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Some Engineering Factors Affecting the Performance of an Automatic Sugarcane Seed Cutting Machine

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Abstract:

The current study aimed to study some engineering factors affecting the performance of a new automatic sugarcane seed cutting machine based on an RGB color sensor and internet of things technology assisted by sugarcane seed monitoring and a counter-remote system. In the current study, we evaluated the performance of the developed machine using two saw knives with different tooth numbers (80 teeth and 30 teeth), five different cutting times (t1 = 1000 ms, t2 =1500 ms, t3 =2000 ms, t4 =2500 ms, and t5 =3000 ms), and four different sugarcane stalk diameters (d1 = 2.03 cm, d2 = 2.72 cm, d3 = 3.42 cm, and d4 = 3.94 cm). The obtained results showed that the invisible losses and cutting efficiency decreased with the decrease in the diameter of the sugarcane stalks, the increase in the cutting time, and the increase in the number of teeth of the rotary saw knife. While machine productivity followed the opposite trend. Where it decreased with increasing cutting time and increasing the diameter of the sugarcane stalks, while the number of teeth of the rotary saw knife had no significant difference.

Keywords: *sugarcane; PV system; Machine vision, Internet of things (IoT); machine learning*

1- Introduction

Sugarcane is an essential industrial cash crop, accounting for around 80% of the world's sugar production, and it is one of the most viable biofuels and renewable energy sources **(Elwakeel et al. 2021a; Elwakeel et al. 2021b; Yadav et al. 2003)**. The amount of sugarcane produced worldwide was approximately 2925 million metric tons **(Statista, 2023)**, and Egypt cultivates 141,000 hectares of sugarcane **(FAO, 2021)**.

Agricultural nurseries often rely on sugarcane seed-cutting machines to efficiently extract sugarcane seeds for crop cultivation. These machines play a crucial role in the nursery's operations by separating the seeds from the sugarcane stalks, which are then sold to farmers for further cultivation.

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Currently, sugarcane accounts for approximately 80% of global sugar production. However, the sugarcane industry often acquires sugarcane stalks from farmers without separating the valuable planting material, known as the seed, resulting in its wasteful disposal through crushing or other means during conventional sugar processing. To address these challenges, our aim is to develop a machine capable of effectively separating the sugarcane seed from the fibrous portion of the stalk. This innovative solution would allow for the preservation of the seed, which can be utilized in future sugar processing and as planting material. The resulting seed chips would have several advantages, including reduced bulkiness, improved transportability, and greater cost-effectiveness as a seed material. Moreover, the remaining cane can be efficiently utilized for preparing juice, sugar, or jaggery. The proposed seed cutting machine for sugarcane inter-node cutting operations would involve cutting the sugarcane at its nodal parts into small pieces, facilitating the separation of the seed for seedling purposes. Traditional tools currently used for sugarcane seed cutting are unsafe, messy, and require significant skill and training. The associated risk of injury is also high. Therefore, the development of a dedicated seed cutting machine for sugarcane is imperative to address these concerns and enhance operational efficiency **(Elwakeel et al. 2021c; Kuri and Naik, 2015; Prasads et al. 2017; Ragupathi et al. 2017; Zein El-den et al. 2020a, 2020b; Zhou et al. 2020)**.

Many researchers have designed, evaluated, and improved many designs of sugarcane seed cutting machine (SBCM) so far. **Pujar and Banakar, (2020)** designed and evaluated a sugarcane seed chipping machine. The cutting system was operated with 20 strokes per minute, with motor speed of 1330 rpm. The machine productivity was 30 seeds per minute. **Elwakeel et al. (2021b)** manufactured and evaluated the performance of a sugarcane node cutting machine. The cutting efficiency of sugarcane seed cutting machines was found to range between 83.67% and 100%, with a maximum machine productivity of 65.7 seeds per minute. The total operating cost varied from 3.75 to 7.89 USD per hectare, depending on the cutting speed and stalk diameter. **Ahmad et al. (2020)** developed a prototype of a sugarcane seed chips cutting machine powered by an air compressor at 10 bar pressure. The machine utilized a pneumatic cylinder and a special punch to separate the seeds from the cane stalk. In their tests, the machine achieved an average production rate of approximately 17.6 seeds per minute. **Jadhav et al. (2023)** designed and fabricated a semi-automatic sugarcane seed cutting machine that ensures the preservation of the sugarcane seed without compromising efficiency. The machine cuts one seed every two seconds, resulting in a production rate of 30 seeds per minute. The cost of this machine is 3258 USD, whereas similar machines on the market are priced at 6400 USD**. Mahmoud and Abu El-maaty, (2021)** developed a sugarcane seed cutting machine that was tested at three different transmission ratios, resulting in cutting rates of 22, 32, and 40 seeds per minute. The preliminary test results showed that the machine achieved percentages of damaged seeds, cutting efficiency, and productivity of 2.37%, 5.39%, and 8.99%; 97.63%, 94.61%, and 91%; and 1266, 1782, and 2136 seeds per hour at the cutting rates of R1, R2, and R3, respectively**.** While the use of machines has made the harvesting of sugarcane easier, certain agricultural processes still require special care, such as the sowing of sugarcane crop seeds. Current semi-automatic machines available for this purpose indirectly damage the sugarcane seed **(Jadhav et al. 2023)**. However, existing machines still suffer from issues like low cutting efficiency, high invisible losses, and inability to adapt to stalks of different diameters, which reduce productivity. The objective of this study was to evaluate the effects of saw blade tooth number, cutting time, and stalk diameter on the performance of an automatic sugarcane seed cutting machine.

2. Material and methods

2.1.Description of the automatic sugarcane seed cutting machine (ASSCM)

Figure 1 shows a smart, automatic sugarcane cutting machine that was manufactured by the Department of Agricultural Engineering and Biosystems, Faculty of Agriculture and Natural Resources, Aswan University. To obtain the best operating performance of the machine in the field, it is necessary to study some of the various engineering factors that could affect the machine's performance in the future. The machine, as shown in Figure 1, consists of a group of main components: the main frame, the feeding and transporting system for the stalks, the scanning system, the sugarcane cutting system, the separating system, and the monitoring system for counting the cut cuttings.

The main frame was made of iron. The main dimensions of the frame are 100 cm in length, 70 cm in height, 40 cm in width at the base, and 20 cm in width at the top. The frame is mounted at the bottom on four rotary wheels to make it easy to move from one place to another. The feeding system for the stalks consists of six compressed plastic rollers that are driven using a stepper motor (mode: Nema 23), sprockets, and chains. The feeding system is used to convey the sugarcane stalks through the scanning system and then to the cutting system to cut and separate the pre-colored seeds (buds) at specific speeds according to the operating codes. The scanning system is responsible for detecting the sugarcane seeds that have been colored to cut them. It consists of a pair of color sensors that sense the location of the color and then transfer the data to the Arduino Mega board, which makes the decision. The sugarcane cutting system consists of an AC motor that rotates at a speed of 12,000 rpm and is equipped with pairs of rotary saw knives spaced 3.5 cm apart. The assembly is permanently switched off unless it receives a start command from the Arduino Mega board. The ASSCM was provided with a monitoring system for counting the sugarcane seeds that have been cut. A PV system (4*330W polycrystalline module with 72 cells, 1*70 A.h battery, 1500 W power inverter, and solar controller with PWM battery charger LCD display dual USB 5V output 30A) was used to provide the necessary power to operate the machine to increase the possibility of using the machine anywhere, especially in open fields.

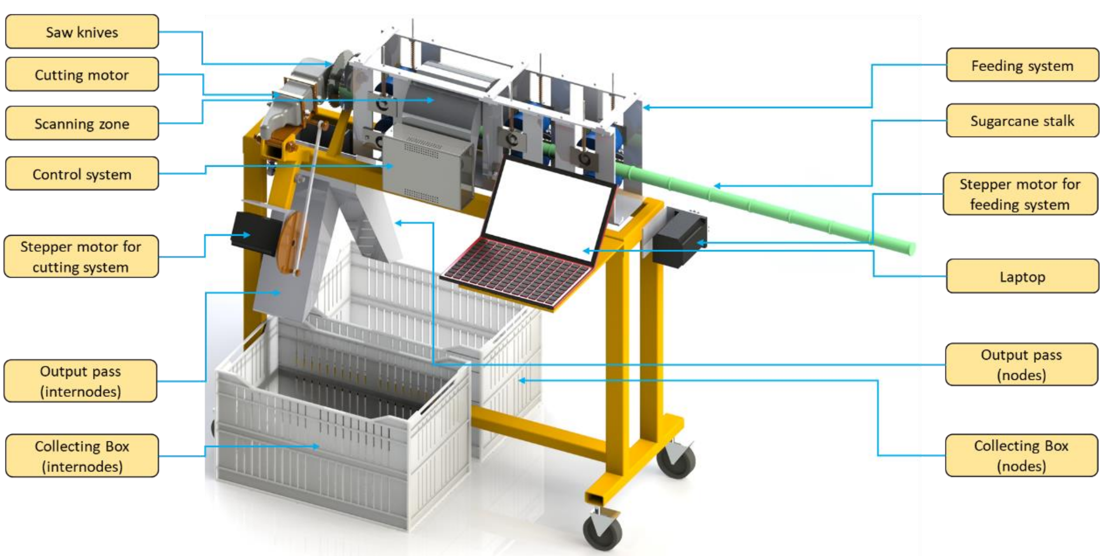

Figure 1. Isometric view showing main components of the ASSCM.

The principle of operation of the machine depends on coloring the desired sugarcane seeds to be cut with a specific color, then placing the sugarcane stalk with colored seeds in the feeding system, which conveys it smoothly through the scanning system, then the cutting system, to cut the colored seeds.

2.2. Experimental Set up

There are many variables that can affect the performance of the sugarcane cutting machine. During the current study, the focus was on studying three basic variables, which are:

a) The number of teeth on saw rotary knives, two pairs of saw knives were used, having the same diameter but different number of teeth (saw knife with 80 teeth, and saw knife with 30 teeth).
b) Cutting time, the performance of the machine was studied when using five different cutting times (t1 = 1000 ms, t2 =1500 ms, t3 =2000 ms, t4 =2500 ms, and t5 =3000 ms).
c) Sugarcane stalk dimeter, where four groups of sugarcane stalks were used as follows (d1= 2.03 cm, d2 = 2.72 cm, d3 = 3.42 cm, and d4 = 3.94 cm).

For the laboratory tests, a total of 100 sugarcane stalks with different diameters were harvested from a local farm located in Aswan, Egypt. Performance tests were conducted during the period of December 1, 2023, to December 12, 2023. After that, sugarcane stalks were divided into four categories according to stalk diameters, (d1= 2.03 cm, d2 = 2.72 cm, d3 = 3.42 cm, and d4 = 3.94 cm).

2.3. Studying the engineering factors affecting the performance of the ASSCM

2.3.2. Invisible losses (L_i)

The invisible losses during seed cutting were calculated according to Eq.1 adapted from **(Filho et al. 2022**; **Neves et al. 2006)**. The difference between the weight of the sugarcane stalk before cutting, and after cutting represents the invisible losses.

$$L_i = W_i - \left[[w_n \times N_n] + [w_i \times N_i] \right] \qquad \dots (1)$$

where: L_i is the invisible losses in g per sugarcane stalk, W_i is the initial weight of sugarcane stalk before cutting in g, w_n is the weight of seeds after cutting in g, N_n is the number of seeds after cutting, w_i is the weight of internodes after cutting in g, and N_i is the number of internodes after cutting.

2.3.3. Cutting efficiency

The cutting efficiency was determined after cutting each whole stalk. The nodes were then separated into those that were completely cut correctly, and those that were cut incorrectly or not cut. The cutting efficiency was calculated according to the following formula **(Zein El-den et al. 2020a; Mahmoud and Abu El-maaty, 2021)**,

$$\eta_n = \frac{N_C}{N_t} \times 100 \qquad \dots (2)$$

where: N_c is the number of seeds completely cut correctly, N_t is the total number of sugarcane seeds per sugarcane stalk**.**

2.3.4. Machine productivity (Q)

The productivity of the ASSCM was calculated according to **(Abu El-maaty and Mahmoud, 2021; Elwakeel et al. 2021b)**. As the ASSCM was operated by an experienced worker for marking the desired seeds for cutting, both number of seeds cut and consumed time were recorded, and then the ASSCM productivity (seed/min) was calculated using Eq. 3.

$$Q = \frac{NS_{act}}{t} \qquad \ldots.(3)$$

where: Q is the machine productivity in seed/min, NS_{act} is the number of sugarcane seeds, and t is the consumed time in minute.

2.3.5. Thermal balance of PV system

The energy consumed by the AC motor for the cutting system, stepper motors, and control circuit is used as an output source of energy in the calculation of the efficiency of the PV system, as stated by **(Shen et al. 2020; Elwakeel et al. 2023a)**, as shown in Eqs 4 - 8.

$$P_{input} = \frac{R_s \times A_{PV}}{1000} \qquad ..(4)$$

where: P_{input} is the input power in kW, R_s is the solar radiation in W/m^2, and A_{PV} is the total surface area of the PV system in m^2.

$$A_{PV} = A_{SPV} \times N \qquad ..(5)$$

where: A_{SPV} is the surface area of a single PV panel in m^2, and N is the number of PV panels.

$$P_{output} = V_{oc} \times I_{sc} \qquad ..(6)$$

where: P_{output} is the output power in Kw, V_{oc} is the open-circuit voltage in Voltage (V), and I_{sc} is the short-current current in Amber (A).

$$P_{loss} = P_{input} - P_{output} \qquad ..(7)$$

where: P_{output} is the output power in Kw, V_{oc} is the open-circuit voltage in Voltage (V), and I_{sc} is the short-current current in Amber (A).

$$\eta_{PV} = \frac{P_{output}}{P_{input}} \times 100 \qquad ..(8)$$

where: η_{PV} is the efficiency of the PV system in %.

According to **Qi and Wang, (2013)**, the fill factor may be defined as the ratio of the maximum output energy of the PV system to the output energy. The fill factor was calculated according to Eq. 5.

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} \qquad ..(9)$$

where: FF is the fill factor, and P_{max} is the maximum power in Kw.

2.4. Statistical analysis

Each treatment combination was replicated 3 times, for a total of 60 stalks. Data were analyzed by ANOVA followed by Tukey's HSD test to determine significant differences between treatment means ($p < 0.05$) (**Elsayed et al. 2023; Elwakeel et al. 2023b)**.

3. Results and Discussions

3.1. Invisible losses

Figures 2a and 2b show the relation between cutting time in ms (milliseconds) and invisible losses (g) for sugarcane stalks with different diameters (d). As shown in Figures 2a and 2b, invisible losses increase with increasing sugarcane stalk diameter. This is because increasing sugarcane stalk diameter leads to an increased volume of cutting area or cross-sectional area, where the highest invisible losses were recorded with sugarcane stalks with 3.94 cm in diameter, while the lowest invisible losses were recorded with sugarcane stalks with 2.03 cm. Where increasing the cut area with the stability of the thickness of the saw knife used leads to an increase in the volume of the cut part of the sugarcane stalk and thus increases the invisible loss. However, the relationship between invisible losses occurring and cutting time is not linear at the different sugarcane stalk diameters, as shown in the same figure and the different curve equations illustrated in Figure 2. The nonlinear relationship between sugarcane stalk diameter and cutting time has implications for the design and operation of sugarcane harvesting machines. For example, sugarcane harvesters should be equipped with saw blades with a sufficient number of teeth to cut sugarcane stalks with a large diameter.

Additionally, sugarcane cutting machines should be designed to gradually increase cutting speed with increasing sugarcane stalk diameter. As shown in Figure 2a, there is an inverse relationship between the invisible losses resulting from the process of cutting sugarcane seeds and the time-cutting process, as we find that the curve decreases steadily. As we notice in the cutting time from 1000 ms to 2000 ms, the differences were noticeably large, but during the cutting period from 2000 ms to 3000 ms, these differences decreased significantly. But this trend is opposite to what is in Figure 1b. We also notice that the invisible losses decrease when using a saw knife that contains 80 teeth, compared to the invisible losses that decrease when using another saw knife that contains 30 teeth, which have the same diameter. This is due to the size of the cut particles in the knife, which contains 30 teeth. Significantly larger compared to a saw knife that has 80 teeth. The results shown in Figures 2a and 2b can be used to improve the efficiency of sugarcane seed cutting. For example, these results can be used to select the appropriate saw blade with the appropriate tooth number for the sugarcane stalk diameter to be cut. Unfortunately, there are no previous studies worldwide that studied the relationship between invisible losses and cutting time using different diameters of sugarcane, with which the results of the current study could be compared.

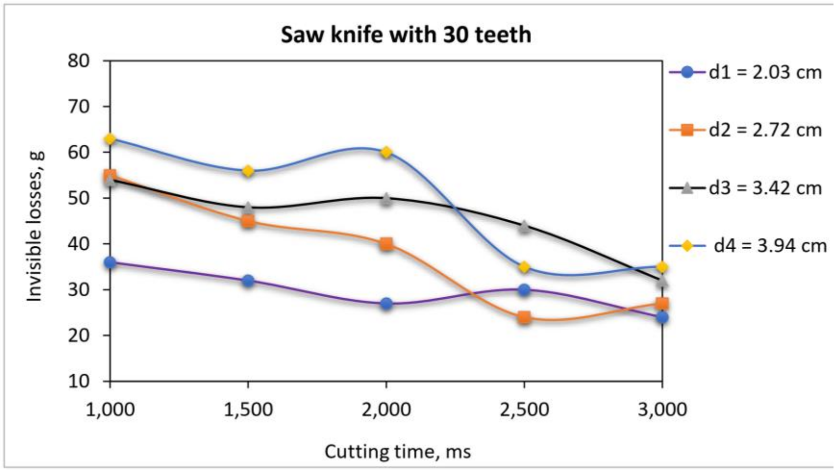

Figure 2a: Relation between cutting time and invisible losses for sugarcane stalks with different diameters using cutting knife with 30 teeth.

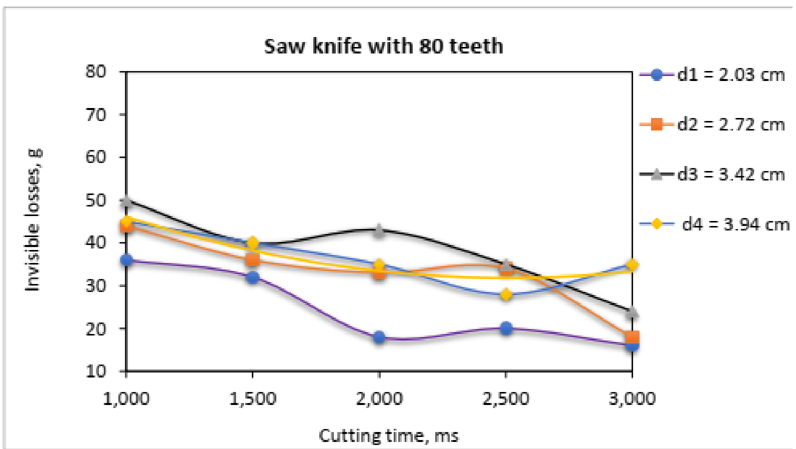

Figure 2b: Relation between invisible losses and cutting time for sugarcane stalks with different diameters using cutting knife with 80 teeth.

3.2.Cutting efficiency

Figures 3a and 3b demonstrate the relation between cutting time (t) and cutting efficiency (%) for sugarcane stalks with different diameters (d). As shown in the same figures, the cutting efficiency decreases with increasing sugarcane stalk diameter. Whereas the maximum cutting efficiency when using a saw knife with 80 teeth was 85% and it was achieved when cutting sugarcane stalks with a diameter of 2.03 cm, the maximum cutting efficiency when using a saw knife with 30 teeth was 95% and it was achieved when cutting sugarcane stalks with a diameter of 2.03 cm. In addition, the lowest cutting efficiency was recorded when cutting sugarcane stalks diameter of 2.03 cm, 3.94 cm with both saw knives. This is because increasing sugarcane stalk diameter leads to increased cutting resistance. As a result, more cutting force is required, which reduces the cutting efficiency. In addition, there is a direct relationship between the cutting efficiency of sugarcane seeds and the time required for cutting. We find that the cutting efficiency increases with the increase in the time specified for the cutting process. This is due to the fact that the reduced cutting time leads to the occurrence of strong pressures on the seeds during their cutting and thus leads to a reduction in the cutting efficiency. Figure 3 also shows that there is a nonlinear relationship between cutting efficiency and cutting time at different sugarcane stalk diameters. This is because the cutting resistance of sugarcane stalks is not a linear function of sugarcane stalk diameter. As sugarcane stalk diameter increases, the cutting resistance increases at an increasing rate. This is because the cutting force required to cut through sugarcane stalks is proportional to the cross-sectional area of the stalks. As sugarcane stalk diameter increases, the cross-sectional area of the stalks increases at an increasing rate. We also notice that the cutting efficiency decreases when using a saw knife that contains 80 teeth, compared to another saw knife that contains 30 teeth, which have the same diameter. The obtained results on the current study come in agreement with **(Elwakeel et al. 2021a; Mahmoud and Abu El-maaty 2021; Zein El-den et al. 2020a)**, where they found that increasing the cutting speed (decreasing the cutting time) and average stalk diameters led to decrease the cutting efficiency.

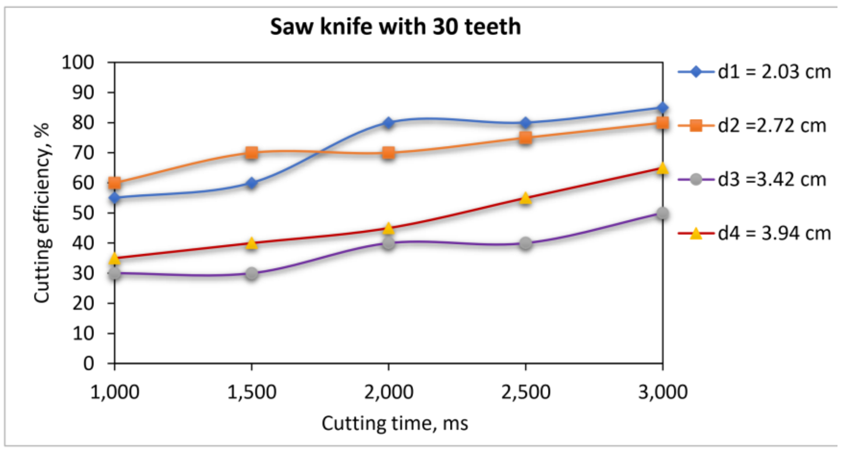

Figure 3a: Relationship between cutting efficiency and cutting time for sugarcane stalks with different diameters using cutting knife with 30 teeth.

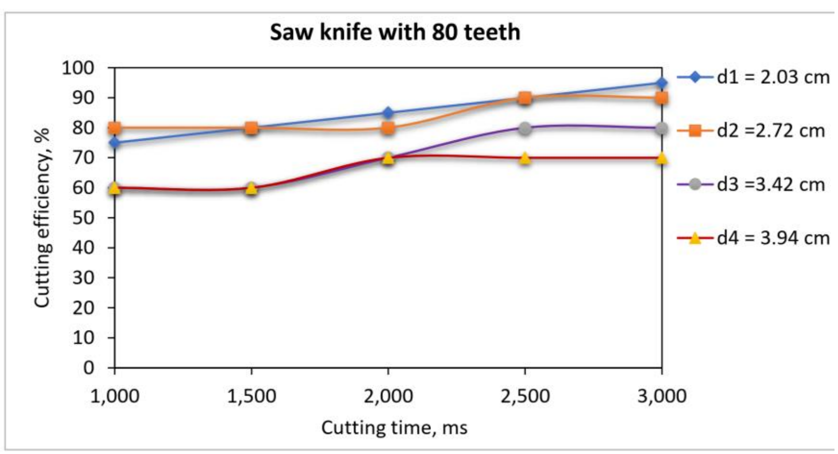

Figure 3b: Relationship between cutting efficiency and cutting time for sugarcane stalks with different diameters using cutting knife with 80 teeth.

3.3. Machine productivity

Figures 4a and 4b illustrate the relationship between cutting time and machine productivity for sugarcane stalks with different diameters (d). The y-axis represents machine productivity, which is measured in seeds per minute (seed/min), and the x-axis represents cutting time, which is measured in milliseconds (ms). The nonlinear relationship between machine productivity and cutting time is due to the nonlinear relationship between sugarcane stalk diameter and cutting time. As cutting time increases, machine productivity decreases at a decreasing rate. This is because the cutting time required to cut through sugarcane stalks is proportional to the machine's productivity. The machine productivity of the developed machine ranged between 25 and 30 seeds per Minute for both saw knives.

When comparing Figures 1a and 1b, we find that there are no significant differences between the types of knives used. We also find in the machine productivity curves that there is a fluctuation, and this fluctuation is due to the presence of some parts of the stalk that are damaged or infected with insect infestations and that it is not desirable to cut, an interval between the feeding process (between the end of the previous sugarcane stalk and the next sugarcane stalk), and also as a result of the machine's inability sometimes to read the signal and detect the sugarcane node.

The obtained results of the current investigation come in agreement with the previous studies, where **Zhou et al. (2020)** designed and testing a sugarcane seed cutting machine based on machine vision and reported that machine productivity was 40 seed/min. However, detecting stem nodes quickly and accurately is still a significant challenge **(Zhou et al. 2022)**; **Ahmad et al. (2020)** designed and testing a prototype of sugarcane seed cutting machine for nursery planting and reported that that machine productivity was 18 seed/min; **Mahmoud and Abu El-maaty, (2021)** developed a sugarcane seed cutting machine and reported that the maximum machine productivity was 36 seed/min; **Elwakeel et al. (2021b)** manufactured and evaluated the performance of a double side sugarcane seed cutting machine and reported that the machine productivity was 66.7 seed/min; **Wang et al. (2022)** designed and evaluated a sugarcane seed cutting machine based on machine vision in pre-seed mode and reported that the machine productivity was 85 seed/min; and **Jadhav et al. (2023)** designed and fabricated of a semiautomatic sugarcane seed cutting machine and reported that machine productivity was 30 seed/min.

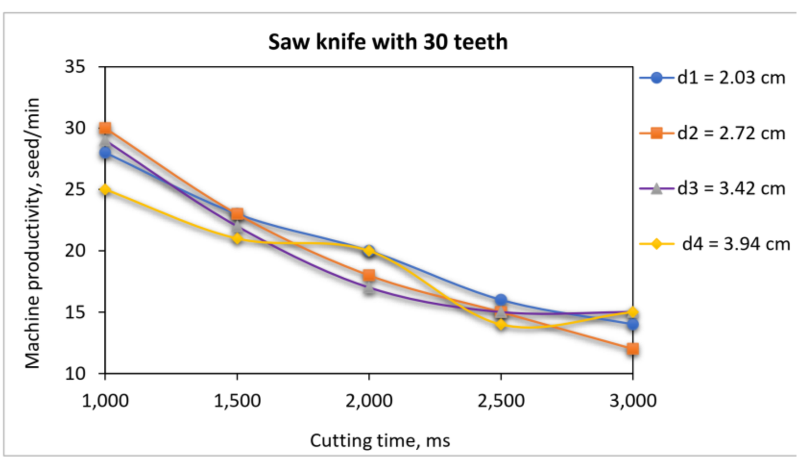

Figure 4a: Relationship between machine productivity and cutting time for sugarcane stalks with different diameters using cutting knife with 30 teeth.

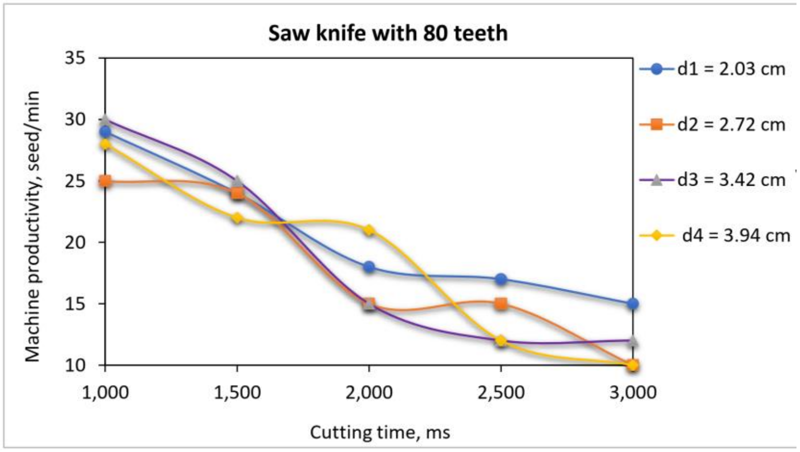

Figure 4b: Relationship between machine productivity and cutting time for sugarcane stalks with different diameters using cutting knife with 80 teeth.

3.4.Thermal analysis of the PV system

The performance of the photovoltaic system was evaluated on December 12, 2023, from 8.00 a.m. to 4.00 p.m., where the short-circuit current (Isc) and open-circuit voltage (Voc) were measured hourly. After that, the amount of solar energy falling on the solar array was measured, as well as the output power and the power losses. Figure 5 shows the relationship between solar irradiance, input power, output power, and loss power during the daytime from 8.00 a.m. to 4.00 p.m. The main findings of the study are as follows: the output power increases with increasing solar irradiance, and the loss power decreases with increasing solar irradiance. The intensity of solar radiation falling on the panels ranged between 288 W/m^2 at 8.00 a.m. and 898 W/m^2 at 1.00 p.m. The average intensity of solar radiation during the day is 694.6 W/m^2. In addition, the peak output power generated by the PV system was 873.6 Kw at 1.00 p.m.

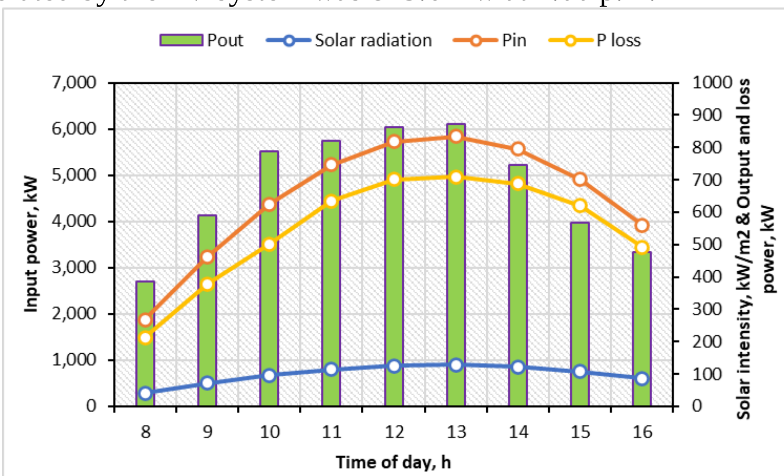

Figure 5. Relation between solar irradiance, input power, output power, and loss power of the PV system at different times of day.

Also, Figure 6 shows that the maximum efficiency of the PV system was 16.09% at 8.00 a.m. The results obtained in this study are consistent with the results obtained in previous studies that have been conducted on the relationship between solar irradiance, output power, and loss power of solar panels. **Jaiganesh and Duraiswamy, (2013)** reported that the efficiency of the PV panel ranged from 9.52 % to 14.5 %. **Yamamoto et al. (2018)**; **Haschke et al. (2018)** reported that the PV efficiency ranged between 24 and27%. **Ho et al. (2018)**; **Müller et al. (2017)** stated that PV systems currently commercially produced have an efficiency of between 14% and 19%. **Elwakeel et al. (2023c)** stated that the efficiency of the PV system ranged between 7 % and 17 %.

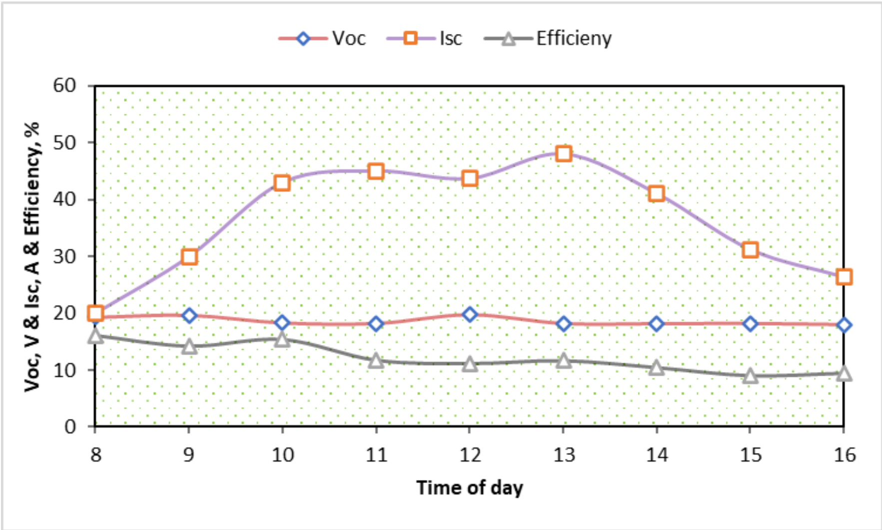

Figure 6. Relation between Voc, Isc, and efficiency of the PV system at different times of day.

4. Conclusion

The obtained results showed that:

- The maximum invisible losses were 63 g per sugarcane stalk, and they were recorded at a cutting time of 1000 ms and a sugarcane stalk diameter of 3.94 cm when using a saw knife with 30 teeth. The invisible losses decreased with increasing the number of teeth on the saw knife, cutting time, and decreasing the sugarcane stalk diameter.
- The maximum cutting efficiency when using a saw knife with 80 teeth was 85 %, and it was achieved when cutting sugarcane stalks with a dimeter of 2.03 cm. As well as the maximum cutting efficiency when using a saw knife with 30 teeth, was 95 % and it was achieved when cutting sugarcane stalks with a dimeter of 2.03 cm. In addition, the lowest cutting efficiency was recorded when cutting sugarcane stalks dimeter of 2.03 cm and 3.94 cm with both saw knives.
- The machine productivity of the developed machine ranged between 25 and 30 seed/min for both saws' knives. There are no significant differences between the types of knives used in the current study.

Based on the previous results, it is recommended to use a saw knife containing 80 teeth, sugarcane stalks with an average dimeter of 2.03 cm, and a cutting time of 3000 ms to obtain the highest cutting efficiency (95%) of the cuttings. Future works

The current study was limited to three variables, further research should explore impacts of other parameters like blade speed, blade thickness, blade material, etc.", In addition testing the machine under field conditions is needed to confirm its performance.

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