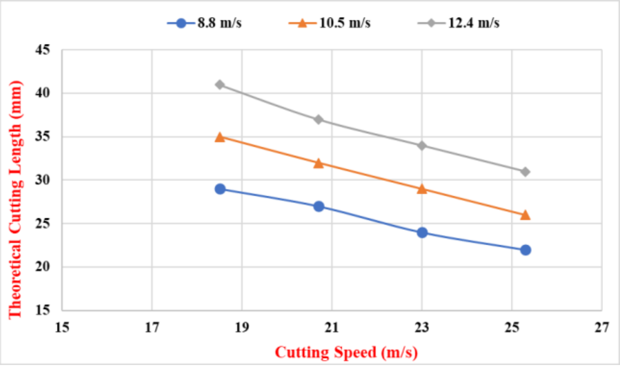

Fig. 3. Effect of feeding and cutting speeds on theoretical cutting length.

3.3. Productivity with different cutting speeds at different feeding speeds.

The highest productivity, 65 kg/h was at a feed speed of 12.4 m/s and a cutting speed of 25.3 m/s, and the lowest productivity was 30 kg/h at a feed speed of 8.8 m/s and a cutting speed of 18.5 m/s. As shown in Table 3 and Fig. 4.

Table 3

Productivity with different cutting speeds at different feeding speeds.

Cutting Speed (m/s)	18.5 m/s	20.7 m/s	23 m/s	25.3 m/s
Feeding Speed (m/s)	Productivity			
8.8 m/s	30	39	42	49
10.5 m/s	37	42	46	57
12.4 m/s	39	49	53	65

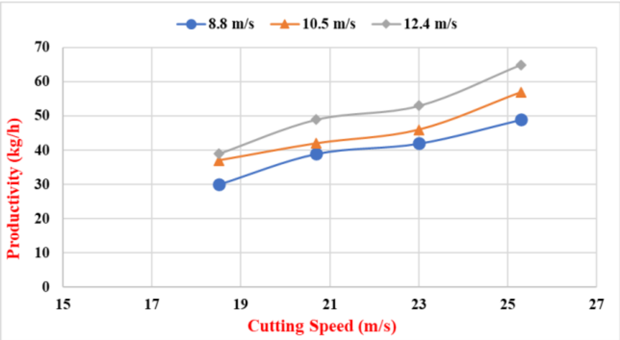

Fig. 4. Productivity with different cutting speeds at different feeding speeds.

3.4. Efficiency with different cutting speeds, chopping speeds at feeding speeds 10.5 m/s with (sieve 3 mm).

The best efficiency (98 %) was scored at a chopping speed of 22m/s and a cutting speed of 20.7 m/s. On the other hand, the lowest efficiency (64 %) happened at a chopping speed of 35.1m/s, with a cutting speed of 18.5m/s. While the feeding speed was fixed at 1100 rpm, the sieves of holes 3mm. As shown in Table 4 and Fig. 5.

Table 4

Efficiency with different cutting speeds, chopping speeds at feeding speeds (10.5 m/s) and with (sieve 3 mm).

Chopping speed m/s	18.8 m/s	22 m/s	25.1 m/s	35.1 m/s
Cutting Speed (m/s)	Efficiency			
18.5 m/s	90%	80%	84%	64%
20.7 m/s	87%	98%	80%	73%
23 m/s	84%	76%	88%	80%
25.3 m/s	86%	75%	84%	71%

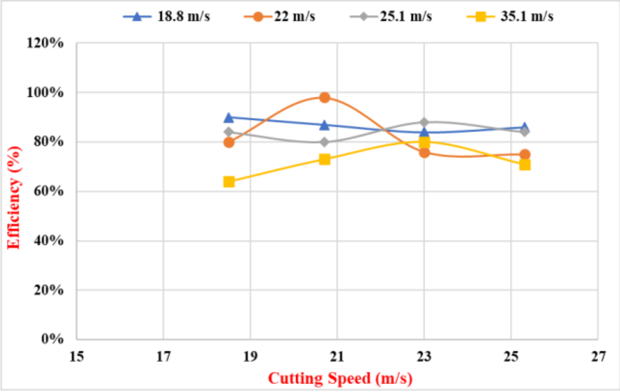

Fig. 5. Efficiency with different cutting speeds, chopping speeds at feeding speeds (10.5 m/s) with (sieve 3 mm).

3.5. Power Consumption with different cutting speeds, chopping speeds and feeding speeds at 8.8 m/s with (sieve 3 mm).

On the other hand, the lowest power consumption (1201 W) happened at a chopping speed of 18.8 m/s, with a cutting speed of 18.5 m/s. In contrast the feeding speed was fixed at 8.8 m/s, the sieves of holes were 3 mm.

The best power consumption (1745 W) was scored at a chopping speed of 35.1 m/s and 25.3 m/s cutting speed. As shown in Table 5 and Fig. 6.

Table 5

Power Consumption with different cutting speeds, chopping speeds at feeding speeds (8.8 m/s) with (sieve 3 mm).

Chopping speed (m/s)	18.8 m/s	22 m/s	25.1 m/s	35.1 m/s
Cutting Speed (m/s)	Power Consumption			
18.5 m/s	1201	1258	1302	1639
20.7 m/s	1278	1287	1342	1683
23 m/s	1496	1349	1362	1701
25.3 m/s	1624	1408	1417	1745

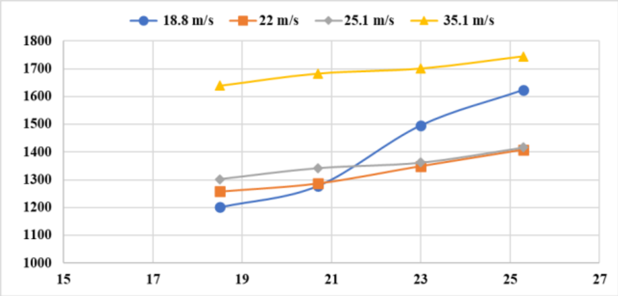

Fig. 6. Power Consumption with different cutting speeds, chopping speeds at feeding speeds (8.8 m/s) with (sieve 3 mm).

4. Conclusions

The following is clear from the productivity results obtained:

1. The best cutting speed was 2200 rpm (25.3m/s) and the best feeding speed was 1300 rpm (12.4 m/s).
2. The best chopping speed was 2800 rpm (35.1 m/s) and the best feeding speed was 1300 rpm (12.4 m/s) and with (sieve 3 mm)
3. From the results obtained, it is also clear that using the cutting machine alone is better than using the chopping machine with it.
4. Using only one motor to save the consumed power and operating costs is preferable.
5. Using a 3 mm sieve or less for easy-producing soft material to press and produce pellets is preferable.

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تطوير وتصنيع آلة لتقطيع وفرم المخلفات الزراعية

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الملخص العربي

أصبحت مخلفات المحاصيل الحقلية عبئا ثقيلا علي المزارع المصري، الأمر الذي جعلها موطنا لإعادة انتشار الإمراض وانتقالها للمحصول الجديد مما دفع المزارع لتخلص من خلال حرقها، الذي أدي بدوره إلى كوارث بيئية وصحية خطيرة على الإنسان. وتمثل المخلفات الزراعية حوالي ٤٠ مليون طن وتمثل المخلفات المأخوذة من القطن والأرز والذرة والفول السوداني والبطاطس والبطاطا حوالي ٣٠٪ إلى ٥٠٪. (الجزء الثالث من النموذج السنوي الاحصائيات سنة ٢٠٢٢ م). ويعتبر حرق المخلفات إهدار لبعض عناصر الثروة المتاحة التي يمكن تحويلها ببعض الطرق العملية البسيطة الي مواد مفيدة ذات عائد اقتصادي، ويبلغ مخلفات عروش الفول السوداني حوالي (١٦٪) من المخلفات الزراعية. **وكان الهدف من البحث ما يلي:**

إجراء الدراسات المعملية والحقلية على عروش فول السوداني وذلك لتحويلها إلى مادة خام من خلال عملية التقطيع والفرم قابلة للتصنيع إلى أعلاف حيوانية طبقا للمواصفات القياسية. وذلك من خلال تصنيع آلة تقطيع وفرم صغيره لعروش الفول السوداني مع مراعاة ما يلي:

- التصنيع المحلي المناسب للمساحات الصغيرة مع توفير العملة الصعبة.
- سهلة الاستخدام وقليلة التكاليف - ويتم ذلك من خلال استخدام آلة مكونة من وحدة التقطيع وحدة الفرم ويتم اختبار وحدة التقطيع بمفردها، ثم وحدة الفرم بمفردها واختبار الوحدتان معا من خلال دراسة المتغيرات الاتية:

١. سرعة التغذية:(٩٢٠، ١١٠٠، ١٣٠٠ لفة / د ويمثل (٨,٨، ١٠,٥، ١٢,٤ م/ث على التوالي).
٢. سرعة القطع: (١٦٠٠، ١٨٠٠، ٢٠٠٠، ٢٢٠٠ لفة / د ويمثل (١٨,٥، ٢٠,٧، ٢٣، ٢٥,٣ م/ث. على التوالي).
٣. سرعة الفرم : (١٥٠٠، ١٧٥٠، ٢٠٠٠، ٢٨٠٠ لفة / د ويمثل (١٨,٨، ٢٢، ٢٥,١، ٣٥,١ م/ث على التوالي).

٤. اثنان غربال (٣ مم، ٤ مم).
٥. استخدام مصدر قدره مكون من محركين كهربي (٤ – ١,٥ حصان).
٦. رطوبة المخلف ١٠٪ على الاساس رطب.

- تقيم الآلة من خلال:

١. انتاجية القطع لوحدة القطع.
٢. انتاجية الفرم لوحدة الفرم.
٣. كفاءة عملية القطع.
٤. القدرة المستهلكة.

وكانت اهم النتائج كالتالي:

١. انتاجية وحدة القطع: كانت اعلي انتاجية للقطع (٦٥ كجم / الساعة) مع استخدام سرعة التغذية (١٣٠٠ لفة/د) وسرعة القطع (٢٢٠٠ لفة/د).
٢. انتاجية وحدة الفرم: كانت اعلي انتاجية للفرم (٤٨ كجم / الساعة) مع استخدام سرعة التغذية (١٣٠٠ لفة/د) وسرعة الفرم (٢٨٠٠ لفة/د) عند فتحة غربال ٣ مم.
٣. انتاجية الوحدة المزدوجة: كانت اعلي انتاجية (٥٧ كجم / الساعة) مع استخدام سرعة التغذية (١٣٠٠ لفة /د) وسرعة التقطيع (٢٢٠٠ لفة/د) وسرعة الفرم (٢٨٠٠ لفة/د) عند فتحة غربال (٣مم).
٤. كفاءة التقطيع: كانت اعلي كفاءة للقطع (٩٨٪) مع استخدام سرعة تغذية (١١٠٠ لفة/د) وسرعة القطع (١٨٠٠ لفة/د).
٥. كفاءة الفرم: كانت اعلي كفاءة للفرم (٩٠٪) مع استخدام سرعة تغذية (٩٢٠ لفة/د) وسرعة فرم (٢٨٠٠ لفة/د) عند فتحة غربال (٣مم).
٦. كفاءة الوحدة المزدوجة: كانت اعلي كفاءة (٩٨٪) مع استخدام سرعة تغذية (١١٠٠ لفة/د) وسرعة تقطيع (١٨٠٠ لفة/د) وسرعة فرم (١٧٥٠ لفة/د) عند فتحة غربال (٣مم).
٧. القدرة المستهلكة لوحدة القطع: كانت اقل قدرة مستهلكة (٧٣٧ وات) مع استخدام سرعة تغذية (٩٢٠ لفة/د) وسرعة تقطيع (١٦٠٠ لفة/د).
٨. القدرة المستهلكة لوحدة الفرم: كانت اقل قدرة مستهلكة (٢٥٧ وات) مع استخدام سرعة تغذية (٩٢٠ لفة/د) وسرعة فرم (١٥٠٠ لفة/د) عند فتحة غربال (٤ مم).
٩. القدرة المستهلكة للوحدة المزدوجة: كانت اقل قدرة مستهلكة (١٢٠١ وات) مع استخدام سرعة تغذية (٩٢٠لفة/د) وسرعة تقطيع (١٦٠٠ لفة/د) وسرعة فرم (١٥٠٠ لفة/د) وعند فتحة غربال ٣ مم).