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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(10): 1455-1463

www.thepharmajournal.com
Received: 01-08-2022
Accepted: 06-09-2022

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Design and development of single row auto-feed potato planter cum fertilizer applicator for small farmers

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DOI: https://doi.org/10.22271/tpi.2022.v11.i10Sr.16347

Abstract

Background: Traditional methods of potato planting on the field is labor intensive, time consuming and produce low yields of potato per hectare**.** Agriculture mechanization plays very important role for horticulture crops. To reduce the labour scarcity, labour drudgery, time consumption in manual planting of potatoes in local areas of different villages, a prototype was designed, fabricated and evaluated in the field. The present study was carried out at Indira Gandhi Agricultural University, Raipur (C.G.).

Methods: The potato tubers taken were divided into three categories i.e., round, oblong and long-oblong and their physical and mechanical properties were required for designing different units of planter, they were found out.

Result: The model of all components of potato planter were designed by solid work software and fabricated. Developed potato planter consists of seed metering device, seed tube, seed tuber covering duct, fertilizer tube, furrow openers, power transmission wheel, seed and fertilizer hopper. Capacity of seed and fertilizer hopper was kept at 55 kg and 15 kg respectively.

Keywords: Fertilizer adjustment lever, K-1 attachment chain, seed container, shaft and sprocket

Introduction

Potato (*Solanum tuberosum* L.) Family-Solanaceae popularly known as 'The king of vegetables' is the most important food crop in the world and has emerged as fourth most important food crop in India after rice, wheat and maize**.** Indian vegetable basket is incomplete without potato **.**It is a starchy tuberous food crop containing many vitamins and minerals **.** Potato is temperate crop grown under subtropical conditions in India **.**The fleshy part of the root ***)***potato ***(***is commonly eaten as a vegetable **.**Potato is efficient food crop and alluded as helpless man companion. Planting of potato is considered as quite possibly the main activity that includes factors like correct seed rate, fitting profundity of seed arrangement and required seed dispersing. For planting of potato crop land is furrowed immediately and develop double cross with rotavator at a profundity of 24-25 cm. Potatoes are grown in almost every state in India. India's major potato-growing states include Uttar Pradesh, West Bengal, Punjab, Karnataka, Assam, Bihar, Madhya Pradesh, Jharkhand, and Chhattisgarh. Mechanical potato planting performs the functions of furrow opening, seed metering, tuber placement at proper depth and formation of ridges to cover seed tubers**.** In traditional method of potato planting, farmers cover less area in more time where tuber distance and profundity of planting is not kept up with consistently**.** Also, it is exceptionally sluggish, dull, tedious and requires 60 man-days for development activity. Generally, 2142 man-h/ha is required in potato planting and earthing up operation by manual method whereas, 544 man-h/ha by tractor drawn semi-automatic potato planter (Singh *et al*., 2006) [21]. Three strategies for manual potato planting are continued in India i.e., planting potatoes on ridges; after preparation of field, ridges are made at distance of 45-60 cm with the help of spade**.** Planting of potato is done on the ridges with the help of khurpi. Flat method; Planting of potato is done on the flat surface in narrow furrows**.** Ridges are made after germination when plants attain 10-12 cm height**.** This method is suitable for light soils**.** Later, two to three earthing up are done to make the ridges thick. Planting potatoes on flat surface followed by ridges; in this method field is prepared and then shallow furrows are opened on the flat surface**.** Potatoes are planted in furrows and immediately after planting 3 tubers, small ridges are made**.** Indian agriculture is characterized by small and marginal farm holders with the population of more than 60 million bovine for draught power. In many parts of India, large holding farmers possesses tractor-operated 3-row or 4-row potato planters for enormous fields.

Materials and Methods

The design and development of automatic feed potato planter cum fertilizer applicator requires study of different parameters of the machine component and their inter relationship**.** It was proposed that the machine should be suitable for all shapes and size of potato tuber**.** It should place the tubers at desired depth and ensure even placement**.** Hence this requires correct study of tuber engineering and physical parameters, soil parameters, component design, material used and fabrication techniques and the performance evaluation of developed prototype in the laboratory as well as in field**.** The automatic feed potato planter cum fertilizer applicator was developed at workshop of Swami Vivekananda College of Agricultural Engineering and Technology and Research Station, Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur, ***(***C.G.***)*** in the year of 2019-20**.** Before designing of planter, the performances of existing traditional method of potato planting were evaluated and identified the problems**.** Design parameters of developed machine were taken as consideration accompanied to different properties of tubers, soil condition, yield and farmer's income which belong to marginal and small categories and to give a correct shape in form of prototype**.** The mechanical design details were also measured with due attention so, that it gave adequate functional stiffness for the design and fabrication of machine**.**

Design Considerations of Potato Planter Cum Fertilizer Applicator

The conceived machine should require to be capable to plant all sizes of potato seeds as well as fertilizer at a uniform spacing and proper depth with accurate covering proficiency.

Main frame design and selection

The mild steel square section frame of 25 mm x 25 mm and 2.5 mm thickness (L×W×T) was used to give the required strength and rigidity, withstand to all forces as well as all types of loads acting on it during operation (Fig.1)**.** The entire weight of the seed hopper and fertilizer hopper rested on the axel that, carry the wheel, chain, sprockets, two discs (ridger). At front side of the frame, cup-chain unit was covered by circular mild steel sheet of the width of 80mm which is called covering duct.

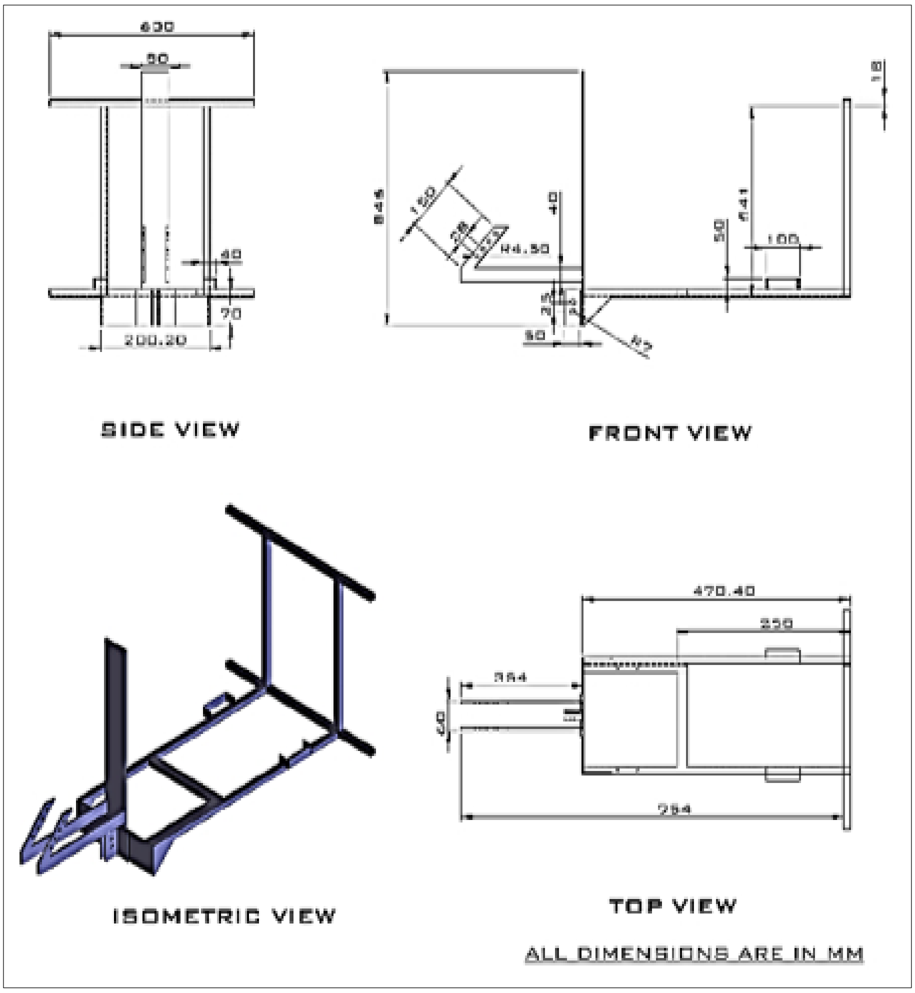

Fig 1: Views of the main frame of potato planter

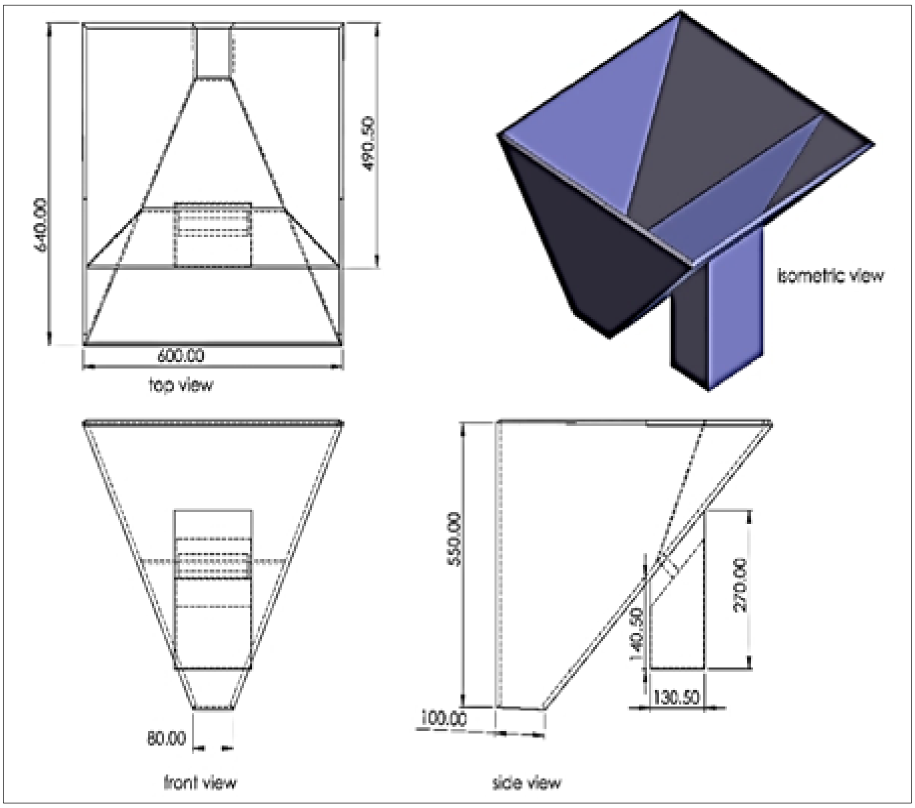

Fig 2: Front, side and top view of fabricated hopper

Design, selection and fabrication of hopper

Hopper was made of mild steel cut sheet because of their capacity to withstand with higher loads. According to observed physical properties of tubers as round, oblong and long-oblong sized. The volume of the hopper was determined on the basis of average bulk density of seed. The angle of repose of all the tuber shapes as round, oblong and long-oblong seeds were found as 27.6, 33.2 and 42.6° so, the hopper of the machine was made to facilitate easy sliding of potato tubers from the hopper to the metering cups.

Volume and capacity of hopper

The seed hopper was combination of two trapezium shape (Fig. 2). To work out the volume of entire hopper, the capacity of both trapeziums was taken into consideration.

$$\text{Volume of trapezoidal box}(m^3) = \frac{(X_t + X_b)}{2} \times Y \times Z \quad \dots (1)$$

Where

X_t = X dimension's top width, m
X_b = X dimension's bottom width, m
Y = Vertical dimension (up-down), m
Z = Back side lower width of the hopper, m

The seed box was designed as combination of two trapezium so;
Volume of upper trapezoidal (1) = (46+49.50)/2×48×22 = 47.75×48×22 = 50, 424 cm^3

Volume of lower trapezoidal (2) = (46+10)/2×33×8 = 28 × 33 × 8 = 7392 cm^3

Entire volume of hopper (m^3) = 50,424 + 7392 = 57816 cm^3 or .057816 m^3

Now,
Bulk density of seed (kg/m^3) = M/V
935 kg/m^3 = M/.057816 or M = 935 kg/m^3 × .057816 m^3 = 54.57 kg ≈ 55 kg

Thickness of hopper

The thickness of seed box is given by following relationship (Sharma and Mukesh, 2008)

$$t_s = \frac{\sqrt[3]{3 \times \rho \times a^2 \times h^2}}{4 \times a \times bs} \quad \dots (2)$$

Where

t_s = thickness of seed hopper, cm;
ρ = bulk density of seeds, (930kg/m^3)
a = bottom width of seed box, cm (8 or 10 cm);
h = height of seed box, cm (55 cm); and
bs = bending stress, kg/cm^2 (let, 1000 kg/ cm^2)

$$\text{So, } t_s = \frac{\sqrt[3]{3 \times 930 \times 10^2 \times 55^2}}{4 \times 10 \times 1000} = 0.203 \text{ cm} \approx 2.0 \text{ mm}$$

Design of fertilizer system

It has three components i.e., Fertilizer box, Adjustment lever and fluted roller.

Fertilizer box

The primary fertilizer box was triangular prismatic in shape whereas the secondary fertilizer box was combination of triangular prism upper box and rectangle box lower box according to Fig. 3.

$$\text{Volume of primary triangular prismatic box} = \frac{1}{2} \times a \times b \times h \quad \dots (3)$$

Where, a = length; b = width; h = height of the prism
= ½ × 11.8 × 60 × 22 cm^3 = 7788 cm^3

Volume of secondary fertilizer box

Upper triangular box, cm = ½ × 18.2 × 13.5 × 12.9 =1584.76 cm^3

Lower rectangle box, cm^3 = 13.5 × 18.2 × 14.5 = 3562.65 cm^3

Complete volume of box = 7788+1584.76+3562.65 = 12936 cm^3 or .012936m^3

Now,
Bulk density of fertilizer (DAP) in kg/m^3 = M/V
1150 kg/m^3 = M/.012936m^3 or M = 1150×.012936 = 14.87 ≈ 15 kg

Fertilizer adjustment lever and fluted roller

Fluted roller was welded below the secondary fertilizer box. Pitch length of fluted roller cylindrical gear was 10.8mm. There is threaded type nut attached that may rotate clockwise (for tightening the grooves) for smaller fertilizer proportion and anticlockwise (for loosening the grooves) for application of larger amount of fertilizer (DAP).

Design and fabrication of power transmission wheel (Drive wheel)

Verma (1986) [25] suggested diameter of power transmission wheels as 22.5 to 40 cm for bullock driven planter and 40 to 60 cm for tractor driven planter. In order to alter the number of cups and plant spacing, the 3 selected diameter of power transmission wheel (380, 420, 520 mm) were taken in present design. The dimension of rim, hub and number of pegs were decided as follows:

a) Rim: Rim width of ground wheel was chosen as 50 mm which is in the range of recommended values of 30 to 50 mm for planter application (Pandya & Shah 1962) [16]. Thickness of the peg (lugs) and rim was designed on similar ratio. The thickness of rim (T) was calculated by following relationship given by Pandya and Shah 1962[16]. Three levels of wheels have been used so;

Wheel (W1); T, mm = (D, mm/200) + 3.175 = (380/200) + 3.175 = 5.07 ≈ 5mm

Wheel (W2); T, mm = (D, mm/200) + 3.175 = (420/200) + 3.175 = 5.27 ≈ 6mm

Wheel (W3); T, mm = (D, mm/200) + 3.175 = (520/200) + 3.175 = 5.77 ≈ 6mm

b) Hub: The inner diameter of hub of the drive wheel was taken equal to the diameter of the shaft i.e., 16mm. Two bush type bearing hubs were provided and fitted on the main frame to support both the end of the shaft.

c) Peg (lugs): On the periphery of ground wheel 12 pegs of length 24mm, width of 50mm were provided to improve lugging ability and to avoid slippage of ground wheel during operation. Thickness of the pegs was 5 to 6mm as per diameter of the wheel.

Fabrication of furrow opener

Since shoe type furrow opener makes wider furrow and offers low draught, this type was selected and used in the present machine, the mild steel shoe type furrow opener was fabricated to penetrates the soil and for making furrow. Nut and bolt were used to fasten the device to the front side of machine frame through a hole (dia. =10 mm at 25 mm apart on the shoe bar for maintaining depth) drilled on the frame for adjusting sowing depth according to crop. Shoe type furrow openers of different lengths, widths and angles were fabricated. Shoe angles of all the furrow openers was 45^o, 90^o, 120^o.

Ridger selection and fabrication

It is easily replaceable. Two disc was attached on back side of the main frame and preferably made up of cast iron to make the ridge. The diameter of disc was 280mm, thickness 5mm and concavity was 300 mm respectively.

Bearing selection

Four steel ball bearing was used for metering mechanism. Upper shaft of metering system is attached to ball bearing and bush bearing to the other side. They allow carrying of a compressive load without wear and tear and with reduced friction. Two bush type bearings are fixed on the frame for fluted rollers shaft. The material for the bearing is high speed steel.

Design of metering mechanism

Rotary motion of ground wheel rotates the elevator cup-chain through the vertically fixed 2 gears having similar teethes and diameters. Diameter of round conical cup was 60mm and thickness is 4 mm. Determination of chain length was calculated as;

A k-1 attachment type chain (made of hardened steel) was used for elevator purpose, potato brackets (cups) was fixed at regular interval on the chain with the help of nut and bolts. Number of links, m was determined by following relationship (Sadhu Singh. 1988).

$$m = \frac{2C}{P} + \frac{Z_1+Z_2}{2} + \frac{P(Z_2-Z_1)^2}{4\pi^2 C} \quad \_\_\_ (4)$$

Where,
m = number of chain links;
C = center to center distance of gears Z_1 and Z_2; 63 cm or 630 mm
Z_1 = number of teeth on smaller sprocket; 19
Z_2 = number of teeth on larger sprocket; 19
P = pitch length in mm; 15

$$m = \frac{2\times630}{15} + \frac{19+19}{2} + \frac{15(19-19)^2}{4\pi^2\times630}$$ = 1260/15 + 38/2 + 0 = 84 + 19 = 103 links.

Length of the chain (Fig. 3.16) was determined as;

$$L = L_n \times P \quad \_\_\_ (5)$$

Where,
L_n = Number of chain links;
P = Pitch of chain, mm
L= 103 × 15 = 1545 mm or 154.5 cm length

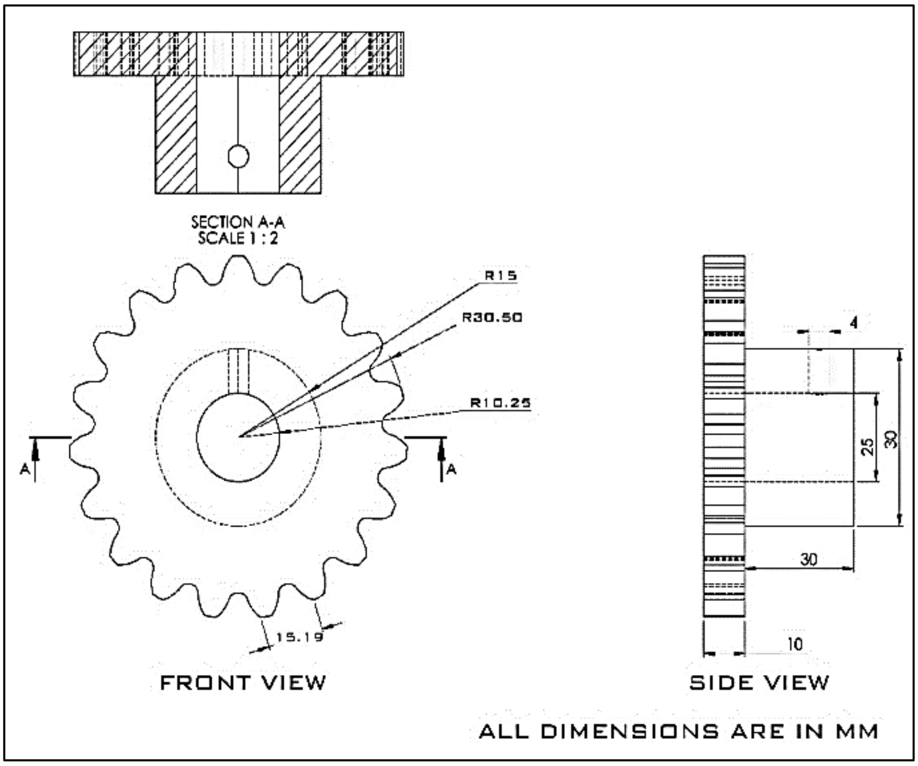

Fig 3: Front, top and side views of the standard

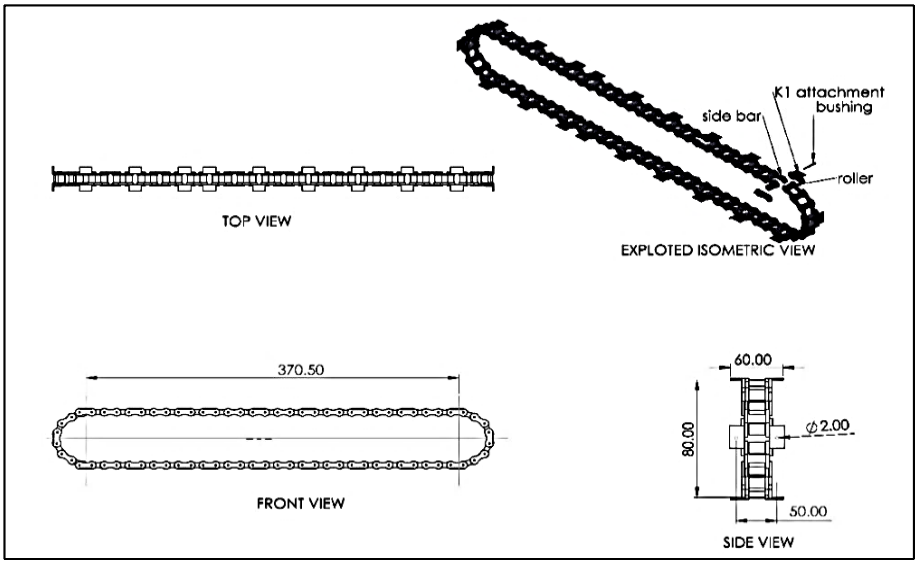

Fig 4: Dimension of the chain in mm

Design of length of the chain

Length of the potato planter chain on designed basis was calculated by the following formula described by (Yunnus *et al*. 2015)

$$L = 2C + 1.57\,(D_1 + D_2) + \frac{(D_2 - D_1 2)^2}{4C} \qquad \text{\_\_\_ (6)}$$

$$L = 2 \times 630 + 1.57\,(30 + 30) + \frac{(30-30)^2}{4C} = 1260 + 1.57 \times 60 + 0 = 1354.2 \approx 1400 \text{ mm}$$

Pitch of the elevator K-1 attachment chain was determined as

$$\text{Pitch, } P = D \sin\left(\frac{180}{Z_1}\right)$$

$P = 60 \sin (180/19) = 9.87 \approx 1$ mm

Theoretically length of the one pitch of chain was obtained 1mm but according to design basis the center pitch length of two adjacent pins at their centers and it was calibrated as 1.2 mm.

Pitch angle on the sprocket (gear)

$\alpha = 360/Z_1 = 360/19 = 18.94^o$

Design of shaft

The diameter of the shaft used for both mechanism (Seed + fertilizer) was same and length of the shaft for seed metering mechanism and fertilizer metering mechanism was 690 mm and 595 mm (with adjustment mechanism). From the equation of drive machines (Khan *et al*., 2015) [26] is

$$HP = (2\pi \times N_w \times T_w)/4500 \qquad \ldots(7)$$

Hp = (2π×0.4× 399)/4500 = 0.2068 Hp

Where
N_w is speed of ground wheel in RPM while T_w is the torque on the wheel. Since the speed of the machine is 2.5km/h. However, in practice the animals are operated at about 2.0 km/h average speed, but the machine was made for 2.5 km/h to allow some margin than maximum speed.

N_w = (speed of machine in m/s × 100)/π × 60 = (0.7 × 100)/3.14 × 60 = 0.3713 ≈ 0.4

And the torque on each wheel is

$$T_w = K_w \times W_t \times R_w \quad \_\_\_ (8)$$

Where, K_w is the coefficient of rolling resistance (0.3 for the metal wheel) and W_t is the active weight of the machine (70 kg approx.) and R_w is the radius of ground wheel (19 cm).

T_w = 0.3 × 70 × 19 = 399 kgf

Determination of maximum bending moment on the shaft
The power is transferred to the machine by the drive wheel and chain drive system. For the measurement of bending moment of a shaft or machine is measured by the theorem of chain drive system. So, load on the chain or chain load (Q) (Khan *et al*., 2015) [26] is;

$$Q = K_l \times P_t kgf \quad \_\_\_ (9)$$

Where,
K_l = coefficient of chain (1.15 for the mild steel) and
P_t = push force of the chain;
So, Q = 1.15×45kgf = 51.75kgf
Now chain drive is working at an angle θ (90°) for seed metering and 30° for fertilizer metering shaft with the horizontal. Therefore, equivalent chain load on the machine is

$$Q_v = Q \sin(\theta)$$
Q_v = 51.75 × sin (90) = 51.75kgf

Now, maximum bending moment on the shaft given by the chain drive system
M_b= (Weight on wheel × Overhang) + (Q_v × Overhang)
M_b = (45×15) + (51.75×5) = 933.75kgf or 9156.86N.m (∵ 1kgf = 9.81Nm)
Assume the overhang of wheel = 15 cm and so that the overhang of sprocket = 5 cm

Hence, Equivalent bending moment $= \sqrt{(Mt^2 + Mb^2)}$ = $\sqrt{399 + 933.7}$ = 1014.73 kgf

Where
$M_t = T_w$
$M_{eq} = \frac{\pi}{16} \times d^3 \times \tau_s$ (Allowable shear stress, τ_s in shaft is 600kg/cm²)

So, from the above equation the diameter of the shaft is

$$d^3 = \frac{16}{\pi \tau_s} M_{eq} \quad \ldots(10)$$

$d^3 = \frac{16}{\pi 600} \times 1014.73$ = $\sqrt[3]{8.61}$ = 20mm (Approx)

Design of fertilizer delivery metering chain
Fluted roller shaft of diameter 16mm and length 595mm was driven by ground wheel shaft at the same time with the elevator chain transmission, the chain drive and shaft of fertilizer metering unit was attached between the drive wheel shaft and fluted roller shaft with the help of gears. Sprocket (19 teeth) parameters for fertilizer metering mechanism was same as sprocket (19 teeth, diameter = 30 mm) used for seed metering mechanism, the length of chain attached between drive wheel shaft and fluted roller shaft was calculated as;

$$L = 2C + 1.57 (D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C}$$

Where C is center to center distance of two sprockets (gears) in mm
= 2×380 + 1.57 (19+19) + (19-19)²/ (4×380)
= 760 + 59.66 + 0 = 819.66 ≈ 820 mm chain length

During continuous operation of machine on undulated field condition, the length of chain increased as 10 to 20 mm due to the tensile force acting on them. So, the new length of the chain;

= 820 + 20 = 840 mm

Number of links on fluted roller metering chain

$m = \frac{2\times380}{15} + \frac{19+19}{2} + \frac{15(19-19)^2}{4\pi^2\times630}$ = 760/15 + 19 + 0=69.66 ≈ 70 links

Design of cup-to-cup distance on the chain
The recommended plant to plant distance for potato tuber is 10-15 to 20 cm
Dia. (d) of ground wheel three types for analysis (38, 42, 52 cm). During the laboratory test it was found that larger the diameter of wheel results the larger the plant to plant spacing rather than smaller wheel.
Required bracket cups for 15-20 cm plant to plant spacing = 16
Length of the chain = 1545 mm
So, recommended spacing between two adjacent cups was

$= \frac{1545}{16}$ = 96.56 mm ≈ 10 cm

Now as per designed basis;
No. of cups on metering chain can be calculated by (Ranjan, 2014)

$$i = \frac{c \times t}{a}$$

i= No. of cups; c = circumference of ground wheel, 164 cm
t = speed ratio (Drive wheel shaft to metering shaft)

$$\text{Speed ratio of ground wheel to metering shaft} = \frac{\text{No. of teeth on metering shaft } (T_M)}{\text{No.of teeth on driven shaft } (T_D)} = \frac{N_g}{N_m} = \frac{T_m}{T_g}$$

Where

N_g= rpm of ground wheel; N_m= rpm of metering shaft

T_m = No. of teeth on sprocket of metering shaft; T_g = No. of teeth on driven shaft

Speed ratio $Sr = \frac{N_g}{N_m} = \frac{19}{19}$ =1, let selected drive wheel size was 52 cm so,

Circumference of ground wheel$\pi d = 3.14 \times 52163.36$ cm ≈ 164 cm

No. of cups, i = $\frac{c \times t}{a} = \frac{164 \times 1}{10}$ = 16.4

Therefore, no. of cups was taken as 16

Peripheral distance between cups = $\frac{\text{Circumference of ground wheel}}{\text{No.of cups}}$

= $\frac{164}{16}$ = 10.25 cm ≈10 cm

Fabrication of metering mechanism covering device (duct)

The seed conveyer chain moves upward along with the potatoes in the cup, out of the hopper it turns over the upper sprocket**.** At this point, the potatoes fall on the back of the next cup and are confined within this sheet metal duct.

Table 1: Name of each part of metering unit depicted in Fig. 5

S. No	Parts name	S. No.	Parts
1.	Potato bracket cups	6.	Seed metering chain
2.	Drive wheel	7.	2nd gear of fertilizer metering unit
3.	Upper gear of seed metering	8.	Fertilizer metering shaft
4.	Steel ball bearing	9.	Fertilizer metering chain
5.	1st gear used for fertilizer metering unit	10.	Fluted roller and shaft

Table 2: Name of each part depicted in Fig. 6

S. No.	Parts name	S. No.	Parts name
1	Shovel or furrow opener	9	Fertilizer metering gear
2	Draught power pulling beam	10	Ridge height adjusting hollow shaft
3	Drive (ground) wheel	11	Slant seed box
4	Ridge former (disc type)	12	Seed box inside
5	Angled frame	13	Fertilizer box
6	Furrow height adjustment nut-bolt	14	Hitch point
7	Fertilizer metering shaft	15	Chain and cup
8	Fertilizer metering sprocket (gear)	16	Seed metering duct

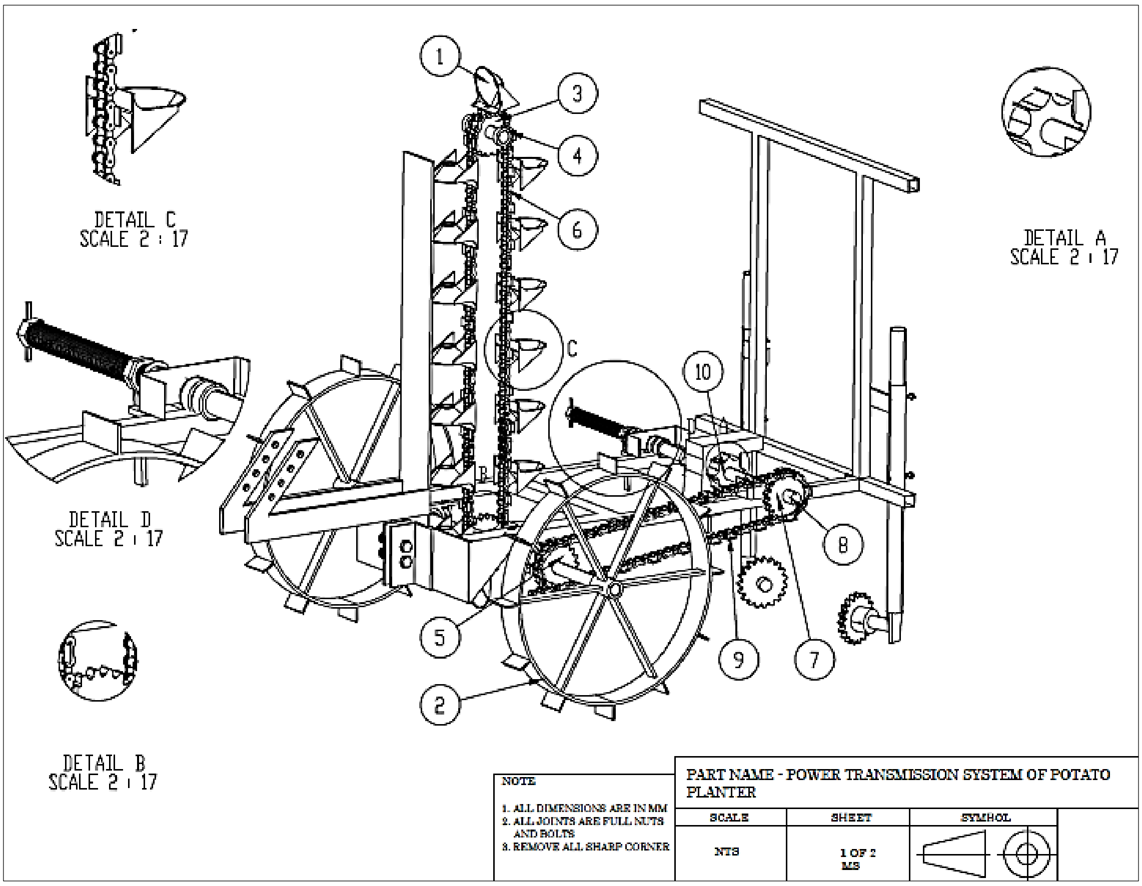

Fig 5: Metering mechanism of machine

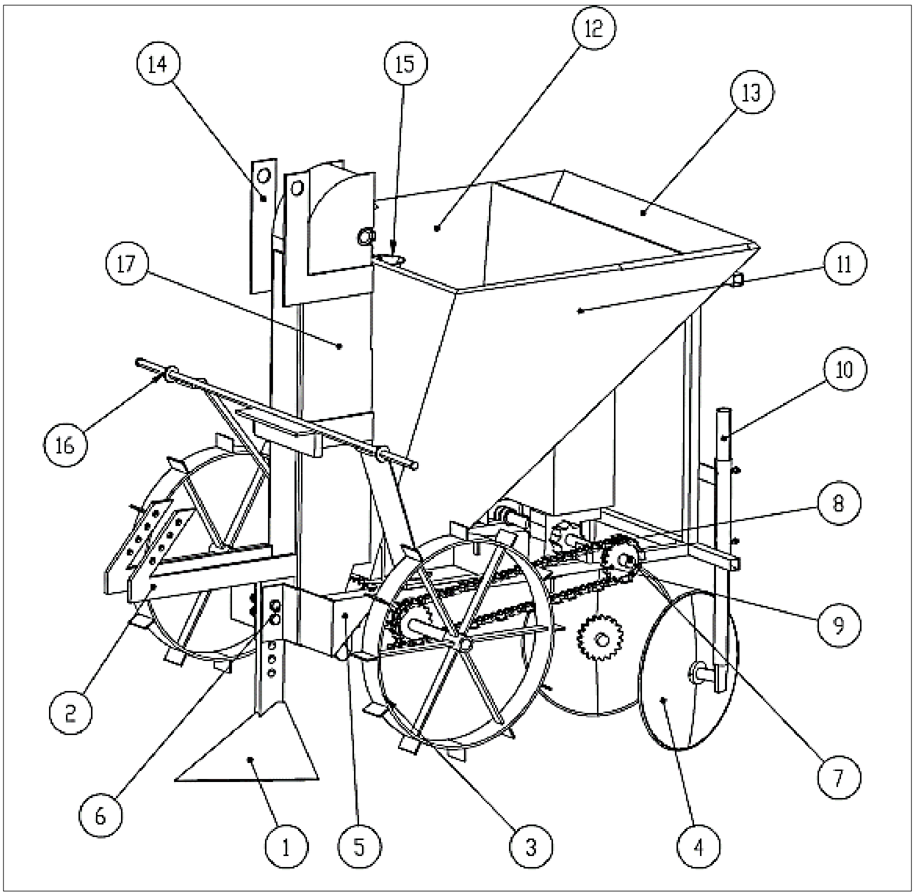

Fig 6: All the parts of the machine

Fig 7: Views of developed prototype

Result and Discussion

Based on above methodology and results of different parameters involved under optimization of various laboratory tests and field "development of animal drawn one row automatic feed potato planter cum fertilizer applicator" has been developed. A prototype of single row automatic feed potato planter was developed**.** The planter consists of seed metering device, seed tube, seed tuber covering duct, fertilizer tube, furrow openers, power transmission wheel, seed and fertilizer hopper.

Conclusion

Based on various methodologies involved in designing of farm machinery were studied and optimized. Potato planter cum fertilizer applicator was designed, developed and fabricated successfully and optimized on laboratory and field. It was operated by the pair of bullocks as well as small tractor (18-25 hp). Working of all the interrelated components of developed prototype were gives satisfactory performance either in laboratory or in field with potato tuber and fertilizer.

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