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ARTICLE

Development and Evaluation of Self-propelled Cabbage/Cauliflower Harvester

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ABSTRACT

In the present study, self-propelled cabbage/cauliflower harvester was designed, developed and evaluated. The machine consisted of different components like engine, frame, shearing (cutting) unit and power transmission unit. The power transmission unit consisted of main clutch, shearing blade operating clutch, belt drive unit, chain and sprocket drive, universal joint and cutter blade assembly. The main working principle of harvester is based on shearing of crop stem against high-speed rotating blade. The power from the engine is transmitted by belt-pulley drive unit to transmission shaft on which chain and sprocket is mounted on one side and then power is transmitted to shearing blade coupling with the help of a stationary pulley and fixed socket. Average mean head diameter of the selected cabbage and cauliflower was 89.5 ± 15.24 mm and 107.5 ± 15.24 mm, respectively. Average mean stem (plant) diameter of the selected cabbage and cauliflower was 18 ± 4.85 mm and 21.5 ± 3.08 mm, respectively. The shearing force increased with increase in diameter of stem. The optimum performance of the machine was achieved when it was operated at 1.5 km/h forward speed and the shearing blade moving at speed of 147 rpm. The mean field capacity for developed prototype was observed as 0.063 ha/h and 0.053 in case of cabbage and cauliflower, respectively with field efficiency of 91.97 and 90.48 %. The average head damage was negligible (0.15 %) for both the crops. The average un-trimmed percentage with developed harvester was 3.2 and 3.0% in case of cabbage and cauliflower crop, respectively. The developed machine helps to increase the field capacity in cabbage/cauliflower harvesting due to 7-times more capacity and 50% cheaper compared to traditional method of cabbage/cauliflower harvesting. At the operating condition of forward speed (1.5 km/h) and shearing blade speed (147 rpm), the machine could harvest 0.5 ha of cabbage and 0.42 ha of cauliflower farm per day of 8-h. This same task would have required between 15 labour per day if entirely done manually.

1. Introduction

Agriculture plays an important role in economic development in India. India is the second largest in farm output, seventh largest in its export worldwide. India is the second largest producer of cabbage/cauliflower (*Brassica oleracea*)/ next to China in the world. Cabbage is famous for its nutritional values, medicinal effects, and

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other therapeutic properties. It is consumed throughout the country by every class of people as fresh vegetable or raw as salad. Cabbage may be cheap in price but very high in protective vitamins having a very low caloric value and very rich in nutrients. The cultivated area is about 400138 ha with a production of 9039219 MT per year i.e. about 12.80% of total world production and has rank 6th among all the vegetables in India [1] but the productivity of the crop is quite low 22.6 metric tons per hectare. However, being a large area under vegetable cultivation farm practices like transplanting and harvesting are done by traditional methods such as hand picking or by use of a sickle to cut the stem and leafy portion in India. Some researchers worked on mechanical harvesting of cabbage. An one-row towed harvester operated at a speed of 0.5-1.0 mile per hour uproots the cabbage, conveys it to a circular cutting blade, separates the leaves from the heads, and delivers it to transportation vehicles [2]. [3] while conducting studies on the relationship of yields and physical properties to the mechanical harvesting of cabbage found that a fixed cutting height can be found for each field so that 2.5% of the heads will be cut too high and a varying percentage dependent upon variety and location. On the other hand, it would be very difficult to sense the proper cutting height for each head and adjust the cut to that elevation. [4] attempted to mechanize the operation by designing a mechanical harvester for the vegetable. The machine lacerates and bruises the vegetable and there by reduces its quality. Also, provision was not made to collect harvested vegetable. An empirical formulae established of unit cutting force and mechanics model for sugarcane stalk [5]. Based on high speed photography analysis, they also found that cutting speed, cutting position and forward velocity had significant effects on stubble damage. A tractor PTO operated leafy vegetable harvester for herbaceous vegetables in which the ground wheel powered the conveyor belts for transporting the harvested vegetable from the cutting unit to the storage bin [6]. Results indicated that the field capacity of the machine increased linearly with increase in knife speed and forward speed. But at high vegetable height (average of 69.60 cm), the harvesting efficiency reduced considerably due to the frame of the machine which tends to push “standing” vegetables away from the reach of the cutting unit. Cutting the cabbage root with single point clamping way could reduce the maximum and the average cutting force effectively, but may cause increase in the splitting failure [7].

The traditional methods of transplanting and harvesting require lots of skilled labour and capital, sometimes there is a shortage of labour during harvesting. The unavailability of labour, causes delay in harvesting operations which directly affects the crop production and economic returns of the farmers. Alone harvesting requires more than 50% of processing cost. There are no mechanical cabbage/cauliflower harvesters available at present in India. With cauliflowers/cabbage requiring selective picking it means that the only currently available mechanized harvesting technique is to use humans to detect the maturity, cut and trim the product and collect the product. Keeping in view of these, there was a need of mechanization in the harvesting process of cole crops like cabbages/cauliflowers.

2. Materials and Methods

Before designing of harvester, physical properties like head height, head diameter, plant diameter, length of stem, plant height and length of leaf stem, shearing (cutting) force of cabbage and cauliflower were measured using vernier caliper (Figure 1). The measurement of cutting force was done with the help of a texture analyzer in PHT lab of SKUAST-K Srinagar. The cutting force was determined at a pre-test speed of 2.00 mm/sec and post-test speed of 10 mm/s. The distance of cut was maintained at 30 mm with trigger force of 0.04903N and a load cell of 50 kg. The cutting force in cabbage and cauliflower stem was obtained by cutting stem of different diameters (Figure 2). A conceptual view (Figures 3 & 4) of the self propelled cabbage/cauliflower was prepared using Auto CAD-2016 software keeping in view of its functional requirement. An existing power weeder was used for modification and development of self propelled harvester. The rotary weeder unit was removed and a guiding wheel was fitted in the front of developed harvester.

Design of different components

The developed harvester consisted on a power source, frame, power transmission unit and cutting blade (Table 1).

Power Source

An I.C. engine of 5.5 hp (rating) with cubic capacity 255 cubic cm single stroke was used in the machine which runs on kerosene with petrol start. It was having a throttle lever on handle frame used to increase or decrease the forward speed of machine. There was a provision of 3 different speed levels low, medium and high speed.

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Figure 1. Measurement of physical dimensions of cabbage

Figure 2. Measurement of stem cutting force using Texture Analyzer

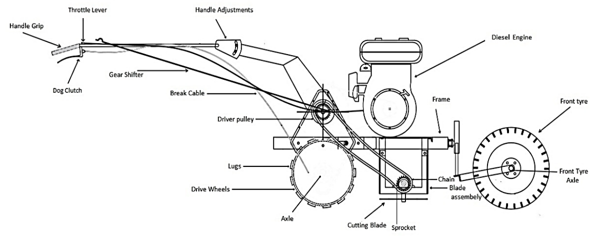

Figure 3. Conceptual view of self propelled Cabbage/ cauliflower harvester

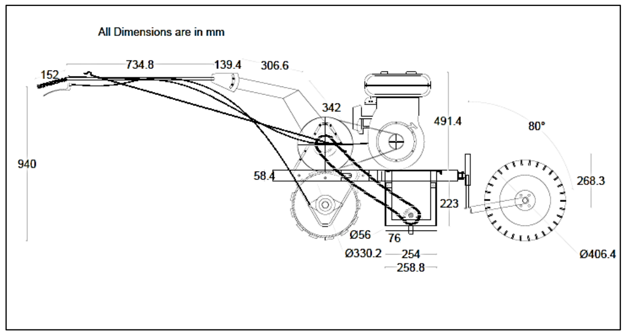

Figure 4. Back view of the developed machine

Frame

The frame was made up of mild steel angle iron of 25 mm section. It is made up of two rectangular parts of different length. The front and back part are joined with the help of welding corners of flat angle iron to form a rectangular frame of dimensions 462.8×175 mm. The frame is bolted to the angle iron support provided in the machine, so that proper cutting height is sensed from the ground level during conducting field operation. The shearing/cutting blade was fitted on a frame made of flat angle iron. The overall dimensions of frame are 462×175×95 mm.

Power transmission unit

The power transmission unit consisted of main Clutch, cutting blade operating clutch, Belt drive unit, Chain and Sprocket Drive, Universal joint, Cutter Blade Assembly. The descriptions of the components are given below.

Main clutch: It was provided to control the forward speed of the machine as well as to control the power transmission unit i.e. used to control the whole power of the machine. The dog clutch was used as main clutch.

Cutting blade operating clutch: It was provided to engage or disengage the power from the engine to cutting blade. The engine power could be disengaged by way of cut off the belt drive power.

Belt drive unit: The power from the engine is transmitted to transmission shaft through belt-pulley

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drive. The purpose of this drive unit is to reduce the speed. The size of driver and driven pulley was taken as 275 and 100 mm. The center to center distance between these two pulleys was 350 mm through which power was transmitted to shaft. A V-belt of size B-48 was used.

Chain and Sprocket Drive: The power from the transmission shaft is transmitted to the cutting/shearing blade assembly through chain and sprocket unit. This driver sprocket consisted of 16 teeth while driven sprocket consisted of 12 teeth. A pintle chain of length 48 links 1219 mm length was used to transmit power through shaft of diameter 25 mm to cutter bar assembly i.e. (from universal joint of 200 mm to cutter blade).

Table 1. Specifications of self-propelled cabbage/ cauliflower harvester

S. No.	Description	Dimensions (mm)
1.	Power source	: I.C. engine petrol start, kerosene run 5.5 hp (rating), Displacement volume: 255 cubic cm, single stroke
2.	Frame Overall dimension (lxbxh)	: rectangular shape 462×175× 95 mm
3.	Power transmission unit	: Chain and sprocket (driver sprocket consisted of 16 teeth while driven sprocket consisted of 12 teeth) : Belt and pulley (size of driver and driven pulley was taken as 275 and 100 mm)
4	Shearing/Cutter blade Size (diameter x no of teeth), mm Material	: 250 ×80 : high carbon steel of 20 mm top
5	Angle of power transmission	30˚
6.	Chain sprocket (No. of teeth)	16
7.	Length of Pintle chain	1219

Shearing (Cutting) unit

Cutting unit was mounted on the upper part of the frame. It is made up of high carbon steel of 20 mm top and is bolted on the upper part of frame, and cutting blade of diameter 250 mm rotates at its periphery with dimensions 250 mm×80 (No. of teeth). The brush cutter shaft of diameter 20 mm is adjusted in to the coupling mounted on the upper part of frame with the help of internal threads and welding.

Working of the self-propelled mechanical cabbage/ cauliflower harvester

The main working principle of self-propelled cabbage/ cauliflower harvester is based on shearing of crop stem against high-speed rotating serrated blade. The power from the engine is transmitted by belt-pulley drive unit to transmission shaft on which chain and sprocket is mounted on one side and then power is transmitted to cutter blade coupling with the help of a stationary pulley and fixed socket. The speed at main pulley of engine was measured as 317 rpm while the speed of cutting blade was measured as 58 m/s corresponding to the machine at stationary position.

Evaluation of machine

The machine was evaluated to analyze the effect of independent parameters on individual dependent parameter by taking different levels of following independent parameters. The evaluation of self-propelled mechanical cabbage/cauliflower harvester was carried out on two different sites at Haran and Wompora villages of district Budgam during 2017-2019 (Figure 5). An area of 180 m^2 along 10 m row length each for cabbage and cauliflower was selected for field evaluation. The dependent and independent parameters are given below:

Independent Parameters	Level	Dependent parameters
Number of crops	2 levels (Cabbage, Cauliflower)	• Field capacity (ha/h) • Percentage of trimmed cabbage/ cauliflower
Shearing blade speed (km/h)	3 levels (S_1: 291, S_2: 319 S_3: 447 rpm	• Field Efficiency (%) • Damage percentage • Labour Requirement (man-h/ha)

Figure 5. An overview of harvesting of cabbage and cauliflower with developed harvester

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Measurement of Dependent Variables

Field capacity

The field capacity of the machine was determined by using the standard formula. The time taken to harvest cabbage and cauliflower in 180 m^2 area was recorded and field capacity in ha/h was determined.

$$\text{Effective field capacity (ha/h)} = \frac{\text{Actual area covered by machine (ha)}}{\text{Effective time (h)}}$$

$$\text{Theoretical Field Capacity (ha/h)} = \frac{\text{Width (m) x speed (km/h)}}{10}$$

Field efficiency (%)

The field efficiency was determined by using following formula:

$$\text{Field efficiency (\%)} = \frac{\text{Actual field capacity (ha/h)}}{\text{Theoretical field capacity (ha/h)}} \times 100$$

Damage (%)

For calculating the damage percentage of cabbage and cauliflower total weight of damaged cabbages and cauliflower on the 30 m row length was recorded and damage percentage was determined using following formula:

$$\text{Percentage of damage} = \frac{\text{Wt. of damaged cabbage/cauliflower}}{\text{Total Wt. of cabbages/cauliflower}} \times 100$$

Labour requirement

The man hours required to harvest cabbage/cauliflower was calculated from field capacity of the machine.

$$\text{Labour requirement (man-h/ha)} = \frac{1}{\text{Effective field capacity}}$$

Percentage of trimmed cabbage

The number of total trimmed cabbage and cauliflower were recorded on the given area and then percentage of trimmed cabbage and cauliflower were determined.

$$\text{Percent of trimmed cabbage} = \frac{\text{No. of fully trimmed cabbage}}{\text{Total No. of cabbage in selected area}} \times 100$$

Percentage of un-trimmed Cabbage (%) = 100-percentage of trimmed cabbage

The observed data were analysed for significant differences between treatments using factorial design in complete randomized block design with Opstat software-1988 The experiments were planned in a Randomized completely block design having two factors one with two levels, and other with three levels. Each treatment was replicated thrice. The developed prototype was evaluated as per 18 different treatment combinations.

3. Results and Discussion

Physic-mechanical properties

The minimum and maximum values of head height, head diameter, plant diameter, length of stem, plant height and length of leaf stem of cauliflower were 95 and 134 mm, 85 and 130 mm, 85 and 75 mm, 120 and 130 mm, 330 and 400 mm, 35 and 55 mm respectively (Table 2) while the minimum and maximum values of head height, head diameter, plant diameter, length of stem, plant height and length of leaf stem of cabbage were 68 and 195 mm, 35 and 144 mm, 110 and 230 mm, 45 and 70 mm, 250 and 400 mm, 25 and 60 mm respectively (Table 3).

Table 2. Physical properties of cauliflower

Stem Diameter (mm)	Head height (mm)	Head diameter (mm)	Length of stem (mm)	Plant height (mm)	Plant (stem) diameter (mm)	Length of leaf stem (mm)
Minimum	95	85	120	330	18.5	35
Maximum	134	130	130	400	26.0	55
Mean	114.5	107.5	125	365	21.5	45
SD	16.42	15.24	15.57	28.63	3.08	7.90

Table 3. Physical properties of cabbage

Diameter (mm)	Head height (mm)	Head diameter (mm)	Length of stem (mm)	Plant height (mm)	Plant (stem) diameter (mm)	Length of leaf stem (mm)
Minimum	68.0	35.0	45.0	250	11.0	25.0
Maximum	195.0	144.0	70.0	400	23.0	60.0
Mean	131.5	89.5	57.5	325	18.0	42.5
SD	16.31	15.24	10.36	23.87	25.64	7.90

Cutting/shearing Force

It was observed that the shearing force required to shear the stem portion of cabbage and cauliflower was dependent on stem girth. The cutting force increases with the stem diameter. The depth of cut and trigger force influenced the cutting force. The lower cut percentage at high speed levels may be due to moisture/fibre ratio, fertility gradient.For all the selected cabbages and cauliflower, cutting force for selected cabbages was recorded highest (396.52N) for cabbage stem of diameter 30-40 mm. while it was recorded lowest (212.17N)) for diameter 20-25 mm and for cauliflower stem, cutting force was recorded highest (410.52N) for diameter 35-45 mm, while it was recorded lowest (185.20N) for diameter 15-25 mm (Tables 4&5).

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Table 4. Effect of stem diameter of cauliflower on cutting force (N)

Stem diameter (mm)	R1	R2	R3	Mean	S. D
35-45	406.83	410.52	378.54	398.80	17.50
25-35	312.24	205.10	378.54	288.05	22.92
15-25	185.20	198.81	223.10	202.40	19.19

Table 5. Effect of stem diameter of cabbage on cutting force (N)

Stem diameter (mm)	R1	R2	R3	Mean	S. D
35 – 40	396.52	347.74	327.38	357.21	35.53
25 – 30	302.55	295.16	288.78	295.49	50.18
20 – 25	259.95	235.49	212.17	235.87	23.89

Effect of shearing blade speed on head damage

For both the crops, the head damage was negligible while harvesting with developed harvester however, the head damage percentage increased with an increase in forward speed of the machine (Table 6). For cabbage, the minimum head damage (0.13%) was observed at shearing blade speed of 291 rpm while the maximum head damage (0.19%) was at 347 rpm. Same trend was observed for cauliflower harvesting. The average damage was 0.15% and 0.16% for cauliflower and cabbage, respectively irrespective to the shearing blade speed of the machine. The increase in head damage at higher blade speed can be attributed to the decreased resistance of stem to shear force which causes slippage of blade corresponding to the stem texture.

Table 6. Effect of shearing blade speed of harvester on head damage

A. Cabbage	R1	R2	R3	Mean
S1	0.12	0.16	0.13	0.13
S2	0.17	0.17	0.16	0.16
S3	0.18	0.20	0.21	0.19
Average	0.15	0.17	0.16	0.16
C.D (p>0.05) ± sem 0.02±0.006				
B. Cauliflower	**R1**	**R2**	**R3**	**Mean**
S1	0.10	0.14	0.13	0.12
S2	0.16	0.15	0.17	0.16
S3	0.19	0.20	0.18	0.19
Average	0.15	0.16	0.16	0.15
C.D (p>0.05) ± sem 0.03±0.01				

Percentage of un-trimmed head

The quantity of untrimmed heads decreased linearly with an increase in shearing blade speed of the harvester. For the cabbage crop, mean untrimmed head was found lowest (1.6%) at shearing blade speed of 347 rpm and highest (5.0%) at shearing blade speed of 291 rpm, respectively. Similarly for cauliflower, the mean untrimmed percentage was 2.0% and 4.0% at shearing blade speed of 347 and 291 rpm, respectively. Statistically there was a significant difference of shearing blade speed and for both the crops on untrimmed percentage (Table 7 and Figure 6). The higher un-trimmed percentage in cabbage as compared to the cauliflower was due to the bulged stem with high moisture content which resists the cutting.

Table 7. Effect of shearing blade speed on percentage of untrimmed cabbage and cauliflower

A. Cabbage	R1	R2	R3	Mean
S1	6.0	5.0	4.0	5.0
S2	3.0	2.0	4.0	3.0
S3	1.0	2.0	2.0	1.6
Average	3.33	3.0	3.33	3.2
C.D (p>0.05) ± sem 1.29±0.42				
B. Cauliflower	**R1**	**R2**	**R3**	**Mean**
S1	4.0	3.0	5.0	4.0
S2	4.0	2.0	3.0	3.0
S3	1.0	2.0	3.0	2.0
Average	3.0	2.33	3.6	3.0
C.D (p>0.05) ± sem 1.05±0.33				

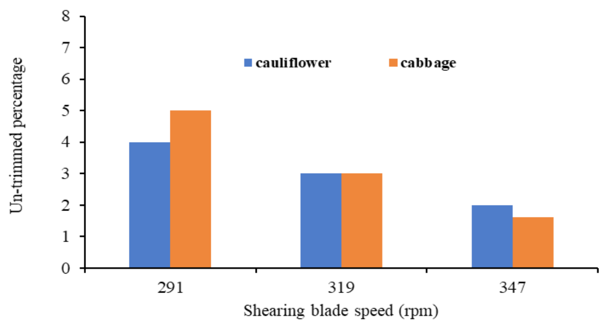

Figure 6. Mean effect of shearing blade speed on untrimmed cabbage and cauliflower head

Effect of shearing blade speed on field capacity

There was a significant effect of shearing blade speed on field capacity of the developed harvester. The field capacity of the developed harvester increased linearly with shearing blade speed for both the crops as the trimming of head stem is directly related with shearing blade speed. The mean lowest field capacity of 0.047 ha/h was observed at shearing blade speed of 292 rpm and the highest field capacity of 0.068 ha/h was observed at shearing blade speed of 347 rpm (Table 8). The mean field capacity of the harvester was significantly lower for cauliflower than cabbage. It was mainly due to hard stem of cauliflower which require more force to shear the stem (Tables 4 & 5).

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Table 8. Effect of shearing blade speed on field capacity (ha/h)

Shearing blade speed (rpm)	Field capacity(ha/h)		Mean
	C1: Cabbage	C2: Cauliflower	
S_1	0.050	0.045	**0.047**
S_2	0.065	0.052	**0.058**
S_3	0.075	0.062	**0.068**
Mean	**0.06**	**0.05**	

$CD_p \leq 0.05$

CD for blade speed : 1.35 CD for crop type : 0.98

C: Crop type S: shearing blade speed

S_1: 292 rpm S_2: 319 rpm S_3: 347 rpm

Effect of shearing blade speed on field efficiency

The field efficiency of the developed prototype was found highest (96.80%) for cabbage crop, at shearing blade speed of 347 rpm, while it was lowest (84.2%) at shearing blade speed of 292 rpm (Figure 7). The mean field efficiency was found highest (95.99%) at shearing blade speed of 347 rpm and lowest (87.36%) at shearing blade speed of 292 rpm. For both the crops, the field efficiency increased with increase in shearing blade speed of the cutting mechanism. The mean field efficiency was found lowest (80.21%) at shearing blade speed of 292 rpm for harvesting cauliflower and highest (96.53%) at shearing blade speed of 347 rpm. Statistically there was significant difference of field efficiency at 5% level of significance.

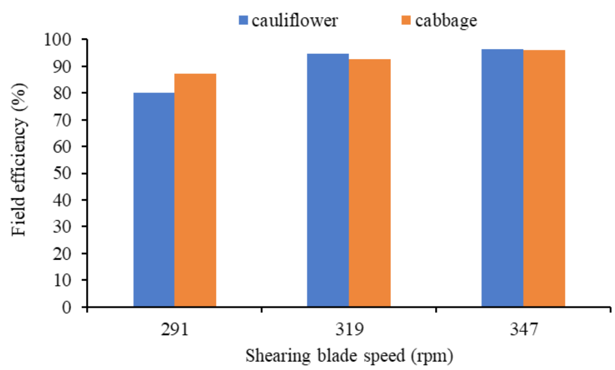

Figure 7. Effect of shearing blade speed on field efficiency of developed harvester

Effect of shearing blade speed on labour requirement

The labour requirement in man-hours per hectare was determined from field capacity. The shearing blade speed significantly affected labour requirement for harvesting of both crops and it decreased with increase in shearing blade speed of the cutting mechanism (Figure 8) as less time was required for shearing the crop stem at higher blade speed. The mean labour requirement for cauliflower was found highest (27 man-h/ha) at shearing blade speed of 292 rpm and lowest (14 man-h/ha) at shearing blade speed of 347 rpm. While as mean labour requirement for cabbage was found highest (23 man-h/ha) at shearing blade speed of 292 rpm and lowest (17 man-h/ha) at shearing blade speed of 1.5 km/h.

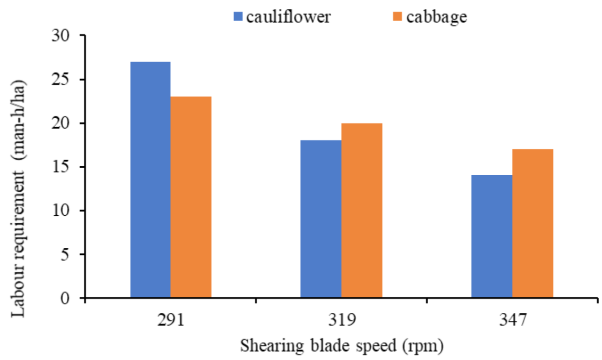

Figure 8. Effect of shearing blade speed on labour requirement

Standardization of shearing blade speed

The independent parameter viz. shearing blade speed was standardized keeping in consideration the lesser un-trimmed percentage, higher field capacity, lower head damage and lower labour requirement. The optimum response parameters obtained were 3.4%, 0.065 ha/h, 0.16% and 20 man-h/ha for cabbage at shearing blade speed of 347 rpm while for cauliflower the optimum response parameters obtained were 3%, 0.052 ha/h, 0.16% and 18 man-h/ha, for un-trimmed percentage, field capacity, head damage and labour requirement, respectively. Hence the shearing blade speed of 347 rpm was recommended for the mechanical harvesting of cabbage/cauliflower using developed harvester.

Comparison of developed harvester with traditional method of harvesting

The mean performance data of developed harvester was computed and compared with that of traditional harvesting method (Table 9). The field capacity of the developed harvester was more than 7-times than traditional harvesting of cabbage/cauliflower. The damage percentage was observed slightly higher for developed prototype (0.16%) as compared to manual method (0.05%). About 104 man-h/ha labour requirement and Rs 2809 per hectare could be saved with the use of developed harvester for harvesting of cabbage/cauliflower.

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Table 9. Comparison of manual and developed prototype method of harvesting

Parameters	Developed harvester	Traditional harvesting Method
Damage, %	0.16	0.05
Field capacity, ha/h	0.063	0.0083
Labour requirement, man-h/ha	16	120
Untrimmed Percentage	3.2	0.1
Cost of operation, Rs/ha	2791	5600

*wages= Rs. 35/h man-h for manual harvesting= 120 man-h/ha

4. Conclusions

The developed self-propelled harvester efficiently harvested the cabbage and cauliflower at forward speed of 1.5 km/h and shearing blade speed of 347 rpm. The shearing blade speed of the cutting mechanism affected the field capacity, efficiency, head damage and untrimmed head. The shearing (cutting) force increased with increase in stem diameter. The developed machine helps to increase the field capacity in cabbage/cauliflower harvesting due to 7-times more capacity and 50% cheaper compared to traditional method of cabbage/cauliflower harvesting. The developed harvester could be a viable option for harvesting of cabbage/cauliflower for small to medium sized land holdings.

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