

Acta Technologica Agriculturae 4  
Nitra, Slovaca Universitas Agriculturae Nitriae, 2024, pp. 219–226

## DEVELOPMENT OF POWER SUPPLY SYSTEM SOLAR BASE FOR COFFEE PULPER

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Coffee pulpers generally use combustion and electric engines in operation, which have many disadvantages such as expensive fuel, pollution, and limited usage in places where electricity is supplied by the government. Therefore, a wet pulper coffee powered by an alternating current electric engine based on solar panels was developed. This study aims to produce and test a solar-powered alternating current electric engine wet pulper for coffee. This research went through several stages which are collecting secondary data, designing the tools to be developed, technical analysis, and performance test. The development of the pulper machine included an electric motor with a power of 1103.64 W, with a maximum machine rotational speed of 1400 rpm, an inverter, a 12 V and 100 A battery, a solar panel, and a 24 A solar charge controller. The performance results showed a stripping capacity of 783.176 kg·h<sup>-1</sup> and the best percentage of stripped coffee pulp at a machine rotational speed of 467 rpm and a mass of 3 kg. The findings show that a pulper powered by a solar-based alternating current electric engine can be a viable solution for areas without electricity and a suitable replacement for combustion engines.

**Keywords:** renewable energy solutions; eco-friendly pulping; solar-powered machinery; alternative power systems

Coffee production in Indonesia continues to increase. Despite being ranked fourth in the world after Brazil, Vietnam, and Colombia (Maulani and Wahyuningsih, 2021; Pratiwi et al., 2021), the quality of coffee after processing is generally low. Therefore, the coffee beans of better quality must be handled appropriately (Eshetu

et al., 2022; Freitas et al., 2024; Kieu Tran et al., 2020; Marhaenanto et al., 2015). Coffee bean processing consists of several postharvest stages. The first stage is the peeling process. This process is known as wet coffee stripping or pulping. Currently, farmers strip coffee using machines powered by combustion engines (Bizimungu et

al., 2024; Sahar et al., 2020; Susilawati et al., 2023).

The coffee peeler machine (pulper) works with a petrol motor power source and has a working principle that starts by placing the beans into the hopper and then entering the grinding drum. Coffee beans break because of the pinch between the grinder and the pulper wall. After the coffee fruit was broken and peeled, the skin and coffee beans separated and exited the machine through the existing outlet. To design this machine, it is necessary to design tools that include the machine body, skin and seed separator, precision roller, hopper, and frame (Bizimungu et al., 2024; Wiranata et al., 2021).

The disadvantages of using a pulper with a combustion engine as a power source include its environmental impact and high operating costs (Killian et al., 2013). Figure 1a shows the common pulper used in a combustion motor. An alternative to replacing a combustion engine is the use of an electric engine. Using an alternating current (AC)



**Fig. 1** The coffee peeler machine (pulper) with (a) combustion motor, and (b) electric motor  
Source: Wiranata et al., 2021

electric engine requires an electrical power source, and this tool cannot be used in places where electricity is not available. An example of a pulper machine that uses an electric motor is shown in Fig. 1b.

Some research related to the application of solar power has been carried out on agricultural machinery, for example on paddy threshers (Hafijur et al., 2022), maize grinding machines (Sharma et al., 2020), grain dryers (Gebremicheal et al., 2021; Purio et al., 2016; Román et al., 2020), seed sowing machine (Shanmugasundar et al., 2022; Prakash et al., 2021), weeder machine (Velmurugan et al., 2023), harvester machines (Tefera and Aschenaki, 2019; Zeeshan and Aized, 2023), agricultural land irrigation machines (Liu et al., 2022; Mehta et al., 2020; Rana et al., 2021; Saney et al., 2020), multipurpose agriculture machines (Chadalavada et al., 2021; Kanthraju et al., 2021; Singh et al., 2019), and so on. To the best of our knowledge, the development of solar-powered coffee processing machines is still limited. Some of the existing research is on coffee-drying machines (Kusmiyati and Fudholi, 2021, 2022; Suherman et al., 2020). Based on these problems, the pulper was developed by replacing the driving force of the electric engine (which comes from the State Electricity Company (PLN) electricity) with an AC electric engine based on solar power. As one of the countries located on the equator, Indonesia is able to use solar energy more effectively than countries that are not on the equator. The average solar irradiation value is around  $4\text{--}5 \text{ kWh}\cdot\text{m}^{-2}$  which is distributed throughout Indonesia (Rumbayan et al., 2012). Alternating current electric engines have many advantages, such as low maintenance costs and no residual gas, which can cause environmental pollution. Alternating current electric engine solar panels can reduce operational costs and can be used directly on agricultural land where there is no source of electrical energy (Setiawan et al., 2020).

By using an AC electric engine, solar panels can reduce fuel consumption and expand the adoption of renewable energy. This can reduce engine's fuel consumption as well as the maintenance costs of machines

used to peel coffee (Killian et al., 2013; Purwoto et al., 2018). Through this process, the expenses of coffee farmers are minimised so that business capital is smaller, which has an impact on the increase in farmers' income.

The testing of pulpers that use solar panels needs to be performed to identify the level of effectiveness of the machine. The tests carried out included machine capacity, machine rotational speed (rpm), slip, stripping speed, and stripping results, including the percentage of whole beans, unpeeled beans, skin flakes, beans (including skin flakes), yield, yield loss, and broken coffee beans. This was done to determine the effectiveness of an electric engine-powered machine in carrying out wet coffee peelers (Iqbal et al., 2018). The main purpose of this research was to develop a coffee pulper system using an AC electric motor solar-based system and to determine the work capacity of the pulper.

## Material and methods

### Tools and materials

The tools used in this research were wet coffee pulpers, AC electric motors, solar panels, batteries, solar charge controllers, inverters, and cables. The materials used in this study were iron, nuts and bolts, electrodes, pulleys, V-belts, and Arabica coffee cherries (*Coffea arabica*) obtained from local farmers.

### Research procedure

The development of pulper machines is in several stages. Initially, a development plan for existing equipment is created. This is followed by the development part, the replacement of the power source, which in this case is the PLN, with solar panels. The functional design of the machines is then created, which involves a number of calculations to ensure that the machine runs according to its intended functions. The details of each stage are explained as following.

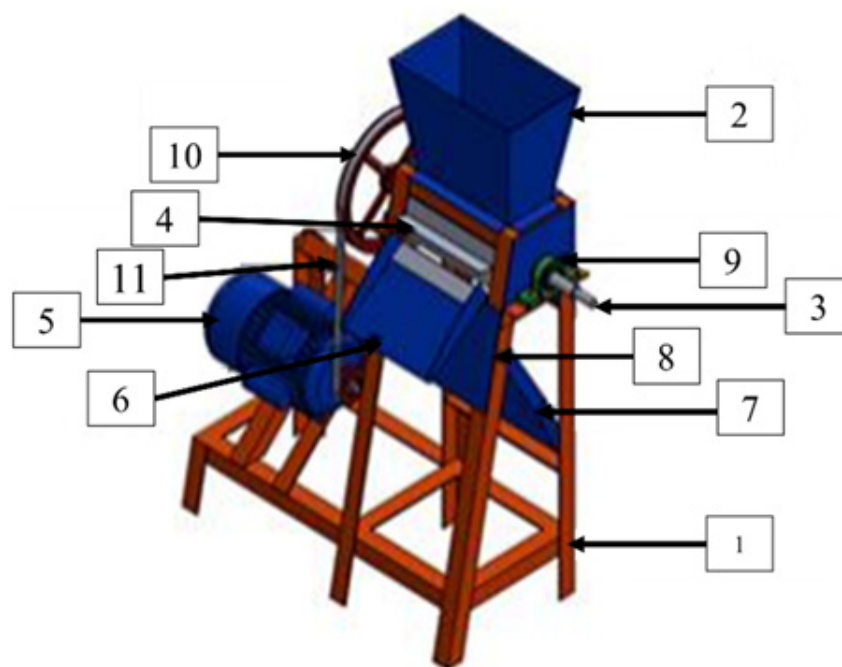


**Fig. 2** Pulper powered by an electric motor drive

1 – the frame to support other components; 2 – the hopper as a place to accommodate or enter coffee beans; 3 – the shaft as the successor of transmission received from driving force to the roller; 4 – the rolling pin to crush coffee beans; 5 – the place where coffee beans come out; 6 – the coffee skin output place; 7 – the front body covering the grinding drum so that when stripping, coffee beans do not scatter; 8 – the bearings serving as support and facilitating shaft rotation; 9 – the pulley as a component for transmitting rotation produced by the driving motor; 10 – the V-belt as a motor power distributor to the roller shaft; 11 – the electric motor as a source of propulsion

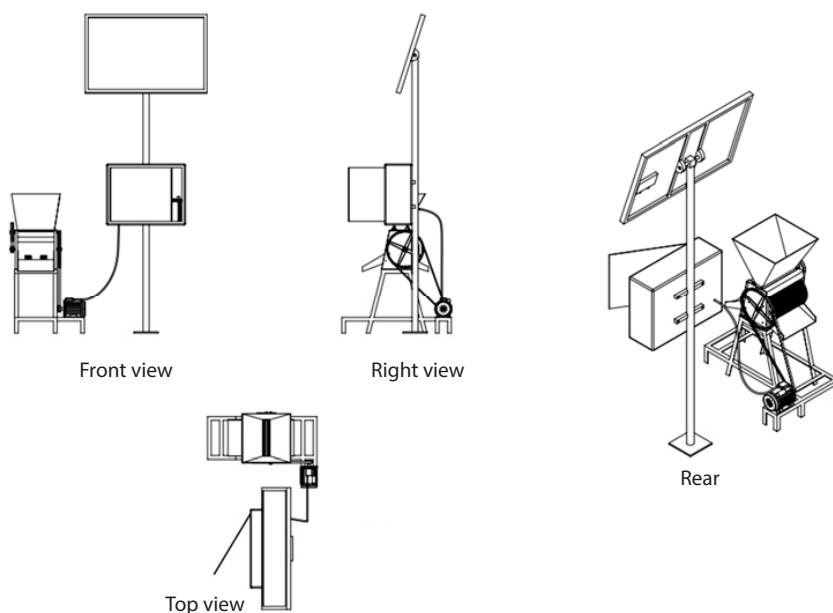


**Fig. 3a** The partial section view of the developed pulper machines with AC electric motor solar-based system

### Development plan

Figs 2 and 3 show the pulper using the AC electric motor power sourced from the state electricity company (PLN).

### Development part

Development was carried out on the electrical energy source used, namely, replacing the PLN electricity source with a solar panel electricity source. The following are the components of the solar panels used to produce electrical energy that supplies the needs of AC electric motors:

1. solar panels are used to convert sunlight intensity into electrical energy;

2. a charge controller is used to regulate the battery charging process to avoid overcharging;
3. the battery acts as a reservoir for electric current obtained from solar panels;
4. an inverter to convert direct current (DC) to alternating current (AC).

### Functional design

The machine was driven using an AC electric motor with a power source from solar panels. The function of this machine is to peel coffee and then separate the beans and skin.

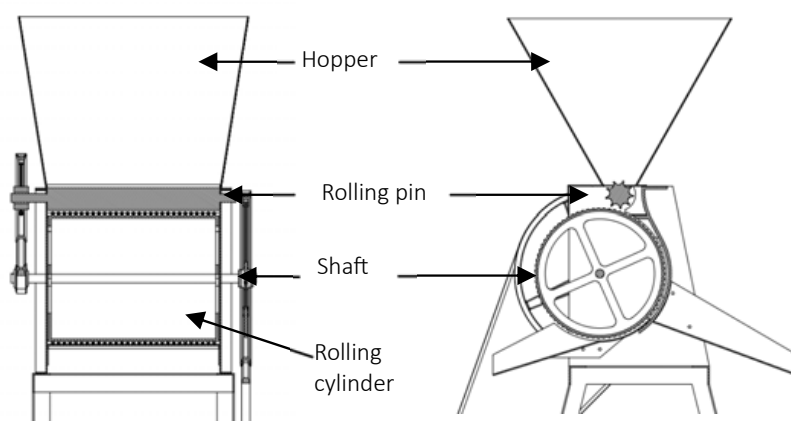


**Fig. 3b** The partial section view of the developed pulper machines with pulper machines

### Technical Analysis

The calculation of shafts and transmission planning was determined according to Wiranata et al. (2021):

$$Pd = Fc \times p \quad (1)$$

where:  $Pd$  – power requirement (W);  
 $Fc$  – correction factor;  $p$  – engine power (W)

Stripping capacity was calculated according to Sugandi et al. (2017):

$$K = (w \times t_1^{-1}) \times 3600 \quad (2)$$

where:  $K$  – stripping capacity ( $\text{kg} \cdot \text{h}^{-1}$ );  
 $w$  – total weight peeled (kg);  
 $t_1$  – time for stripping (h)

Installing solar panels requires calculations. According to Masdar and Asriandi (2018), the solar cell installation calculations can be performed as following.

Equation (3) was used to determine how many panels are used to meet energy needs (Masdar and Asriandi, 2018):

$$JP = TE (KP \times Psh)^{-1} \quad (3)$$

where:  $JP$  – the number of panels;  
 $TE$  – total energy (W);  $KP$  – panel capacity (W);  $Psh$  – optimum exposure time (h)

Charge controller capacity (Masdar and Asriandi, 2018) was calculated according to Eq. (4):

$$I = ISC \times Np \times F_{\text{safe}} \quad (4)$$

where:  $I$  – current (A);  $ISC$  – short circuit current (A);  $Np$  – the number of panels;  $F_{\text{safe}}$  – safety factor

Battery specifications to meet energy needs (Masdar and Asriandi, 2018) were determined using Eq. (5):

$$P = V \times I \quad (5)$$

where:  $P$  – battery power (W);  $V$  – voltage (V);  $I$  – current (A)

The number of batteries required (Masdar and Asriandi, 2018) was calculated using Eq. (6):

$$JA = TE \times P^{-1} \quad (6)$$

where:  $JA$  – the number of batteries;  
 $TE$  – total energy (W);  $P$  –  
 battery power (W)

Alternating current electric engines convert electric currents into mechanical energy. The principle of this engine is that it generates force or rotation on the rotor using a phase-difference source. Based on the source, AC electric engines are divided into two types: synchronous and inductive (Pattiapon et al., 2019).

## Results and discussion

### Pulper overview

The development of a pulper powered by an AC electric engine solar-based system can be seen in Fig. 4. It consists of two parts, namely, the pulper part and the solar panel part, which produces electricity. The construction of the pulper can be seen in Fig. 3b. Furthermore, the construction of the solar panel section is slightly different from the design in Fig. 3a. This is based on the results of field observations that show sunlight can hit the photovoltaic (PV) panel which is in a flat position on the table without tilt. Figure 5 shows the working mechanism of this machine. The PV panel collects energy from the sun in the form of sunlight and converts it into electricity. Then, generated electricity passes through the solar charge controller to control the charging of the battery. The battery serves to accommodate



**Fig. 4** Solar AC electric motor pulper

the electrical energy produced by solar panels. Electrical energy then enters the inverter to convert DC into AC, which in turn becomes the driving force of the 220 V (AC) electric motor.

Solar panels replace the electricity sources from PLN to reduce operational costs. Utilising this renewable energy source, the use of solar panels to run AC electric engines has the potential to produce high productivity but low production costs. The use of PV panels as a source of AC electric motor drive power is highly effective because Indonesia is a tropical country that is directly exposed to sunlight and

sunlight availability is high (Setiawan et al., 2020; Zeeshan and Aized, 2023).

### Pulper power requirement

The power of the electric motor plan was calculated to determine the amount of power needed to operate the pulper. The results of calculation using Eq. (1) show that the required electric motor power is 593.54 W. Using the correction factor of 1.5, the power requirement obtained is 887.38 W (Table 1). The correction factor is chosen based on the criteria listed by Sularso and Suga (2004) for a shredder machine with the maximum

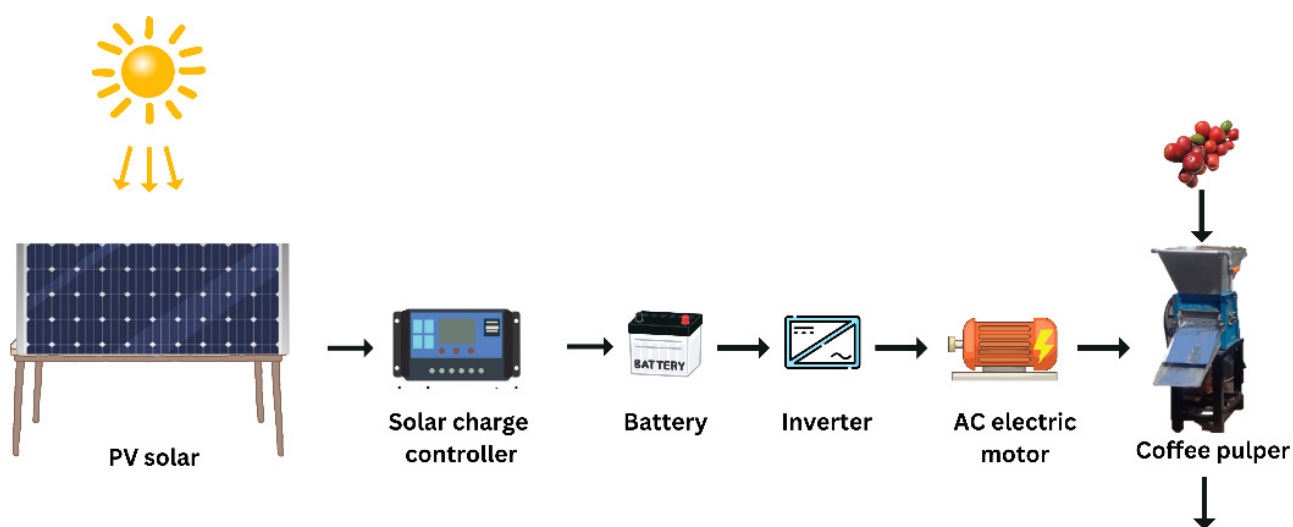


**Fig. 5** Developed machine scheme

torque of 200% for working hours of 3–5 h·day<sup>-1</sup>. Therefore, the electric motor used as driving force is WIPRO brand, model Yo905, with the specifications listed in Table 1.

**Table 1** Pulper specification and power requirements

| Machine specification     | Value   | Unit                |
|---------------------------|---------|---------------------|
| Rolling pin weight        | 4.5     | kg                  |
| Rolling pin radius        | 0.09    | m                   |
| Intended rotational speed | 1400    | rpm                 |
| Torque                    | 4.05    | N·m                 |
| Angular velocity          | 146.53  | Rad·s <sup>-1</sup> |
| Calculated engine power   | 593.54  | W                   |
| Power requirement (Pd)    | 887.38  | W                   |
| <b>Electric motor</b>     |         |                     |
| Power                     | 1103.64 | W                   |
| Current                   | 5.03    | A                   |
| Voltage (AC)              | 220     | V                   |
| Frequency                 | 50      | Hz                  |
| Machine maximum speed     | 1400    | rpm                 |

### Solar power design

#### Inverter requirements

Inverters are used to convert DC current into AC current to satisfy the requirements of AC electric motors. The selection of inverter power must be greater than the power of the electric motor used, as Purwoto et al. (2018) stated that the usable power of the inverter is only 95%. Therefore, an inverter of the brand STEC, model STC-2000 W with the specification listed in Table 2 is used.

**Table 2** Specifications of the solar power design components used

| No. | Item                    | Value              | Unit |
|-----|-------------------------|--------------------|------|
| 1   | inverter                | 2000               | W    |
|     |                         | 12 (DC) – 220 (AC) | V    |
|     |                         | 50                 | Hz   |
| 2   | battery (accu)          | 1200               | W    |
|     |                         | 12                 | V    |
|     |                         | 100                | A    |
| 3   | solar charge controller | 720                | W    |
|     |                         | 12                 | V    |
|     |                         | 24                 | A    |
| 4   | solar panel             | 100                | W    |
|     |                         | 17.8               | V    |
|     |                         | 5.62               | A    |

#### Battery requirements

The battery stores the electrical energy generated by the solar panel, which is not immediately used. The battery was used when the solar period was low. The requirement

for batteries to store electrical energy and meet the load needs for 1 h is 0.9225, or it can be roundup one battery unit. However, based on the findings of Budiyanto et al. (2021), who indicate that only 50% of the energy can be utilised, the battery used in this study is two-unit. The specifications of the battery are GS Gold Shine Brand, N100 (95E41R) model, 12 V, and 100 A (Table 2).

#### Solar charge controller requirement

The solar charge controller (SCC) regulates the electric current, both the incoming current from the PV panel and the outgoing current used. In addition, it prevents the battery from overcharging and regulates the voltage and current from the solar panel to the battery. The specifications of the required SCC are Steca Brand, Solaric PRS 2020 model (Table 2).

#### Solar panel requirement

The selection of a solar panel or PV panels is based on the total energy needs of three electric motors with the specifications of monocrystalline materials, Green Cell brand, Model SM100-18P, power 100 W, maximum power volt 17.8 V, maximum power current 5.62 A (Table 2), with the consideration of optimum energy absorption for 5 h. According to Budiyanto et al. (2021), solar energy that can be absorbed and converted into electrical energy in Indonesia lasts for 5 h.

### Functional and performance test

#### Pulper functional test

Functional tests are conducted for each component utilised in machine's development to ascertain its ability to function correctly. The functional tests are deemed successful if the machine is observed to be capable of peeling wet coffee. Based on the results, it can be concluded that all the components are functioning as intended.

#### Pulper performance test

The performance test evaluates the uniformity of the product, pulper capacity, and the yield of the pulper at different weight inputs. For the uniformity test, 2 kg of coffee beans is pulped with three replicates. The mean and standard deviation of the pulped coffee bean and skin are listed in Table 3.

**Table 3** Statistical analysis for coffee pulper performance test

| Weight after pulper (kg) | Mean  | SD    |
|--------------------------|-------|-------|
| Whole bean               | 0.863 | 0.062 |
| Damaged bean             | 0.012 | 0.008 |
| Skin                     | 0.830 | 0.030 |
| Unpeeled bean            | 0.095 | 0.030 |
| Total                    | 1.800 | 0.043 |
| Losses                   | 0.200 | 0.043 |

The yield of coffee beans after pulping is 43% (whole bean in comparison to the initial weight of the sample). A similar result is reported by Yadav et al. (2021) who obtained 45.3%

of pulp and beans during the wet processing of coffee. Based on the standard deviation, the coffee pulper resulted in a consistent yield for three repetitions.

Furthermore, pulper capacity and product yield are evaluated at three different weight inputs. Each experiment used 2, 3, and 5 kg of wet coffee beans with the engine speed of the AC electric motor measured at 467 rpm. Motor rotation speed significantly affected the working capacity of the engine. This is in accordance with Mulyawan et al. (2018) who state that the higher the rotational speed of the engine used, the faster the processing process. When the rotational speed of the machine is low, the processing process is slow. This is influenced by the rotational speed of the motor, which in turn is influenced by the size of the pulley used. The faster the rotation of the machine, the greater the stripping capacity. This is in accordance with Iqbal et al. (2018) who state that work capacity is influenced by various factors that also affect the level of efficiency of a tool or machine.

Table 4 shows the working capacity of the solar panel-based AC electric motor-powered pulper. In the 2 kg stripping experiment, the time required for stripping was 12.27 s with a stripping capacity of 586.797 kg·h<sup>-1</sup>. In the second experiment with a coffee weight of 3 kg, the time required for stripping was 13.79 s, with a stripping capacity of 783.176 kg·h<sup>-1</sup>. In the third experiment using 5 kg of coffee, the length of time required for stripping was 22.72 s with a stripping capacity of 792.243 kg·h<sup>-1</sup>. According to Wiranata et al. (2021), pulper stripping capacity using the AC electric motor power sourced from PLN electricity had an average working capacity of 235 kg·h<sup>-1</sup>. According to Marbun et al. (2015), the average pulper stripping capacity using a combustion motor drive power is 206.57 kg·h<sup>-1</sup>. This shows that the use of solar panel-based AC electric motor-powered pulpers can work as well as pulpers using AC electric motors sourced from PLN electricity and combustion motors.

Table 5 shows the results of wet coffee stripping at 467 rpm; different stripping criteria were obtained according to the amount of material used. The results show that using 3 kg of coffee yields cleaner results than those obtained from 2 kg and 5 kg of coffee. This was influenced by the speed of rotation of the machine, which was hampered by too few or too many coffee beans. This is in accordance

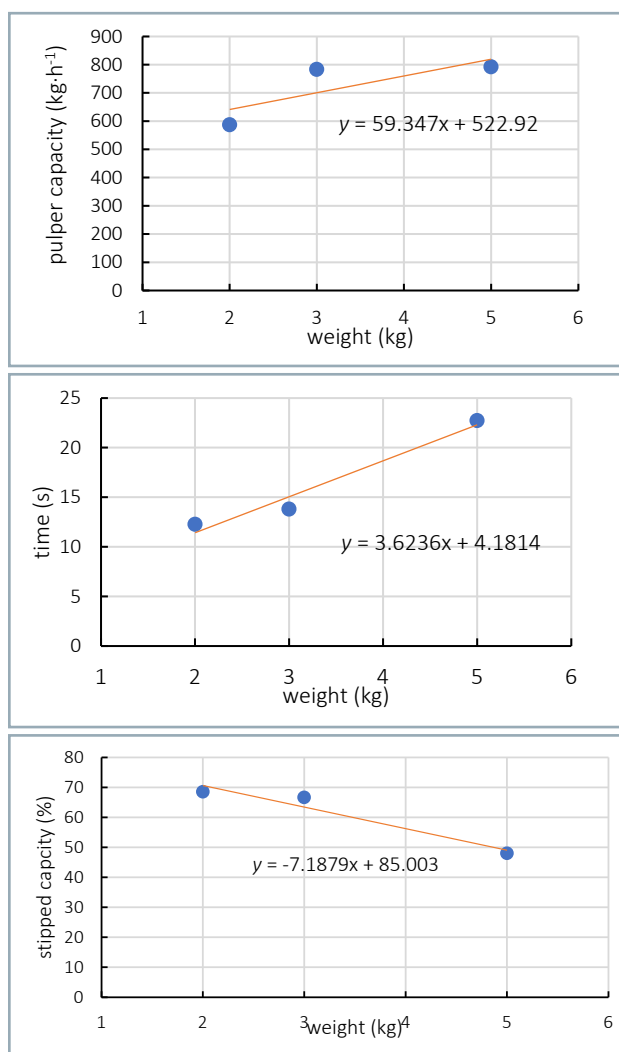


**Fig. 6** Regression analysis of the dependence of coffee weight on pulper capacity (a); time (b); and stripped capacity (c)

**Table 4** Working capacity test results of solar panel AC electric motor powered pulper

| Experiment | Weight (kg) | Time (s) | Pulper capacity (kg·h <sup>-1</sup> ) |
|------------|-------------|----------|---------------------------------------|
| 1          | 2           | 12.27    | 586.797                               |
| 2          | 3           | 13.79    | 783.176                               |
| 3          | 5           | 22.72    | 792.243                               |

**Table 5** Wet coffee bean hulling yield criteria

| Weight (kg) | Weight of striped wet coffee (kg) | Criteria (%) |              |
|-------------|-----------------------------------|--------------|--------------|
|             |                                   | stripped     | not stripped |
| 2.00        | 1.37                              | 68.5         | 31.5         |
| 3.00        | 1.99                              | 66.63        | 33.37        |
| 5.00        | 2.40                              | 48.00        | 52.00        |

with the statement of Sidi et al. (2018), who state that the higher the rotation speed of stripping, the less perfectly the resulting coffee beans are peeled, while the lower the rotation, the better the stripping results obtained.

The regression analysis of the dependence of coffee weight on pulper capacity, time, and stripping capacity is shown in Figs 6a–c. Regarding the dependence among coffee weight and the three parameters, the statistical analysis has no significant difference ( $\text{sig} > 0.05$ ). However, from the graph of the performance test results, it is known that the greater the coffee weight, the higher the pulper capacity and stripping time with a constant increase of 59.347 for pulper capacity and 3.6236 for stripping time. A different trend occurred when comparing coffee weight to stripping capacity, which decreased with greater coffee weight. The constant decrease is 7.1879. This shows that excessive weight will cause a lot of beans that are not peeled. It implies that as coffee weight increases, stripping capacity decreases, leading to a potential increase in waste and a decrease in efficiency.

### Conclusion

In this study, a pulper machine with solar-based energy resources was developed. The pulper machine featured components functioning properly, including an electric motor with a power of 1103.64 W, the maximum speed of 1400 rpm, an inverter, a 12 V and 100 A battery, a solar panel, and a 24 A solar charge controller. Furthermore, the machine demonstrated effective performance, achieving a stripping capacity of 783.176  $\text{kg}\cdot\text{h}^{-1}$  and a stripping efficiency of 66.63% at an engine rotation speed of 467 rpm and a coffee mass of 3 kg. Statistically, feeding different coffee weights did not give significant differences in pulper capacity, time, and stripping capacity. The constant increase was 59.347 for pulper capacity and 3.6236 for stripping time, while stripping capacity decreased by 7.1879.

The findings of the study indicate that there is significant potential for using this technology by farmers in plantations or remote areas not served by electricity, reducing air pollution and fossil fuel consumption, and therefore providing overall sustainable agricultural solutions and alternative energy sources. Future research should concentrate on optimising the design, investigating the long-term durability and maintenance requirements of the solar-powered system, and exploring the potential for scaling up the pulper for broader coffee postharvest processing applications.

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