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A critical study on paddy and wheat harvesting machine used in Chhattisgarh

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Abstract

Harvesting of crops is a critical Agricultural task that requires significant labor. The availability and cost of labor during the harvesting season present major challenges, leading to potential losses for farmers due to labor shortages and unpredictable weather. To address these issues, it is crucial to adopt mechanical methods to ensure timely harvesting. In recent years, the use of mechanical harvesting devices has increased, with farmers utilizing reapers and combines. However, combines are particularly expensive, making them unaffordable for many small-scale farmers. Although some manually operated reapers have been developed, they have not gained widespread popularity due to limitations in manual power, which affects the machine's ability to transport, cut, and convey crops effectively. This research involved studying various types of harvesting machines and techniques used in Chhattisgarh for harvesting paddy and wheat crop.

Keywords: Grains, harvesting, losses, labour cost, field capacity, efficiency

Introduction

Global consumption of rice and wheat is rising due to population growth, necessitating increased production and technological advancements. India holds the second position in rice production only after China. India is also the second largest producer of wheat with a share of around 14.14% of the world's total production in 2020. India is also inching towards self-reliance in Pulse production. The production of food grains in the country is estimated at 329.68 million tonnes in 2022-23, which is higher by 1.4 MT than the production of food grains during 2021-22. In which, total production of rice and in the country was 135.29 MT and 110.84 MT in 2022-23 respectively. Total food grain production in Chhattisgarh was 11 MT, in which production of rice and wheat was 105 MT 0.5 MT respectively during 2022-23.

India's soil is remarkably productive; with an average land holding of 1.08 hectares, it sustains a population of 1.3 billion. Small and marginal land holdings (< 2.0 ha) make up 86% of total operational holdings and cover 47% of the operated area (Anonymous, 2018a)^[4]. The share of farm power from draught animals is declining, and Agricultural power correlates directly with farm yield. In 2020-21, average farm power availability was 2.76 kW/ha. To meet the growing food grain demand, this must increase to 4.0 kW/ha by 2030 (Tiwari *et al.*, 2019)^[112]. The share of workforce employed in the Agriculture sector has declined from 70% in 1951 to 42.3% in 2019 and this will further reduce to 25.7% by 2050 (Anonymous, 2018b)^[5]. Lack of workforce availability and pressing need for improving crop productivity calls for a strong focus on increasing mechanization in Agriculture. A substantial increase is found in Agriculture mechanization in India. However, the level of farm mechanization is just about 40-45% compared to other countries such as US (95%), Brazil (75%) and China (57%) (Anonymous, 2019)^[6].

Timely harvesting, which involves cutting and gathering crops at the proper ripeness, is crucial to minimize losses and ensure better crop quality. Labour shortages during the harvest season can significantly impact farmers, making mechanical methods essential to ensure timely and efficient harvesting. Manual harvesting, using sickles, is labour-intensive and time-consuming. For example, harvesting paddy and wheat manually requires about 25% of the total labour for these crops, taking approximately 158 to 160 man-hours (Tripathi *et al.*, 2018)^[113].

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Cutting and bundling these crops can take 185-340 man-h/ha (Michael and Ojha, 1987) ^[63] with harvesting alone accounting for a substantial portion of labour needs. Mechanical harvesting utilizes power from IC Engines and can be categorized into self-propelled and tractor/power tiller-mounted machines. Self-propelled machines have permanently attached Engines, whereas mounted machines can be connected to tractors or power tillers as needed. Although versatile, mounting and detaching is time-consuming. Self-propelled reapers are increasingly used in developing countries, while combine harvesters are common in developed nations. Chhattisgarh is an agrarian state with 70% of its population involved in Agriculture. Chhattisgarh have 41.10 lakh farmers, about 82% are small and marginal (Anonymous, 2018b) ^[5]. In Chhattisgarh, there are 4 power reapers and 0.09 combines per 1000 hectares, compared to the national average of 10 reapers and 0.2 combines per 1000 hectares (Singh and Singh, 2019) ^[78]. Combine harvesters and self-propelled reapers are efficient but expensive, posing challenges for small and marginal farmers in India. Custom hiring is an alternative but problematic for small, fragmented lands. Tractor/power tiller-operated reapers have high initial and running costs and contribute to environmental pollution.

Therefore, mechanical harvesters like power tiller operated, tractor operated, self-propelled reapers and combine harvesters are not getting popularity among small and marginal farmers because of its high initial and operating cost which makes them unaffordable. Also, rising of fuel prices day by day, increases the cost of harvesting. Further, non-availability of these machines on custom hiring for small and marginal farmers, force to go for manual harvesting. Manual harvesting by sickle is laborious, costly and time consuming. Reapers are essential for timely harvesting of field crops. Manually operated harvesting equipment is available, using a ground wheel as the power source to operate the cutter bar. However, the available traction force in the ground wheel is insufficient to cut and convey the crop. Additionally, the reapers currently on the market (both self-propelled and tractor-mounted) are high-cost and not eco-friendly. Due to their high initial and operating costs, small and marginal farmers cannot afford to adopt them.

Traditional harvesting technique

Harvesting of field crops is generally done manually with the help of sickle. The shape and size of the sickle varies with the region.

Singh and Singh (1978) ^[98] found that a sickle with a serrated surface gave better performance than a plain one with shearing force at the cutting edge. Ojha and Nath (1980) ^[78] emphasized the need for introduction of efficient harvesting equipment for the cereals crops seems to minimize the time of harvesting and the grain loss suffered due to slow rate of work in process of manual harvesting. About 5 - 15% loss may occur, if proper care was not taken. Usually a stalled person can harvest about 15 kg of paddy per hour. A shattering loss high as 16% was reported. Pitra and Gite (1980) ^[82] said that non-serrated sickles was taken more time for harvesting as compared to improved sickles. Devnani and Pandey (1981) ^[77] designed the sickles with the size of 255 mm, 1.27 mm thick carbon steel and the shape of the blade was elliptical with eccentricity of the ellipse of 0.7. The blade was riveted to the reinforcing strip, which in

turn was riveted to the handle. The field performance of the newly designed sickle along with the Maharashtra, Punjab and Local sickle was evaluated. The result showed that the performance of the improved sickles was better as compared to other sickles. Kulkarni and Sirohi (1985) ^[54] said that sharpened part of a sickles was the most important factor affecting the working capacity of the farmers, and the handle determined the convenience in using this tool may also have an indirect effect on working capacity. Nag *et al.* (1988) ^[69] analyzed with reference to design features of nine different types of sickles and they indicated that blade geometry contributes significantly to human performance. They suggested modifications in design of improved sickle. Gite and Agarwal (2000) ^[37] concluded that improved sickle with serrated edge reduced drudgery of farm women by about 16.5% as compared to local sickle for harvesting wheat crop. Sutjana (2000) ^[107] used serrated sickle to increased farmer's productivity. Thirty-three harvesters voluntarily joined the study using serrated and non-serrated sickles. The productivity was measured by divided the number of paddy stalks cut every 15 minutes by increment of heart rate over the resting value. The results showed that, the sharpness of serrated sickles was more stable than non-serrated, the use of serrated sickles reduced the workload and work time loss, the productivity of serrated sickles was always higher than those using non-serrated sickles, Singh (2012) ^[102] compared the performance of Naveen and Vaibhav sickles with the local sickles for harvesting paddy crop with 12 farm women. Mean heart rate during work in operation of these sickles were 103 beats/min, 107 beats/min and 106 beats/min, respectively. The workload was under acceptable limit for day-long work with normal rest pause for studied sickles. The output of Naveen, Vaibhav and local sickles was 47.3, 60.7 and 65.4 m²/h, respectively. Output with local and Vaibhav sickles was significantly higher than Naveen sickle. Mishra *et al.* (2013) ^[64] carried out investigation to evaluate the weeding efficiency of tools and performance evaluation of weeding activity performed by farm women using newly introduced and traditional tools. Improved sickle resulted in higher field capacity (0.07 ha/h) than simple sickle. Average gross return per farm women was increased from Rs. 112.50 to Rs. 150.00 for improved sickle. Results of the study showed that improved sickle was more suitable for crop harvesting by farm women and their preference was shown towards improved sickle as compared to the simple sickle. Verma *et al.* (2016) ^[114] studied the superiority of the Naveen serrated sickle over the traditional sickle for wheat harvesting. The experiment was conducted involving twenty non-pregnant farm women voluntarily joining the study using serrated and non-serrated sickles. The results showed that the total cardiac cost of work was 290 beats, the physiological cost of work was 7.45 beats/min, the average working heart rate was 115 beats/min and the average energy expenditure was 8.26 KJ/min during the harvesting activity performed by improved tool, the Naveen serrated sickle. The sickle proved efficient on ergonomic parameters as it reduced average working heart rate and energy expenditure along with increased output when compared to traditional tool. The percent reduction in average working heart rate was 8.00 with the use of Naveen serrated sickle. It was observed that harvesting was classified as moderately heavy and heavy while using Naveen serrated sickle as compared to very heavy while using traditional tool. Hence it was found that

the improved tool was ergonomically good, friendly to women, reduced drudgery and thus was helpful in improving the efficiency of women. Tiwari *et al.* (2029)^[112] designed 12 different local sickles with 12 selected subjects were investigated during harvesting of paddy and wheat crop in Bastar district of Chhattisgarh. It observed that the blade geometry contributes significantly to measured physiological parameter therefore the blade geometry is optimized. The anthropometric data of selected subject were collected and incorporated in design of the sickle and handle, particularly. The handle length was designed considering 95th percentile value of hand breadth cross the thumb i.e. 12.6 cm and handle diameter 5th percentile value of inside grip diameter i.e. 3.2 cm. Physiological assessment with sickle stated that the average heart rate was 114 bpm whereas energy expenditure rate found to be 9.40 kJ/min with 0.6198 l/min oxygen consumption rate. The performance of the newly designed sickles covers 20.5 m²/h which is more than the traditional sickle. It also reduced the cost of harvesting and reduction in farm labours by 47% and 20% respectively. It is concluded that the new design of sickle is suitable for the Bastar tribals and reduced injury and drudgery.

Improved harvesting technique

Manual operated harvesting equipment

Srivastava and Dyck (1978)^[106] developed a single row push type manually operated safflower machine, required two men power to operate the machine. The frame was made of rectangular steel tubing and supported the ground wheels, components of power transmission system, two circular blade and handle. Each ground wheel transmitted power to one circular blade through sprockets and chain. It reaped safflower at a height of 7-8 cm and its capacity was 0.1 ha/h. It reaped safflower faster and more efficiently than the traditional Indian sickles. Rahman *et al.* (1980)^[86] constructed a push type harvesting machine operated by human power. The power was transmitted from ground wheel to the cam wheel and then transmitted to the knife with the help of the knife actuating lever arm. The cutter bar knife was giving reciprocating motion through the oscillating arm. A cutting speed of 200-225 rpm was taken. But due to the lighter weight of the machine, the available traction force in the wheel for overcoming the various friction forces was not sufficient. It was cut the paddy at a height of 10 to 15 cm. Mollah and Kilgour (1986)^[65] worked on cutting and bunching machine, consisted of two serrated edged discs, rotating in opposite direction for single row cutting. They tested the machine for two sets of experiments. In the first set the discs overlapping was kept constant at 10 mm four different carriage speeds, 0.8 km/h, 1.6 km/h, 2.4 km/h and 3.2 km/h. In the second set, the carriage speed was kept constant at 2.4 km/h and four different discs over lapping 0 mm, 5 mm, 10 mm and 15 mm. In the first set, the average pull required to cut 18 stalks was a maximum of 106.6 N. The individual maximum pull was 187 N at 1.6 km/h carriage speed to cut 14 stalks. The pull of the machine varied significantly at different forward speeds and different number of stalks. The power requirement was higher at higher forward speeds and varied significantly between 63.6 W and 83.11 W at different forward speeds and different number of stalks. Singh *et al.* (2009)^[100] fabricated a manually operated vertical conveyor reaper and compare its performance with Naveen and local

sickle for harvesting paddy crop. Its effective cutting width was 25 cm and the weight was 45 kg. The Fabrication cost of machine came around Rs. 4740. The performance of developed reaper was found satisfactory; it gave field capacity and field efficiency were 0.03 ha/h and 62% respectively. The average field capacity for Naveen and local sickle was 0.0083 ha/h and 0.0066 ha/h respectively. The harvesting cost for developed reaper, Naveen and local sickle were Rs. 619/ha, Rs. 1500/ha and Rs 1875 /ha respectively. Chavan *et al.* (2015)^[21] developed manually operated reaper. The Manual operated reaper was high labour saving equipment requiring only 20 man-h/ha. The field efficiency was satisfactory which more than 66%. The cost of harvesting with this manual operated reaper was Rs 1250.4 /ha which was much less as compared Rs 2000 /ha for traditional method. Sinha and Jogdand (2019)^[96] designed and developed a manually operated women friendly reaper. The machine includes handle, main frame, cutter bar, crop divider and lifter, star wheel, ground wheel and supporting wheel. Cutter bar operated directly by ground wheel power. The forward speed of the machine was obtained 1.7 km/h. the effective field capacity and field efficiency was found to be 0.048 ha/h and 71.2% respectively.

Bullock drawn harvesting equipment

Khanna (1973)^[50] worked on bullock drawn reaper with an additional provision to windrow the harvested crops at one side. Machine was operated by an auxiliary Engine and pulled by a pair of bullock. It was observed that a two or three Hp Engine was sufficient to provide the necessary power for cutting and reaping. A V-belt drive provided the necessary speed reduction from 1500 rpm of the Engine to 400 rpm at the crank wheel to which the pitman head was fixed. This produced 800 strokes per minute of the knife bar. Two men were required to operate the machine, one man to control the bullocks and other for unloading the collection deck. Separate seats were provided for the two operators. A control lever was provided near the operators' seat by which the cutter bar could be raised and lowered. The capacity of machine was from 0.3 ha/h to 0.35 ha/h. Singh (1981)^[97] carried out work on design and development of animal drawn reaper and established the relationship between power requirement and plant density at different speed of operation. He found that, the power requirement for the operation of the machine increased with the increase in plant density and speed of operation. At lower speed of 1.5 km/h, the power requirement was of 583.2 W at plants density of 200 plants/m². At higher speed of 2.5 km/h power requirement increased to 978.7 W the same plant density. Yadav and Yadav (1992)^[120] developed a simple, rugged oxen- drawn reaper for harvesting cereals, pulse crops and oil seeds. It was a light weight machine requiring less draught than earlier designs of bullock- drawn reapers. The crop harvested by the machine was delivered in uniform bunches behind the cutter bar. The special feature of this reaper was transformation of low soil thrust developed from the traction wheel into a greater force for cutting crops by means of crank and lever mechanism at the cutter bar. The field capacity was 0.12-0.14 ha/h. The harvesting losses were less than 5%, recoverable which consists of mainly loose stalks. The cost of harvesting was Rs 135/ha. Singh and Singh (1995)^[103] designed and fabricated an animal drawn reaper with Engine-operated cutting and

conveying mechanism for harvesting wheat and paddy crops. The reaper was tested on wheat crop and the capacity was 0.27 ha/h with an observed field efficiency of 84.36%. The draft at no load and load conditions were recorded at 62.9 kg and 42.68 kg, respectively. The consumption was about 1 L/h.

Tractor operated harvesting equipment

Garg *et al.* (1985) ^[31] developed and evaluated field performance of a tractor-front-mounted vertical conveyor-reaper-windrower. A frontmounted vertical conveyor-reaper-windrower had 1.9 m cutting width, operated by a tractor of about 25 hp, could effectively harvest wheat and rice and place the harvested crop on the ground in neat windrows that could be easily collected. Its average EFC was 0.29 ha/h. Total grain losses were only 0.72-1.51%. When compared with traditional manual methods, the machine could save 130.85 man-h/ha. Yadav and Yadav (1985) designed a tractor drawn side mounted reaper to cut the green crops and form crop bunches. Field efficiency of the machine was 66.66%. Shattering losses was 2-5%. Non-recoverable loose stalk losses were 4.12 and 3.46% for 2 varieties at 15% moisture content. The cost of harvesting soybean crop by this machine was Rs 150/ha as compared to Rs 216/ha for manual harvesting. Bukhari *et al.* (1986) evaluated grain losses for wheat crop harvested by reaper-windrower at two different farms and also compared with the conventional method of harvesting. The total grain losses by machine was average 41.1 kg/ha and 48 kg/ha whereas by manual harvesting losses was average 84.9 kg/ha and 139.6 kg/ha. Grain losses in manual harvesting were 51.58% and 65.6% higher than the harvesting machine. The labour requirement was 60.4 man-h/ha and 58.5 man-h/ha. Rahman (1980) ^[86] introduced two prototype vertical conveyor reapers for wheat; one was a power tiller-mounted 1.0 m cutting width and the other 2.0 m cutting width tractor front-mounted machine. Modifications to the headers, star wheels, cutter bar drive mechanism, cutter bar knives, back retaining wall, drive train, lifting mechanism and chain-type conveyor were made. Garg and Sharma (1991) ^[32] worked on a tractor front mounted reaper-windrower with vertical conveyor belts for harvesting wheat and rice. The unit was capable of harvesting 0.4 ha/h, and unlike combine, harvester did not destroy the straw, important for cattle fed. They reported that labour requirement reduced by two-third by the new unit as compared to conventional manual harvesting with sickles. Nalawade *et al.* (2009) ^[70] designed and developed tractor operated Jowar reaper windrower, had 2.2 m cutting width, which equals to seven rows at 30 cm. The basic consideration of design was average height of the Jowar and the weight distribution. Three conveyor belts were provided on the machine to facilitate better conveying of the cut stalks. Veerangouda *et al.* (2010) ^[116] evaluated performance of tractor operated combine harvester for harvesting of paddy crop. The average value of effective field capacity of the machine was found to be from 0.64 to 0.81 ha/h with field efficiency of 67.02 to 76.83%. The harvesting losses were in the range of 2.88 to 3.60% for paddy harvesting. The cost of operation was lesser for tractor operated combine harvester as compared to manual method by 57.65 to 65.55%.

Self-propelled harvesting equipment

Chaudhry (1978) ^[20] developed self-propelled multi crop reaper, had two front driving wheels and one rear wheel

with pneumatic tires and was powered by a 6 - 8 hp petrol Engine. A V-belt drive and bevel gear transmit power to the cutter-bar, which was operated at 700 strokes/min and was mounted 5 cm behind the front wheels, with a 20 cm diameter supporting wheel at the other end. The cutter-bar height was adjustable up to 33 cm. Its capacity was 0.4 ha/h and harvesting cost was US \$ 7.5/ha for harvesting wheat and paddy. Amjad and Gee (1983) ^[11] evaluated the field performance of a vertical conveyor reaper and compared performance with the conventional method of harvesting. Optimum machine performance obtained with forward. Speed 4.2 km/h. harvesting losses increased rapidly as harvesting date was delayed. The EFC of reaper was 0.43 ha/h for 3.4 km/h forward speed and 0.47 ha/h for 4.2 km/h forward speed with 76 and 70% field efficiencies respectively. Reaping by machine required only 6.5 man-h/ha compared to 122.6 man-h/ha required for hand reaping. Garg *et al.* (1984) ^[30] developed and evaluated performance of power tilleroperated vertical conveyor reaper for wheat crop. The average field capacity was 0.284 ha/h and fuel consumption was 0.5 L/h. The total grain losses were very low (approximate 1%). Labour savings and financial savings were 129 man-h/ha and Rs 226/ha with machine harvesting compared to the traditional method. Devnani and Panday (1985) ^[26] developed two models of vertical conveying reaper windrowers, one for power tiller i.e., 1.6 m cutting width and other for tractor i.e., 2.05 m cutting width for harvesting wheat and rice. The field capacity achieved with 1.6 m wide unit was 0.269 ha/h and for 2.05 m tractor unit 0.337 ha/h. The cost of operation with tractor and power tiller models were low as compared to manual method by 20 to 38%. The total harvesting losses were in the range of 4 to 6% of grain yield when grain moisture content was 7 to 11%. The labour requirements are reduced to 40-42 man-h/ha, i.e., one third of the manual harvesting method. Fouad *et al.* (1990) ^[28] compared the performance of two types of combines in harvesting rice crop in Egypt. The combines were operated at three forward speeds of 0.9, 2.3 and 2.8 km/h for rice combine, and 0.8, 2.1 and 2.9 km/h for the conventional combine. There was a highly significant decrease in total harvesting costs with an increased in operation speed from 0.9 and 0.8 km/h to 2.3 and 2.2 km/h for the rice and conventional combines, respectively. Guruswamy *et al.* (1996) ^[41] modified and evaluated performance a self-propelled vertical conveyor reaper cum windrower for harvesting of safflower and compared with manual harvesting. The study indicated that the capacity of SPVCR was 0.1 ha/h as compared to 0.006 ha/h by manual harvesting. The post harvesting, cutting and conveying losses for the machine were 0.05%, 0.47% and 0.23% (total loss of 0.75%) and for manual harvesting these values were; 0.05% and 0.02% (total loss of 0.07%), respectively. The cost of operation of machine and manual harvesting worked out to Rs. 34.69 and Rs 3.33/h, respectively and a net saving of Rs. 150/ha was observed for machine harvesting as compared to manual harvesting. Datt and Prasad (2000) ^[25] modified the self-propelled reaper for harvesting soybean by reducing the height of cutter bar knife and speed of cross conveyor belt. The machine was evaluated for three crop years with different crop varieties. The average plant height for the three crop varieties, Punjab1, Durga and MACS 58 were 64.5, 64.1 and 80.6 cm, respectively. The average values of effective field capacity, fuel consumption, forward speed and stubble height were 0.206 ha/h, 0.747 l/h, 3.27 km/h and 87.6 mm respectively. Stubble loss, shattering loss, header loss, conveying loss and

total machine losses were 0.45, 2.28, 2.73, 0.84 and 3.57% of grain yield, respectively. Gawali (2005) [33] developed and compared the performance of the self-propelled vertical conveyor reaper with the traditional method of harvesting. It was found that the reaper gave 0.2 ha/h average effective field capacity and 80% field efficiency with minimum labour requirements 5 man-h/ha. The cost of operation was found to be Rs 375/ha which was the lowest from traditional (Rs 1125/ha) with additional saving (Rs 750 /ha) and total harvesting losses was 2% in case of reaper. Matin *et al.* (2006) [60] modified the power tiller operated reaper in to self-propelled reaper for harvesting paddy and wheat. The field performance of the reaper was satisfactory. The average capacity of reaper was 0.18 ha/h for paddy and 0.27 ha/h for wheat. Operational costs of harvesting were Tk. 245/ha for paddy and Tk. 157/ha for wheat (fuel and labor only). Total cost of harvesting paddy and wheat were Tk. 392/ha and Tk. 261/ha (fixed and variable cost), respectively. The reaper had a break-even use of 3.5 ha/year and 3.4 ha/year for paddy and wheat, respectively. Hossain and Faruque (2008) [45] evaluated performance of self-propelled cereal reaper. The study showed that the effective field capacity, field efficiency and fuel consumption were 0.21 ha/h 80.76% and 0.45 L/h, respectively at forward speed of 2.15 km/h. The cutting width of the reaper was 1.2 m and total loss of crop was 3%. The labour requirement of mechanical harvesting was 15 man-h/ha against for manual harvesting was 240 man-h/ha. Mechanical harvesting saved 94% labour requirement of manual harvesting. The reaping cost by reaper was Tk. 626/ha. While, the manual harvesting cost was Tk. 3000/ha. Harvesting of rice with reaper saved 79% cost of manual harvesting. Manjunatha *et al.* (2009) [59] worked on performance evaluation of vertical conveyor power reaper. The overall performance of the vertical conveyor reaper was quite satisfactory. The actual field capacity of the power reaper was 0.3 ha/h with a field efficiency of 73% at an average operating speed of 3.2 km/h. The fuel consumption was 5.5 L/ha. Cost of mechanical harvesting was Rs.420/ha as compared Rs 800/ha in the case of manual harvesting. Abo *et al.* (2010) [1] evaluated the performance of local combine for harvesting wheat crops. They found that the highest cutting efficiency of 94.81% was obtained at forward speed of 0.53 km/h and grain moisture content of 12.13%. The highest effective field capacity and efficiency (0.48 ha/h and 78.38%) were obtained at forward speed of (1.15 and 0.53 km/h) and grain moisture content of 12.13%, respectively. Whereas the lowest value of energy requirements of 311.01 kWh/fed was at forward speed of 1.15 km/h and grain moisture content of 12.13%, respectively. The lowest value of criterion cost of 312.10 L. E / fed was obtained at forward speed of 1.15 km/h and grain moisture content of 12.13%. Handaka and Pitoyo (2011) [43] modified the grass cutter into a small rice harvester. Modifications that had been made were (1) replacing the cutter blade with a rotary blade; (2) changing the dynamic balance of the harvest machine into a mower type; (3) adding aguide and a propeller; and (4) adding an operator belt. The modified harvester had a power of 2 hp and 6000 rpm. Performance tests on 100 m² with a standard Engine for crop harvest showed that the modified machine had a working capacity of 0.05 ha/h, fuel consumption of less than 15 L/ha, work efficiency of 95%, and weight was of about 10 kg. Gajakos *et al.* (2013) [35] carried out the feasibility testing of self-propelled vertical conveyor reaper for harvesting of soybean crop. The average effective field capacity and field efficiency of the self-propelled vertical

conveyor reaper was found to be 0.255 ha/h and 88.59%, respectively. Fuel consumption of self-propelled vertical conveyor reaper was 0.728 L/h, and 2.84 L/ha. The average harvesting losses in mechanical harvesting and manual harvesting were found to be 5.68% and 4.73%, respectively. The cost of operation of self-propelled vertical conveyor reaper and manual harvesting were Rs 775.64 /ha and Rs 1264 /ha, respectively. In mechanical harvesting the percentage of saving in the cost of operation and time were found to be 38.63% and 67.81%, respectively. Shamabadi (2013) studied harvesting of wheat by 8 combines. Results showed that, the mean of loss in 3 samples was 16.1%. Crop loss of combine end and natural loss were 1.24% and 0.49%, respectively. Harvesting delay and unadjusted combines were the most causes of crop loss. Also, results showed that about 90% of the studied combines were more than 13 years old, but these combines had less loss than newer combines, if their operators were skilled and they were adjusted properly. Karahle *et al.* (2013) [49] evaluated the performance of self-propelled Reaper binder for harvesting of wheat and paddy crop. The average forward speed was 3.22 km/h, average field capacity of the reaper binder was 0.359 ha/h. and field efficiency was 91.76%. The average shattering loss was found 0.23% only. The average cost of operations was found to be Rs 1725.76 /ha. Jain *et al.* (2013) [48] designed and fabricated small scale sugarcane harvesting machine, consisted of petrol Engine and different mechanisms. The cost of the machine was Rs 30,000. The machine had a capacity to cut 3.75 ton of sugarcane per hour. Compared with manual harvesting 50% of harvesting time and 60% of labors are reduced (in manual sugarcane harvesting 15-16 labors are required). The cost of harvesting is reduced by 34% compared to manual harvesting. Mehetre *et al.* (2014) [61] evaluated the performance of self-propelled riding type vertical conveyor reaper. The result indicated an average effective field capacity of 0.17 ha/h at an average forward speed of 1.7 km/h with 60% efficiency. The vertical conveyor reaper was found to be suitable for reaping the crops up to 55 to 60 cm crop height. Operating cost of the machine was worked out to be Rs.115.27/h. Aung *et al.* (2014) [14] evaluated performance and compared with manual harvesting by sickle of power reaper for rice harvesting. The actual cutting width of the reaper was 1.2 m. The results showed that the actual field capacity of the reaper was 0.24 ha/h compared to 0.05 ha/h for manual harvesting. Labor requirements for reaper and manual harvesting were 4 and 28 man-h/ha, respectively. The fuel consumption, knife speed, field efficiency and cutting efficiency were 1.89 L/h, 1.223 m/s, 92% and 98% respectively. The cutting cost of power reaper was 67% less as compared with manual harvesting. The grain loss was less than 0.5%. Zami *et al.* (2014) [123] developed a self-propelled reaper and compared its performance with Chinese reaper and manual harvesting. Average field capacity was 0.250 ha/h, 0.203 ha/h and 0.004 ha/h of the selfpropelled reaper, Chinese reaper and manual harvesting respectively. Labour requirements for rice harvesting including bundle making were 248 man- h/ha, 69 man-h/ha and 68 man-h/ha for manual, Chinese reaper and self-propelled reaper, respectively. On an average, 72 and 3% labour was saved by the self-propelled reaper over those of manual harvesting and Chinese reaper, respectively. Harvesting costs were saved by self-propelled reaper and Chinese reaper about 68 and 61%, respectively over that of manual harvesting. Average fuel consumption of Chinese reaper and self-propelled reaper were 0.727 and 0.826 L/h,

respectively. The walking speed of self-propelled reaper (3.78 km/h) was 62% higher than that of Chinese reaper (2.33 km/h). Laukik *et al.* (2014) ^[58] developed compact harvester for cutting up to two rows of soybean plant. It had cutting blades, which cut the crop in a Scissoring type of motion with diesel Engine of 3 hp, power from Engine, was provided through pulley and gear box arrangement to the cutter. A collecting mechanism was provided for the collection of crops at one side after cutting. After testing, it was found that the cost of harvesting was considerably less as compare to manual harvesting. Shreen *et al.* (2014) ^[93] conducted study on wheat harvesting systems at three average grain moisture contents of (MC1 =20.80, MC2 =18.50 and MC3 =16.65%) namely: traditional harvesting (Hand cutting), partial mechanization (modified combine harvester, self-propelled reaper binder, SPVCR and tractor mounted vertical conveyor reaper windrower). The results indicated that, traditional harvesting system gave the lowest values of grain loss by average 2.00, 2.92 and 2.34% under moisture contents of 20.80, 18.50 and 16.65%, respectively. The highest value of cutting efficiency 97.2% for combine machine with forward speed of 1.5 km/h and moisture content of 16.65%. The minimum cost requirements values were obtained by using selfpropelled reaper binder of 17.17, 15.20 14.00, L.E/fed at the higher forward speed of 3.3 km/h under different grain moisture contents of 20.80, 18.50 and 16.65%, respectively. While the maximum cost requirements were obtained by using modified combine of 73.96, 72.8 and 70.71 L. E/fed at the lower forward speed of 1.5 km/h under different grain moisture contents of 20.80, 18.50 and 16.65%, respectively. Dange *et al.* (2015) ^[23] conducted study on the harvesting of wheat and paddy by using a SPVCR. The actual field capacity for paddy harvesting was 0.276 ha/h whereas for wheat it was found 0.311 ha/h with fuel consumption 6.12 L/ha and 5.29 L/ha respectively. Cost of mechanical harvesting with reaper was found 47.11% less for paddy and 44.4% for wheat as compared to the manual harvesting. Shalini *et al.* (2015) ^[92] developed self-propelled crop reaper cuts up to two rows of soybean plant. The components of the machine comprised of a diesel Engine of 3.5 hp, pulley, a belt drive, a collecting mechanism and a cutter bar. The machine used Scissoring type of motion for cutting crop. The power from the Engine was provided to the cutter through pulley and belt arrangement. As compared with manual harvesting only 20% of labours were required. Gupta *et al.* (2020) ^[39] developed and evaluated a portable crop harvester for hilly region of Jammu and Kashmir state for wheat. The labor requirement of sickle was almost five times more as compared to the developed portable harvester. Iareishahamat *et al.* (2019) devised, constructed, and assessed a small-scale farmer-oriented reaper. The machine performance evaluation revealed that the forward speed significantly impacted field efficiency and crop losses. Augmenting the machine's forward speed led to reduced field efficiency and increased crop losses. At a forward speed of 0.5 m/s, the crop losses were minimal, and energy consumption was minimized compared to 1 and 1.5 m/s, making it the most favorable speed. The cost analysis indicated a machine total cost of 20 \$/ha, whereas manual harvesting cost 154 \$/ha. Gupta *et al.* (2020) ^[39] conducted field experiments at farmer fields in Mandsaur district of Madhya Pradesh to study the comparative performance of different harvesting methods for wheat crop consisting of three treatments *viz.*, self-propelled reaper binder with crop bundle collection in the field manually (T₁), self-propelled

vertical conveyer reaper with crop bundles making and their collection in the field manually (T₂), and manual harvesting using sickle with crop bundle making and collection in the field (T₃). The self-propelled reaper binder shows significant effect on field efficiency with 88.43 percent saving of labour in comparison to manual harvesting of wheat. The harvesting losses were found minimum in treatment T₃ (21.3 kg/ha, 1.52%) whereas maximum in treatment T₁ (28.8 kg/ha, 2.06%) followed by treatment T₂ (24.5 kg/ha, 1.75%). Also, the lowest cost of harvesting was found in treatment T₃ (2875 Rs/ha) with a payback period of 535 h.

Harvesting of crop by using brush cutter

Bora and Hansen (2007) devised a small Engine-powered aid for rice farmers, replacing the original cutter blade with a 25 cm circular saw blade. A metal plate and rubber guard guided the cut stalk to the left side. The machine performed effectively in field conditions, with a 0.51 ha/day field capacity, using 0.25 L fuel in one hour. It exhibited a significant speed advantage, being 7.8 times faster than manual harvesting, despite a slightly higher field loss of 2.3% compared to 1% in manual harvesting. The break-even area was one hectare, and the investment paid back within one year. Baneh *et al.* (2012) ^[16] designed a cutting head for a portable brush cutter for harvesting rice, cutting head consisted of a circular saw blade with 24 cm diameter and 2 mm thickness. Designed blade had 136 teeth with 0° rake angle, 30° clearance angle and 6 mm pitch. A simple windrowing system made from aluminium sheet was constructed. Results indicated that compared to local rice varieties maximum power consumption of about 1.132 kW was obtained. Results also showed that rice losses of the portable reaper were lower than manual harvesting and field capacity of machine was 4.20 times greater than manual harvesting. Sarkar *et al.* (2016) ^[89] employed a brush cutter equipped with a conveying attachment for mechanized rice and wheat harvesting, followed by an evaluation. The results indicated that the crop cutter's field capacity was 2.44 times higher than manual operation, requiring 32.74 man-hours per hectare versus 149.25 man-hours. For wheat, the crop cutter's field capacity was 2.23 times greater than manual harvesting, with labour involvement at 23.20 man-hours versus 115.74 man-hours per hectare. Wheat harvesting cost Rs. 2,340.40 with the crop cutter, and Rs. 3,750 for manual operation. Rice harvesting cost Rs. 2,464.28 with the crop cutter and Rs. 5,596.87 manually. Dixit *et al.* (2022) ^[27] modified and evaluated the brush cutter for rice harvesting. The modifications included replacing existing blade with circular saw blade, incorporating a guider and a driver to lay down the harvested crop in swath and attachment of a harness belt for easy and comfortable operation. The machine was evaluated keeping in view major influencing factors *i.e.*, crop establishment (conventional transplanting, system of rice intensification (SRI), and mechanical transplanting), blade type (B1: 40 teeth, pitch 1.92 and B2: 80 teeth, pitch 0.96) and straw moisture content (38%-42%, 33%-37% and 28%-32%, d.b). The results showed that the height of cut was significantly affected ($p < 0.05$) by the crop establishment and blade type however straw moisture content did not have significant effect on height of cut. The height of cut for the machine with blade B1 ranged from 21.40-31.95 mm for different crop establishment; which was much lower than existing reapers/combines. Fuel consumption increased with decrease in row to row spacing or increase in plant population per m² area giving rise to the

trend: SRI < mechanical transplanting < conventional transplanting and decreased with decrease in straw moisture content. Cutting efficiency was higher under mechanical transplanting/SRI over conventional transplanting because of symmetrical transplanting of rice. With respect to straw moisture content, cutting efficiency was highest at moisture content of 33%-37%, because of desirable turgidity of the straw. The results showed that the field capacity of the machine ranged from 0.031-0.033 ha/h under different crop establishment. Resting cycle was found to be 10 minutes for every 30 minutes of work. The benefit-cost ratio, payback period and breakeven point were determined as 1.35, 74.91 h and 0.134 ha, respectively for the portable rice harvester. Importantly, the developed harvesting machine successfully harvested rice crops when equipped with a 40-tooth circular saw blade featuring carbide tips.

Electric powered harvesting equipment/machine

Chieh (2012) ^[22] converted internal combustion Engine operated brush cutter into the electric brush cutter. To obtained some very attracting advantages such as low vibration and acoustic noise, free of air pollution and low using cost, a DC motor was used as the mechanical power source of new electric type brush cutter. In addition, a Li-ion battery and electronic control board designed for DC motor speed control and circuit protection purposes were included as well. The performances of the proposed electric brush cutter were validated through extensive experiments and a laboratory scale implementation. Bodele *et al.* (2015) ^[17] developed pollution free solar powered brush cutter. This brush cutter was the replacement of the petrol Engine brush cutter. This cutter was totally eco-friendly and was so useful to the people for multi agro purpose also. The cost of the system was reduced because the use of solar energy in the replacement of the conventional fuel energy. Compared to all parts of cutter assembly solar panel was costlier. The maintenance and operating cost was also low. Okafor (2013) ^[74] designed and developed self-powered lawn mower. The heart of the machine was a battery-powered dc electric motor. It comprised of a system of speed multiplication pulleys which drive the cutting blades and the charging unit comprising of a 12V alternator and a lift mechanism meant to alter the height of cut. Used of collapsible blades and incorporation of an alternator for recharging the battery make the design unique such that no Engine was involved. Performance test gave a cutting efficiency of 89.55% with 0.24 kN human effort. Thus, the machine was considered highly efficient and was readily adaptable to different cutting conditions. Amrutesh *et al.* (2014) ^[12] fabricated solar powered grass cutter using scotch yoke mechanism. The results obtained was satisfactory. Suitable for a common man as it was having much more advantages i.e., no fuel cost, no pollution and no fuel residue, less wear and tear because of less number of moving components. This system was having facility of charging the batteries while the solar powered grass cutter was in motion. Nkakini and Yabefa (2014) ^[72] developed a manually operated apparatus for cutting grass with an internal spur gear system which transfers the torque to the mower spiral mechanism. The cutting mechanism was made of a flat blade rigidly fixed to the frame behind the spiral arrangement which was configured to contact at least one-reel bar of the spiral blades during the rotation of the spiral mechanism. The field capacity of 0.115 ha/h and field efficiency of 63.2%, were

obtained. The cutting effectiveness was achieved with a total power of 934.3 watts at a rotary speed of 1500 rpm of shaft. Machine was eco-friendly to the environment, because it does not emit carbon monoxide into the environment and the noise level was drastically reduced. The machine was more efficient in a soil with low moisture content. Tanimola *et al.* (2014) ^[110] designed solar powered lawn mower, consisted of direct current (D.C.) motor, a rechargeable battery, solar panel, a stainless steel blade and control switch. Mowing was achieved by the DC motor which provides the required torque needed to drive the stainless steel blade which was directly coupled to the shaft of the DC motor. The solar powered lawnmower was operated by the switch on the board which closes the circuit and allows the flow of current to the motor which in turn drive the blade used for mowing. The battery recharges through the solar charging controller. Performance evaluation of the developed machine was carried out with different types of grasses. The machine was found to have an efficiency of 93% and a field capacity of 1.11×10^{-4} ha/h. Satwik *et al.* (2015) ^[91] designed and fabricated the lever operated solar lawn mower. The grass cut could be varied from the 1cm to 6.5cm from the ground. The motor runs 45min continuously until the batteries are depleted. Solar panel, the batteries required 23 hours to recharge completely, so it required 4 days considered 6 h/day direct sunlight. Rpm of motor was changed in four steps namely 700, 1200, 1600 and 2000. It was observed that the proposed machine provided more productivity when compared to the traditional lawn mower. The cost of the machine including material cost and fabrication cost was Rs 7000. Gandhewar *et al.* (2015) ^[29] developed human powered mini paddy harvester which were divided into two parts i.e. a battery charging unit with the help of peddling mechanism and a motor & blade assembly for cutting purpose. First part consists of peddling mechanism, in which the kinetic energy of human being was transferred through peddling mechanism from sprocket to shaft with the help of chain drive. Due to which the shaft starts rotating on which the flywheels were mounted as well as another sprocket also starts rotating which was connected to bicycle wheel with the help of chain drive, so that wheel also starts rotating. After that kinetic energy of wheel was supplied to alternator through a belt drive. Due to the rotation of shaft of alternator electric current was produced which was useful to charge the battery the circular blade or cutter was mounted on the shaft of DC motor. As the electric current provided to battery the cutter mounted on the shaft of motor starts rotating and which was used to cut the paddy crops. Human powered mini paddy harvester was efficient as compared to modern harvesters. Lanka *et al.* (2015) ^[57] fabricated solar grass cutting machine, which was designed such that the solar plate generates solar energy and utilizing this energy for running the grass cutter motor. Integrating features of all the hardware components used have been developed in it. Presence of every module has been reasoned out and placed carefully, thus contributing to the best working of the unit. Secondly, using highly advanced IC's with the help of growing technology. They were adding more features like displaying the solar voltage generated on LCD display unit, also alerting when the battery voltage level goes low below threshold limit and added power bank to charge the battery instantly. Verma (2016) ^[114] designed a push-based battery powered reaper, in which cutting as well as conveying

operation was done mechanically through the means of electric power and transportation via manual power. The battery powered reaper included DC motor, battery, cutter bar, crop row dividers, star wheel, gear box and vertical conveyor chain. The reaper weight along with battery was found as 32kg. The reaper performance was evaluated by varying forward speed, cutter bar speed and cutting angle in a wheat field. The total harvesting losses was observed as 2.67% of total yield. The field capacity and field efficiency were found as 0.069 ha/h and 85.06%, respectively with a forward speed of 1.55 km/h. Kiran *et al.* (2017) [53] designed and fabricated an electro-mobile harvester for rice and wheat crops. They conducted a performance assessment, considering technical metrics such as operating velocity, cutting velocity, cutting efficacy, effective field capacity, power consumption economics, and grain loss percentage. The electro-mobile harvester exhibited an effective field capacity of 0.13 hectares per hour and a cutting efficiency of 98.24%. The cutting width of the harvester was 0.6 m, and its average forward speed was measured at 2.17 km/h speed of the reaper was found as 2.17 km/h. Ayay and Keber (2019) [15] developed prototype multi-crop solar powered harvester. The prototype of the solar grain harvester had one hp DC motor, a 2.4 m² solar panel, a four-wheel vehicle, and a cutter assembly. It could harvest a width of 600 mm of grain at a speed of 500 mm/s, resulting in a harvesting capacity of 0.108 ha/hr, which was 18.73 times more than a single person could achieve. Therefore, the small-scale solar grain harvester became a preferable means of harvesting because it was non-polluting and freely available. Tanti *et al.* (2019) [111] developed battery powered reaper at CAET, JAU, Junagadh. Performance evaluation of developed machine was carried out at different forward speeds (0.8-1.2 km/h, 1.3-1.7 km/h and 1.8-2.2 km/h) and different cutter bar speeds (200 rpm, 300 rpm and 400 rpm). The maximum effective field capacity and field efficiency was found 0.074 ha/h and 90.77% respectively. The maximum cutting and conveying efficiency of the developed reaper was found 95.01% and 89.66% respectively. Kumar (2020) [55] developed battery operated manual push type mini harvester of 53 cm cutter bar for paddy and wheat crop. It consists of main frame, two wheels, an 85 A-h battery, two DC motor, pushing handle, cutter bar and vertical conveying unit. The power requirement of the harvester was about 160 W out of which cutter bar and conveying unit take about 80 and 20%, respectively. It was also calculated that a fully charged battery will be able to run 5.6 h. The developed harvester could not be tested in wheat field due to national lockdown due to Covid-19 during April 2020. Sahoo and Raheman (2020) [87] designed an electric reaper called the Electric Vertical Conveyor Reaper (E-VCR) for harvesting matured paddy crops. The E-VCR, a walk-behind type machine, was equipped with a 600 mm cutting width and powered by an 800 W 48 V DC motor, utilizing four 12 V 18 Ah lead-acid batteries for cutting and a 24 V 350 W DC motor with two 12 V 12 Ah lead-acid batteries for propulsion. The performance of the E-VCR was compared to a self-propelled fossil fuel operated vertical conveyor reaper (VCR). The results showed that the E-VCR had a field capacity of 0.06 ha/h, cutting efficiency of 95%, and header loss of 2.05%, while the VCR had higher values of 0.20 ha/h, 98%, and 2.42%, respectively. The use of the E-VCR resulted in reduced drudgery compared to the VCR, with noise and hand vibration reduced by 8% and 50%,

respectively. The manpower required for harvesting with the E-VCR, VCR, and manual sickle was 16 man-h/ha, 5 man-h/ha, and 185 man-h/ha, respectively. Consequently, the harvesting cost per hectare was Rs. 2904, Rs. 2318, and Rs. 8094 for E-VCR, VCR, and manual sickle, respectively. Based on the economic analysis, it was found that the annual use of the E-VCR below 2.9 ha and the VCR below 5.2 ha was considered uneconomical for harvesting purposes.

Conclusion

Chhattisgarh is an agrarian state with 70% of its population Eng. aged in Agriculture. The state has approximately 4.11 million farmers, with about 82% classified as small and marginal. In most regions of Chhattisgarh, farmers use sickles for harvesting paddy and wheat. However, they frequently encounter a labor shortage during the peak harvesting season, which can lead to grain losses due to over-maturity of the crops. From the reviewed literature, it is evident that reapers are crucial for the timely harvesting of field crops. While manually operated harvesting equipment is available, it relies on a ground wheel as the power source, which does not provide sufficient traction to cut and convey crops effectively. Additionally, both self-propelled and tractor-mounted reapers on the market are expensive and not environmentally friendly, making them inaccessible to small and marginal farmers due to their high initial and operating costs. Although push-type battery-powered reapers exist, their limited manual power for pushing has restricted their widespread use. Therefore, there is a need for a cost-effective and eco-friendly self-propelled battery-powered reaper that uses battery power for cutting, conveying, and propelling the machine. Such a reaper would require only one operator and be more affordable for farmers, contributing to improved farming practices.

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