Design Development and Performance Evaluation of Solar Operated Pigeon Pea (*Cajanus cajan* L. *Millsp*.) Pruner

ABSTRACT

Pigeon pea (*Cajanus cajan* L. *Millsp.*) is a vital grain legume known for its contribution to food security and soil fertility. However, pruning, which enhances plant architecture and yield, remains a significant challenge in its cultivation, especially in large-scale operations. Manual pruning is labor-intensive, time-consuming, and costly, which has led to the need for mechanized alternatives, a solar-operated pruner was developed at IGKV, Raipur, to reduce labour, time, and costs. This study focuses on the design, development, and performance evaluation of a solar-operated pruner tailored specifically for pigeon pea.The pruner integrates key components such as a cutting blade, DC motor, solar panel, battery, and charge controller. A 12 V DC motor, generating 10.53 N of force and operating at 8500 RPM, ensures efficient pruning. The motor is powered by a 7.2 Ah battery, which can be charged in 4 hours using an AC adaptor or 8 hours via a 10 W solar panel. The battery allows for 4-6 hours of continuous operation. The pruner's lightweight PVC frame makes it portable and user-friendly, while the protective blade guard ensures operator safety. Performance evaluation of the pruner indicated a field efficiency of 81% and pruning efficiency of 76%. The actual field capacity was measured at 0.097 ha/h, with a walking speed of 1.2 km/h. Losses due to half-cut stems were calculated at 9.04%. The pruner demonstrated its ability to reduce labor costs, improve pruning efficiency, and promote sustainable agriculture through its solar-powered operation. This study highlights the economic and environmental benefits of adopting solar-operated pruners for pigeon pea cultivation.

Keywords: Pruning, Pigeon pea, Cutting unit, eco-friendly, DC motor, solar panel, solar charge controller.

1. INTRODUCTION

Pigeon pea (*Cajanus cajan* L. *Millsp.*), commonly known as red gram or *tur*, is a significant grain legume crop grown in tropical and subtropical regions. It plays a crucial role in food security and soil fertility due to its nitrogen-fixing properties. Despite its agricultural importance, pigeon pea cultivation faces challenges, particularly in the area of pruning. Pruning, especially the removal of terminal buds to stimulate lateral branching, is essential for enhancing plant architecture and boosting yield. However, manual pruning is labor-intensive, time-consuming, and physically demanding, especially in large-scale farming operations.

Despite its agricultural importance, pigeon pea cultivation faces challenges, especially regarding pruning. Pruning, specifically the removal of terminal buds, promotes lateral branching, improves plant architecture, and enhances yields. However, manual pruning is labor-intensive, time-consuming, and physically taxing, particularly for large-scale farmers. Given these limitations, mechanized solutions are essential to reduce labor requirements, minimize drudgery, and improve time efficiency while maintaining effective pruning.

The time required for pruning pigeon pea manually can vary based on field size, plant density, laborers' skill level, and tools used. On average, manual pruning is labor-intensive and time-consuming, taking approximately 3-4 days per hectare with a team of 2-3 laborers working 8-10 hours per day. These estimates assume average labor efficiency and favorable conditions. Using hand tools like sickles or pruning shears, laborers can typically prune between 0.03 to 0.035 hectares per person per day. Traditional methods increase time and operational costs, reducing farmers' profits in Chhattisgarh.

Solar-powered agricultural equipment offers a sustainable alternative, reducing dependence on fossil fuels and promoting environmentally friendly farming practices. Utilizing solar energy not only lowers operational costs but also supports global efforts to reduce carbon emissions. In this context, the design and development of a solar-operated pigeon pea pruner provide an innovative solution to these challenges.

This research focuses on the design, development, and performance evaluation of a solar-operated pruner tailored specifically for pigeon pea. The pruner integrates solar energy capture, a control unit for power management, and a cutting unit driven by a DC motor to deliver efficient and eco-friendly pruning. This study aims to assess the pruner's field performance in terms of pruning efficiency, yield improvement, and economic viability, providing a sustainable approach to optimize pigeon pea production.

2. MATERIALS AND METHODS

This chapter covers the materials and methods involved in the design and development of a solar-operated pigeon pea *(Cajanus cajan* L. *Millsp.)* pruner.

The study was conducted at the research farm of the Department of Agronomy at DKS CARS Bhatapara and the machine Fabrication /development work will be carried out in the workshop of Swami Vivekanand College of Agricultural Engineering and Technology & Research Station, FAE, IGKV, Raipur (C.G.), during *kharif*, 2023. Pigeon peas *(Cajanus* *cajan* L. *Millsp.)* were cultivated on ridges and furrows in the fields of DKS CARS Bhatapara.

Design of the Different Functional Component of the Pigeon pea Pruner

Design ofthe different functionalcomponentofthepigeon pea pruner:

1. Cutting blade
2. Battery
3. Solar Panel
4. Solar Charge Controller
5. DC motor
6. Protective guard
7. Frame and Battery Box
8. Handle

1. Cutting mechanism

Sharp, durable blades made from high-quality steel to ensure clean cuts and longevity.Sharpness was evaluated by testing the force required to cut through standard materials, ensuring minimal effort for clean cuts.

Force generated by motor

Find the motor generating force, given by (Malviya *et al.* 2016):

$$F = \frac{T}{R}$$

Where,

T = Shaft torque, = 0.79 N-m

R = Radius of cutting blade = 0.075m

F = 0.79/0.075

F = 10.53 N

Torque requirement

The torque required by the cutting blade was determined by the following Equation given by (Sinha and Mathur 2020):

$$\text{Torque (T)} = W \times R$$

Where,

W = Weight of the blade, N;

R = Radius of the blade, m;

Mass of the blade = 0.014kg

$W = 0.014 \times 9.81 = 0.14$ N

$T = 0.14 \times 0.075 = 0.0105$ N-m

$T = 0.0105$ N-m

Power requirement

Power required by the blade for cutting of grass use the following formula given by (Sinha and Mathur 2020):

$$P = T \times \omega$$

Where,

$$\omega = \frac{2\pi N}{60}$$

Hence, average speed of motor is 8500 rpm was selected.

N = rotational speed of motor;

ω = Angular velocity, (1 RPM = 0.105 rad/sec)

$\omega = 8500 \times 0.105 = 892.5$ rad/sec

$P = T \times \omega$

$P = 0.0105 \times 892.5$

$P = 9.37$ W.

The voltage required to operate the motor, V = 12 V

The power of a motor is expressed by, (Sinha and Mathur 2020):

$$P = V \times I$$

$I = 1.2$ A.

$P = 12 \times 1.2$

$P = 14.4$ W.

It is assumed that the pruner should run at least for 4 hours,

Hence, the total Ampere- hour required to pigeon pea pruner was,

$1.2 \times 4 = 4.8$ Ah

2. Battery

Batteries come in a variety of voltage and ampere-hour ratings. To choose the appropriate one, the voltage and ampere-hour rating were considered. Since the motor requires 14.4 W, a 12 V battery was selected. The ampere-hour rating indicates how long the battery will discharge while in use without recharging. A 7.2 Ah battery can provide 7.2 A of current for one hour, which is more than sufficient for the motor's current requirements.

Fig 1. Battery

3. Solar panel

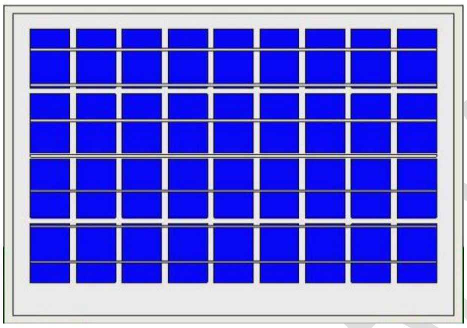

Fig 2. Solar panel

Photovoltaic effect

The photovoltaic effect generates voltage or electric current in a material when exposed to light. Electrons in the valence band absorb energy, become excited, and jump to the conduction band, creating free electrons. The material's chemical structure plays a key role, as ionized atoms produce an electric imbalance that drives electron movement. The photovoltaic effect is related to the photoelectric effect but differs as electrons move directly between materials rather than through a vacuum. In a solar cell, sunlight excites electrons, which diffuse and reach a junction where they are accelerated by a built-in potential, generating electricity. Silicon, often doped with boron or phosphorus, is commonly used due to its semiconductor properties. The photovoltaic effect, first discovered by A.E. Becquerel in 1839, also includes contributions from thermal effects like the Seebeck effect, where absorbed light generates temperature gradients that produce additional voltage. Solar cells are primarily composed of charge collectors, semiconductors that create electron-hole pairs, and regions that separate charges.

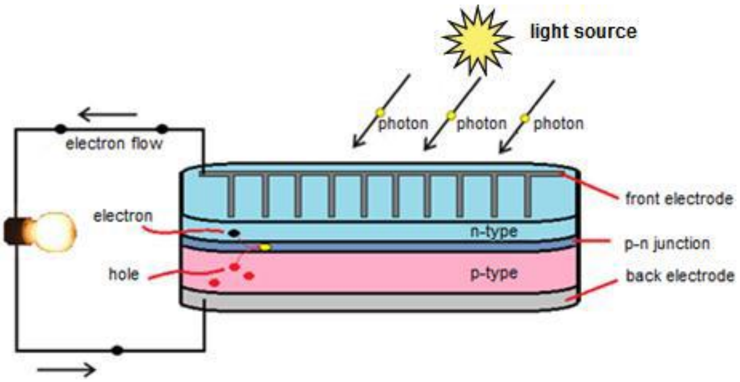

Fig 3. photovoltaic effect principle

Technical Specifications

Solar panels, also known as photovoltaic (PV) panels, convert sunlight into electricity. They are composed of many solar cells made from silicon or other semiconductor materials. When sunlight hits these cells, it excites electrons, creating an electric current. In this pruner, we are using a 12 volt, 10-watt loom solar panel for charging the battery, which is a light-weight, more power-efficient panel and it was placed.

4. Solar charge controller

A solar charge controller, or power charge regulator, is a key component in solar power systems, positioned between solar panels, batteries, and loads to manage battery charging and discharging. It prevents overcharging by disconnecting panels when the high voltage disconnect (HVD) is reached and prevents over-discharging by cutting off loads at low voltage disconnect (LVD). Regulators, connected in series, avoid battery gasification and discharge at night, often utilizing pulse width modulation (PWM) for efficient charging. Modern controllers feature indicators for charging status, low battery, and full charge, enhancing system reliability and battery lifespan.

Fig 4. Solar charge controller cicuit board

I-V Characteristics and P-V Characteristics

The **I-V (Current-Voltage)** and **P-V (Power-Voltage)** characteristics of a solar panel provide essential information about its performance under various conditions.

I-V Characteristics:

- **Current (I)** decreases as **Voltage (V)** increases.
- At zero voltage (short-circuit), the current is at its maximum value, called the **short-circuit current (Isc)**.
- At zero current (open-circuit), the voltage reaches its maximum value, known as the **open-circuit voltage (Voc)**.
- The shape of the I-V curve is typically nonlinear, with a knee or bend near the maximum power point (MPP), which represents the most efficient operating point of the panel.

P-V Characteristics:

- **Power (P)** is the product of current and voltage ($P = I \times V$).
- Initially, as voltage increases from zero, power also increases, peaking at the **maximum power point (Pmpp)**.
- Beyond the MPP, as the voltage increases further, the power decreases sharply due to the rapid fall in current.

These characteristics help in determining the optimal operating point (MPP) of the solar panel to maximize efficiency, and they vary based on environmental factors like irradiance and temperature.

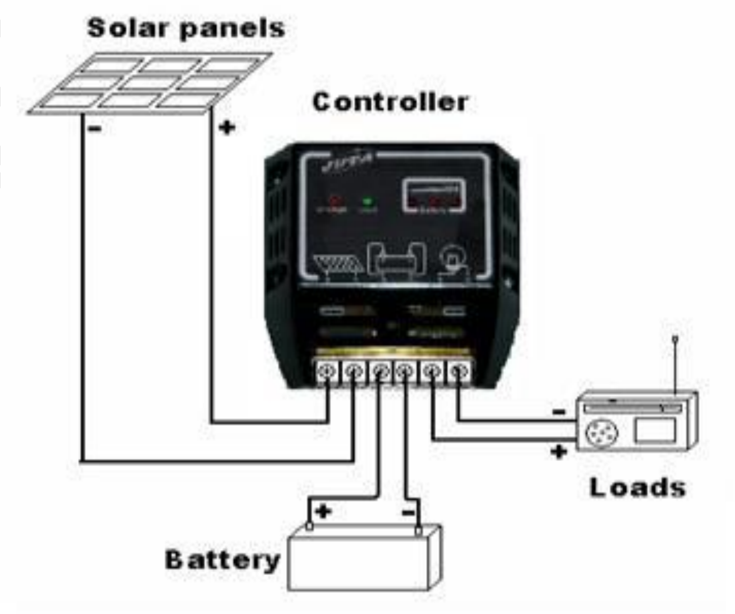

Fig 5. Flow chart of solar charge controller

5. DC motor

A 12-volt DC motor, operating at 8500 rpm and requiring 14.4 W of power, was selected to rotate the blade, mounted at the end of the handle with the blade directly attached. This compact, rust-proof motor is easy to clean, maintain, and consumes low electricity to minimize weight. DC motors convert direct current into mechanical power, providing the torque needed for cutting, with two types available: brushed, which generates torque directly from DC power, and brushless, where a controller converts DC to AC. The high-speed rotation of 8500 RPM is crucial for efficient cutting of pigeon pea branches, as increased RPM provides the blade with sufficient kinetic energy for smooth, precise cuts. Featuring copper windings, the motor's lightweight design makes it ideal for trimming upper pigeon pea branches.

Fig 6. DC motor

6. Protective guard

A protective blade guard in a pruner is a crucial safety feature designed to protect the user from the rotating blade and to prevent debris from being thrown during operation. Solar-operated pruners are powerful tools used for pruning pigeon pea top heads, and the blade guard helps to ensure safe and effective use. A protective blade guard is an essential safety component for pruner, providing protection from the rotating blade and deflecting debris. By ensuring the guard is made of durable materials, properly designed, securely attached, and regularly maintained, users can significantly enhance their safety and the efficiency of their pruning.

7. Frame and battery box

To design and build a frame for the pruner, first determine the dimensions based on anthropometric data, the pruner size (980×473×939 mm), and the battery compartment (290×190×65 mm). Sketch a basic design with the battery box positioned within the frame.

Measure and mark PVC pipes according to the design, cutting them to length using a PVC pipe cutter or saw and sanding the edges to remove burrs. Connect the pipes using appropriate elbows and tees, dry fitting first to ensure accuracy. Once satisfied, disassemble each joint, apply PVC primer and cement, then reassemble. Attach a transparent plastic locking box behind the frame using nuts and screws to house the battery and solar charge controller. Finally, route the pruner wiring inside the PVC pipe frame.

8. Handle

To enhance the usability of the PVC pipe pruner frame, focusing on a comfortable handle with a non-slip grip (plastic grip 32 mm diameter), lightweight materials, and balanced weight distribution is crucial. The handle is made of aluminum pipe (830 mm length and 25 mm diameter) with hard plastic brackets to hold the DC motor used in the pruner. The handle uses a non-slip grip to hold the pruner the pruner properly and balance it. A cable is attached to the battery box of the pruner to supply power to the motor.

Developed Solar Operated Pigeon Pea Pruner

A 3D model of the solar-operated pigeon pea pruner was created using CREO-Parametric 4.0, as shown in Figures 1 and 2, finalizing the design after positioning all components. This pruner was developed to reduce time and effort during pruning, with various parts fabricated and assembled accordingly. The pruner features a rotating blade powered by a rechargeable battery, charged by lightweight solar panels mounted on the pruner, allowing extended use even in varying sunlight conditions. A hard plastic safety guard, measuring 150 mm in length and 80 mm in width, shields the rotating blade and prevents accidental activation, improving user safety.

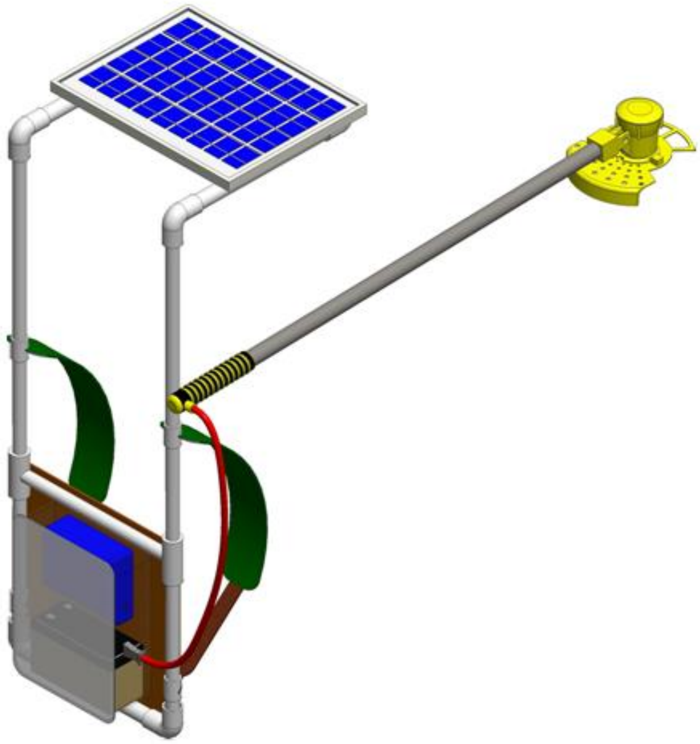

Fig 7. Isometric view of solar operated pigeon pea pruner

Performance Evaluation of Solar Operated Pigeon Pea Pruner

Fig 8. Pruning of pigeon pea by developed pigeon pea pruner

Fig 9. Increased in number of branch after pruning

Losses due to half-cut stem

This refers to the crop loss resulting from stems that are only partially cut during the pruning process. Such half-cut stems can negatively impact the overall health and productivity of the plant, potentially leading to reduced yield and increased mortality rates.

Effective pruning should aim to minimize these losses to ensure optimal plant growth and maximize yield.

$$\text{Losses due to half} - \text{cut stems } (\%) = \frac{\text{Number of half} - \text{cut stems}}{\text{Total number of stems}} \times 100$$

Walking speed

The walking speed during the pruning of pigeon pea with a pruner is crucial for determining the efficiency and effectiveness of the pruning process. This speed refers to the rate at which the operator moves through the field while operating the pruner, typically measured in meters per second (m/s) or kilometres per hour (km/h). The optimal walking speed ensures that the pruner covers the field efficiently without compromising the quality of pruning.

$$\text{Walking Speed } \left(\frac{\text{m}}{\text{s}}\right) = \frac{\text{Distance Covered}}{\text{Time Taken}}$$

Actual fieldcapacity

Actual field capacity for pruning refers to the productive area covered by a pruner per unit of productive time, accounting for both operational efficiency and time lost due to factors like turning and adjustments.

$$\text{AFC } = \frac{\text{A}}{\text{T}}$$

Theoretical field capacity

Theoretical field capacity (TFC) in pruning represents the maximum area that a pruner can potentially cover per unit of time under ideal operational conditions, disregarding practical limitations such as turning and adjustments.

$$\text{TFC} = \frac{\text{W} \times \text{S}}{10}$$

Field efficiency (%)

Field efficiency is the ratio of Actual field capacity to pruning capacity.

$$\text{FE } (\%) = \frac{\text{AFC}}{\text{TFC}} \times 100$$

Pruning efficiency

Pruning efficiency quantifies the effectiveness of a pruning operation by measuring the proportion of the intended plants or branches pruned relative to the total targeted.

$$\text{Pruning Efficiency } (\%) = \frac{\text{Number of successfully growing plant after pruning}}{\text{Total number of plant}} \times 100$$

3. RESULTS AND DISCUSSIONS

The results obtained from the proposed study on the design, development, and performance evaluation of a solar-operated pigeon pea pruner.

Development of Solar Operated Pigeon Pea Pruner

The solar-operated pigeon pea pruner was developed using specific machine parameters to meet the unique needs of pigeon pea cultivation, focusing on efficiency and sustainability. Key components include a DC motor that generates 10.53 N of force, slightly above the required 10 N, ensuring smooth cutting. The motor also provides 0.0105 N-m of torque and requires 9.37 W of power, calculated based on force and torque requirements. A 12 V/7.2 Ah battery powers the motor, complemented by a 10 W solar panel for sustainable operation. The battery charges fully in 4 hours with an AC adaptor or in 8 hours using solar energy, providing 4 to 6 hours of operational time. A 12 V/6 Amp solar charge controller manages power flow, preventing overcharging and maintaining system efficiency. The pruner's DC motor operates at 8500 RPM, ensuring precise cuts, while the lightweight PVC frame and battery box make it durable and easy to handle. This pruner, designed for improved pruning efficiency, reduces labour costs, promotes uniform crop growth, and supports environmental sustainability through its integration of renewable energy sources.

Performance Evaluation of Solar Operated Pigeon Pea Pruner

Losses due to half-cut stems in pigeon pea cultivation accounted for 9.04% of the total yield, determined by evaluating 10 plants with 210 stems, of which 19 were half-cut. The walking speed during pruning was 1.2 km/h, calculated from a distance of 30 m covered in 88 seconds. The actual field capacity of the solar-operated pruner was measured at 0.097 ha/h, while the theoretical field capacity was 0.12 ha/h, resulting in a field efficiency of 81%. The pruning efficiency was determined to be 76%, based on 160 successfully growing plants out of 210 total plants. These metrics reflect the pruner’s performance in terms of yield losses, speed, and overall efficiency during operation.

4. CONCLUSION

The study successfully designed, developed, and evaluated a solar-operated pruner specifically for pigeon pea, addressing the challenges of manual pruning, such as labour intensity, time consumption, and costs. The pruner, powered by a 12 V DC motor generating 10.53 N of force, and sustained by a 7.2 Ah battery chargeable via a 10 W solar panel, demonstrated effective pruning with a field efficiency of 81% and pruning efficiency of 76%. The lightweight and portable design, combined with its eco-friendly solar power usage, makes the pruner a sustainable solution that promotes both economic and environmental benefits in pigeon pea cultivation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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