DEVELOPMENT OF TRACTOR FRONT MOUNTED CONVEYOR BASED PULSES CROP HARVESTER
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ट्रैक्टर फ्रंट माउंटेड कन्वेयर आधारित दलहन फसल हार्वेस्टर का विकास

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ABSTRACT
The aim of the study was to develop an efficient and cost-effective tractor-front-mounted conveyor-based pulse crop harvester to meet the increasing demand for mechanized harvesting methods, particularly for crops like chickpeas, lentils, and black gram. The research is based on the principles of agricultural mechanization, focusing on optimizing key crop parameters such as cutting force requirements, plant spacing, row spacing, and stem diameter. These factors are crucial in selecting appropriate motors and cutting blades to enhance harvesting efficiency of pulse crops. The study involves torque calculations to determine the power requirements for cutting and conveying units, with results showing 1.24 Nm and 7.06 Nm, respectively. A gear motor was employed to ensure the proper conveyance of cut crops at a linear speed of 0.54 m/s. Field tests were conducted in a black gram field to evaluate the harvester's effectiveness under varying conditions. Field tests demonstrated the harvester's ability to handle premature crops, with cutting efficiency ranging from 71.04% to 75.06% at different forward speeds. The harvester achieved a maximum field capacity of 0.225 ha/h at a speed of 1.50 km/h, with a corresponding field efficiency of 75.02%. The working capacity varied from 0.831 ha/day to 1.80 ha/day, proving its suitability for pulse harvesting. Power consumption analysis indicated a total power requirement of 0.569 kW, enabling the harvester to operate for approximately 4 hours on a fully charged 12V, 200 Ah batteries. The developed harvester provides a viable solution for pulse crop harvesting, addressing the need for mechanization in pulse cultivation. Its efficiency and economic feasibility make it an attractive option for widespread adoption, contributing to improved productivity in Indian agriculture.

सारांश:
अध्ययन का उद्देश्य एक कुशल और किफायती ट्रैक्टर-फ्रंट-माउंटेड कन्वेयर-आधारित दलहनी फसल हार्वेस्टर का विकास करना है, ताकि चना, मसूर और उड़द जैसी फसलों के यंत्रीकृत कटाई तरीकों की बढ़ती मांग को पूरा किया जा सके। यह अनुसंधान कृषि यंत्रीकरण के सिद्धांतों पर आधारित है, जिसमें कटाई बल की आवश्यकता, पौधों की दूरी, कतारों की दूरी और तने के व्यास जैसे प्रमुख फसल मापदंडों के अनुकूलन पर ध्यान केंद्रित किया गया है। ये कारक उपयुक्त मोटर और काटने वाले ब्लेड के चयन में महत्वपूर्ण भूमिका निभाते हैं, जिससे दलहनी फसलों की कटाई की दक्षता बढ़ाई जा सके। अध्ययन में कटाई और कन्वेइंग यूनिट्स की शक्ति आवश्यकताओं को निर्धारित करने के लिए टॉर्क गणनाएं शामिल हैं, जिनके परिणाम क्रमशः 1.24 एन-मी और 7.06 एन-मी पाए गए। कटे हुए फसलों को 0.54 मीटर/सेकंड की रेखीय गति से ठीक प्रकार से स्थानांतरित करने के लिए एक गियर मोटर का उपयोग किया गया है। फील्ड परीक्षण उड़द की फसल में किए गए ताकि विभिन्न परिस्थितियों में हार्वेस्टर की प्रभावशीलता का मूल्यांकन किया जा सके। परीक्षणों में यह पाया गया कि हार्वेस्टर अधपकी फसलों को भी संभालने में सक्षम है, जिसमें कटाई दक्षता विभिन्न आगे की गति पर 71.04% से 75.06% तक पाई गई। हार्वेस्टर 1.50 किमी/घंटा की गति पर 0.225 हेक्टेयर/घंटा की अधिकतम क्षेत्र क्षमता प्राप्त करता है, जिसके साथ 75.02% क्षेत्र दक्षता पाई गई। इसकी कार्य क्षमता 0.831 हेक्टेयर/दिन से 1.80 हेक्टेयर/दिन तक भिन्न पाई गई, जो इसे दलहनी फसलों की कटाई के लिए उपयुक्त बनाती है। विद्युत खपत विश्लेषण से कुल 0.569 किलोवाट की शक्ति आवश्यकता पाई गई, जिससे हार्वेस्टर एक पूर्ण चार्ज की गई 12 वोल्ट, 200 एएच बैटरी पर लगभग 4 घंटे तक संचालित हो सकता है। यह विकसित हार्वेस्टर दलहनी फसल कटाई के लिए एक व्यावहारिक समाधान प्रदान करता है, जो दलहन उत्पादन में यंत्रीकरण की आवश्यकता को पूरा करता है। इसकी दक्षता और आर्थिक व्यवहार्यता इसे व्यापक रूप से अपनाने के लिए एक आकर्षक विकल्प बनाती है, जिससे भारतीय कृषि में उत्पादकता में सुधार हो सकता है।

1. INTRODUCTION

Agriculture is a cornerstone of India's economy, serving as a primary livelihood source for a substantial portion of the population. Within the agricultural sector, cereals, pulses, and oilseeds constitute the core of crop production. Consequently, enhancing pulse production has become a strategic priority due to its dual importance in nutritional security and economic viability. Pulses are recognized for their high nutritional value, being rich in dietary fiber and having a low glycemic index, which helps mitigate health issues such as hypertension and cholesterol *(Curran et al., 2012)*. These crops can fix atmospheric nitrogen and enhance soil fertility, and they are well-suited for inter-cropping and crop rotation, making them an economically and environmentally sustainable choice. Prominent pulse crops in India, including Bengal gram, black gram, chickpea, lentil, and others, are cultivated across diverse agro-climatic regions, depending on the seasonality of each crop. In states like Rajasthan, Madhya Pradesh, Maharashtra, and Uttar Pradesh, pulses are grown mostly. In fiscal years 2019–20, 2020–21, and 2021–22, total pulse production was 23.25, 25.46, and 27.30 million tons, respectively. The targeted pulse production in India during the financial year 2022–23 was 29.550 million tons. Approximately 20% of India's agricultural land, with India being the world's largest pulse producer (*FAO-2017 Report*). A crucial stage of pulse production faces considerable challenges, particularly in the area of harvesting. Mostly, the sowing to harvesting of pulses is carried out using traditional methods. Manual harvesting remains the predominant method due to the unique morphological characteristics of pulses, such as their shrubby growth and low plant height, which complicate mechanical harvesting efforts. In a study, it was found that the farm mechanization status of pulses like chickpeas is about 30-40% in terms of harvesting and threshing *(Patel et al., 2020)*. Manual harvesting of chickpeas and lentils requires 98.76 man·h/ha and 163.58 man·h/ha, respectively *(Dutt, 2021)*.

Pulse crops are grown in most of the states in India, and the production is also ratcheting year by year. In the states of Bihar, Jharkhand, and West Bengal, pulses like lentil, chickpea, and black gram have comparatively higher yields than other pulses. It is known that the harvesting machines developed in other countries, like America, Canada, and Australia, are expensive and/or unavailable in India, which is not feasible for small to marginal-scale farmers. For this reason, most harvesting of pulses is done using the manual method. A two-row battery-operated manually push type two-row harvester was utilized and required only 56.81 man·h/ha for lentils and 68.46 man·h/ha for chickpeas (*Dutt*, *2021*). However, the two-row battery harvester requires comparable man-hours with manual labor, takes time, and covers only two rows in a single pass. Hence, a tractor-operated, front-mounted harvester-cum-windrower is needed to improve the efficiency of pulse harvesting by reducing human labor through mechanization and by increasing field coverage within a single pass. It will also be cost-effective, considering the adaptability of the small and marginal scale farmers on a custom hire basis. While machine harvesting necessitates more experienced workers to operate the machine and more space for operation, manual harvesting is time-consuming and ineffective. In order to boost yields, contemporary farms now combine computers with satellite imagery and GPS guiding systems. Compared to manual harvesting, this way of operation saves 50–60% labour costs and 60–70% harvesting costs *(Yogaraj et al., 2022)*.

Mechanization of crop harvesting has received increasing attention worldwide due to rising labor costs, declining availability of farm workers, and the demand for higher field efficiency. Considerable progress has been made in developing specialized harvesting machinery for different cropping systems. For example, integrated harvesting in intercropping systems has been an active area of research. The practice of separate harvesting is useful in regions where maize and soybeans have different harvesting seasons. Separate harvesting techniques, however, pose serious difficulties in areas where maize and soybeans are harvested concurrently. Harvesters used for one crop may unintentionally harm another, causing losses. Additionally, customers must purchase separate corn and soybean machines, which results in significant labour and equipment expenses. Separate processes also result in repeated land compaction, increased labour intensity, and decreased labour efficiency. These disadvantages show that separate harvesting is not very adaptable to soybean-corn strip composite planting methods. Creating a low-loss, high-efficiency integrated harvester especially for the soybean-corn strip composite planting system is crucial to overcoming these obstacles. To further this technology, a customised header for soybean-corn integrated harvesters was developed. In addition to increasing labour efficiency and offering strong equipment support for the mechanised harvesting of soybean-corn strip planting systems, this innovation was essential for improving the mechanisation of soybean-corn integrated harvesting *(XU, et al., 2025)*.

Similar challenges are also observed in other crops, such as root and tuber harvesting, where soil and climatic conditions complicate efficient separation of produce from the soil. Around the world, 30 to 35 million hectares of land are currently used for the planting and cultivation of root crops *(Leff, et al., 2004)*. In practically every nation, growing and collecting root crops constitutes a significant part of agricultural productivity. The creation of extremely effective and resource-saving technical tools that guarantee root crop digging with the least amount of energy consumption is also given a lot of attention *(Ibrahim, et al., 2011; Ulyanov, et al., 2022)*. Harvesting root crops presents a number of challenges due to the diverse climates, soil types, and water supplies found in every location of the world *(Xaliqulov et al., 2023)*. For example, under Uzbekistan's soil and climatic conditions—marked by high summer temperatures, low relative humidity, and soil compaction following irrigation—the tuberous layer tends to disintegrate into large, hardened clods during root-crop harvesting. These clods are more resistant than the root crops themselves, making separation at the lifting stage difficult. This challenge constitutes the primary obstacle to the widespread implementation of root and tuber harvesters *(Norchayev, et al., 2021)*. Depending on the season, it is preferable to employ the appropriate methods for harvesting the root fruit crop *(Norchayev, et al., 2022)*. Harvesting tuberous roots imply the following steps: removing the tops a few weeks before harvesting, extracting the roots from the soil and separating them from it, and then loading the harvested material onto a vehicle to transport it to the location for sorting and storage *(Ulyanov et al., 2022)*. Harvesting is completed by either loading the crop into storage facilities (in-line technology) or putting it in temporary storage clamps before sending it to a sorting station for storage, depending on the technique used to cultivate tuberous roots *(Uspensky, et al., 2014)*.

The Government of India has implemented various initiatives to promote agricultural mechanization, but the adoption of mechanical harvesting for pulses is still limited, primarily due to the unavailability of suitable machinery and the high labor costs associated with manual harvesting. Addressing these challenges by developing cost-effective and efficient harvesting technologies is essential to support small and marginal farmers and ensure the long-term viability and profitability of pulse cultivation in India. In other developed nations, there are some modified machineries available for pulse harvesting. The third kind of combine harvesters with unique drum configurations for pulse harvesting is commercially accessible in Europe and the US, but not in India *(Dogra, 2018; Singh, 2018)*.

Research on pulse harvesting is still ongoing, but it is not commercially available to date. Sidahmed and Jaber *(Sidahmed, 2004; Jaber, 2004)* designed a cutter bar to harvest lentils. Field performance tests revealed that lentil crops with an average height of 0.59 m were suitable for harvesting using the harvester. Dange and Thakare *(Dange, 2010; Thakare, 2010)* developed a tractor front-mounted stem cutter for harvesting pigeon peas. The power transmission arrangement consisted of the tractor power take-off (PTO) connected to a gearbox, which was coupled with a motor and a hydraulic cylinder. The conveyor arrangement was also utilized to carry out crop cutting.

Golpira, (2013), modified passive fingers with V-shaped slots to develop a tractor-operated mechanical harvester. The width of the machine was 1.0 meters, reel index was 1.6, reel velocity was 50 rotations per minute, and slot width was 0.04 meters. *Mehetre et al., (2014),* examined the performance of a self-propelled riding-type vertical conveyor reaper (VCR) for harvesting soybean crops. The study revealed that the reaper had an effective field capacity of 0.17 ha/h and a field efficiency of 60% when operated at a speed of 1.70 km/h. *Wahane, (2017),* conducted a performance evaluation for the chickpea and wheat crops using a reaper. In chickpea fields, the reaper recorded a field capacity of 0.249 ha/h with 89.00% efficiency, while in wheat it achieved 0.360 ha/h with 91.76% efficiency. *Kiran et al., (2017),* developed a battery-powered reaper, having an effective width of 0.6 m. Performance evaluation revealed that the reaper achieved an effective field capacity of 0.13 ha/h and an average cutting efficiency of 98.24%. *Kumar, (2020),* developed a battery-powered vertical conveyor-based mini paddy harvester, which required 0.160 kW for cutting and conveying, having a width of the cutter bar of 0.53 m. *Dutt, (2021),* developed a manually push-type battery-powered lentil and chickpea harvester for two rows. The harvester's cutting unit operated through the clockwise and counterclockwise rotation of the cutting blade. It was tested on chickpea and lentil crops, with a cutting width of 0.45 m. The field capacity was 0.0221 ha/h at 89.04% efficiency for chickpea, and 0.0176 ha/h at 86.50% efficiency for lentil. Based on these results, the present research was undertaken to develop a tractor front-mounted conveyor-based pulse harvester.

2. MATERIALS AND METHODS

2.1. Description of the Harvester

The tractor front-mounted conveyor harvester was specifically developed for pulse crop harvesting, targeting species such as chickpea, lentil, black gram, and Bengal gram etc. The harvester mainly consisted of the cutting unit, conveying unit, power transmission unit, and machine holding cum adjusting unit, which were assembled on the main frame. The components of the harvester are presented in Fig.1. The Top view and side view of the harvester are shown in Fig.2.

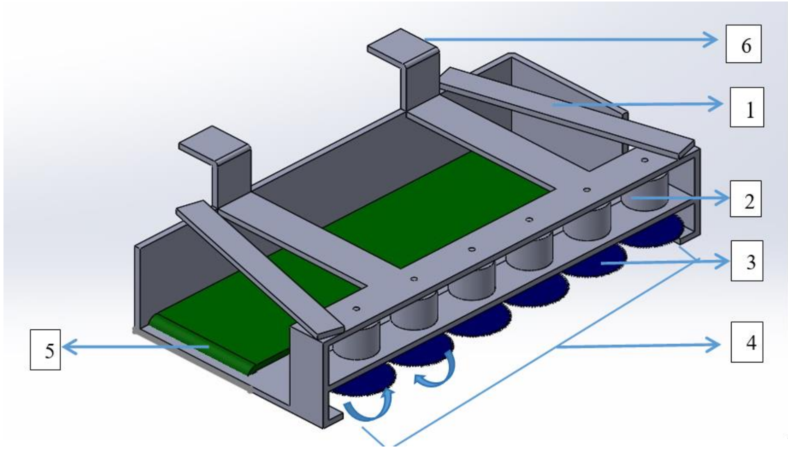
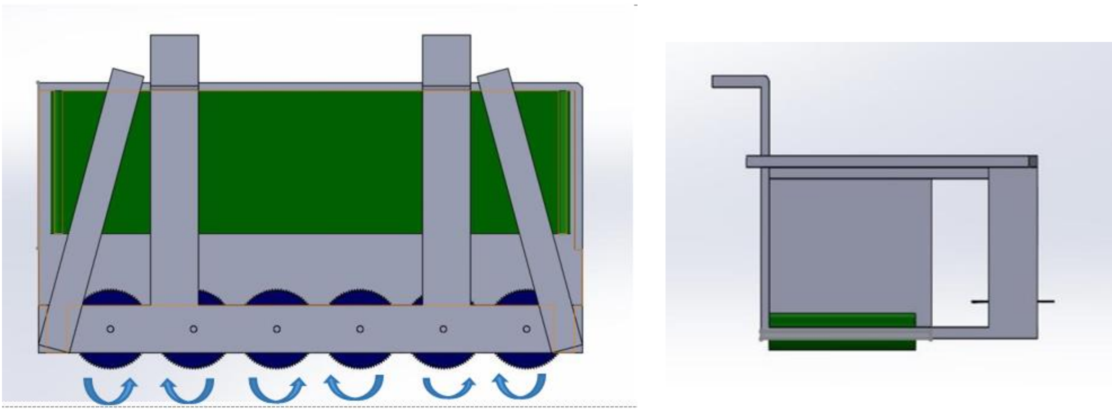


Fig. 1 - Conceptual design of the developed harvester by CAD software

1. Main Frame; 2. Motor for cutting; 3. Cutting blade; 4. Cutting unit; 5. Conveying unit; 6. Machine holding attachment



Top view of the harvester Side view of the harvester

Fig. 2 -Top view and side view of the harvester

2.1.1 Main Frame

The main frame of the harvester, with a length of 2.00 m, supports all the components of the harvesting unit, namely the motors and saw blades, the conveying unit, and the power transmission unit. The frame was also shielded with an MS sheet. Its dimensions were designed to accommodate six motor-driven blades, enabling the coverage of six crop rows.

2.1.2 Cutting unit of the harvester

The cutting unit of the harvester was attached to the front of the mainframe, consisting of six assemblies, each one formed by a 12 V DC motor and a cutting saw blade. The saw blades were connected to the motors using a spindle, rotating clockwise and in anti-clockwise direction alternatively. Six motors were used for the cutting unit of the harvester, having the cutting blades rotate alternatively to create centrifugal force, which leads the crop to be cut onto the conveyor. Each of the motors generated 1.24 Nm of torque at 917 rpm, which was able to cut the crops, such as chickpea, lentil, and black gram. The saw blade was designed with a diameter of 0.254 m, with 100 teeth, considering the maximum stem diameter of 25 mm.

2.1.3 Conveying unit of the harvester

The conveying unit was mounted directly behind the cutting unit of the harvester, directing the crop into a windrow on the right side of the tractor. It consisted of a pulley-driven conveyor belt. The material of the conveyor belt was rubber-blended, to produce a better grip on the conveyor roller or pulley. The conveying unit was powered by one gear motor using a chain sprocket. The ratio of the driver and driven pulley was 2:1 to achieve the required linear speed of 0.54 m/s with the reduced 175 rpm of the motor. The gear motor had a torque generation capacity of 8.18 Nm (as per specifications). Under laboratory conditions, the torque required to operate the conveyor with a 22 kg load was 7.76 Nm. Therefore, the selected motor was deemed compatible for operating the conveyor.

2.1.4 Machine holding attachment cum height adjuster

The harvester's holding attachment was mounted on the main frame after the conveying unit. This attachment secured the main frame to the tractor and allowed adjustment of the cutting height in field conditions as required. It was constructed with a screw lever mechanism, enabling height adjustment from 0.05–0.07 m at the lowest setting to 0.35–0.40 m above ground level, thereby ensuring smooth operation and stability of the harvester.

2.1.5 Power source to the cutting and conveying unit

The cutting and conveying units of the harvester were powered by a 2.4 kW rated battery. The battery was selected to ensure continuous operation of both units for at least 4–5 hours on a single charge. In case of battery discharge, power could alternatively be drawn from the tractor.

2.2. Field evaluation of the harvester

The performance evaluation of the harvester was carried out on a premature black gram crop in an experimental field measuring 65 m × 35 m at the Tirhut College of Agriculture, Dholi Parisar, Bihar. The harvester was tested at four tractor's speed: 0.75, 1.00, 1.25, and 1.50 km/h and a fixed 917 rpm cutting speed. For performance evaluation of the harvester, the following parameters were considered: effective width of the harvester, operation speed, cutting efficiency, theoretical field capacity, effective field capacity and field efficiency. The effective working width of the harvester was determined after harvesting a predetermined 25 m² area of the experimental field, with the width measured at three different points within the selected area. Cutting efficiency was calculated based on the ratio of the number of plants before harvesting to the number of uncut plants over a 10 m² section of the field. Field efficiency was expressed as the percentage of the machine's theoretical field capacity achieved under actual operating conditions, considering factors such as turning, machine adjustments, and reduced operational width. Crop parameters, such as plant height, spacing between rows, height of the lowest branch, minimum height of the pod from the ground, number of branches, and diameters of the plants, were measured. The plant height was taken from the base of the plant to the apical bud. The spacing between rows for black gram was measured between two adjacent rows at ten different locations using a measuring tape. Also, the height of the black gram plants was measured using the measuring tape. Plants height were measured from ten random places within the standing crop at the maturity time. Diameters of the black gram plant stems were taken also from ten random locations from the selected field crop. Measurement of stem diameter was done using Vernier calipers. This paper presents the average data for all measured performance parameters, derived from field evaluation of the harvester.

3. RESULTS AND DISCUSSIONS

A tractor was used to support the harvester, whose main power source was a 2.4 kW battery. The harvester measured 2.00 m in length, 0.609 m in height, and 0.452 m in width. The conveyor had a length of 4.267 m, a width of 0.254 m, and a thickness of 0.8 mm. The conveyor roller measured 0.254 m in length and 0.06 m in diameter. The attachment of the harvester to the tractor bumper was fabricated from a 0.304 m square pipe welded to a 0.304 m threaded shaft. After assembly, the total weight of the harvester was 83 kg. The developed harvester is presented in Fig. 8, and the specifications of the harvester are shown in Table 1.

Fig. 8 - General view of the developed harvester

Table 1

Specifications of the tractor-mounted harvester

Sl. No.	Machine components	Specification
1.	**Main frame**	
	Frame length	2.00 m
	Frame width	0.609 m
	Frame height	0.452 cm
2.	**Machine holding attachment**	
	Square pipe	0.304 m
	Threaded shaft length	0.304 m
	Attached MS flat	0.12 m
3.	**Power source**	
	a) Battery	200Ah, 2.4 kW
4.	**Power transmitting unit**	
	I. Cutting unit	
	DC motor	0.12 kW, 917 rpm
	No. of motors	6 nos.
	Shaft diameter	0.025 m
	Length	0.060 m
	Blade diameter	0.254 m
	Blade-to-blade distance	0.510 m
	II. Conveying unit	
	a) Conveying belt (Rubber blended)	
	Length	4.267 m
	Width	0.254 m
	Thickness	0.008 m
	b) Pulley or roller (MS pipe)	
	Roller length	0.304 m
	Number of rollers	4 nos.
	Roller diameter	0.060 m
	Spacing of rollers	0.500 m
	c) Gear motor	0.25 kW, 350 rated rpm

3.1. Field performance of the harvester

3.1.1 *Crop parameters of the black gram crop harvester*

The field data of black gram was taken before harvesting the crop and is presented in Table 2. It was observed that the spacing between crop rows had a maximum of 280 mm and a minimum of 240 mm. The maximum and minimum height of the plant were found to be 200 mm and 350 mm, respectively. The maximum and minimum diameter of the stem was found to be 1.2 and 1.4 mm, respectively. Therefore, the biometric data of the crop was suitable for harvesting using the developed harvester. Sidahmed and Jaber also reported that the lentil crop height of 59 mm from the ground was suitable for harvesting the crop *(Sidahmed, 2004; Jaber, 2004)*. In the same line, *Mehetre et al., (2014),* also reported that soybean was harvested at a plant height of 550 to 600 mm. Lower plant height and excessive dryness of the stem increase vibration and shattering losses, thereby reducing the effective cutting efficiency. Conversely, if the crop is too green due to delayed maturity, it creates an extra load on the knife section, which results in incomplete cutting and lodging of uncut stems *(Kumar, 2021; Maji, 2021)*.

Table 2

Crop parameters of black gram in the experimental field

Sl. No.	Crop parameters	Minimum (mm)	Maximum (mm)	Average (mm)
1.	Spacing between rows	240	280	260
2.	Height of the plant	200	350	275
3.	Height of the lowest branch	63	78	70.5
4.	Minimum height of the pod from the ground	60	83	71.5
5.	Number of branches	7	12	9.5
6.	Diameter of the stem	1.23	1.42	1.32

3.1.2 Power requirement for the cutting and conveying unit

During harvesting, the power drawn from the battery was measured. The cutting unit required 0.479 kW at a current of 39.96 A for six motors, while the conveying unit required 0.089 kW at a current of 7.46 A. Thus, the harvester consumed a total of 0.569 kW at a constant supply of 12 V (Table 3).

Other authors also reported that the power requirement for pulse harvesting units ranges from 1.7–3.0 kW, with 1.2–2.0 kW used for cutting due to tough stems and 0.5–1.0 kW for conveying *(Singh, 2018; Verma, 2018; Patel et al., 2020; Chauhan, 2019; Sharma, 2019; Mandal et al., 2021)*. Serrated blades reduce energy demand and improve efficiency.

Table 3

Power consumption of both units (cutting and conveying)

Sl. No.	Function	Measured current, A	Voltage, V	Power, kW
1.	Cutting (for six motors)	39.96	12	0.479
2.	Conveying (one-gear motor)	7.46	12	0.089
Total power required				0.569

3.1.3 Torque developed by the cutting and conveying unit at field conditions

The torque developed by each motor from the cutting unit was 1.24 N·m. The conveying unit gear motor developed 7.06 N·m of torque needed to run the conveyor with 20 kg of premature black gram crop load. Torque requirement was influenced by stem hardness and cutting blade load. Pulses need 25–40 N·m torque for effective cutting at 600–900 strokes/min *(Chauhan et al., 2018)*. Insufficient torque causes choking. Moderate speed and sharp blades maintain efficiency *(Kumar, 2019; Singh, 2019; Mandal, 2020; Verma, 2020; Patel et al., 2021)*.

3.1.4 Effect of forward speed on different performance parameters

The speed of operation of the harvester was measured in four replications: 0.75, 1.00, 1.25, and 1.50 km/h. The operation speed, namely the tractor forward speed, governed the harvester's performance. The cutting efficiency, theoretical field capacity, and effective field capacity of the harvester were calculated under optimized conditions, and the results are presented as follows:

3.1.5 Cutting efficiency of the harvester

The cutting efficiency of the harvester was influenced by the forward speed of operation. The maximum efficiency was 75.06% at the lowest trial speed of 0.75 km/h, while the minimum efficiency was 71.04% at the highest trial speed of 1.50 km/h. This result occurred because the cutting blade operated at a fixed speed of 917 rpm, irrespective of the forward speed. The results are presented in Table 4, and Fig. 9 clearly illustrates the variation in cutting efficiency under field conditions. High cutting efficiency is generally difficult to achieve in pulse crops due to their non-uniform plant height, hard stem structure, and lodging tendency at maturity (*Sundaram and Singh, 2017*). Studies reported that the cutting efficiency of mechanical reapers or harvesters in pulses usually ranges between 85% and 95% depending on crop variety, moisture condition, cutter bar design, and forward speed of the machine (*Patel et al., 2019*).

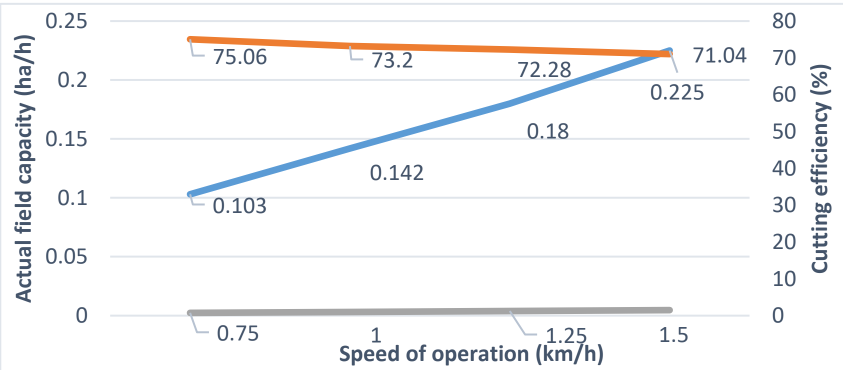


Fig. 9 - Effect of operational speed on actual field capacity and cutting efficiency

Table 4

Cutting efficiency at different speeds of operation

Sl. No.	Particulars	Values			
1.	Speed of operation (km/h)	0.75	1.00	1.25	1.50
2.	Cutting efficiency (%)	75.06	73.20	72.28	71.04

The cutting efficiency declined as the forward speed increased, likely due to the fixed speed of the cutting blade, which did not vary with the operational speed. However, Tanti *(Tanti, 2019)* observed the opposite trend, where the cutter bar speed increased along with the operational speed. These results highlight the need to optimize the fixed cutting blade speed in relation to the forward speed of operation to improve harvesting efficiency.

Fig. 10 - Pictorial representation of the harvested crop rows following harvester operation

3.1.6 Effective Field capacity and Field efficiency of the developed harvester

The field efficiency and effective field capacity of the developed harvester were assessed at four speed replications: 0.75, 1.00, 1.25, and 1.50 km/h. The results showed that the harvester's theoretical field capacity (TFC) ranged from a minimum of 0.150 ha/h to a maximum of 0.300 ha/h. The actual field capacity varied from a minimum of 0.103 ha/h, corresponding to a field efficiency of 69.30%, to a maximum of 0.225 ha/h, with a field efficiency of 75.02%. Overall, the field efficiency of the operation was between 69.30% and 75.02%. On an 8-hour workday basis, the harvester's maximum capacity was 1.80 ha, while the minimum capacity was 0.831 ha (shown in Table 5).

Table 5

Performance evaluation parameters

Particulars	Values			
Forward Speed(km/h)	0.75	1.00	1.25	1.50
Effective width (m)	2.00	2.00	2.00	2.00
Theoretical field capacity (ha/h)	0.150	0.200	0.250	0.300
Field efficiency (%)	69.30	71.20	72.38	75.02
Actual field capacity (ha/h)	0.103	0.142	0.180	0.225
The capacity of the harvester on a day 8h basis (ha)	0.831	1.136	1.440	1.800

Moreover, changes in operating speed, whether an increase or a decrease, also led to corresponding changes in both effective field capacity and field efficiency. These parameters were further influenced by factors such as crop type, plant spacing, and plant population during cutting. Maharana *(Maharana et al., 2018)* reported similar findings. The effective field capacity of reapers used for pulses generally varies from 0.3 to 0.6 ha/h, depending on machine width, forward speed, and turning losses (*Kumar and Singh, 2018*). Field efficiency typically ranges between 65% and 80%, largely affected by field size, crop density, operator skill, and time lost in maneuvering and clogging (*Patel et al., 2020*). Higher forward speeds increase theoretical capacity but often reduce field efficiency because of missed plants and frequent blockages. Irregular field boundaries and lodging of crop cause additional turning time and idle run, thereby reducing effective field capacity. Studies have shown that self-propelled reapers achieve higher field efficiency compared to tractor-mounted types due to better maneuverability and reduced turning radius (*Sharma and Verma, 2019*). Selection of appropriate machine width and optimum speed (around 2.5–3.5 km/h) was recommended to improve field capacity without compromising the harvest quality (*Chand et al., 2017*).

4. CONCLUSIONS

The study revealed that the mechanical harvesting of pulses not only reduced labor hours but also harvesting time. The developed harvester was found to be cost-effective for small and marginal-scale farmers. A tractor front-mounted pulse harvester was found suitable for harvesting the black gram. Although the harvester was developed to harvest pulses, such as Chickpea, lentil, and black gram, the performance was evaluated only in premature black gram. All the harvester’s parameters, field capacity, field efficiency, and speed of operation, were determined under optimized conditions. Hence, the tractor front-mounted pulse harvester was found suitable for small and marginal farmers as an alternative to manual harvesting.

Declaration

All authors have read, understood, and complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the instructions for authors.

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