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Evaluating Economic Feasibility and Harvesting Cost ofDeveloped Indigenized Carrot Harvesting Machine in Comparison with Manual Harvesting

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ABSTRACT

Carrot harvesting in traditional methods is highly labor-intensive, time-consuming, and costly. Manual harvesting requires a large workforce, involving digging, pulling, and trimming carrots in a stooping position, which not only a difficult job but also poses physical stress in back and health risks. Moreover, labor availability during peak seasons is also hard and they often charge extra for harvesting. To address these challenges, a study was conducted to evaluate the cost-effectiveness of a developed carrot harvesting machineand compared with the manual harvesting. The cost of harvesting was evaluated at optimized machine operational parameters. The machine's operational parameters such as forward speed (1.5, 2.5, and 3.5 km/h) and blade angle (15°, 19°, and 25°) were optimized using response surface methodology. The results showed that the machine achieved minimal damage of 4.06% at 1.5 km/h and 25° blade angle, with a field capacity of 0.31 ha/h and field efficiency of 66.7%. The machine took round 3.5 hours for harvesting one hectare of carrot field and fuel consumption for harvesting obtained was 5.5 L/h.The economic analysis revealed that mechanical harvesting saved 51-60% of costs compared to manual harvesting, resulting efficiency, reduce labor force and minimizing cost.

Keywords:*Carrot harvesting, Cost analysis, Field efficiency, Manual harvesting, Mechanical harvesting,*

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1. INTRODUCTION

Carrots (Daucus carota) are an economically and nutritionally important root vegetable widely cultivated and consumed crop in Pakistan due to its large per unit area yield (Ahmad et al., 2004; Sikora et al., 2020). Carrots are a rich source of beta-carotene, dietary fiber, vitamins and essential minerals, contributing significantly to human health by improving vision, boosting immunity, and promoting skin and digestive health (Arscott &Tanumihardjo, 2010). In Pakistan carrots are cultivated on approximately 17368hectares, yielding around 554787 tons annually (Fruit, vegetablesand condiments statics of Pakistan 2022-23). However, carrot yield in Pakistan still lags that of developed countries due to several challenges that span from sowing to harvesting.The reasons for lower productivity and quality are attributed to limited adoption of improved cultivation practices among growers and relying on manual labor for farm operations like planting, weeding and harvesting which is labor intensive and costly (Kumar and Pateriya, 2022). In Pakistan manual method for harvesting are commonly used. The manual harvesting requires digging, pulling and trimming of leaves through spade, pickaxes and sickles (Gaadhe and Tiwari, 2022). The manual harvesting is labor demanding method, and it requires about 250–350 man-hours for harvesting carrots through one hectare (Wang et al., 2007; Shirwal et al. 2015). Furthermore, manual harvesting poses physical challenges to workers. Laborers must continuously stoop and bend while digging, making the task extremely difficult and leading to ergonomic issues such as back stress and musculoskeletal strain (Hagen *et al*., 1993). Additionally, manual harvesting often results in higher losses due to damage during digging and picking, which reduces overall efficiency, marketability, and profit (Srivastava, 2000). In addition, the shortage of skilled labor during peak harvesting seasons and unpredictable weather conditions cause harvestingdelays and increase crop losses (Bashir *et al*., 2005).Beyond the challenges of manual harvesting another problem is the higher cost of such huge labor especially in peak seasons. Thus, mechanizing carrot harvesting is essential for saving time, reducing labor drudgery, and lowering harvesting costs (Chaudhry *et al.*, 2000). Many researchers reported that using mechanical means for harvesting can reduce cost of harvesting. For example, Sukhwinder *et al*., (2007) reported that mechanical harvesting considerable reduced manpower by 60% relative to manual harvesting. Vatsa *et al*, (1996) stated that mechanical harvesting reduced cultivation costs by 30-50% compared to manual methods, while also increasing efficiency.

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Some researchers have developed tractor operated carrot diggers, but they only pull up carrots from soil and again manual labor must put for cleaning, trimming and gathering carrots. Ikram *et al*., (2018) developed a carrot digger for uprooting carrots, but that uproot carrots from soil only and manual labor again must engage for trimming of leaves and cleaning of carrots. Similarly, carrot digger developed byAshraf *et al*., (2018) dug out carrots but leaves them untrimmed in the field. However, large size mechanical harvesters are commonly used in developed countries, their substantial size and high capital and operational costs make them unaffordable for small-scale farmers.

A machine's performance is also heavily dependent on optimizing its operational parameters. Effective optimization of field parameters is critical for agricultural machinery, as it directly influences crop yields, farm profitability, and ultimately, food security.Various studies have optimized harvesting machines for root crops. For example, Oda *et al*. (2018) optimized an indigenous carrot harvester, while Nour *et al*. (2016) optimized a peanut harvester. Similarly, Shirwal*et al*. (2015) and Narender *et al*. (2019) optimized carrot diggers and harvesters achieving best results at optimized conditions. Researchers have also employed prediction methods, including computer simulations, regression analysis, and mathematical modeling, to optimize carrot harvesting machines. (Askari *et al*., 2021). To address the challenges in carrot harvesting, an indigenous mechanical carrot harvester was developed and evaluated in field to check its cost effectiveness compared to manual harvesting. Statistical analysis was employed using response surface methodology (RSM) for optimizing harvesting parameters. The harvesting cost was evaluated at the optimized machine parameters for best results and the cost comparison of the harvesting with machine was compared with that of manual harvesting.

2. MATERIAL AND METHODOLOGY

The developed carrot harvesting machine efficiently digs, lifts, and trims carrot roots while collecting them in a box. This mechanized system automates all harvesting operations, eliminating manual labor.The study evaluated optimum parameters of developed machinefor efficient working and evaluation of cost analysis of machine and harvesting cost compared with manual harvesting were also carried out. The detail of parts and specifications are shown in Table 2.1.

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Table 2.1 Specifications of carrot harvesting machine

Items		**Specifications**
Structure		Tractor operated
Main frame		MS pipes
	Length	1372 × 165 mm
Digging unit	Dimension	1482 × 246 × 30 mm (2 No.)
Conveyor unit		V belts (4 in Number)
Collection box		1282 x 1368 x 365 mm
Hyd. Pump		Vane pump
	Pressure	3000 PSI, Flow (60 GPM)
Hyd. motor		DH-315, rpm ≈ 345 rpm
Oil Reservoir	Dimension	455× 460× 455 mm (110 litres)

2.1 Experimental site and method

The research was carried in the experimental fields of Agriculture Mechanization Research Institute Faisalabad (latitude 30^{o}22'55" N - longitude 72^{o}03'15" E). The area selected was 4605 m^2 having length of 175 m and width of 42 m and the soil was sandy loam soil with pH of 6.4. The average annual rainfall of the region is 375 mm during the season and the moisture content of the soil at the time of harvesting was 12-14%. The carrots variety T-29 was sown using manual dibbling methods on rows which were made from ridger and then seeds were sown manually. Rows were having bottom width of 490 mm and height of 195 mm and intra row spacing kept was 670.2 mm as per the optimum spacing for carrot crop. Length of each row was 175 m with bare spacing at both ends for the turning operation at each go.A rectangular field (60 x 27m) was prepared by removing water channels to ensure stable machine operation. The area was divided into three blocks (24 x 26m), each comprising 13 plots (1.64 x 25m) with two carrot rows per plot. Tractor forward speed was measured using a stopwatch and measuring tape. Harvested carrots were collected, labeled, and collected in sealed bas for lab analysis, where carrot damage% and harvesting efficiency were calculated using equations (Eq. 1 and 2).

$$Damage\ (\%) = \frac{Weight\ of\ damage\ \ carrots}{Weight\ of\ harvested\ \ carrots} \times 100 \qquad (1)$$

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$$Harvesting\ Efficiency\ (\%) = \frac{Weight\ of\ harvested\ carrots}{Weight\ of\ total\ carrots} \times 100 \quad (2)$$


(a)


(b)

Figure 2.2 (a)Manual Harvesting, (b) Harvesting with machine

2.2 Carrot harvesting machine parameters

A Central Composite Design (CCD) with 13 trials was employed to optimize machine harvesting parameters using Design-Expert v13.0 software. Forward speed (X1) and blade angle (X2) were the independent variables, with carrots damage percentage serving as response variables. The table 2.2 shows the independent variables along with their code levels.

Table 2.2 Independent variables with level codes in RSM

Independent Variables	Code	Actual	Levels		
			-1	0	1
Forward speed (km/h)	x_1	X_1	1.5	2.5	3.5
Blade angle (θ)	x_2	X_2	13	19	25

Here: x_1 = (X1 – 2.5); x2 = (X2 - 19)/6

2.3 Field Efficiency

Field efficiency was calculated by the ratio of actual field capacity to the theoretical field capacity Eq. 3.

$$\text{FE} = \frac{AFC}{TFC} \times 100 \quad (3)$$

FE = Field efficiency (%), AFC = Actual field capacity (ha/h), TFC = Theoretical field capacity (ha/h)

2.4 Fuel Consumption

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The fuel consumption for the harvesting over unit time was calculated by measuring the volume of fuel used for that unit time. The volume of fuel was measured by refilling the tank after the unit time operation of the machine. The fuel consumption was determined by following expression.

$$\text{Fuel Consumption} = \frac{V}{T} \quad (4)$$

Where:

F_c = Fuel consumption, (l/h), V_c = Volume of fuel consumed(l), T = Time of operation(h)

2.5 Cost analysis

The cost analysis included calculating the machine's cost (with tractor) and harvesting costs at optimized parameters. Manual harvesting costs were determined through consultations with laborers and carrot growers.

3. Results and Discussion

Carrot properties

The length, diameter, and weight of carrot was found to 23.4±2.42 – 27.4±2.95 cm, 4.6±2.43 – 68.5±.71 cm, and 80±3.12 – 100±3.58 g respectively.

3.1 Regression model

For predicting the response variables, regression model for independent variables were developed.

$$\text{Damage percentage} = 15.98 - 1.4\,X1 - 0.798\,X_2 - 0.03\,X_1 X_2 + 0.7971\,X_1^2 + 0.020\,X_2^2 \quad (5)$$

Table 3.1 Analysis of variance

Source	SS	DF	MS	F-value	p-value	Results
Model	46.36	5	9.00	34.43	< 0.0001	Significant
X_1-Forward speed	21.34	1	21.67	86.16	< 0.0001	
X_2-Digging blade angle	21.04	1	21.13	81.03	< 0.0001	
X_1X_2	0.2134	1	0.2197	0.8428	0.3549	
X_1^2	4.46	1	4.61	16.87	0.0039	
X_2^2	3.28	1	3.28	12.05	0.0210	
Residual	1.46	7	0.2636			

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Lack of Fit	1.37	3	0.4315	4.07	0.1254	not significant
Pure Error	0.4987	4	0.1413			
Cor Total	52.24	12				
Std. Dev	0.5146		R^2	0.9587		
Mean	6.49		Adj. R^2	0.9412		
C.V%	8.14		Pred. R^2	0.8014		
			Adeq Precision	17.432		

3.2 Effect of independent variables on damage percentage of carrots

The ANOVA results revealed that model was significant at 95% confidence interval and significant effects of forward speed and blade angle on carrot damage percentage ($p < 0.05$The statistical analysis confirmed the model's accuracy and reliability. A non-significant lack of fit test ($p > 0.05$) indicated that the model effectively predicted damage percentage. With a coefficient of determination R^2 of 0.95877, the model revealed a strong fit and was above the recommended threshold of 0.8. Furthermore, the predicted R^2 0.8014 and adjusted R^2 0.9412 values were closely correlated, and the adequate precision ratio exceeded 4, signifying a strong signal-to-noise ratio and validating the model's predictive capability.The interaction effect of forward speed and belt angle were also significant. From (Figure 3.1) increasing machine speed from 1.5 km/h to 2.5 km/h and 3.5 km/h at a constant blade angle of 25° raised damage percentages from 4.06% to 4.58% and further to 7.59%, respectively, likely due to increased vibrations and turbulence. Conversely, increasing the blade angle from 13° to 25° at constant speeds of 1.5 km/h and 2.5 km/h decreased damage percentages from 6.43% to 4.06% and 7.01% to 4.58%, respectively. The lowest damage percentage of 4.06% occurred at 1.5 km/h and 25° blade angle. These findings align with previous studies (Narender, 2019; Horia *et al*., 2008; Shirwal*et al*., 2015), indicating that slower speeds and larger blade angles minimize carrot damage.

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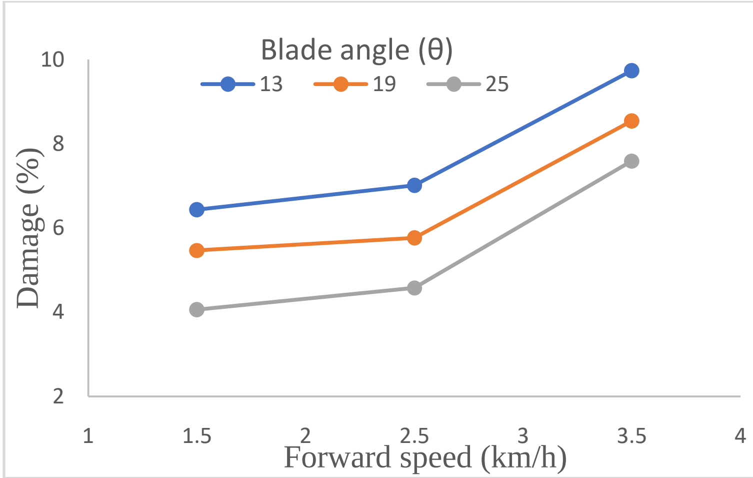

Figure 3.1 Interaction effect of forward speed and blade angle on damage (%)

3.3 Cost analysis

The field capacity at optimized parameters i.e., forward speed 2.5 km/h and blade angle 25°was foundto be 0.30 ha/h, while actual field capacity calculated was 0.45 ha/h and the field efficiency of machine was obtained to be 66.66%. The machine could harvest a hectare of carrot field in 3.5 hours.The fuel consumption was obtained to be 6L/h and took about Rs.1814/h.The total purchase prices for the carrot harvesting machine and tractor were PKR 1,979,129 and PKR 2,400,000, respectively. The expected working life was 10 years for the machine and 12 years for the tractor, with both operating at 400 hours per year. Based on ASABE standards, the salvage values were estimated at 29% of the purchase price for the machine and 22% for the tractor. A detailed breakdown of the costs is provided in Table 3.2.

Table 3.2 Cost analysis of tractor and carrot harvesting machine

Ownership cost of tractor			Ownership cost of machine
Items	**Formula**	**PKR**	**PKR**
Depreciation (D)	(P – S)/L	360/hour	385.9/hour
Interest @ 8% (I)	(P+ S)/2 × i	460.8/hour	362.2/hour
Insurance and housing (IH)	(P+ S)/2 × 0.01	38.4/hour	30.2/hour
Total ownership cost	D + I + IH	859.2/hour	778.3/hour
	Operating cost		
Repair & maintenance (RC)	accumulated repair cost useful hours	66/hour	495/hour

Fuel cost (FC)	0.04 × Hp × Price/gallon	1814.4/hour	0.0/hour
Lubrication cost (LC)	15% of Fuel cost	408.24/hour	88/hour
Labor (L)	1200/day (8hr/day)	200/hour	125/hour
Total operating cost	RC + FC + LC + L	3396/hour	708/hour
Total cost	**Ownership + Operating**	**3348/hour**	**1486.3/hour**
Total cost of both machine			
Tractor + Machine		**Rs.4834.3/hour**	
Harvesting cost	**0.280 ha/hour**		**Rs.17264.35/ha**

3.4 Cost comparison of mechanical and manual harvesting

Manual harvesting of carrots takes about 250- 300 man-hours for harvesting over 1 hectare (Shirwal*et al.*, 2015) while cost of manual labor in Pakistan charges i.e., PRs. 1200/day (8 hours) (Ahmad and Afzal, 2018). The cost of manual harvesting of carrots over one hectare is (PRs. 37,500 to 45,000/-). Table 3.2 indicates that using carrot harvesting machine will cost 4834.3/hour and PRs. 17264.35 per hectare. Comparing with manual harvesting, the machine has a cost saving of 51% – 60.35%. The comparison of manual and mechanical carrot harvester is shown in figure 3.2.

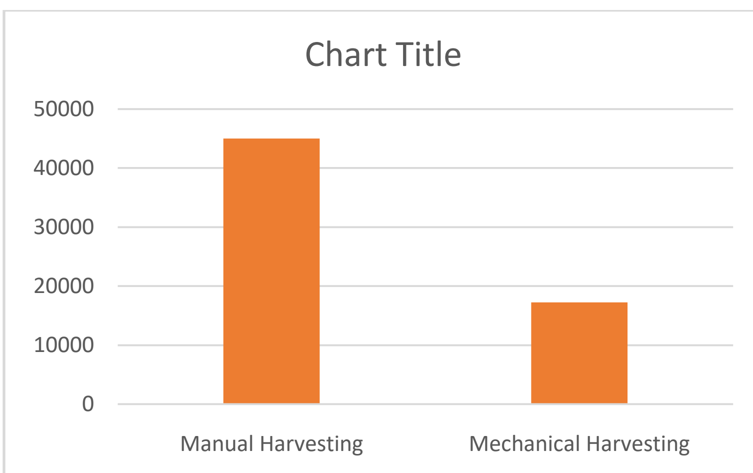

Figure 3.2 harvesting cost comparison of manual and mechanical harvesting

4. Conclusion

The manual harvesting of carrots has become increasingly challenging due to rising labor costs, time constraints, and a shortage of skilled workers. Delayed harvesting not only affects the quality of carrots but also leads to lower market prices. To address these issues, a carrot harvesting machine was developed and field-tested to evaluate its cost-effectiveness compared to manual harvesting. After optimizing the machine's performance, the operational costs were determined. The results showed that the machine efficiently harvested carrots, completing one hectare in just 4 hours, and yielded significant cost savings of 51-60.35%.

Conflict of interest

The authors declare that there is no conflict of interest.

Author's contribution

S.Z. writing original draft, data acquisition, analysis, A.G.: supervision, data acquisition, analysis, proofreading, S.A. and A.T.: review and editing.

5. References

Askari, M., Gilandeh,Y. A., Taghinezhad,E.,El Shal, A.M., Hegazy, R.,&Okasha, M.(2021). Applying the response surface methodology (RSM) approach to predict the tractive performance of an agricultural tractor during semi-deep tillage. MDPI Agriculture. 11:1043.

Ashraf, M., Sadique, G., S. Ahmad, S., &Ahmad, M. (2018). Development of tractor operated carrot digger and its performance evaluation. J Agric. Res., 56(3): 203-207.

ASABE (2008a). Uniform Terminology for Agricultural Machinery Management. ASABE Standards, 49th edn. S495.1 NOV2005. ASABE, St. Joseph, MI.

Bashir, A., Hassan, S., & Bakhsh, K.(2005). Factors affecting yield and profitability of carrot in two districts of Punjab. Int. J. Agric. Biol. 7:794-798.

Chaudhry, M.G., & Ahmad, B.(2000). Dynamics of vegetable production, distribution and consumption in Asia. Asian Vegetable Research and Development Centre, Taiwan. Publication No. 00-498. 271-308.

Fruit, vegetablesand condiments statics of Pakistan 2022-23.

Gaadhe, S.K., & Tiwari, V. K.(2022). Carrot Harvesting Methods: A Review. International Journal of Plant and Soil Science 34(10): 7–16.

Hagen, K.B., Jostein,H.,&Ringdahl, K.H.(1993). Physiological and subjective responses to maximal repetitive lifting employing stoop and squat technique. European Journal of Applied Physiology and Occupational Physiology. 67(4):291-297.

Ikram, K., Nadeem,M., Ghani,M. U., Omar, M. M.,& Malik, M. S.(2018). Fabrication and performance evaluation of carrot digger. J. Glob. Innov. Agric. Soc. Sci. 6:84-87.

Kumar, R., &Pateriya,R. N. (2022). Design of a Tractor Operated Carrot Digger. Pantnagar Journal of Research 20(3): 512-518.

Narender,& Rani, V.(2019). Optimization of performance parameters of digger for carrot crop at farmer's field. International Journal of Agricultural Engineering, 12(2): 217-222.

Narender, Rani, V.,kumar,A.,Mukesh,S.,&Singh,A.(2016). Performance evaluation of tractor operated root-crop digger for sandy loam soils of Haryana. Journal of Agricultural Engineering, 53(1):9-15.

Narender, Rani,V., Mukesh,S.,kumar,A.&Sharma,P. (2019).Optimization of performance parameters of root crop digger for potato crop. Current Agriculture ResearchJournal,7(2): 276-282.

Nour, M.A., El Shal,M.S.,El Shazl,M.A., & Ali,M.M. (2016). Development of a harvesting machine for peanut. Zagazig Journal of Agriculture Research, 48(6A): 2225-2236.

Oda, A.M., Abd El-Wahab,M.K., Tawfik, M.A.&Wasfy,K.I.(2017). Evaluating of a prototype machine for carrot crop harvesting suitable for small holdings. Zagazig J. Agric. Res., 45(1):213-216.

Shirwal, S., Mani,I.,Sirohi,N.P., & Kumar,A.(2015). Development and evaluation of carrot harvester. Ama, Agricultural Mechanization in Asia, Africa & Latin America. 46(1): 28-34.

Srivastava, N. S. L. (2000). Role ofmechanization of horticulturalcrops with emphasis onautomation.Agricultural EngineeringToday. 24(5): 13-28.

Sukhwinder, S., Sanjay,R.,&Manjit,S.(2007). Design and developmentof offset type digger forsugarcane + potato intercropping.Journal of the Indian Potato Association34: 3-4.

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ISSN: 2059-6588(Print)| ISSN: 2059-6596 (Online)
Vatsa, D.K., Singh,S.P., Gupta,R.K.,& Verma,M.K. (1996). Comparative studies on performance of power tiller operated potato diggers in hills. Journal of the Indian Potato Association, 23(3/4): 121-129.

Wang, Z., Zhao,M.Q., Shi-jie,S. L., Da-Qing, L., Han-Tao & Wen-zhong. (2007).Combinedseparationtype carrot digger. J. Inner Mongolia Teach. Univ. 4:87-98.