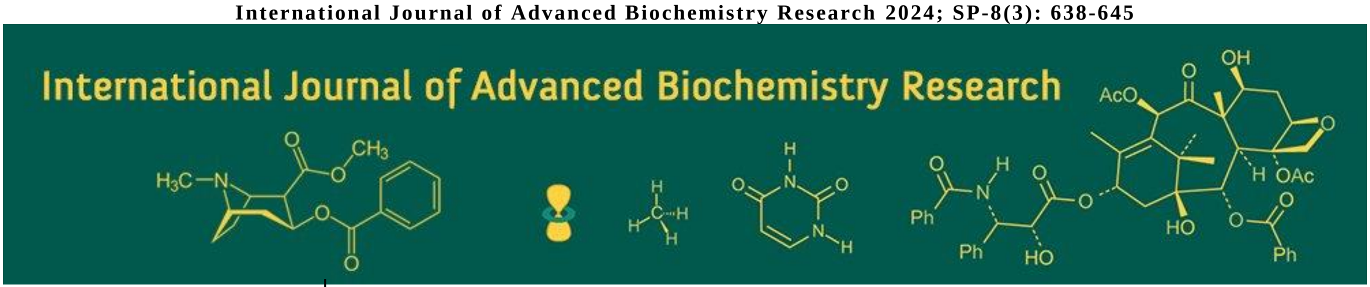

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Design and development of battery operated single row weeder for chickpea SVCAET&RS, FAE, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.)

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Abstract
This paper introduces the idea of a battery-powered weeding mechanism that can be used to weed at chickpea plants with 300 mm row spacing. In order to take on clay soil, a single row battery-operated weeder was designed, developed, and evaluated. The results showed that, at 5% significance levels, the depth of operation and operation speed had a substantial impact on both weeding and field efficiency. Operating at a speed of 1.5 to 2.0 km/h and a depth of 30 to 50 mm, the average weeding efficiency, field capacity, field efficiency, and percentage plant damage were found to be 90.79%, 0.046 ha/h, 84.72%, and 3.18%. The specific type of weeding blade increases weeding efficiency and lowers the possibility of weed escape. All things taken into account the battery-powered single-row weeder that has been designed could be a useful tool for chickpea farmers to carry out their weeding activities more effectively and with less effort.

Keywords: Battery operated, field capacity, single row, plant damage, weeding efficiency

Introduction

Removing undesirable plants from field crops is known as weeding. To design a low-cost, portable weed-removal machine for use on agricultural land, minimize the laborious procedure of removing weeds by hand. Farmers' time would be saved, and agricultural productivity would rise as a result. The yield loss is estimated as the cumulative loss caused by all weeds. It has been demonstrated that weeds have a greater economic impact than pest species including fungus, insects, and others Savary *et al.* (2000) [19]. The goal to develop an efficient weed-removing machine design is to cut down on the duration of time required to remove weeds that grow in between the growing plants. According to Adetola (2019) [1], weeds' greater competitiveness when compared to crop harvests poses a serious risk to agricultural productivity. The expense of weeding accounts for about 16 percent of the cultivation cost, while weeds have the potential to cause 33 percent of crop loss. It is suggested that weeds constitute a significant biotic obstacle to food production. The competition they face with crops decreases agricultural production both in terms of quantity and quality, and it rises the cultivation costs associated with weed control. Anwar *et al.* (2012) [2] reported that weed control's key stage acts as an essential component of integrated weed management and, as such, may be thought of as the initial stage in developing a weed control strategy. According to estimates and suggestions made by Bhan *et al.* (1999) [6], weeds in India lower crop yields by 31.5% (22.7% during the winter and 36.5% during the summer and Kharif seasons). In addition to degrading produce quality and causing environmental and health risks, weeds have been shown in other studies to account for up to one-third of yield losses (DWSR, 2013) [3]. The losses attributed to weeds were estimated by Indian weed experts as ranging from 10% to 100%. With a yield of 990 kg/ha, 331.68 thousand tonnes of chickpeas are produced in Chhattisgarh on 335.03 thousand hectares of land. In terms of providing food for the nation's expanding population, chickpeas, also known as chana, are a crucial pulse crop. *Cicer arietinum*, as it is known scientifically, is a member of the Leguminosae family. Bengalgram is produced worldwide on an area of 137 lakh hectares, with a productivity of 1038 kg/ha and a production of 142.4 lakh tonnes (*FAO* stat, 2019). With a productivity of 1036 kg/ha in 2020–21, India accounts for 70% of the world's total chickpea production, which is grown over 112 lakh hectares. (agricoop.nic.in). One of the biggest difficulties in reaching potential chickpea produce is weeds. To manage weeds, one must obtain a comprehensive knowledge of the weed population from the field. Since many weed species imitate crop plants, it can be difficult to differentiate between them in their earliest phases. By using a mechanical weeder, one can mitigate the adverse outcomes of chemical damage and degradation of the environment. They can also solve the challenges of low efficiency, high labor costs, and long processing times associated with various types of cutlass or hoe. Since it is exceedingly difficult to estimate the yield loss due to a single weed species, According to Devanathan *et al.* (2021) [7], the cost of weeding alone accounts for about 33% of cultivation expenses, with manual labor being used. Kumar *et al.* (2017) [13] stated that effect of speed of operation on damaged plant percent at different level of depth of operation increased with increase in speed of operation as well as with increase in depth of operation.

Mechanization lowers the cost of production per unit by increasing production and minimizing inputs. For the purpose of weeding 150 to 250 mm wide row crops, a variety of manually operated mechanical weeders have been developed across the nation (Gavali and Kulkarni 2014 and Singh *et al.* 2016) [8, 21]. Jakasania *et al.* (2019) [11] developed automated intra row weeder. Main components of the automated weeder was ultrasonic sensor, D.C. motor, microcontroller, battery, frame, tine, inter and intra row blade. Engine and electrical power sources are being used for the operation to increase production in order to overcome the limits of manually driven weeders. Mathan *et al.* (2019) [15] converted the power weeder is to an electrically operated system. The DC motor of power 1.49 kW and 1500W is replaced for the 4.10 kW existing gasoline engine according to the engine and motor power equilancy. Jayaseelan *et al.* (2020) [10] designed, constructed and tested battery operated weeder, to provide the best opportunity to farmer's to easily control and removing the weed from farm. Therefore, the design of a battery-operated weeder is required for intensive and commercial farming systems.

Materials and Methods

A battery-operated weeder was designed and developed at Department of Farm Machinery and Power Engineering, SV College of Agricultural Engineering and Technology & RS, FAE, IGKV, Raipur,. Minimizing labor and increasing efficiency was the primary goal of the battery-powered weeder. In addition, it was made to use the power source as efficiently as possible in order to extend the run time while causing a minimum of injury to the crop during operation.

Design and Development of Battery operated Weeder

The functional requirements of the machine for weeding operation and theoretical design calculations were used to build and create a prototype of a battery-operated single row weeder. Agronomic and soil parameters that affect weeding efficiency, such as crop and weed parameters, soil type, soil resistance, etc., were the primary development requirements for the weeder. Fig. 8 shows the isometric view of the battery-operated single-row weeder. The walk-behind mode of operation of the weeder was developed to make it easier for the user to operate while weeding. The battery, DC motor, transport wheel, weeding blade, mainframe, and handle are the key parts of the developed weeder.

Mainframe and Handle

The main frame was made of three sections; one for mounting of the battery, power transmission gears mounting and power transmission to the rotary weeding unit. The rectangular frame were made from M.S. angle section of size 25x25x5 mm welded together to form a composite frame having a rectangular frame for motor and battery on top and for ground wheels. Therefore, the main frame was made of three sections; one for mounting of the battery, power transmission gears mounting and power transmission to the rotary weeding unit shown in Fig 1.

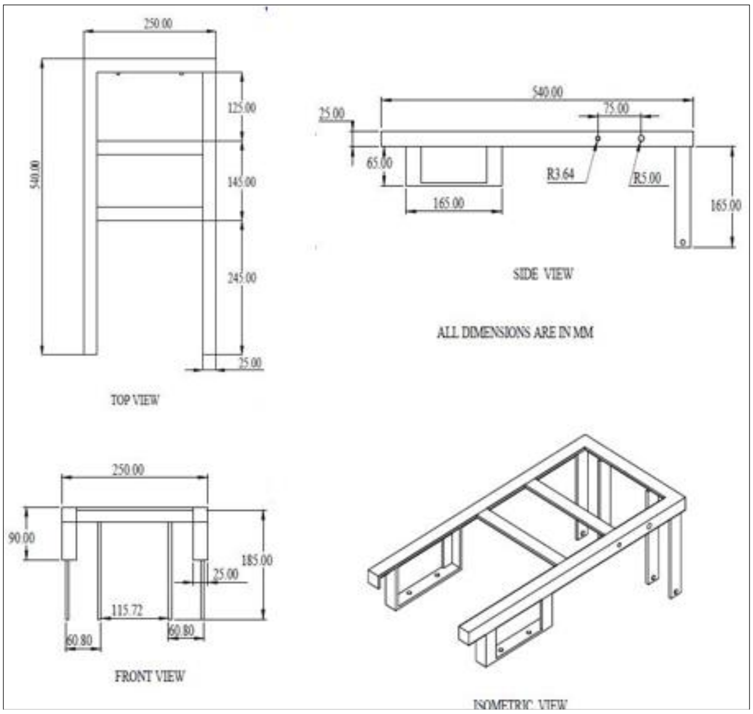

Fig 1: Frame of weeder

The handle of the weeder was designed as per the anthropometric data of Chhattisgarh region. The recommended shape of handle grip is cylindrical and recommended grip diameter is 25 to 37 mm (Verma, 2004).

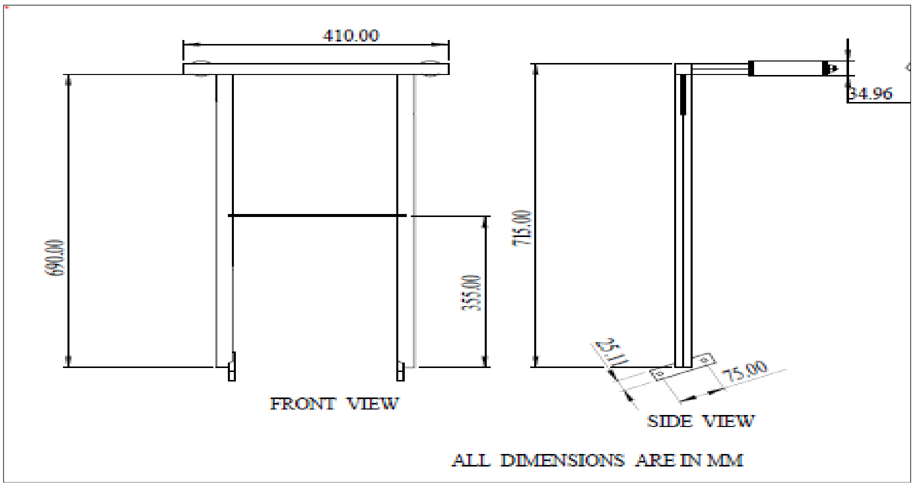

Fig 2: Handle of weeder

Motor size for weeder

Soil resistance has a considerable effect upon the power requirement of weeder. Also, width of cut and speed of operation influences power requirement of weeder. Due to soil moisture and tilled condition soil resistance were kept for calculating power requirement of the weeder was taken as 0.5 kg/mm^2. The speed of operation of the weeder was considered as 0.5 m/s. Width of operation was considered same because of spacing between row crops have 300 mm and more. Total width of coverage of cutting blades was in the range of 120 to 300 mm. The depth of operation was considered as 30 to 50 mm and the transmission efficiency is 82%. Power requirement for battery operated weeder was calculated using following formula (Sahay, 2010) [18].

$$P = \frac{SR \times d \times w \times v}{75}$$

Where,

P = Power, hp;

SR = Soil resistance, kg/mm^2;

d = Depth of cut, mm;

w = Effective width of cut, mm; and

v = Speed of operation, m/s.

$$P = \frac{0.0056 \times 50 \times 30 \times 0.5}{75}$$

$= 0.56$ hp $= 0.42$ kW

Hence, the total power required is estimated as follows

$$P_t = \frac{P}{\eta}$$

$$= \frac{0.42}{0.82} = 512W = 0.51\ kW$$

Where,

P = Power requirement for digging the soil, kW; and

η = Transmission efficiency, %.

Thus, a DC motor of above 512W should be used. On the basis of availability of DC motor in the market, a 650W, DC motor will be suitable for weeder.

Fig 3: PMDC motor

Torque transmitted by the shaft

A shaft is a rotating machine element which is used to transmit the power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque setup within the shaft permits the power to be transferred machine or components linked up to the shaft. The torque transmitted through the shaft is worked out using the following formula (Khurmi, 2005) [12].

$$T = \frac{P \times 60 \times 10^3}{2 \times \pi \times N}$$

Where,

P = Power, kW;

T = Torque transmitted by the shaft, Nm; and

N = Revolutions per minute.

Considering motor speed as 4200 rpm and motor power 0.51 kW we get torque as

$$T = \frac{0.51 \times 60 \times 10^3}{2 \times \pi \times 4200}$$

$= 1.16$ N-m

Thus the torque of 1.16 Nm was obtained.

Rotor shaft design

For designing the rotor shaft, the maximum tangential force which can be endured by the rotor should be considered. The maximum tangential force occurs at the minimum of blades tangential speed is calculated by the following (Bernacki *et al*., 1972) [5]

$$K_s = \frac{C_s \times 75 \times Nc \times \eta_c \times \eta_z}{u}$$

Where,

K_s=Maximum tangential force, kg;

C_s=Reliability factor (1.5 for non-rocky soils and 2 for rocky soils);

N_c=Power of motor, hp;

η_c =Traction efficiency for the forward rotation of rotor shaft as 0.95;

η_z =Coefficient of reservation of motor power (0.65); and

u =Minimum tangential speed of blades.

$$K_s = \frac{1.5 \times 75 \times 0.87 \times 0.95 \times 0.65}{4.48} = 13.49 \text{ kg}$$

Tangential peripheral speed, u, can be calculated using the following equation:

$$u = \frac{2 \times \pi \times N \times R}{6000}$$

Where,

u = Tangential peripheral speed, m/s;

N = Revolution of rotor, rpm; and

R = Radius of rotor, cm.

$$u = \frac{2 \times \pi \times 300 \times 20}{6000} = 6.28 \text{ m/s}$$

After substituting values for revolution of rotor shaft (300 rpm) and its radius as 20 cm in equation, tangential peripheral speed was obtained as 6.28 m/s. Using the tangential peripheral speed and other parameters in equation, the maximum tangential force was determined to be 13.49 kg.

The maximum moment on the rotor shaft (M_s) is calculated through the following:

$$M_s = K_s \times R$$

Where,

M_s = Maximum moment on the rotor shaft, kg-cm;

K_s = Maximum tangential force, kg; and

R = Radius of rotor, cm.

M_s = 13.49 x 20

M_s = 269.80 kg-cm

The yield stress of rotor made from rolled steel (AISI 302) was 520 MPa. The allowable stress on the rotor (τall) was calculated by the following equation (Mott, 1985) [16]:

$$\tau_{all} = \frac{0.577 \times k \times \sigma_y}{f}$$

Where,

τ_{all}=Allowable stress on rotor shaft, kg/cm^2;

k =Coefficient of stress concentration (0.75);

f =Coefficient of safety (1.5); and

σ_y =Yield stress, 520 MPa.

$$\tau_{all} = \frac{0.577 \times 0.75 \times 520}{1.5}$$

= 150.02 MPa = 1530.6 kg/cm^2

By substituting above values in the following equation, rotor shaft diameter was calculated as:

$$D = \sqrt[3]{\frac{16 \times M_s}{\tau_{all} \times \pi}}$$

Where,

D =Rotor shaft diameter, mm;

M_s=Maximum moment on the rotor shaft, kg-cm; and

τ_{all}=Allowable stress on rotor shaft, kg/cm^2.

$$D = \sqrt[3]{\frac{16 \times 269.80}{1530.6 \times \pi}}$$

D= 9.64 mm

In order take into account fluctuating load during the operation, diameter of the rotor shaft was selected higher than the calculated value as 20 mm.

Design of cutting blades

Blades of the rotor are the components which directly interact with soil and as such have major impact on the operation of the weeder. The material used for manufacturing machines could be changed but this increases the associated costs significantly. The way of reducing the power requirement and to improve the life of machine is to improve geometry of blade. For cutter blade design, number of blade, cutting width and thickness were important parameters. During cutting, blades would be subjected to shearing as well as bending stresses. Total working width of the weeder was 300 mm having rotor shaft of length of 280 mm. Total of 8 blades were provided with cutting width of 25 mm. Therefore, four blades were provided on each flange and two flanges were mounted on rotor shaft. The soil force acting on the blade (K_e) was calculated by the following equation:

$$K_e = \frac{Ks \times C_p}{i \times Z_e \times n_e}$$

Where,

K_e=Soil force acting on the blade, kg;

C_p=Coefficient of tangential force as 0.8,

i =Number of flanges is 2,

Z_e =Number of blades on each side of the flanges is 4, and

n_e =Number of blades which act jointly on the soil by total number of blades.

$$K_e = \frac{13.49 \times 2}{2 \times 4 \times \frac{1}{4}} = 13.49 \text{ kg}$$

By solving equation, the soil force acting on the blade (K_e) was determined as 13.49 kg. The values of be, he, S_s, S and S1 were equal to 0.2 cm, 5.0 cm, 5.0 cm, 9.0 cm and 1.5 cm respectively. Considering the shape of the blades, the bending stress (σ_{zg}), shear stress (τ_{skt}), and equivalent stress (σ_{zt}) can be calculated by the following equations (Bernacki *et al*., 1972) [5]:

$$\sigma_{zg} = \frac{6 \times K_e \times S}{b_e \times h_e^2}$$

Where,
σ_{zg} = Bending stress, MPa;
K_e = Maximum tangential force, kg;
S = Blade length, cm;
b_e = Blade thickness, cm; and
h_e = Width of blade, cm.

$$= \frac{6 \times 13.49 \times 9}{0.2 \times 25} = 145.69 \text{ kg/cm}^2 = 14.28 \text{ MPa}$$

$$\tau_{skt} = \frac{3 \times K_e \times S_1}{\left(\frac{h_e^1}{b_e} - 0.63\right) \times b_e^3}$$

Where,
τ_{skt} = Shear stress, MPa;
K_e = Maximum tangential force, kg;
S_1 = Distance from the shank, cm;
b_e = Blade thickness, cm; and
h_e = Width of blade, cm.

$$= \frac{3 \times 13.49 \times 1.5}{\left(\frac{5}{0.2} - 0.63\right) \times 0.2^3} = 311.37 \text{ kg/cm}^2 = 30.53 \text{ MPa}$$

$$\sigma_{zt} = \sqrt{\sigma_{zg}^2 + 4\tau_{skt}^2}$$

Where,
σ_{zt} = Equivalent stress, MPa;
σ_{zg} = Bending stress, MPa; and
τ_{skt} = Shear stress, MPa.

$$= \sqrt{145.69^2 + (4 \times 311.37^2)} = 639.55 \text{ kg/cm}^2 = 62.71 \text{ MPa}$$

The bending stress, shear stress and equivalent stress were determined as 14.28 MPa, 30.53 MPa and 62.71 MPa, respectively.

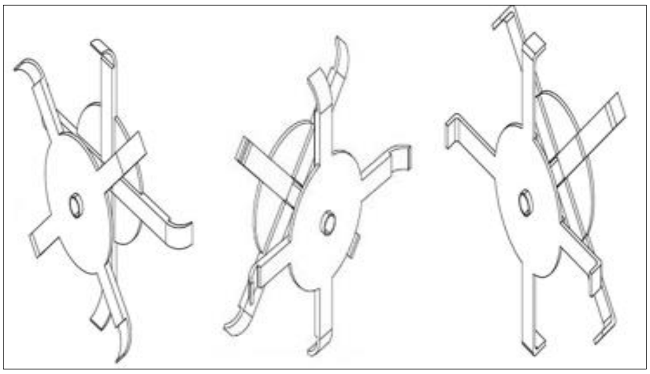

Fig 4: Type of blade

Speed reduction

Speed reduction of motor consists of spur gears received the mechanical power from the DC motor by a coupling. It consists of set of speed reduction gears having number of teeth as 10 and 14, respectively. The input shaft to the gear box was rotating at the speed of 420 rpm by the motor. The speed of output shaft of the gear box was 300 rpm. The calculations of the same are given below (Sharma and Mukesh, 2010) [20]:

N_1 = 420 rpm, T_1 = 10 teeth, T_2 = 14

$$N_2 = \frac{N_1 \times T_1}{T_1}$$

$$N_2 = \frac{420 \times 10}{14}$$

N_2 = 300 rpm

Transmission mechanism design

The chains are mostly use to transmit motion and power from one shaft to another, when the center distance between the shafts is short. In order to obtain a constant velocity ratio, chain drive is mostly preferred. The length of chain (L) attached from motor axle to rotary shaft was calculated as (Khurmi and Gupta, 2005) [12].

$$m = \frac{2c}{p} + \frac{(T_m + T_g)}{2} + \frac{(T_m - T_g)^2}{2\pi p}$$

Where,
m = Number of chain links;
c = Centre to centre distance between two sprockets;
T_g = Number of teeth in ground wheel sprocket;
T_m = Number of teeth in metering shaft sprocket; and
P = Chain pitch.

P = chain pitch = 15 mm

$$m = \frac{2 \times 30}{1.5} + \frac{(10+14)}{2} + \frac{(10-14)^2}{2 \times 3.14 \times 1.5} = 50.29$$

Length of chain (L) = number of chain links × pitch = 50.29 × 15 = 754 mm

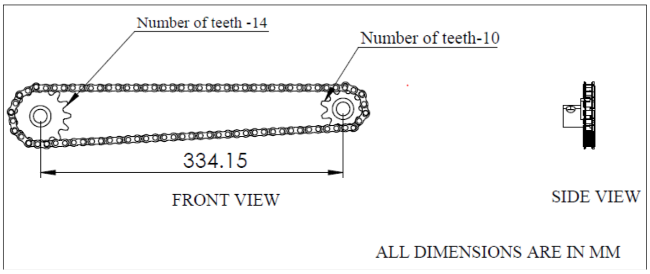

Fig 5: Chain and sprocket

Consumption of battery

A battery was consisting of one or more electrochemical cells which can be charged with an electric current and discharged whenever required. The battery capacity is directly proportional to days of autonomy and inversely to discharge rate.

$$\text{Battery capacity, (Ah)} = \frac{\text{Total Watt hours per day used by appliance} \times \text{Days of autonomy}}{\text{Discharge rate of battery} \times \text{nominal battery voltage}}$$

Where,
Total watt hours per day = Total power used by appliance in one day

= 650 x 4 = 2600

Days of autonomy is defined as the number of days that the battery can supply the site's loads without any support from generation sources.
Discharge rate is defined as the steady current in amperes (A) that can be taken from a battery of defined capacity (Ah) over a defined period (h) =18/3 = 6
Nominal battery voltage = the total battery voltage on full charged condition = 27
Assumption,
For 1 hour application and for single day storage

Nominal voltage = 27 V

$$\text{Battery capacity} = \frac{2600 \times 1}{6 \times 27} = 16.04$$

Battery capacity = 16.04 Ah (No-load)

Size of battery
Single battery of 27 V and 18 Ah. Equivalent voltage = 27 V Equivalent charge = 18 Ah

Charging time of battery
Charging time of battery = Battery Ah / Charging Current = 18/6 = 3 h.

Discharging time of battery when connected to motor
Fully charged deep cycle battery, could up to 95% discharge

$$\text{Discharging time, h} = \frac{\text{Battery amp delivered}}{\text{amp required by PMDC motor}}$$

= (18 × 0.95) / 2.2 = 17.1/2.2 = 7.77 h (No-load condition).

Fig 6: LFP battery

The developed machine was powered by an 18 Ah lithium ferrous phosphate (LFP) commercially available. It was mounted on a rectangular horizontal frame in back. The PMDC motor 650 W rotational speed was 4200 rpm. The motor rpm was stepped down through inbuilt gear reduction in motor and chain sprockets arrangement to the rotary blades of the weeding unit.

Transport wheel
Two transport rubber wheels were used. Wheels are 170 mm in diameter and 45 mm width fitted on backside bottom of the frame shown in Fig. The transport wheel connecting bar is a two-piece flat bar. This is made of a flat bar 100x25x5 mm. It connects the transport wheel from the hub to the U-channel. The essence of the wheel is to enable easy movement while the implement is in use.

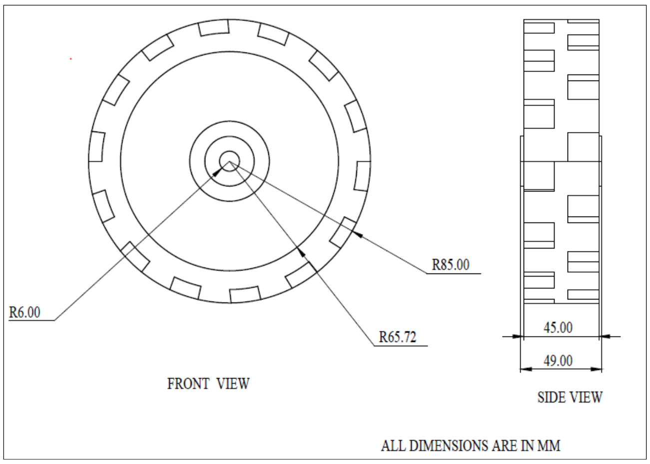

Fig 7: Transport wheel

Results and Discussion
The isometric view of the developed battery operated weeder machine is shown in Fig. 8 The unit consisted of main frame, battery, motor, power transmission, rotary unit, rotary weeding unit, handle assembly, safety cover and transport wheel.

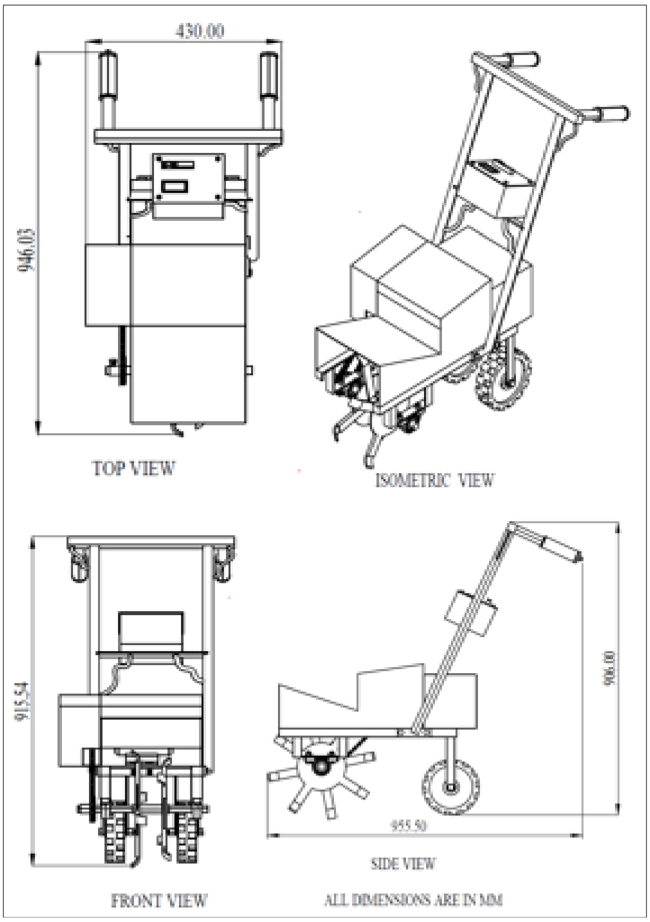

Fig 8: Isometric view of developed battery operated weeder

Table 1: Main technical parameters of the prototype

Parameters	Values
Overall dimension frame, mm	540x250x165
Weight of machine (kg)	30 kg approx.
Travel speed (km/h)	1.5 to 2.0
Battery (Ah)	18
No. of battery	1
Motor power (kW)	0.65
Blades	8
Weeding depth, mm	30-50
Weeding width, mm	300
No. of blades on a flange	4
No. of flange	2
Transport wheel	2

Field Performance of Developed Battery Operated Single Row Weeder

The field experiment was laid out in factorial randomized block design for weeding in which 3 main plot and 3 sub plots are made. Sub plots are also divided in 3 separated plots for each sub plot, resulting 27 different treatments with 3 replication. The quantitative data was quantified according to standards established criteria and tabulated to write the meaningful inferences. In order to see the significance of results for weeding efficiency, plant damage percentage, field capacity, field efficiency and performance index the data was analyzed with the help of Randomized Block Design with factorial arrangement (Gomez and Gomez, 1984) [9]. The machine was operated in chickpea (300 mm of row spacing) crops during the Rabi season. The experimental trials were conducted on a 25 to 30 DAS. The average value of soil moisture content, bulk density, and cone index was measured as 13.03% (db), 0.00138 g/mm^3 and 218.98 kPa, respectively. The average value of weed density, plant population, weed height and crop height was recorded as 52.80 weeds/m^2, 36.90 plants/m^2, 93.8 mm and 142.30 mm, respectively. To prevent damage to the plants, a safety zone was used when operating the developed prototype.

Fig 9: Performance of battery operated weeder at field

Field capacity and field efficiency

The effect of different type of blade (B_1), (B_2) and (B_3) on field capacity of the weeder was also found to be significantly different (α= 0.05). This is because of varying blade types B1, B2, and B3 types' speeds S1, S2, and S3 as well as depth of cut D1, D2, and D3. The field capacity were observed highest (0.046 ha/h) and lowest (0.026 ha/h) with speed (S_2) depth of cut (D_2) with L- type blade (B_3), while speed (S_1), depth of cut (D_3) of C- type blade (B_1), respectively. The field capacity decreases with C- type blade (B_1) and increase field capacity with L- type blade (B_3), due to the its better mixing and pulverization during weeding and more area covered in less time. The effect of type of blade of weeder, speed and depth of cut blade (B×S×D) on field efficiency of the weeder was also found significantly different (α= 0.05, CD=0.349). Due to interaction between type of blade, speed and depth of cut of weeder the highest field efficiency of 84.72% was observed at L- type blade (B_3) of weeder, 1.8 km/h speed (S_2) with depth of cut (D_2) whereas, lowest field efficiency of 56.46% was found at C-type of blade (B_1) of weeder, 2.0 km/h speed (S_3) with depth of cut (D_3).

Plant damage and weeding efficiency

The effect of different type of blade *viz*., B_1 (C- type), B_2 (J-type) and B_3 (L- type), speed *viz*., S_1 (1.5 km/h), S_2 (1.8 km/h) and S_3 (2.0 km/h) and depth of cut *viz*., D_1 (30 mm), D_2 (40 mm) and D_3 (50 mm) of weeder on plant damage percentage. The data revealed that type of blade of the weeder affect the damage percentage significantly at 5% level of significance. It was observed that the lowest damage percentage at L- type blade B_3 and speed (S_2) of 1.8 km/h with 40 mm depth of cut (D_2) while, it was observed highest when C- type blade B_1 and speed (S_1) were 1.5 km/h with 50 mm depth of cut (D_3). The highest damage percentage (6.21%) were found at J- type of blade (B_2) of weeder and 1.5 km/h speed (S_1) with 50 mm depth of cut (D_3) whereas, the lowest damage percentage (3.18%) were found at L-type blade (B_3) of weeder and 1.8 km/h speed (S_1) with 40 mm depth of cut. This may be due to the fact at increase depth, maneuverability of weeder became difficult as a result the movement of weeder did not remain a straight line but side line also, resulting damage the row crop.

The impact of various weeder blade types (B1, B2, and B3), speeds (S1, S2, and S3), and cutting depths (D1, D2, and D3) on weeding efficiency The research showed that, at the 5% level of significance, the weeder's blade type has a substantial impact on weeding efficiency. It was observed that the weeding efficiency decreased with an C- type of blade B_1, speed (S_1) of 1.5 km/h with depth of cut (D_3) and it increased with L- type of blade B_3, speed (S_2) of 1.8 km/h with depth of cut (D_2) . Highest weeding efficiency (90.79%) were found L- type blade at 1.8 km/h speed (S_2) of weeder with depth of cut (D_2). The lowest weeding efficiency (82.43%) were found C- type blade at 1.5 km/h speed (S_1) of weeder with depth of cut (D_3).The effect of blade type on weeding efficiency was found to be significantly (B×S×D) different (C.D. =0.083 and α = 0.05). It was noted that the weeding efficiency increased on L-type blade at 1.8 km/h speed of weeder with depth of cut 40 mm and decreased weeding efficiency when found C- type blade at 1.5 km/h speed of weeder with depth of cut 50 mm.

Conclusions

The present investigation indicates that, at 5% levels of significance, the type of blade, forward speed, and depth of cut of the developed battery-operated single-row weeder have a significant impact on weeding efficiency, plant damage, effective field capacity, and field efficiency. The interaction effect was also significant. For the L type blade, the developed weeding mechanism (blade, speed, and depth) worked better at forward speeds of 1.8 km/h with a 40 mm depth of operation. The labor needed for weeding was significantly decreased due to the designed weeder, which eventually resulted in lower operating costs. Its effectiveness and adaptability need to be further refined through more field testing in varying crop and soil situations. Small-scale farmers will find use for the developed weeder.

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