Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 1, Pages 55-76, January-March 2025

Development and Performance Evaluation of Tractor Drawn Faba Bean Row Planter

Abulasan Kabaradin[1*], Rabira Nigussie[2], Abdissa Tashome[3], Ashebir Tsegaye[4],
Wabi Tafa[5] & Degefa Wayessa[6]

[1-6]Oromia Agricultural Research Institute, Asella Agricultural Engineering Research Center, P.O. Box 06 Asella, Arsi, Ethiopia.
Corresponding Author (Abulasan Kabaradin) Email: keberedin@gmail.com[*]

DOI: https://doi.org/10.46382/MJBAS.2025.9105

Article Received: 03 January 2025 *Article Accepted: 08 March 2025* *Article Published: 16 March 2025*

ABSTRACT

In the majority of the nation, manual hand metering of faba bean row planting and broadcasting methods of sowing are still in use. The broadcasting method exposes seeds to rodent and bird consumption, results in uneven seed placement at appropriate intervals, and fails to firmly plant the seeds in the soil hence design, development, and introduction of improved technologies is needed to promote and uphold land and labor productivities. The purpose of this study was to design, build, and assess the effectiveness of a constructed planter that could plant faba bean seeds at depths, inter and intra-row spacing that were predetermined. The investigation to optimize the design of the planter's sections involved the physical characteristics of the Tumsa faba and Gabalcho bean seed varieties. The constructed planter is made up of a frame, drive wheels, a flexible furrow opener, a seed tube/spout, a seed hopper, and seed metering devices. The developed planter was assessed based on the following metrics: field capacity, field efficiency, percent miss index, percent multiple index, percent precision index, and percent quality feed index.

A randomized complete block design comprising three replications, three speed levels, and three hopper loading levels was the experimental setup. According to the study, the faba bean varieties Tumsa and Gabalcho had sphericity values of 65.82±4.42 and 65.42±4.33, respectively. At operating speeds of 3, 5, and 7 km/hr, the planter's percentages of visible mechanically damaged seed were 0.41, 0.87, and 1.34, respectively. The amount and the extent of internal seed damage initiated by the metering device-directed mean percent seed germination of 95.59, 95.13, and 94.66% at 3, 5, and 7 km/hr forward speed, respectively, were evaluated through germination tests. The percentage miss index, percentage multiple indexes, percentage quality feed index, and percentage precision index were all significantly impacted by the planter's forward speed at $p < 0.05$, and the ideal operating speed should not be greater than 5 km/h. At 3, 5, and 7 km/hr speed levels, the average field capacity and field efficiency were, 0.42 ha/hr, 0.66 ha/hr, 0.89 ha/hr, and 87.22%, 82.48%, and 80.48% respectively. It is determined that the constructed planter can be used in faba bean row planting operations in an economical and efficient manner based on the results of the performance evaluation.

Keywords: Broadcasting; Depths; Design; Field capacity; Investigation; Miss index; Multiple indexes; Precision index; Quality feed index.

1. Introduction

1.1. Background

One of the most important consumable legumes in the world, the faba bean (*Vicia faba* L.) comes in fourth place behind lentils, chickpeas, and field peas. Production of faba beans occurs on 2.5 million hectares globally (FAOSTAT, 2016).

After chickpeas and peas, it is thought to have originated in the Near East and is among the first domesticated legumes. The primary producer has been China, followed by Ethiopia, Egypt, Italy, and Morocco (Salunkhe and Kadam, 1989).

With a share of 1.5 million metric tons in 2013, Ethiopia is Africa's top producer of faba beans (FAOSTAT, 2016). Compared to the average yield of the nation (1.8 t/ha), the productivity of improved varieties is extremely high (3.5 t/ha). Approximately 511,908.4 hectares of land were planted with faba beans each year in the country, and 3,682,512 smallholder farmers farmed the crop (CSA, 2021).

The productivity of faba beans is only 2.1 tons per hectare, which is extremely low when viewed alongside the average yield of 3.7 t ha-1 in major producing countries, despite their enormous importance and area coverage (CSA, 2021).

In Ethiopia's highlands, it is one of the most significant cool-season legumes grown. Faba beans are used in processed foods, dry seeds, and green vegetables, among other things. Its products are an excellent source of high-quality protein for human consumption, and animals are fed on its dry seeds, green haulm, and dry straw (Sainte, 2011).

The Oromia region's North Shewa and Arsi zones have been recognized as important faba bean production areas (CSA, 2016). It fixes atmospheric nitrogen, increasing soil productivity, and works well as a cereal rotation crop. A few benefits of rotating pulse crops, like faba beans, with cereal crops include mitigating the effects of low soil fertility and breaking the cycles of disease and insect pests.

The development and application of new agricultural technologies, particularly farm equipment and tools, has long been a source of concern for Ethiopian agricultural experts, policymakers, researchers, and many others working in the field. Investigations, however, indicate that the nation's adoption rate of modern agricultural technologies is remarkably low. Because it can boost income and productivity, agricultural innovation is becoming more and more popular in developing countries. Goals, constraints, and the costs and benefits of agricultural technology all play a role in small-scale farmers' decisions to embrace or reject it.

Because of this, manual hand metering row planting and broadcasting sowing techniques are still in use throughout most of the nation. The broadcasting method of crop establishment exposes seed to rodent and bird consumption, results in uneven seed placement at the proper interval, and fails to firmly plant the seeds in the soil. Reliable, well-made, and lightweight mechanical seeders are critical to boosting seasonal capacity and reducing production expenses. Operational timeliness is one of the most important requirements, and it can only be met by using agricultural machinery correctly.

The uniform and timely establishment of the ideal plant population is a prerequisite for increases in crop yield, cropping reliability, cropping frequency, and crop returns. Planters space seeds appropriately and give each seed a larger growing space (Karayel and Ozmerzi, 2009).

It is commonly known that faba beans are produced in the Arsi Zone's highlands. As a result, the Animal Drawn Faba Bean Row Planter was created by the Asella Agricultural Engineering Research Center to close the broadcasting method gap with encouraging outcomes. With a 30 cm row spacing, the machine was designed to plant three rows at a time. But using an animal-drawn machine to plant faba beans in a straight line is not without its challenges. The animal has to be properly trained to walk steadily before the row can overlap and it will zigzag. Since it is unmanageable, planting crops in a row by animals is typically challenging and time-consuming.

In addition, the Ethiopian government provides farmers with tractors in large quantities in an effort to improve agricultural mechanization and expand mechanized farming in the nation. With the following goals in mind, this research project aims to develop an appropriate tractor drawn faba bean row planter.

1.2. Study Objectives

1. To develop prototype of tractor drawn faba bean row planter.

2. To evaluate performance of the developed machine.

2. Materials and Methods

In the Arsi zone's Hetosa Woreda, testing and performance reviews were conducted. The design, fabrication, testing, and evaluation were completed at the 2,430-meter-high Asella Agricultural Engineering Research Center, which is situated in the Arsi zone of the Oromia Region at latitudes 6° 59' to 8° 49' N and longitudes 38° 41′ to 40° 44' E.

2.1. Determination of Physical Properties of Faba Bean

The Gabalcho and Tumsa varieties of faba bean seed's physical characteristics were identified. Using calipers to measure the three principal diameters of 100 randomly chosen seeds from representative samples, the mean dimension of the seeds used in the study was determined to within 0.01 mm. The length, width, and thickness of the seeds have been used to designate their major, intermediate, and minor sizes.

Table 1. Physical properties determination formulas

No.	Physical Properties	Formula Used	Sources
1	Geometric mean diameter (Dg)	$D_g = \sqrt[3]{L \times W \times T}$	(Mohsenin, 1986)
2	Sphericity of the Seed	$\Phi = \frac{D_g}{L} \times 100$	(Mohsenin, 1986)
3	Bulk density	$BD = \frac{M}{V}$	(Mohsenin, 1986)
4	Angle of repose	$\phi = \tan^{-1}\left(\frac{2h}{d}\right)$	(Mohsenin, 1986)
5	Thousand Seed weight	1000 seeds for each variety	(Mohsenin, 1986)

Where: L is the length (m), W is the width (m) and T is thickness of the tuber (m), BD = bulk density (g/cm^3), M = mass of seeds (g), V = volume of cylinder (cm^3), Φ = angle of repose (degrees); h = height of cone (cm); d = diameter of cone (cm).

2.2. Design of Component Parts of Prototype Faba Bean Planter

The fabricated faba bean seeder was consisting of the following components like main frame, furrow opener, hopper (fertilizer and seed compartments), metering device, furrow covering device and etc.

2.2.1. Design of Main Frame

All other planter components are supported by the frame, which serves as the planter's backbone. Strength and Weight were the two design parameters considered while determining the size of material required for the design of frame. To provide the necessary strength and rigidity in this design, mild steel square hollow pipe measuring 40 mm by 40 mm and 4 mm was used. This allows it to withstand any type of loads during operation.

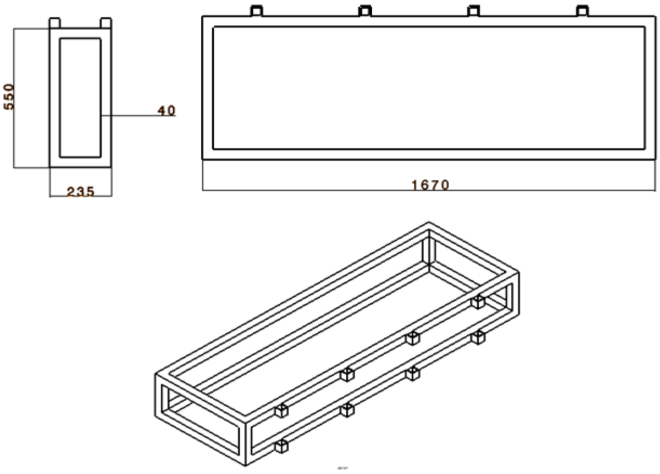

Figure 1. Schematic of designed frame side, bottom and isometric view (all dimensions are in mm)

2.2.2. Design of Hopper

With two compartments—one for seeds and another for granular fertilizer—the hopper was made to feed the metering devices vertically. 1.50 mm thick sheets of mild steel were used to make the hopper. Consequently, the hopper's lower half has a trapezoidal shape, while its upper half height has a rectangular shape.

The average angle of repose of Gabalcho and Tumsa varieties were determined as 22.63^0 and 22.97^0 respectively. The average bulk densities of each variety were determined as 872.3 and 873.89 kg/m^3 respectively. Seed and fertilizer rate of 119.77 kg/ ha and 100.03 kg/ha respectively were considered in the design of hopper capacity.

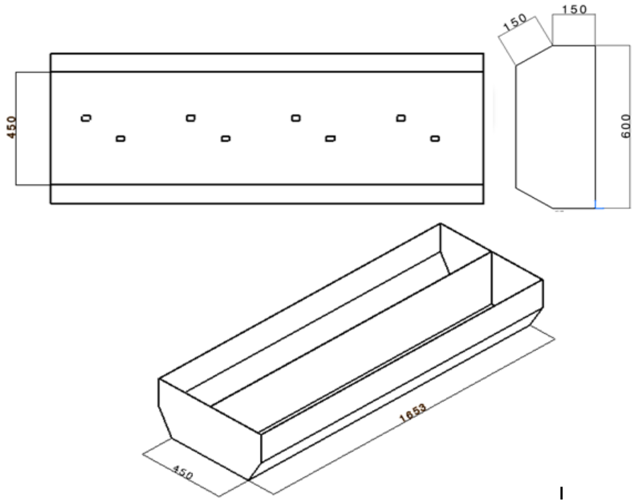

Figure 2. Schematic of designed hopper side, bottom and isometric view (all dimensions are in mm)

The hoppers' volume has been computed using the formula provided by (Olaoye and Bolufawi 2001), based on the seeding rates previously mentioned.

$$V = \frac{S_R}{n\,x\,BD} \qquad \ldots(1)$$

Where: - SR is seeding rate (kg/ha), n is number of refilling per hectare, BD is bulk density of the seeds (kg/ m^3), V is Volume of the hopper.

The hopper's design has two evenly spaced compartments: one for seeds and another for fertilizer, each containing 0.034 m3. The hopper's dimensions were 2067 mm length x 510 mm top width x 150 mm height for the trapezoidal and rectangular part of the hopper, respectively.

2.2.3. Design of Seed Metering Mechanism

Metering devices are made of fluted rollers made of aluminum with slots around the outside. Based on agronomic requirements, the cells were spaced along the circumference of the aluminum fluted roller to provide a plant spacing of 10 cm when planting faba beans. Twenty five slots (flutes) were designed along the periphery of a roller having 12 mm diameter and 12 mm depth for each flute and 3 mm spacing between the flutes. The dimensions of fluted rollers have been selected based on the faba bean seeds' physical properties.

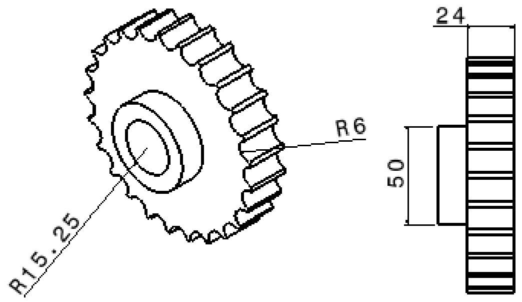

Figure 3. Schematic of diagram of seed metering device (all dimensions are in mm)

The desired number of flutes and their spacing were used to calculate the fluted roller's diameter using the formula below (RNAM, 1991).

$$d_r = \frac{N_f\left(d_f + s_f\right)}{\pi} \qquad \ldots(2)$$

Where, d_f = diameter of the flute (mm); s_f = spacing between flutes (mm); and d_r = diameter of fluted roller (mm).

Therefore, 120mm diameter of fluted rollers was used for seed metering devices.

2.2.4. Design of fertilizer metering devices

Based on the bulk density of NPS- fertilizer and recommended rate as 0.945 g/cm^3 and 119.77 kg/ha respectively, the volume of fertilizer dropped per meter length of row was calculated by (RNAM, 1991).

$$V_f = \frac{s \times r}{10\rho} \qquad \ldots(3)$$

The exposed length of the fluted roller was calculated by the following formula.

$$l_f = \frac{8 \times s \times r \times d_g}{10 \times \rho \times d_f^2 \times N_f \times i} \qquad \ldots(4)$$

Thus, 5.1 cm^3 volume of flute and 2.40 cm exposed length of flute were designed and used.

2.2.5. Design of Furrow Opener

V-shaped adjustable furrow openers were created to increase the precision of seed placement. The shovel was made of 4 mm thick mild steel sheet metal, and the furrow openers' shanks were made of 30 mm x 30 mm mild steel square hollow pipe. The wings of the furrow openers had a 45-degree rake angle to the horizontal and were beveled. The steel shank, which was fastened to the planter's frame with bolts and nuts, was joined by welding to the wings.

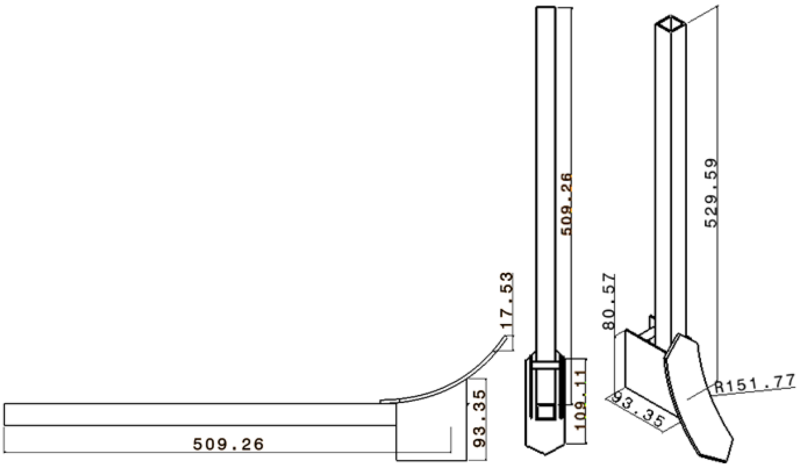

Figure 4. Schematic of Designed Furrow Opener

2.2.5.1. Force acting on the furrow opener

Soil resistance Ko is horizontal and acts in the shovel's axis of symmetry for calculation purposes. For heavy soil, 0.25 kg/cm^2 was the assumed value.

Table 2. Specific Soil Resistances up to a Depth of 15 cm

S.No.	Soil type	Specific resistance, kg/cm^2
1	Light soil	0.12
2	Medium soil	0.15
3	Heavy soil	0.20
4	Very heavy soil	0.25

Source: Dubey, 2003.

Assuming, a = 3 cm at the bottom and b= 5 cm at the top, the cross section of furrow is trapezoidal in shape d = 5 cm substituting the values in Equation below

The following formula was used to calculate the draft force applied to the furrow opener (Kurtz et al., 1984).

$$D = K_o * n * w * d \qquad \ldots(5)$$

The total draft force exerted 196.2N was obtained and the draft force exerted on each furrow opener was determined as 49.05N. Where, K_O = specific soil resistance, W = width of opener (cm); d=depth of opener (cm); n = number of furrow openers.

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 1, Pages 55-76, January-March 2025

2.2.6. Design of Ground Wheels

With an external diameter of 830 mm, the planter's ground wheel is directly attached to the seed metering device and was designed to be a part of the seed metering mechanism (Figure 5).

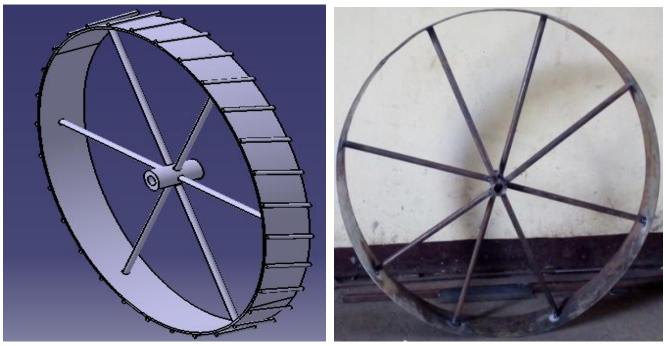

Figure 5. Isometric view of ground wheel

2.2.6.1. Determination the Weight of Component Parts of the Planter

To estimate the loads on all of the prototype planter's component elements, the weight of each component part must be calculated.

Table 3. Weight of each components of the planter

No.	Components	Quantity	Area (m^2)	Volume (m^3)	Density (kg/m^3)	Mass (kg)	Weight (N)
1	Hopper	1	0.89	8.9×10^{-4}	7850	6.98	68.5
2	Main frame	1	0.46	6.88×10^{-4}	7850	5.4	53
3	Fluted roller	4	0.013	2.1×10^{-4}	2700	0.57	5.6
4	Fluted roller	4	0.16	12.1×10^{-4}	2700	3.3	32.37
5	Spout	4	0.29	2.9×10^{-4}	7850	2.54	24.92
6	Furrow opener	4	0.42	5.88×10^{-4}	7850	5.14	50.42
7	Row marker	2	0.12	2.04×10^{-4}	7850	1.78	17.5
8	Hitch	1	0.09	5.74×10^{-4}	7850	5.02	49.25
9	Hopper cover	1	0.55	5.5×10^{-4}	7850	4.81	47.2
	Total weight						**348.76**
	Weight of parts lay on the wheel shaft including 2% for bolts ,nuts and other						**355.73**
	Grain						588
	Fertilizer						490

2.2.6.2. Determination of Force Required Driving the Planter

The following Equation was used to estimate the rolling resistance force (F), which is predicted to move horizontally at the wheel-ground interface or ground-wheel contact patch: 172.13N (Reece, 2002).

$$F = \left(\left(\frac{z}{d} \right)^{\frac{1}{2}} + i \right) \times N \quad \ldots (6)$$

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 1, Pages 55-76, January-March 2025

Where:- d = wheel diameter, 830 mm, z = maximum wheel sinkage depth (on a soft surface z ≈ 0.05d = 3cm), N = weight of the planter on each wheel, (1433.73/2) =716.86N and i = gradient of the ground, let i = 5%.

2.2.6.3. Determination of the Drive Shaft Diameter

The maximum shear stress of ductile material, the foundation of the design, determines its strength. Equation (12) (ASME, 1995) was used to determine the diameter for a shaft with little to no axial loading.

$$d^3 = \frac{16}{\pi Ss}\left[(K_b * M_b)^2 + (K_t * T)^2\right]^{\frac{1}{2}} \quad \ldots(7)$$

Where Mb = bending moment (N.mm), T = torque (N.mm), d = shaft diameter (mm), Kb = combined shock and fatigue factor applied to bending moment, Kt = combined shock and fatigue factor applied to torsional moment, and Ss = permissible stress (KN/m^2). Khurmi and Gupta (2005) suggested Kb = 1.2 to 2.0 and Kt = 1.0 to 1.50 when a load is abruptly applied to a rotating shaft with minimal shock. Assume an allowed stress (Ss) of 120 MN/m^2. As a result, a standard shaft diameter of 30 mm was used.

2.3. Performance Evaluation of Planter on the Field

To gather real data on overall implement performance and work capacity in the field, field performance tests were carried out.

2.3.1. Moisture content of the soil

At random, five samples were taken from the test plots at a depth of 20 cm. The samples were weighed both before and after drying, and they were kept in an oven at 105°C for 24 hours. (Rangapara, 2014) has determined the moisture content (Db).

$$M_c = \left[\frac{M_w - M_d}{W_d}\right] * 100 \quad \ldots(8)$$

Where Ww stands for weight of wet soil (g), Mc for moisture content of soil (%) db, and Wd for weight of oven-dry soil (g).

2.3.2. Bulk Density

A core sampler was used to measure it, gathering soil samples from various spots in the field and estimating the results using a formula.

$$\delta = \frac{M}{V} \quad \ldots(9)$$

Where M is the oven dry mass of soil (g), V is the volume of the core sampler (cm3), and δ is the bulk density of the soil (g/cm^3).

2.3.3. Speed of Operation

The speed of a planting machine pulled by a tractor was determined by timing how long it took to cover the desired distance. The formula below has been used to calculate the speed.

$$speed(Kmph) = \frac{3.6 \times dis\tan cetravelled}{time(s)} \qquad \ldots(10)$$

2.3.4. Wheel Slip

Using colored tape, a mark has been made on the tractor drive wheel. The tractor's distance traveled under no weight at 20-meter intervals and its revolution with a load on the same surface has also been recorded. The mathematical expression for it is as follows:

$$Wheelslip = \frac{A - B}{A} x100 \qquad \ldots(11)$$

Where A is the number of wheel turns without a load and B is the number of wheel turns while carrying a load.

2.3.5. Theoretical Field Capacity (TFC)

It is the rate of field coverage attained if an implement is always covering 100% of its rated width and operates 100% of the time at its rated speed.

$$T_{fC} = \frac{S \times W}{10} \qquad \ldots(12)$$

Where, Tfc is the theoretical field capacity in hectares per hour, S is the travel speed in kilometers per hour, and W is the strip's total width in meters, excluding overlap.

2.3.6. Effective (Actual) Field Capacity

A plot of 50 m × 50 m required, on average, twelve passes with a width of 1.6 m was used to calculate field efficiency and field capacity, which were calculated based on the equations shown below.

$$EFC(ha/hr) = \frac{Actualarea\ \text{covered}(ha)}{Time\ required\ to\ \text{cover}(hr)} \qquad \ldots(13)$$

2.3.7. Field Efficiency (E)

Field efficiency is the percentage of the total time in the field spent working at the theoretical machine capacity. It was calculated by:-

$$FE(\%) = \frac{EFC}{TFC} x100 \qquad \ldots(14)$$

Where, TFC is the maximum theoretical field capacity, EFC is the effective field capacity (ha/hr), and FE is the field efficiency (%).

2.3.8. Seed Damage Percentage

The drive wheels of the hopper rotated at a set speed while it was filled with seeds. To capture the metered and ejected seeds, polythene bags were placed inside each tube. At the end of the predefined revolution, the seeds were collected in polyethylene bags, and their functionality as a metering device was assessed by looking for any obvious breaks or external damage. To determine the degree of internal damage brought on by the metering mechanism, germination tests were conducted on seed samples that were chosen at random and placed in a petri dish. The following equation was used to calculate the percentage of external seed damage.

$$M_d = \frac{S_{tds}}{S_{ns}} \times 100 \qquad \ldots(15)$$

Where: S_{ns} is the total number of seeds; Md is the percentage of damaged seeds; and Stds is the total number of externally damaged seeds.

2.3.9. Evaluation of Seed Spacing

In order to assess the consistency of seed placement, the planter was tested with faba bean seeds at a set forward speed and a hopper loaded to half, three-quarters, and full capacity. While designing wheels and metering devices, the theoretical spacing of 10 cm (xref) is used as the actual seed spacing. The measured and mean spacing values were then compared to the theoretical values.

As a result, five divisions are made based on the observed spacings:-

Division I = 0 to 0.5 of xref denoted the presence of multiple seeds dropped at the same location or a seed spacing that was half of the recommended spacing or less.

A single seed spacing that is near to the theoretical seed spacing is indicated by Division II = 0.5 to 1.5 of xref.

Division III skips range from 1.5 to 2.5 xref.

Division IV consists of double skips from 2.5 to 3.5 xref.

Division V: greater than 3.5 xref; triple skips, etc.

The following formulas and parameters are used to estimate the accuracy of seed spacing (Kachman and Smith, 1995).

2.3.10. Miss Index (MISI)

The following formula was used to calculate it based on the distance measured between seeds that were dropped in the row and separated at a distance greater than 1.5 times the theoretical (nominal 10 cm) spacing:

$$MISI(\%) = \frac{n_{III} + n_{IV} + n_V}{N} \times 100 \qquad \ldots(16)$$

Where, N is the total number of spacing, MISI is the miss index, and nIII, nIV, and nV are the number of spacing in divisions III, IV, and V.

2.3.11. Multiples Index (MULI)

It was calculated using the following formula after the distance between successive seeds was measured and found to be less than or equal to half of the theoretical (nominal) spacing:

$$MULI(\%) = \frac{n_I}{N} \times 100 \qquad \ldots(17)$$

Where, N is the total number of spacing, nI is the number of spacing in region I, and MULI is the multiple index.

2.3.12. Quality of Feed Index (QFI)

Using data collected by measuring the successive distance between seeds in the row with spacing more than half but not more than 1.5 times the theoretical spacing, the quality of feed index—an indicator of the uniformity of seed distribution in the row—was calculated using the following equation:

$$QTFI(\%) = \frac{n_{II}}{N} \times 100 \qquad \ldots(18)$$

Where, N is the total number of spacing, nII is the number of spacing in division II, and QTFI is the quality of feed index.

2.3.13. Precision Index (PREC)

After removing outliers like misses and multiples, it is the coefficient of variation of the distance between the closest seeds in a row that are classified as singles (Singh *et al.*, 2005). A precision for single spacing is comparable to a coefficient of variation (seeds in division II). It has been determined that the percentage of precision in spacing is as follows:

$$PREC(\%) = \frac{S_{II}}{X_{ref}} \times 100 \qquad \ldots(19)$$

Where, xref is the theoretical spacing, SII is the standard deviation of the n observations in zone II, and PREC is precision.

2.3.14. Germination Count

The seed germination count was taken on for 14th days after planting. The germinated seeds include singles and multiples. The germination percentage was calculated as (Rangapara, 2014).

$$Germination\ (\%) = \frac{N_{sg}}{N_{sp}} x100 \quad \ldots(20)$$

Where, N_{sp} is Number of seed planted; M_{gs} is Number of seed germinated

2.3.15. Fuel Consumption

The fuel consumed for sowing operation was determined using refilling methods with known volume of cylinder and it was calculated as:

$$\text{Fuel consumption (l/ha)} = \frac{\text{Fuel Consumption (l)}}{\text{Area Covered (ha)}} \quad \ldots(21)$$

2.3.16. Cost Estimation

The tractor and machine's capital costs, interest, repair and spare part costs, labor costs, and depreciation were used to estimate the tractor and developed planter's annual and hourly operating costs. Wen-yuan Huang *et al.*, (1979).estimated the planter prototypes and the 25-hp tractor's operating costs in Birr (EB). When the implement is used 330 hours a year, the tractor's economic life is estimated to be 10 years and 330 hours.

Table 4. Annual and hourly operational costs of the Tractor and fabricated planter

No.	Cost estimation	Formula Used	Sources
	Fixed Cost		
1	Depreciation	$D_P = \frac{PP - SV}{LxH}, (EB/h)$	(Kepener, 1987)
2	Interest	$I = \left(\frac{PP + SV}{2}\right) \times \left(\frac{I\%}{H}\right), (EB/h)$	(Kepener, 1987)
3	Insurance & taxes (IT)	$IT = 1\% \, of \, PP$	(Kepener, 1987)
4	Housing	Housing = 1% of PP	(Kepener, 1987)
5	Total fixed cost	$D_p + I + IT + Housing$	(Kepener, 1987)
	Variable cost		(Kepener, 1987)
6	Repair and maintenance cost	$RM = 10\% \, of \, PP$	(Kepener, 1987)
7	Total cost per hour	$Fixed\,cost/hr + Variable\,cost/hr$	(Kepener, 1987)

Whereas: Salvage value (SV): 10%, interest rate: 10%, Purchase price (Pp): 123,000 ETB Maintenance and repair (RM): 10%, Taxes and insurance (IT): 1% of total pay 1% of PP goes toward housing. Fuel consumption: FC = 71.19 ETB per lit, or 4.6 lit/hour. Lubrication consumption: 25% of fuel, Lubrication cost (L.C.): 140 ETB per lit, 300 ETB per day is the labor cost (LaC), and Dp is depreciation.

2.4. Experimental Design

There were three replications and a randomized complete block design (RCBD) in this factorial experiment. Three levels of hopper loading and three levels of planter forward speed, each with three replications, made up the treatments. There were three replications in the experimental design of 32, for a total of 27 test runs.

2.5. Statistical Analysis

Using statistical software from GenStat 15th edition and a protocol suitable for the experimental design, the data were subjected to analysis variance (ANOVA) (Gomez and Gomez, 1984). To distinguish between treatment means that varied at the 5% level of significance, the least significant difference (LSD) test was employed. The mean values for actual seed and fertilizer application rates in relation to forward speed and hopper level of filling were calculated using the least significant difference (LSD) test.

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 1, Pages 55-76, January-March 2025

3. Results and Discussion

The purpose of this study was to assess how well a four-row faba bean planter machine performed in terms of seeding faba beans and fertilizer at predetermined depths, row-to-row spacing, and crop-to-crop spacing.

3.1. Physical Properties of the Seeds

The study used varieties of faba beans, specifically Gabalcho and Tumsa. The length, width, thickness, geometric diameter, sphericity, angle of repose, and thousands seed weight mean values and standard deviations are provided in Table 5.

Table 5. Physical properties of Gabalcho and Tumsa seed varieties

Physical properties	Samples size	Tumsa	Gabalcho	Unit
Length (L)	100	16.02±1.39	16.06±1.28	mm
Width (W),	100	11.06±0.92	11.02±0.84	mm
Thickness (T)	100	6.58±0.66	6.52±0.64	mm
Geometric mean diameter (Gd)	100	10.50±0.57	10.46±0.49	mm
Sphericity (%)	100	65.82±4.42	65.42±4.33	%
A. Repose (AR)	100	22.97±0.43	22.63±0.45	Degree
Bulk density(BD)	100	873.89±1.46	872.3±1.70	Kg/m^3
Thousand grain weight (TGW)	1000	814.65±1.04	813.31±1.39	gm

From Table 5 it can be seen that the sphericity of Tumsa and Gabalcho were 65.82±4.42% and 65.42±4.33%, respectively, showing that both seeds varieties was roughly spherical in shape. Similar result (66.52%) was reported by (Al-Gezawe *et al*, 2022). As a result, it was decided to use circular measuring devices with depths equivalent to the seeds' lengths or main diameters. In general, the dimensions of the metering device flute were determined by the major diameter of the faba bean seeds.

3.2. Performance Evaluation of the Prototype

3.2.1. Seed Damage Test

A percentage was determined by counting the number of seeds that were mechanically damaged (bruised, had their skin removed, or were crushed). For faba bean seeds, the mean percentage of seed damaged was found to be 0.41%, 0.87%, and 1.34% at operating speeds of 3, 5, and 7 km/h, respectively. Al-Gezawe *et al*, (2022) reported that maximum seed damages of 4.78% for faba bean at 4 km/hr. The result clearly indicated that cotyledon seeds were the most susceptible to mechanical damage; therefore, caution must be used when creating metering devices for faba bean seeds.

A high metering fluted roller speed and a susceptible seed surface could be the cause of the observed damaged seed percentage. In an experiment using a precision plate planter, Norris, (1982) discovered that the amount of seed damage rose as the metering fluted roller speed increased. This was explained by the seeds shearing and jumping against the hopper wall at high speeds, and the extent of damage was influenced by the strength of the seeds.

Moreover, a seed germination test was performed, and the findings showed that seeds germinated both before and after metering, and internal seed damage was determined by sowing 100 seeds on a petri dish, and it was found that there was slight internal seed damage. The quality of the metering roller, variations in speed, and friction between the metering device and the seeds can all be factors in the difference in the percentage germination rate before and after measuring the seeds. Mean germination percentage of faba bean obtained from seed supplier (Ethiopian Seed Enterprise, Asella Branch), was 96.00%. Table 6 indicated that, the percent germination of faba bean was 95.59%, 95.13% and 94.66% at 3, 5 and 7 km/hr of forward speed respectively. This shows that, at less than 1%, the damages caused by the metering devices at forward speeds of 3 and 5 km/h were within an acceptable range. However, 1.34 % seed mechanical damage was observed at 7 km/hr forward speeds. This suggests that a high percentage of mechanical damage to seeds would occur at forward speeds exceeding 7 km/h. Similar results, 1.39 % of seed mechanical damages were reported by (Ashebir Tsegaye, 2015) for haricot bean crop.

Table 6. Mean seed damage and germination test of the faba bean planter

Observations	**Speed, km/h**	**Seed rate obtained, kg/ha**	**Mechanical damage, %**	**Germination %**
1	3	126.41	0.41	95.45
2	5	119.77	0.87	94.58
3	7	115.22	1.34	94.47

3.2.2. Seed Spacing Analysis

3.2.2.1. The Seed Miss Index

The speed at which the planters operated had a significant impact ($p < 0.05$) on the seed miss index, according to the results of the analysis of variance (ANOVA). Nevertheless, there was no discernible difference in the impact of the hopper filling capacity and the combination of speed level and hoper loading level ($p > 0.05$).

Table 7 shows how the mean percentage of seed miss index is affected by forward speed, hoper filling capacity, and the combined effect of forward speed and seed hopper filling. The relationship between the mean percentages of seed miss index and the planter's linear forward speed is depicted in Figure 6.

Table 7. Effects of planter hopper filling level and forward speed on miss index (MISI)

Parameter	**Source of variation**		**Measure of differences**	
	Speed level		**LSD (5%)**	**SE(M)**
	V_3	7.41^a		
	V_5	9.96^b	1.23	0.41
MISI (%)	**V_7**	10.95^b		
	Hopper			

filling level					
H_{50}	8.85[a]				
H_{75}	9.84[a]			1.23	0.41
H_{100}	9.93[a]				
Interaction(V*H)					
Speed level	**H_{50}**	**H_{75}**	**H_{100}**		
V_3	5.56[a]	8.02[b]	8.64[b]		
V_5	9.55[c]	10.13[cb]	10.21[cb]	2.13	0.71
V_7	10.55[c]	11.35[cb]	10.95[cb]		

Define LSD, SE Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

The percentage of miss index was significantly impacted by operational speed ($p<0.05$). As the operating speed increased from 3 km/hr to 7 km/hr, the percent miss index increased as well. Planting faba bean seeds with the prototype planter generally results in a higher percentage of miss index when operating at a higher rate. At a forward speed of 7 km/h, the highest percentage of seed miss index was recorded at 10.95%, while the lowest percentage of seed miss index was obtained at a speed of 3 km/h. This indicated unequivocally that forward speeds exceeding 7 km/hr would yield a percent miss index of roughly equal to 10 or more, surpassing the upper bound of permissible percent miss (Chhinnan, 1975) and (Karayel and Ozmerzi 2009).Table 7 shows that the percentage miss index was not significantly affected by the hopper filling level or by the combined effect of operational speed and hopper filling level. Nevertheless, differences in speeds and hoper filling level were primarily responsible for the effect. The percentage miss index varied with speed, but it did not significantly change with filler level.

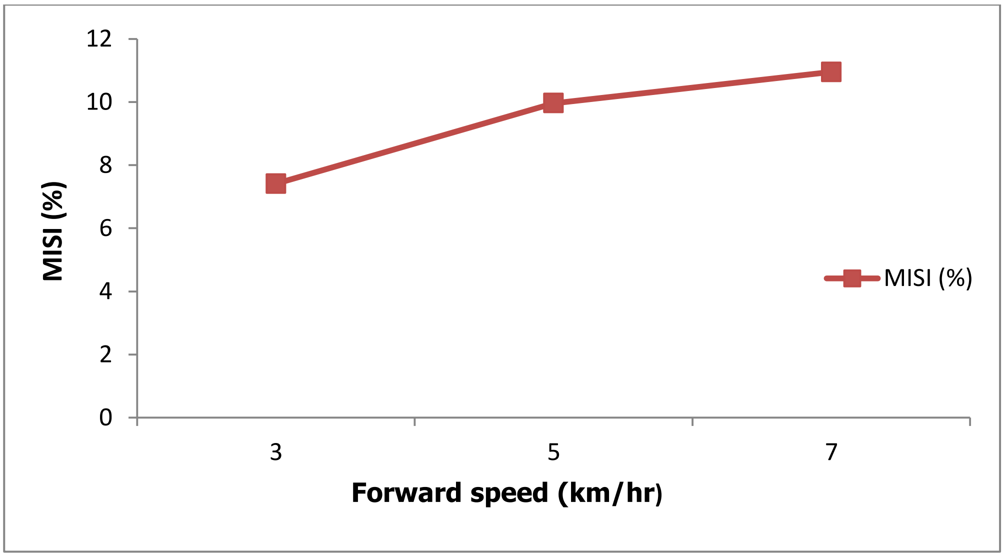

Figure 6. Effects of planter operating speeds on seeds miss index

Mediterranean Journal of Basic and Applied Sciences (MJBAS)
Volume 9, Issue 1, Pages 55-76, January-March 2025

3.2.2.2. The Seed Multiple Index

According to an ANOVA, the seed multiple index was significantly impacted by planter forward speed ($p < 0.05$), but hoper loading level and their interaction had no significant impact ($p > 0.05$). The effects of hopper filling level, planter operating speed, and their combined effect on the percentage of seed multiple indexes are shown in Table 8. The relationship between the percent of seeds multiple indexes and the planter's linear speed is depicted in Figure 7. Table 7 illustrates that while there was a significant difference in the percent multiple index at all selected speeds, there was no significant difference in the effect of hopper filling level or the combination of hopper filling level and operational speed on the percent multiple index.

Table 8. Effects of planter hopper filling level and forward speed on multiple index (MULI, %)

Parameter	Source of variation				Measure of differences	
	Speed level				**LSD (5%)**	**SE(M)**
	V_3	10.00^a				
MULI (%)	**V_5**	6.94^b			2.05	0.68
	V_7	2.78^c				
	Hopper filling level					
	H_{50}	7.5^a				
	H_{75}	6.67^a			2.05	0.68
	H_{100}	5.56^a				
	Interaction(V*H)					
	Speed level	**H_{50}**	**H_{75}**	**H_{100}**		
	V_3	11.67^a	6.67^b	4.17^b		
	V_5	9.17^a	8.33^{ab}	2.5^{db}	3.56	1.2
	V_7	9.17^a	5.83^{ab}	1.67^{cb}		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

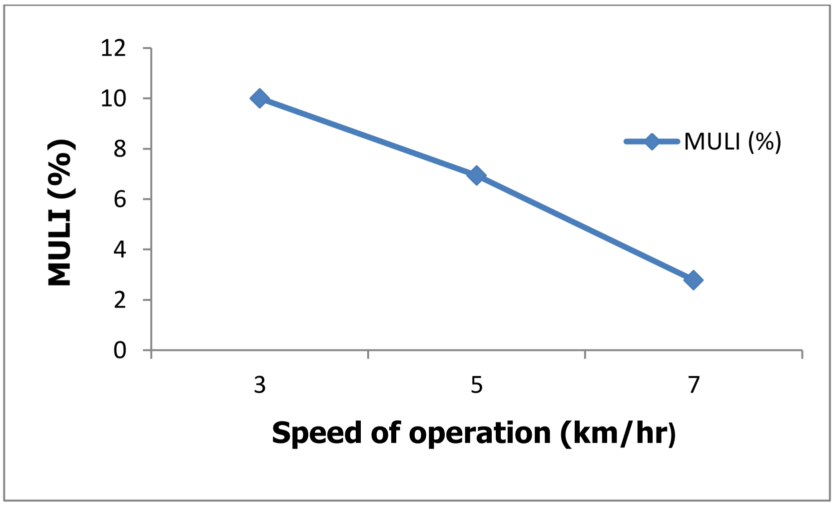

Figure 7. Effect of planter operational speeds on seeds multiple indexes

At three kilometers per hour, the planter forward speed produced the highest percentage of seed multiple indexes. The planter forward speed of 7 km/h produced the lowest results. The percentage of seeds across multiple indexes was not significantly impacted by the hopper filling level or by the speed and hopper filling level combination (Table 8). In contrast to the percent seed miss index, the impact of the planter forward speed on the percent seed multiple index showed a contrasting tendency (refer to Figures 6 and 7).

3.2.2.3. The Quality of Seed Feed Index

The results of a statistical analysis examining the impact of hopper filling level and planter operating speed on the seed feed quality index are presented in Table 9. An ANOVA analysis showed that the feed quality index was significantly impacted by planter forward speed ($p < 0.05$), while the feed quality index was not significantly impacted by hoper loading level or their interaction ($p > 0.05$).

The effects of hopper loading level and planter operating speed on the seed feed quality index are shown in Table 9. The relationship between the seed feed quality index, hopper loading capacity, and planter linear speed is shown in Figure 8. At all operating speeds, the percentage of seed feed index quality was significantly impacted by the planting machine's operating speed.

There was no statistically significant difference in the quality seed feed index depending on the level of hopper loading. This demonstrates unequivocally that the planter's forward speed, or the metering mechanism's speed, had a detrimental impact on the seed feed index's percent quality (Culpin, 1987) and (Nielsen, 1995).

As the planter's operating speed increased from 3 to 7 km/hr, the percentage quality of the seed feed index decreased. At a forward speed of 3 km/h, the highest percentage of the quality of seed feed index, 77.22%, was observed. At a speed of 7 km/h, the lowest percentage of the seed feed index (71.67%) was noted. Operating the planter at speeds faster than 5 km/hr would decrease the plant population per hectare, which could result in lower potential yields per hectare (Kachman and Smith 1995); (Karayel and Ozmerzi 2009).This conclusion can be drawn from the data in Table 8 and Figure 12.

Table 9. Effects of planter hopper filling level and forward speed on quality feed index (QTFI, %)

Parameter	Source of variation		Measure of differences	
	Speed level		**LSD (5%)**	**SE(M)**
QTFI (%)	**V_3**	77.22^a		
	V_5	73.89^b	2.05	0.68
	V_7	71.67^c		
	Hopper filling level			
	H_{50}	74.72^a		
	H_{75}	73.89^a	2.05	0.68
	H_{100}	74.17^a		
	Interaction(V*H)			

Speed level	H_{50}	H_{75}	H_{100}		
V_3	78.33[a]	76.67[a]	76.67[a]	3.56	1.2
V_5	74.17[b]	73.33[bc]	74.17[ba]		
V_7	71.67[b]	71.67[bc]	71.67[ba]		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

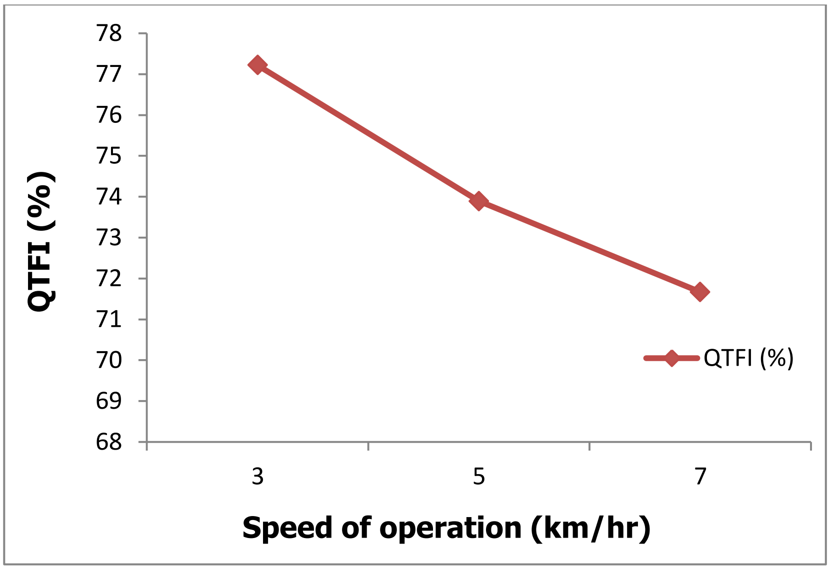

Figure 8. Effect of planter operational speeds on seeds quality feed index

3.2.2.4. The Seed Precision Index

The results of a statistical analysis that looked into how operating speed and hopper filling level affected the percent seed precision index are displayed in Table 10. The results of the ANOVA showed that while hoper loading level and the combination of hopper loading level and operation speed had no significant effect ($p > 0.05$), planter forward speed had a significant effect ($p < 0.05$) on seed spacing precision.

The impact of hopper fill level and planter operating speed on the mean percent seed precision index is displayed in Table 10. The relationship between hopper filling level, percentage seed precision index, and planter linear speed is shown in Figure 9. The percent seed precision index was found to be significantly impacted by the planter forward speed. This suggests that when the planter's linear forward speed increases, there will be a greater variation in seed spacing within a row. This is not a desirable trait, as high variability in seed spacing can be observed as the speed of operation increases. However, the percent seed precision index was not significantly affected by the combination of forward speed and hopper loading level.

For planter linear operating speeds of 3, 5, and 7 km/hr, the percent seed precision index was 12.21, 13.40, and 13.64%, correspondingly. This study unequivocally demonstrated that greater variances in seed spacing throughout the row are caused by a planter's linear forward speed. Nonetheless, 29% is a reasonable upper bound for accuracy. Better performance is indicated by lower precision values than by higher ones (Kachman and Smith 1995); (Ashebir Tsegaye, 2015).

Table 10. Effects of planter hopper filling level and forward speed on precision index (PREC, %)

Parameter	Source of variation				Measure of differences	
	Speed level				**LSD (5%)**	**SE(M)**
PREC (%)	**V_3**	12.21^a			0.13	0.042
	V_5	13.40^b				
	V_7	13.64^c				
	Hopper filling level					
	H_{50}	13.06^a			0.13	0.042
	H_{75}	13.09^a				
	H_{100}	13.11^a				
	Interaction(V*H)					
	Speed level	**H_{50}**	**H_{75}**	**H_{100}**		
	V_3	12.17^a	12.23^a	12.23^a	0.22	0.073
	V_5	13.37^b	13.40^{bc}	13.43^{bd}		
	V_7	13.63^c	13.63^{ce}	13.67^{cf}		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

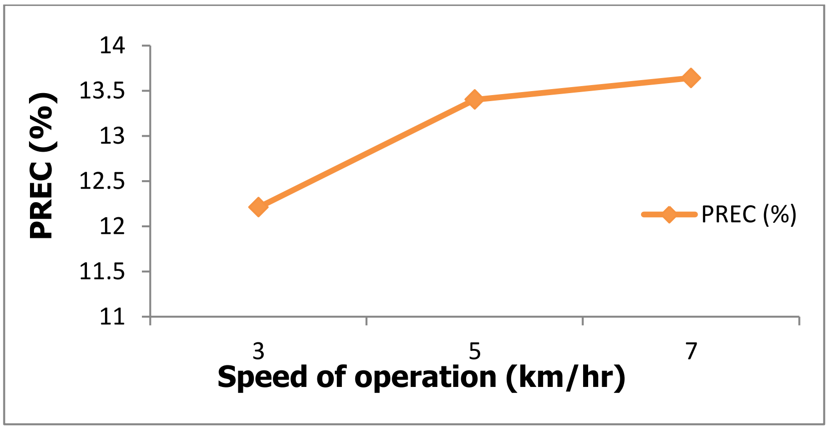

Figure 9. Effect of planter operational speed on precision index

3.2.3. Field Efficiency, Field Capacity and Draft of the Planter

According to Table 11, the planter's mean actual field capacity and efficiency were 0.42, 0.80, and 1.11 ha/hr and 87.82, 82.48, and 80.48 % at operating speeds of 3, 5, and 7 km/hr, respectively. This demonstrates that a hectare of land can be planted by the prototype planter in between one and two and a half working hours.

Table 11. Field performance evaluation of faba bean planter on plot size of 50 x 50m

Operating Speed, km/h	Fuel Consumption, l/hr	TFC, ha/hr	EFC, ha/hr	FE,%	Net draft (N)
3.00	2.5	0.48	0.42	87.82	255.8
5.00	4.3	0.80	0.66	82.48	284.8
7.00	6.2	1.11	0.89	80.48	301

The draft required for operating the developed faba bean planter was determined using a spring dynamometer. The average draft values were 255.8, 284.8, and 301 N for speeds of operation 3, 5, and 7 km/hr, respectively (Table 11). The maximum draft was 301N at 7 km/hr, and the minimum was 255.8 N at 3 km/hr operating speeds.

The plant stand count was carried out in the field as per in methodology. After planting the Tumsa faba bean variety, which has a mean germination of 94.93% (Ethiopian Seed Enterprise, Asella branch), the amount of seeds germinated per 1.6 m^2 area after ten and fifteen days was estimated. However, there was a certain variation of emergence of seeds in the field in comparison to the indicated emergence of seed; this variability could have been related to environmental factors.

3.2.4. Economical Evaluation

The faba bean planter pulled by a tractor only needed one driver. One person needed 8.33 hours to plant and fertilizes a hectare of land using an animal-drawn planter (Ashebir Tsegaye, 2015). In contrast, one person needed only 1.12 to 2.38 hours per hectare when using a tractor-drawn seed drill machine, with operating speeds ranging from 3 to 7 km/hr. Consequently, the time needed per hectare with a tractor-driven planter operating at a speed of 7 km/h is three times less than with an animal-drawn planter.

3.3. Conclusions and Recommendations

3.3.1. Conclusion

To maximize the design of the machine's components, the physical characteristics of the seeds used in the study have been examined. The precision planter's functional fulfillment was evaluated using performance indicators like precision, quality of feed index, miss index, multiple index, and spacing indices.

Tumsa and Gabalcho faba bean seeds varieties were used in the study. The sphericity of the seed was observed as 65.82±4.42% and 65.42±4.33% for Tumsa and Gabalcho variety respectively, indicating that both varieties had more or less spherical shape. Hence, flute with circular shape were used in the design.

Using metered seeds, germination tests were conducted to examine the impact of metering devices on the amount and kind of seed damage. The mechanical damages caused by the metering devices on the seeds were less than 1%. The percentage of miss index, multiple indexes, seed quality feed index, and precision index were all significantly impacted by operational speed. The percentage of the miss index and precision index increased when the operation speed was increased from 3 to 7 km/hr; however, the quality feed index and seed multiple index decreased. Planting a hectare of land at a speed of 3 to 7 km/h only takes 1 to 2.38 hours with a tractor drawn faba bean planter that only requires one operator to operate.

Thus, it can be said that faba bean row planting can be done profitably and efficiently with the help of the developed planter. To avoid significantly and adversely affecting the recommended plant population or the rate at which seeds and fertilizer are applied, the planter's speed should, nevertheless, not be lower than 3 km/h and not higher than 5 km/h.

3.3.2. Recommendations

The results of the performance evaluations demonstrated that farms can effectively use the four-row faba bean planter. To increase the planter's acceptance, versatility, and usefulness among farmers, the following problem needs to be resolved.

- To enhance the field capacity and field efficiency of the developed tractor-drawn faba bean planter, the number of rows covered could be increased.
- To further improve the design, the planter can be tested with various pulse crops and a replaceable metering device.
- Instead of utilizing aluminum for the metering device and the plastic seed and fertilizer hopper in the planter, think about utilizing plastic rollers.
- It would be best to operate at a speed of 5 km/hr in order to achieve the recommended plant population or the ideal seed and fertilizer rate.

Declarations

Source of Funding

This research did not benefit from grant from any non-profit, public or commercial funding agency.

Competing Interests Statement

The authors have declared that no competing financial, professional or personal interests exist.

Consent for publication

All the authors contributed to the manuscript and consented to the publication of this research work.

Availability of Data and Material

Supplementary information is available from the authors upon reasonable request.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

References

Al-Gezawe, A.A., et al. (2022). Development of a Machine for Planting Faba Bean. Journal of Positive School Psychology, 6(2): 6228–6240.

Singh, R.C., Singh, G., & Saraswat, D.C. (2005). Optimization of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. Bio Systems Engineering, 92(4): 429–438. https://doi.org/10.1016/j.biosystemseng.2005.07.002.

Wenyuan Huang, Herbert K. Marutani, Gary R. Vieth & Joseph T. Keeler (1979). Calculating Costs of Using Farm Machinery. Hawaii Agricultural Experiment Hawaii Agricultural Experiment Station, College of Tropical Agriculture and Human Resources, University of Hawaii.

Ashebir Tsegaye (2015). Development of animal drawn multi crop planter. Thesis, Haramaya University.

ASME (1995). Design of transmission shafting. American Society of Mechanical Engineering.

Chhinnan, M.S., Young, J.H., & Rohrbach, R.P. (1975). Accuracy of seed spacing in peanut planting. Transactions of the ASAE, 18(1): 828–831. doi: 10.13031/2013.36689.

CSA (Central Statistical Agency) (2016). Agricultural Sample survey Area and production of major crops (Private Peasant Holdings, Meher season).

CSA (Central Statistical Agency) (2021). The Federal Democratic Republic of Ethiopia Central Statistical Agency Report on Farm Management Practices. Statistical Bulletin, III, 512.

Culpin, C. (1987). Farm machinery (11th Eds.).

FAOSTAT (2016). The state of food and agriculture, 2016. In The Eugenics Review, 59(2).

Salunkhe, D.K., & Kadam, S.S. (1989). Handbook of World Food Legumes. Nutrition Chemistry, Processing Technology, and Utilization, 310.

Karayel, D., & Ozmerzi, A. (2009). Effect of tillage methods on sowing uniformity of maize. Bio Systems Engineering, 44(2): 23–26.

Kepener, R.A., Roy, B., & Barger, E.L. (1987). Principals of Farm Machinery (8th Eds.). TCBS.

Khurmi, R.S., & Gupta, J. (2005). A Textbook of Machine Design. Eurasia Pub House (Pvt.) Ltd.

Kurtz, G., et al. (1984). Design of agricultural machinery. John Wiley and Sons, Singapore.

Mohsenin, N.N. (1986). Physical properties of plant and animal materials. Gordon and Breach Science Publishers.

Nielsen, R.L. (1995). Planting speed effects on stand establishment and grain yield of corn. Journal of Production Agriculture, 8(3): 391–393. https://doi.org/10.2134/jpa1995.0391.

Olaoye, J.O., & Bolufawi, S.J. (2001). Design, fabrication and performance of multi-purpose row planting machine. Sustain. Environ., 3(1): 7–20.

Rangapara, J. (2014). Development of mini tractor operated picking type pneumatic planter. Anand Agricultural University. http://krishikosh.egranth.ac.in/handle/1/96661.

Reece, A.R. (2002). The Mechanics of Tractor Implement Performance. In Transactions of the American Society of Agricultural Engineers. http://www.eprints.unimelb.edu.au/.

RNAM (1991). Agricultural Machinery Design and Data Handbook (Seeders and Planters). Economic and Social for Asia and Pacific, Pages 23–71.

Sainte, M. (2011). The magazine of the European Association for Grain Legume Research. Model Legume Congress, 56.

Kachman, S.D., & Smith, J.A. (1995). Alternative measures of accuracy in plant spacing for planters using single seed metering. 38(2). doi: 10.13031/2013.27843.