The Pharma Innovation Journal 2023; SP-12(9): 04-13

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(9): 04-13 © 2023 TPI
www.thepharmajournal.com
Received: 06-06-2023
Accepted: 14-07-2023

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Enhancing efficiency and reducing costs through self-propelled leafy crop harvester for coriander, fenugreek, and Indian spinach

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Abstract
In Saurashtra, most farmers manually harvest leafy crops like coriander, fenugreek, and Indian spinach. This traditional approach involves various postures like squatting, bending, and sitting while bending. Commonly, hand injuries such as cuts from tools and bruises from plant pulling occur during harvesting. Manual leafy crop harvesting is both time-intensive and demanding. The crops' perishable nature requires timely harvesting with sufficient labor, as delays can harm product quality. At the Department of FMPE, College of Agricultural Engineering, JAU, Junagadh, a self-propelled harvester for leafy crops like coriander and fenugreek has been successfully designed and developed. Powered by a 5 hp diesel engine, this machine incorporates essential elements including the main frame, cutting unit, conveyor unit, storage unit, steering unit, and transportation unit. Through an ergonomic evaluation, the harvesting process using this newly developed harvester has been classified as moderately heavy work. From an economic standpoint, a comparative analysis was conducted between this advanced leafy crop harvester and the conventional harvesting technique. The overall cost of the self-propelled leafy crop harvester was calculated as ₹96,135. Utilizing this harvester reduced the labor requirement to 7.63 (approximately 8) man-hours per ha, whereas manual harvesting demanded a substantial 160 man-hours per ha. Consequently, the newly developed harvester showcases significant cost savings amounting to ₹5,009.62 per ha. This equates to a remarkable 71.57% reduction in costs and an impressive time saving of 95.30% for leafy crop harvesting operations. Evaluating the economics further, the benefit-cost ratio and payback period for this self-propelled harvester were determined as 3.05 and 2.62 years, respectively. The break-even point for the developed leafy crop harvester was found to be 122.9 h/year.

Keywords: Leafy crops, manual harvesting, ergonomics evaluation, cost economics

Introduction
Leafy vegetables form the second most important category of vegetables, next to starchy vegetables. They are considered prime sources of essential minerals, vitamins, and dietary fibre (Gojiya *et al*., 2022) [10, 12]. The highly perishable nature of all horticultural products, particularly leafy vegetables, due to their tender tissues and high surface-to-volume ratio, makes it challenging to preserve their freshness and quality during and after harvest (Mini and Krishnakumary, 2007) [17]. Most of the farmers in India conduct harvesting of leafy crops by manually. Manual method mostly depend upon the characteristics of plant, time of harvesting (morning or evening session) and working posture. Traditional methods for harvesting leafy vegetables include pulling them out by hand and using sharp sickles, knives, or scissors in the early morning. This method is typically performed by a person in a bending-down posture, using their hands to pull plants out of the soil (Gaadhe and Tiwari, 2022) [7]. The harvesting of leafy crops takes more time and skilled labor. The farmer has to physically carry and/ transport cut crops during harvesting operation. Automation is a natural next step for this concept since it has great potential to improve weed control efficacy and minimize to desire the plant damage (Balas *et al*., 2022) [4]. Due to the large availability of biomass resources, India has great potential for the production of biochar (Makavana *et al*. 2021) [33]. Drip irrigation is the drop by drop application of water directly to roots crop (Balas *et al*. 2018) [5].

Review of Literature
The farmers harvest leafy vegetables by nipping of leaves, cutting of plants using hand tools or pulling out of whole plant. For harvesting purpose small tools like scythes or sickles are used, and mostly female labour perform these operations. Kepner *et al*. (2005) [14] pointed out that mechanical aids for hand harvesting have been employed to some extent but often have shown little or no advantage.

In general, harvesting aids result in only a moderate or small increase in productivity and they sometimes represent substantial investments. The harvest must be timed carefully to obtain the maximum yield of marketable and mature product.
FAO's Global Initiative on Food Loss and Waste (Save Food) has carried out several case studies to identified that harvesting (70%) is the most frequently identified critical loss point for all types of food, while inadequate storage facilities and poor handling practices were identified as the main causes of on-farm storage losses (FAO, 2019, Gojiya *et al*., 2020) [6, 9].
Normally, the farmers harvest leafy crops early in the morning or evening. If leafy crops are to send nearby market early morning harvesting is preferred whereas for long distance transportation harvesting is done in evening. During harvesting the cut plants are placed in farm for hours before sending to market makes it loses its freshness and quality (Gojiya *et al*., 2023) [11]. Harvested crops loses its moisture content when exposed to drying winds become wilted and soft.
Unlike other vegetables, no scientific handling (sorting, grading & packaging) of harvested crops observed for leafy vegetables. Vala and Rathod (2019) [29] assessed the post-harvest losses (14.5 – 26%) of leafy crop vegetables and reported that 0.5%, 5-10% and 9-16% loss at wholesale, retailer and farm level, respectively. Mostly shattering losses were observed in leafy vegetables. The small bundles of harvested crops are sprayed with water and packed with cloth before sending to market. The over-packing causes crushing of leaves and bruising and rapid discoloration of stems.

Hand injuries
There are many hand tools available on Indian Farmers. For harvesting tools (sickle), deep cuts of fingers and abrasions on underside of little finger are common injuries seen in harvesting season. Kumar *et al*., (2008) [16] pointed out that there are 1700 injuries related to hand tools per hundred thousand farm workers per year in rural India. There is no mechanism to monitor agricultural accidents and fatalities in rural India. Productivity was impaired to the tune of 24,000 days per hundred thousand population because of injuries caused by hand tools on these farms.

Working posture
Leafy crops are mostly harvested by females, involving a variety of traditional postures like squatting, bending, and sitting while bending, etc. Prolonged exposure to these traditional methods can result in fatigue and occupational diseases. Poor working posture could lead to posture stress, fatigue, and pain. The discomfort adversely affected the work performance, either by decreasing the quantity of work, the quality of work, or both. This leads to the wastage of energy and manpower and less yield per capita labour force. The working capacity of a human labour varies in course of a day. Generally it is higher in the morning and declines in the middle of the day. It also depends upon the weather condition and kind of field work.

Cost of operation
Harvesting is an important operation and labour-consuming. Its cost has gone up considerably in recent years due to an increase in the area of cultivation and unavailability of labour (Ojha and Michael, 2013) [23]. DES (2021) [2] has done survey on the annual average daily wage rate for 8-h field labour in India during 2019-20 and found that all India annual average wage rate for male and female for field labour is ₹ 348 and ₹ 278 respectively. In Gujarat, the annual average wage rate for male and female observed were ₹ 251 /day and ₹ 228 /day. In case of skilled labour, the wage rate is ₹ 449 /day at all India level. The highest wage rate i.e. ₹ 896 /day and lowest wage rate i.e. ₹ 307/day were paid in Kerala and Chhattisgarh respectively. The variation between wages of male and female agricultural labourer for the same category of work has been observed and it is approximately 25 per cent at all India level (Gojiya and Gohil, 2022) [10-12].

Timely harvesting
The harvesting requires manpower and delayed harvesting affects the quality of the product due to perishable nature of leafy crops. The manual harvesting is not only costly but time consuming, tedious and more dependent on availability of labour. In India, nipping operation of some leafy crops done by manual hand plucking method, which was found uneconomical and time consuming operation. Leafy crops like amaranthus, fenugreek and spinach were harvested by sickle and sometime whole plant uprooted from the field. It was found that manual harvesting of leafy crops takes 200 h ha^{-1} whereas manual harvesting with sickle takes 166.97 h ha^{-1} (Diwan *et al*. 2021) [3]. Therefore, there is a need for harvesting equipment to address these problems. Most of the harvesting equipment requires skilled labor, and there is a lack of human labor available for these operations. Additionally, the current trend of labor migration towards other occupations further exacerbates the shortage of agricultural workers. This situation necessitates the introduction of gender-friendly machines suitable for harvesting.

Methodology
A self-propelled leafy crop harvester was developed for harvesting leafy crops like coriander, fenugreek etc. The harvesting machine should be simple in design, safe in operation and should have compatible with power source (Vagadia *et al.*, 2020) [28]. The developed leafy crop harvester was operated by 5 hp diesel engine. It mainly consists of main frame, cutting unit, conveyor unit, storage unit, steering unit and transportation unit. The cutter bar, reel unit, conveyor and transmission wheel were powered by the engine through the gear and belt-pulley arrangement. The reciprocating cutter bar cuts the leafy crop stem and then the reel unit guides the cut crops to the conveying belt. The inclined conveyor carries these cut crops to the storage crate. The forward motion to the transmission wheels is provided by the engine through the gearbox (Nandaniya *et al.*, 2022) [21]. The steering system is provided to direct the leafy crop harvester in the field. The developed leafy crop harvester is able to do four operations simultaneously: cutting the standing crop, lifting the cut crop, conveying it through the conveyor belt, and collecting the cut crop in the crate. Different physical properties of these residues such as moisture content, bulk density, true density, porosity, angle of repose and thermal properties like volatile matter, ash content and fixed carbon was measured (Makavana *et al*., 2018) [22]. Working of the self- propelled leafy crop harvesting machine was tested on the instructional farm of Department of Farm Machinery and Power Engineering, C.A.E.T., J.A.U., Junagadh in January 2023 for coriander, fenugreek and Indian spinach crops. All the test were replicated three times as mentioned. The experiments were conducted for three crank speeds S_1 (175-274 rpm), S_2 (275-374 rpm), and S_3 (375-425 rpm) and three crops

(Coriander, Fenugreek and Indian spinach). The physiological parameters *viz*., heart rate, oxygen consumption, and energy consumption of subjects were recorded. For maintaining better quality of leafy crops, tests were conducted in the morning.

The economical parameters of manual harvesting as well as mechanical harvesting of leafy crop were determined. The cost associated with existing practice (manual harvesting) of leafy crops was compared with the cost of operation of developed leafy crop harvester.

Ergonomics evaluation of self-propelled leafy crop harvester

Ergonomic evaluation was done during the harvesting operation of leafy crop harvester in the field. Three subjects were selected for the experiment and they were having more than 5 years of experience in operating agricultural machineries. The anthropometric measurements were considered (Table.1) and measured in the Laboratory. The subjects were instructed to be in standing posture with the weights equally distributed on both feet while measuring the dimensions (Gite *et al.*, 2009) [8]. Yadav *et al.*, (2018) [32] and Yadav *et al.*, (2020) [31] conducted anthropometric and ergonomic survey for agricultural workers in Gujarat State and anthropometric database and muscular strength database were updated. The anthropometric dimensions of selected subjects were confirmatory with this database. None of the subjects showed any symptoms of illness and nobody were handicapped.

Table 1: Details of anthropometric measurements of selected subjects

Anthropometric measurements		Subject 1	Subject II	Subject III
1	Age, Years	32	29	29
2	Weight, Kg	63	84	69
3	Stature, cm	163	167.9	172
4	Eye height, cm	149	155	160
5	Acromial height, cm	136	141	145
6	Elbow height, cm	104	106.4	112
7	Illiyocrystalle height, cm	91	95	97
8	Forearm hand length, cm	47	47.50	48
9	Coronoid fossa to hand length, cm	39	36.70	39
10	Hand length, cm	17.87	18.60	17.69
11	Palm length, cm	9.97	10.50	9.86
12	Bideltoid breadth	43	45	42
13	Grip diameter (inside), cm	4.45	5.20	4.55
14	Grip diameter (outside), cm	7.95	26.80	8.25
15	Hand breadth across thumb, cm	9.40	11.30	9.74
16	Hand breadth at metacarpal III, cm	7.66	9.1	8.61

The physiological responses such as energy expenditure rate, oxygen consumption rate, and heart rate changes during physical work (Premkumari *et al.*, 2018) [24]. Thus these parameters were observed during each test of developed leafy crop harvester. The following ergonomic parameters were determined during the study.

Heart rate

The heart rate is the speed of heartbeat measured by the number of contractions of the heart per minute. It is measured in beats per minute. The heart rate of the operator were measured by using a heart rate meter during each test.

Oxygen consumption

The oxygen consumption rate is defined as the amount of oxygen consumed by the tissues of the body. It is measured in l/min or ml/min or ml/kg/min. It was calculated by the following equation (Singh, 2012) [27].

$$Y = (0.0114\ X) - 0.68$$

Where,

Y = Oxygen consumption, l/min

X = Heart rate, beat/min

Energy expenditure rate

Energy expenditure rate (kJ/min) of subjects were calculated for the operation of developed self- propelled leafy crop harvester. It is computed by multiplying the calorific value of 20.93 kJ/l of oxygen (Nag and Dutt, 1980) [20] to oxygen consumption rate during each test of experiment. The energy cost of the subjects thus obtained are graded as per the tentative classification of strains in different types of jobs given in the ICMR report as shown in Table 2 (Sen, 1969 and Sam, 2014) [26, 25].

Table 2: Classification of manual jobs based on the physiological response

Grading of work	Physiological response		
	Heart rate (beats/ min)	Oxygen uptake (l/min)	Energy expenditure (kcal/min)
Very light	< 75	< 0.35	< 1.75
Light	75-100	0.35- 0.75	1.75 - 3.50
Moderately heavy	100-125	0.75 - 1.05	3.50 - 5.25
Heavy	125-150	1.05 - 1.40	5.25 - 7.00
Very heavy	150-175	1.40 – 1.75	7.00 – 8.75
Extremely heavy	> 175	> 1.75	> 8.75

Table 3: Borg 10 scale for assessment of overall body discomfort rate

Cost economics of developed Leafy crop Harvester

The cost of operation of the machine in term of ₹/ha and ₹/h was determined based on fixed cost and variable cost. Annual use of developed machine was considered as 400 hours. The operating cost of the developed machine was calculated according to IS: 9164 (1979) [13]. The cost estimation of self-propelled leafy crop harvester were given in Table 3.

Payback Period

It is the number of years that would take for investment to return its original cost through annual cash revenue generated, if the net cash revenue is constant each year. The payback period was calculated from following formula (Gojiya and Gohil, 2022) [10-12].

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Average net annual benefit}}$$

Where,

Average net annual benefit, ₹ = (Custom fee, ₹/h – Total operating cost, ₹/h) × Annual utility

Benefit: Cost Ratio

The benefit cost ratio was calculated using following formula.

$$\text{B:C ratio} = \frac{\text{Total benefit}}{\text{Total cost of investment}}$$

Where,

Total benefit = Average annual net benefit (₹/ year) × Life of machine in year

Total cost of investment = Initial cost of machine, (₹)

Table 3: Cost estimation of leafy crop harvesting operation

Cost Estimation		
Sr. No.	**Items**	**Developed leafy crop harvester**
1	**Assumption**	
	a) Initial cost (P), ₹	96135
	b) Salvage cost (S=10% of C), ₹	9613.5
	c) Service life (L), y	8
	d) Annual use (H), h	250
	e) Interest rate per year (I),%	10
	f) Labour wages, ₹ day^{-1}	400
	g) Number of labour required for operation of the machine	1
	h) Operator wages, ₹ day^{-1}	400
	i) Diesel rate, ₹ l^{-1}	93
2	**Fixed cost**	
	a) Depreciation, D=(P-S)/ (H×L), ₹ h^{-1}	43.26
	b) Interest, I=(P+S)/2 ×I/H, ₹ h^{-1}	39.6
	c) Taxes Housing and Insurances @ 2%, ₹ h^{-1}	7.69
	Total fixed cost, ₹ h^{-1}	72.10
3	**Variable cost**	
	Fuel consumption, l h^{-1}	1.07
	a) Fuel cost, ₹ h^{-1}	99.51
	b) Lubrication cost, ₹ h^{-1}	19.90
	c) Repair and maintenance cost, ₹ h^{-1}	19.23
	d) Operator's wages, ₹ h^{-1}	50
	Total variable cost ₹ h^{-1}	188.64
4	**Total cost of operation, ₹ h^{-1}**	**260.74**
5	**Cost of operation per ha**	
	Actual field capacity, ha h^{-1}	0.131
	Actual field capacity, h ha^{-1}	7.63
	Operational cost, ₹ ha^{-1}	**1990.38**
6	**Manual leafy crop harvesting operation**	
	Man-hour required for leafy crop harvesting per ha	160
	No. of labour required for leafy crop harvesting per ha	20
	Wages per day of labour (8 hours)	350
	Total cost of manual leafy crop harvesting (₹ per ha)	**7000**

4 Results

4.1 Ergonomics evaluation

An ergonomic evaluation was done for the operation of developed self-propelled leafy crop harvester in field and analysed in terms of heart rate, oxygen consumption, and energy consumption of subjects.

4.1.1 Heart rate

The percent increase in heart rate was calculated by the ratio of the difference between heart rate of each operator before and after operation to that of the heart rate which was before starting the operation. The results were statistically analysed and shown in ANOVA Table 4.

Table 4: ANOVA showing the effect on heart rate of subjects for different crop and crank speeds

S.V.	df	SS	MS	Fcal	TEST	Ftab 5%	Ftab 1%	SE(m)	CD
Crop (C)	2	28.25	14.12	6.36	**	3.55	6.01	11.3915	33.8473
Crank speed (S)	2	207.24	103.62	46.70	**	3.55	6.01	11.3915	33.8473
C X S	4	10.459	2.60	1.17	NS	2.93	4.58		
Error	18	39.94	2.2190						
Total	26	285.83							
C.V.% =	**3.57**								
"t" value E =						2.101	2.878		

****** Significant at 1% level of significance, **NS** Non-Significant

Effect on heart rate of subjects for different crops

The increase in heart rate was found during harvesting of different crops (Fig.1) and comparison of mean values of percentage of increase in heart rate was done. Results were analysed statistically and ANOVA (Table 4) shows that different crops had a highly significant effect on the increase in heart rate at 1% significant level.

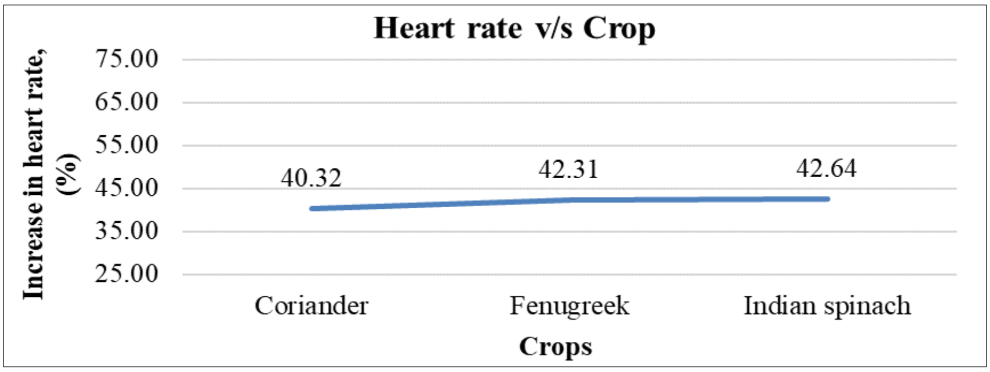


Fig 1: Effect of increase in heart rate for different crops

The heart rate increased during harvesting operation and was found more in Indian spinach as compared to coriander and fenugreek. This may be because of Indian spinach was having comparatively more stem diameter compared to other crops and the needed more time and strength for cutting operation. Thus to harvest Indian spinach crop, operator had to work for comparatively more time for same crop area and may lead to increase stress level. Therefore there was more increase in heart rate in harvesting of Indian Spinach crop compared to other crops,

Effect on heart rate of subjects at different crank speeds

The increase in heart rate was found during harvesting of leafy crops at different crank speed (Fig.2) and comparison of mean values of percentage of increase in heart rate was done. Results were analysed statistically and ANOVA (Table 4) shows that different crank speeds had a highly significant effect on the heart rate at 1% level. It was found that crank speed of 375-425 rpm (S_3) was working with maximum increase in heart rate of 45.26% whereas crank speed of 175-274 rpm (S_1) was working with minimum increase in heart rate of 38.49%. As the crank speed increases resulted in increased forward speed in the developed harvester. As forward speed of machine increases, the walking speed of the subject increases. The forward speed is directly proportional to increase in heart rate. Thus, increment in percentage of heart rate was the found as the crank speed increases.

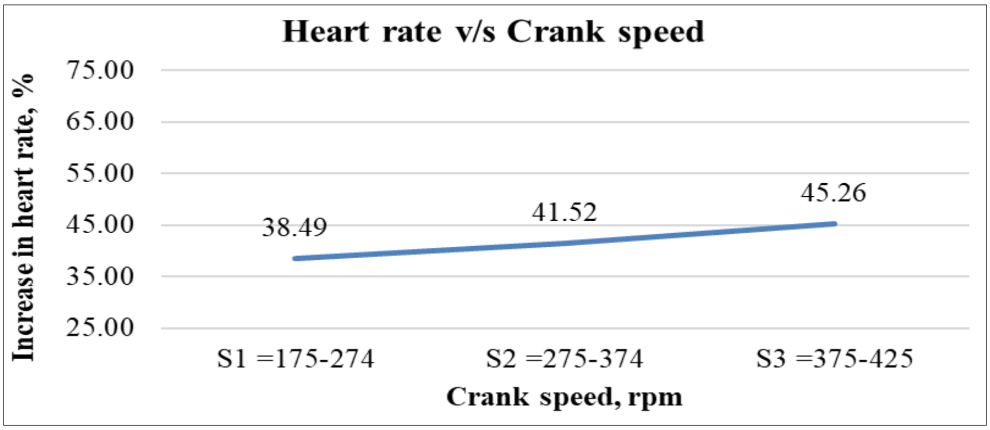


Fig 2: Effect of increase in heart rate at different crank speeds

Oxygen consumption

The oxygen consumption during leafy crop harvesting operation was determined by equation 1. The results of oxygen consumption were analysed statistically and ANOVA table is given in Table 5. All the values was in the normal range of oxygen consumption without fatigue.

Table 5: ANOVA showing the effect of different crop and crank speed on oxygen consumption of subjects

S.V.	df	SS	MS	Fcal	TEST	Ftab 5%	Ftab 1%	SE(m)	CD
Crops (C)	2	0.0156	0.0078	19.17	**	3.55	6.01	0.1544	0.4586
Crank Speed (S)	2	0.1406	0.0703	172.55	**	3.55	6.01	0.1544	0.4586
C X S	4	0.0005	0.0001	0.31	NS	2.93	4.58		
Error	18	0.0073	0.0004						
Total	26	0.1641							
C.V.% =	2.61								
"t" value E =						2.101	2.878		

****** Significant at 1% level of significance, **NS** Non Significant

Effect on oxygen consumption of subjects for different crops

The effect on oxygen consumption during harvesting of different crops was found highly significant at 1% level. The mean values of oxygen consumption for different crops were shown in Fig. 3. The maximum oxygen consumption i.e. 0.80 l/min was recorded with Indian Spinach. This may be because Indian spinach was having comparatively more diameter than other crops. The cutting operation needed more strength and more time. Thus oxygen consumption of the subject increased during harvesting of Indian spinach. The minimum oxygen consumption i.e. 0.74 l/min was observed with coriander. This may be because of diameter of coriander plant was less compared to other crops. Thus subject needed less strength and time resulted in less oxygen consumption. A small capacity (5 kg/batch) biomass pyrolyser was designed and developed for making bio-char from the shredded cotton stalk as feed stalk. Pyrolysis at various experimental temperatures 200, 300, 400 and 500 °C and residence time 60, 120, 180 and 240 min carried out for optimal parameter estimation (Makavana et. al., 2020a) [18].

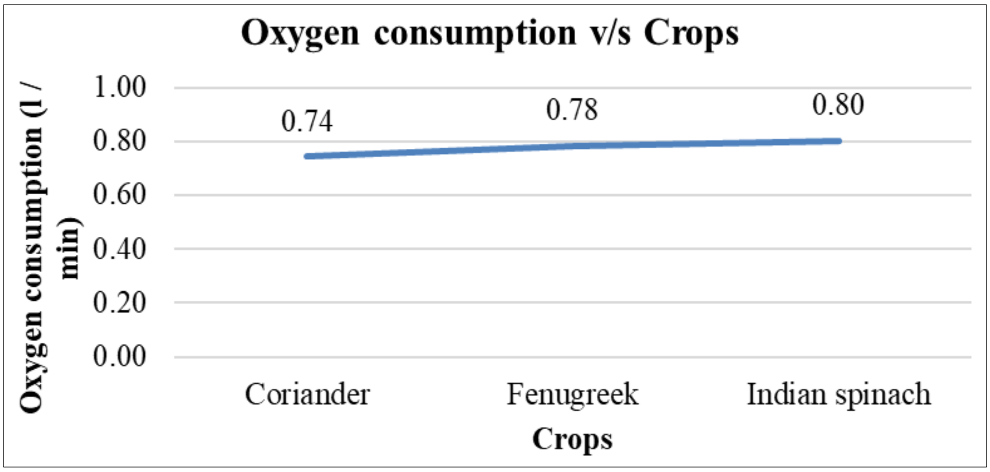


Fig 3: Effect on oxygen consumption for different crops

Effect on oxygen consumption of subjects at different crank speeds

The effect on oxygen consumption during harvesting at different crank speeds was found highly significant at 1% level of significance (Table 5). The graphical representation of mean values of oxygen consumption of subjects at different crank speeds shown in Fig.4. The graph shows that the oxygen consumption increased as crank speed increased from S_1 to S_3 (i.e., Increased oxygen consumption with S_3 (0.86 l/min) followed by S_2 (0.77 l/min) compared with S_1). As crank speed increased, the forward speed of leafy crop harvester was increased. Thus, walking speed of the subject increased. This resulted in the increased oxygen consumption as the increase in crank speed. This increase was due to more stress on the subject when walking speed was increase different forward speed of operation 1.0 – 1.5, 1.5 – 2.0 and 2.0 – 2.5km/h, Plant damage was observed as 7.40,7.86 and 8.45 respectively (Kachhot *et al*. 2020) [15].

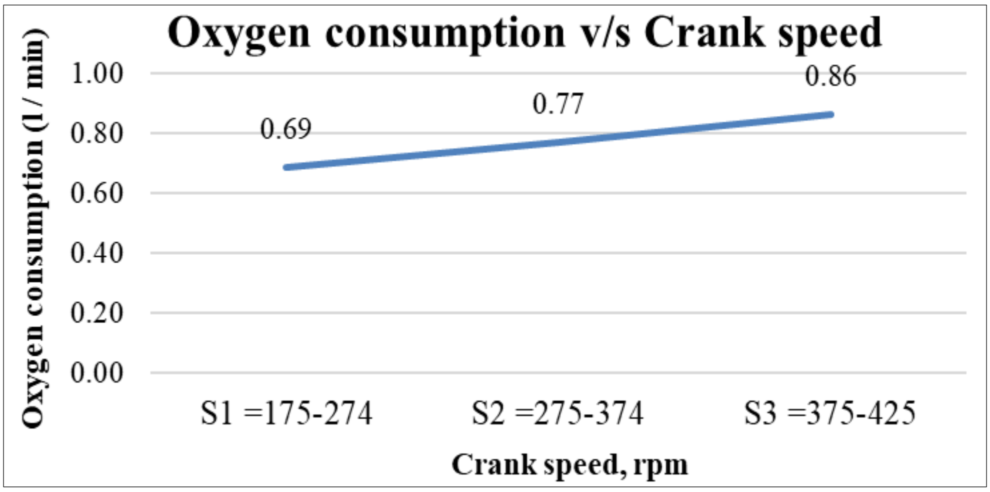


Fig 4: Effect on oxygen consumption at different crank speeds

Energy expenditure rate: The energy expenditure rate during leafy crop harvesting operation was determined. The results of energy expenditure rate during harvesting operation were analysed statistically and ANOVA table is given in Table 6. All the values of energy expenditure rate were in the category of light to moderate work.

Table 6: ANOVA showing the effect of different crop and crank speed on Energy expenditure rate

S.V.	df	SS	MS	Fcal	TEST	Ftab 5%	Ftab 1%	SE(m)	CD
Crops (C)	2	0.3889	0.1944	19.29	**	3.55	6.01	0.7678	2.2814
Crank Speed (S)	2	3.4964	1.7482	173.41	**	3.55	6.01	0.7678	2.2814
C X S	4	0.0167	0.0042	0.41	NS	2.93	4.58		
Error	18	0.1815	0.0101						
Total	26	4.0835							
C.V.% =	2.59								
"t" value E =						2.101	2.878		

****** Significant at 1% level of significance, NS Non Significant

Effect on Energy expenditure rate of subjects for different crops

The effect on energy expenditure rate of subjects during harvesting of different crops was found highly significant at 1% level of significance. The mean values of energy expenditure for different crops were graphically represented in Fig.5. The maximum energy expenditure i.e. 4.01 kcal/min was recorded with Indian Spinach. This may be because Indian spinach was having comparatively more diameter than other crops. The cutting operation needed more strength and more time. Thus energy expenditure of the subject increased during harvesting of Indian spinach. The minimum energy expenditure i.e. 3.71 kcal/min was observed with coriander. This may be because of diameter of coriander plant was less compared to other crops. Thus subject needed comparatively less time for harvesting resulted in less energy expenditure.

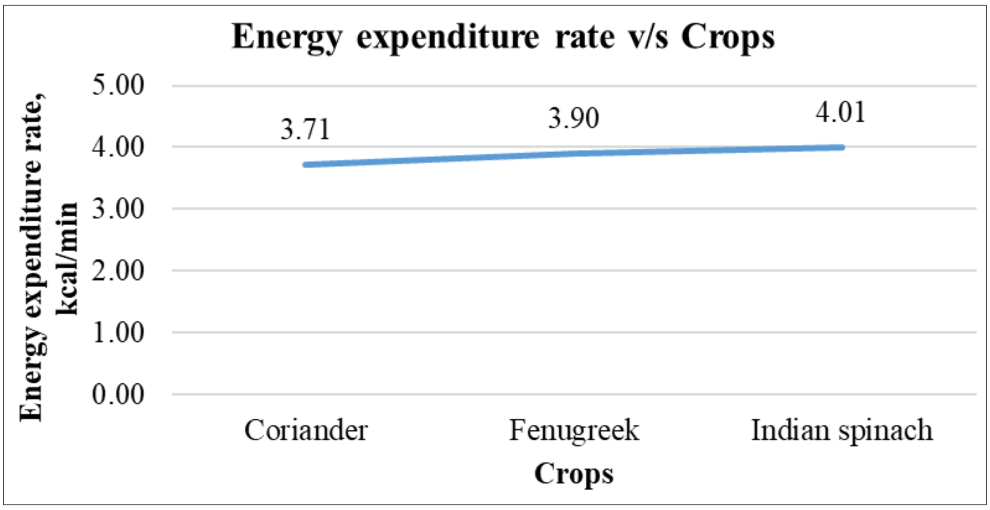


Fig 5: Effect of energy expenditure rate for different crops

Effect on Energy expenditure rate of subjects at different crank speeds

The effect on energy expenditure rate during harvesting at different crank speeds was found highly significant at 1% level of significance. The mean values of oxygen consumption of subjects at different crank speeds were graphical represented in Fig.6. From the Fig.6, results shows that the energy expenditure rate increased as crank speed increased. As crank speed increased, the forward speed of leafy crop harvester was increased. Thus, walking speed of the subject increased. This resulted in the increased oxygen consumption as well as energy consumption rate of subjects. These findings closely aligned with the results reported by Vala *et al.* (2023) [30]. Density was increased by 3.91 times and calorific value was increased by 1.19 times (Makavana *et al.*, 2020b) [19].

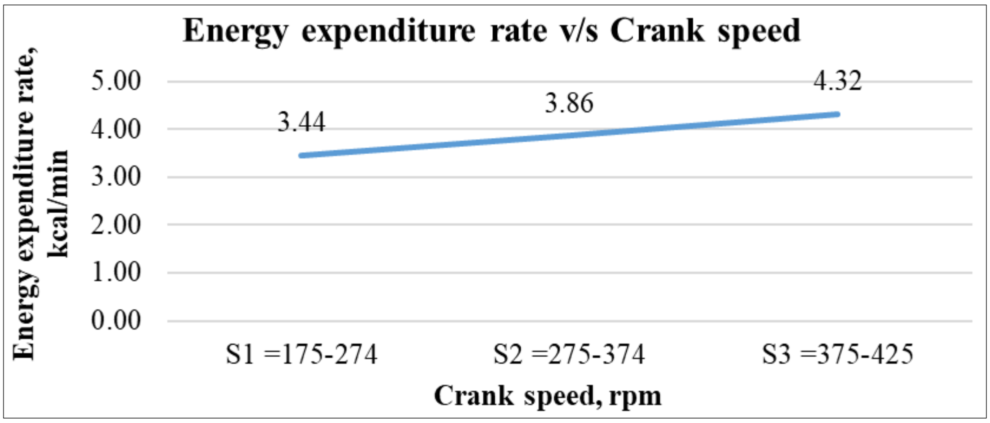
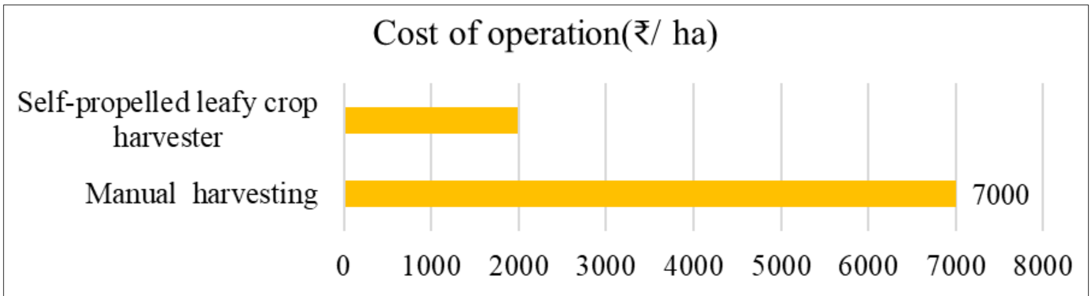


Fig 6: Effect of energy expenditure rate for different crank speeds

Economical Comparison of Leafy Crop Harvesting Methods

The economical comparison between developed leafy crop harvester and manual leafy crop harvesting was done. The operation cost was analysed for the developed leafy crop harvester. Average cost of groundnut threshing, 1.56 Rs/kg (Amrutiya *et al*., 2020) [1]

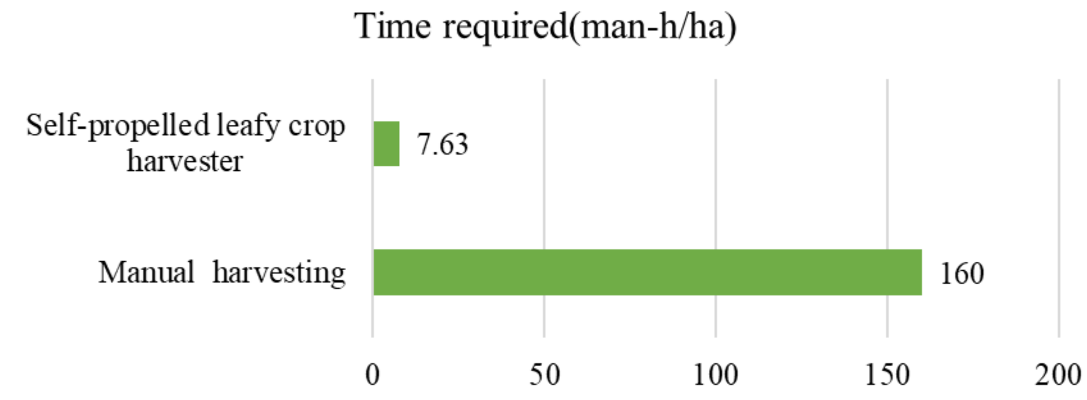
The cost of manual harvesting and developed leafy crop harvester calculated were ₹7000.00 and ₹1990.38 per hectare respectively (Fig.7). The saving in cost per ha with developed leafy crop harvester was ₹ 5009.62. Thus, it saved 71.57% cost of harvesting in one ha area.



	Manual harvesting	Self-propelled leafy crop harvester
Cost of operation(₹/ ha)	7000	1990.38

Fig 7: Cost of operation of leafy crop harvesting

The labour requirements with the developed leafy crop harvester and manual harvesting were 7.63 (≅8) man-hours per hectare and 160 man-hours per ha, respectively (Fig 8). Thus, it saved 95.30% time of harvesting in one ha area.



	Manual harvesting	Self-propelled leafy crop harvester
Time required(man-h/ha)	160	7.63

Fig 8: Time requirement in leafy crop harvesting operation

Break-even point

Fixed cost, ₹ / year = 250×72.10= ₹ 18025 /-

Custom hiring = (260.74+2760.74×0.25) ×1.25 = ₹ 407.41/-

Break-even point = $\frac{18025}{407.41-260.74}$ = 122.90 h y^{-1}

BEP = 3.89 ha y^{-1}

4.2.2 Payback period and benefit-cost ratio

Annual Net Profit = (Custom hiring – Initial Cost of machine) × AU

= (407.41 – 260.74) × 250 = ₹ 36,666.6 /-

Payback period = Initial cost of machine/ Annual Net profit

Payback period = 96135/ 36666.6 = 2.62 years

Total benefit = Average net annual benefit (₹) × Life of machine (L) in year

= 36666.6 × 8 = 293332.8

B: C ratio = $\frac{\text{Total benefit}}{\text{Total cost of investment}} = \frac{293332.8}{96135}$ = 3.05

Conclusion

In conclusion, the findings derived from the experimental investigations in this study yield the following insights. Firstly, an escalation in crank speed led to heightened heart rate, oxygen consumption, and energy consumption rate. Remarkably, Indian spinach exhibited its highest energy consumption rate at 4.41 kcal/min during S3 crank speed, indicating its classification under moderately heavy work. This suggests that while challenges might arise from uneven field conditions during machine operation, the process remains manageable and not excessively strenuous. Secondly, a cost analysis revealed that the cost of harvesting per hectare for leafy crops amounted to ₹1990.38/- and ₹7000/- with self-propelled leafy crop harvesters and manual methods, respectively. The utilization of the developed machine resulted in an impressive 71.57% reduction in harvesting costs per hectare compared to the manual approach, coupled with a significant time-saving of 95.3%. Additionally, the self-propelled leafy crop harvester displayed a benefit-cost ratio of 3.05, a payback period of 2.62 years, and a break-even point of 122.9 hours per year. Ultimately, the innovation of the leafy crop harvester stands out for its substantial contributions: substantial time and cost savings, decreased energy consumption, and a notable reduction in the physical toil associated with leafy crop harvesting.

Acknowledgement
The authors are grateful for the support of the India. Department of Farm Machinery and power Engineering, Collage of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh-362001, Gujarat.

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