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Effect of design parameters on mechanical harvesting of ginger

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Abstract
The mechanical harvester for harvesting of ginger crop was developed and the effect of design parameters on harvesting of ginger was studied in this experiment. The important components of the developed ginger harvester include the Digging unit and the Conveyor unit. The design parameters of digging unit (blade geometries) *viz.*, straight blade, inverted V blade and crescent blade at three rake angles of 15, 20 and 25 degree and at three forward speeds of 2.0, 2.5 and 3.0 km h^{-1} were considered for evaluation of digging unit. The best operating conditions were observed at a forward speed of 2.5 km h^{-1} with a rake angle of 20 degree for inverted V type blade. Also the performance of conveyor unit was conducted using different operational parameters *viz.*, angle of elevator (15, 20 and 25 degree) and speed ratio of elevator (1.0, 1.25 and 1.5). The best operational condition was observed at a speed ratio of 1.25 with 20 degree angle of elevator. The combined effect of these two units on the harvesting of ginger crop resulted with a best harvesting performance in terms of minimum draft (2431.57 N) requirement, maximum digging efficiency (99.20%), least damage to ginger rhizome (1.0%) and less fuel consumption (4.72 Lh^{-1}).

Keywords: Mechanical harvester, ginger, digging unit, conveyor unit, draft, digging efficiency

1. Introduction

Ginger (*Zingiber officinale* Roscoe) is one of the most important cash crops and principal spice of India and abroad. It is a perennial plant that grows to a height of 600 to 900 mm from underground rhizomes in tropical and subtropical climate (Mendi *et al.*, 2009) [20]. It is believed to be a native of South East Asia from where it was introduced to Africa and Caribbean regions and used in food and medicines for over 5000 years. The total production of ginger in the world was 2.09 Mt with from an area of 0.322 Mha. India, China, Nepal, Nigeria and Thailand are the major producers of ginger in the world (Anon, 2014) [4]. In India, it is grown in an area of 0.153 Mha with the production of 0.799 Mt (Nair, 2017) [21].

Ginger is one of the spices that support large number of farmers in the states of Kerala, Karnataka, Arunachal Pradesh, Orissa, West Bengal, Sikkim and Madhya Pradesh (Karthick *et. al*., 2015) [14]. However, Karnataka, Orissa, Assam, Meghalaya, Arunachal Pradesh and Gujarat together contribute around 65 per cent of the country's total production. In Karnataka, the ginger production was 0.019 million tonnes from an area of 0.0524 million ha, with an average productivity of 2.80 tonnes per ha (Anon., 2016) [4].

In ginger crop production, the harvesting is one of the most critical operations in which the rhizomes are dogged below the soil surface without damaging the rhizome, separate them from the soil and collected them from the field. But in the conventional method of harvesting, the rhizomes are dugout manually with the help of hand tools i.e., special fork type of spade/pick axe, bullock drawn and power operated devices and by using traditional diggers drawn by tractors or power tillers. However, most of the digging operation during ginger harvesting is done manually due to non-availability of suitable devices. It is not only laborious, costly affair but also cause considerable damage to rhizome to a tune of 10-15 per cent. This is due to digging of soil clump all around the rhizome using hand fork-spade and fork bruise every time it hits the rhizome (Jayashree and Visvanathan, 2011) [13]. The post-harvest studies of ginger indicated that, about 70 per cent of the rhizomes are spoiled and wasted due to the storage rots caused because of rough harvesting and handling practices which cause injury to skin and flesh of rhizomes (Rattan *et al.*, 1988) [23].

The conventional method of manual harvesting of ginger (digging) results into bruising and damaging of rhizomes which affects quality and market price of ginger. Nowadays, getting timely skilled labour for harvesting of ginger crop is a difficult task. So, there is an urgent need to develop a suitable mechanical harvesting technology for harvesting of ginger crops. For ginger crop, mechanical harvesting is a real challenge and it requires a truly an inter disciplinary approach by considering crop as well as engineering factors.

The design parameters of harvesting machine for any root or rhizome crop affects the performance of the machine. Generally the root harvester consists of digging blade and conveyor unit. The tool geometry of the blade affects the digging efficiency of the harvester and draft required. The tool geometry govern by rake angle of the blade and friction angle of the soil (Agbetoye *et al.*, 1998) [1]. This allows the design of simple tools on the basis of the draft force required pulling and soil cutting efficiency. The specific draft force per unit soil area and degree of soil loosening observed to be increased with the relative narrowness of the tillage blades and rake angle (Ahaneku *et al.*, 2008 [2], Mckyes and Desir, 1984) [18]. The draft increases with the width, depth and rake angle of the tool. The cross sectional area of the soil disturbed not change appreciably with the rake angle, but significant increase in draft with angle results in markedly diminished soil cutting efficiency (Saleh *et al.*, 1997) [24]. The best implement design for low draft, high cutting efficiency and superior soil loosening should have rake angle of about 20º and fairly narrow depth to width ratio of 2 or more (Mckyes and Maswaure, 1997) [19]. The convex type blade with 20º rake angle performed better than the concave type with the total soil recovery of 87.60 to 93.44% while it was only 77.47 to 82.14% for concave type blade for 200 mm depth of operation of turmeric harvester (Annamalai and Udayakumar, 2007) [3] with a minimum damage and loss to rhizomes (Trivedi and Singh, 1975) [26]. Accordingly, these factors are considered while developing tractor drawn ginger harvester.

Very few efforts have been made to develop mechanized systems for ginger harvesting in India. Use of self-propelled and tractor drawn equipment's for root crops is very dismal except in potato cultivation. No information is available for mechanical harvesting of ginger on design and operational parameters and power consumption. Hence, a tractor drawn ginger harvester has been designed and developed for ginger crop harvesting and the objective of this study is to know the effect of design parameters on ginger harvesting and overall performance evaluation of developed harvester.

2. Material and Methods

Design and development of tractor drawn ginger harvester has been taken up by considering soil, biometric and machine parameters. It is operated with three point linkage with PTO power of the tractor. The mechanical harvesting of ginger rhizomes is an operation in which rhizomes are dogged, soil mass is separated from rhizome, and finally windrowing the harvested crop by manual picking. The developed tractor drawn ginger harvester is shown in Fig.1. Accordingly, the main components of the developed harvester comprise a) gigging unit for digging the rhizome from the soil and b) elevator unit for soil mass separation from rhizome. Care was taken to see that, the harvester require minimum power, less damage to plant material and maximum soil separation at economic cost of operation. The commonly grown Ginger (*var*. Mahima-2) crop cultivated as per recommended agronomical practices was tested in the farmer's field (4000 square meter area) at Chitta village of Bidar district, Karnataka state. The moisture content of the soil was maintained constant (12.50%) at desired level by allowing the field to dry after irrigation. The depth of operation was also optimized based on biometric properties of ginger rhizome.

Fig 1: Developed tractor drawn ginger harvester-cum-elevator

Matured crop was harvested using the newly designed and developed tractor drawn ginger harvester cum elevator. Three machine parameters were considered as independent variables for evaluation of digging unit *viz.*, a) blade type (Straight, Inverted V and Crescent) b) rake angle (15°, 20° and 25°) and c) speed of operation (2.0, 2.5 and 3.0 km.h^{-1}) and tested for dependent variables *viz.*, draft, digging efficiency, damage of rhizome and fuel consumption. The digging unit was optimized on the above parameters for choosing the best optimized parameters (inverted V blade, 20º rake angle and 2.5 km. h^{-1} speed of operation) and further these parameters were used for the evaluation of conveyer unit. For the evaluation of conveying unit, two independent variables were considered *viz.*, angle of elevator (15, 20, 25 degree) and speed ratio of elevator (1:1, 1.25:1 and 1.5:1 km/h). The performance of elevator unit was tested in terms of performance parameter *viz.*, soil separation index and conveying efficiency. All experiments were replicated thrice and the statistical analysis was done using Factorial Completely Randomized Design tool.

3. Results and Discussion

The performance evaluation of developed ginger harvester cum elevator for both digging unit and elevator units for ginger crop under different machine components variable explained earlier is presented and discussed here under.

3.1 Performance evaluation of digging blade of developed ginger harvester cum elevator

The ginger harvester cum elevator has been designed and developed for mechanical harvesting of ginger crop. It has two important components *viz.*, a) digging unit for digging of ginger rhizomes from the soil and 2) elevator unit for separation of attached soil mass from the rhizomes. The performance evaluation of digging unit by considering multiple factors which affects the performance of digging unit is explained here under.

a) Effect of type of blade, rake angle and forward speed on the draft requirement of ginger harvester

The effect of different operational parameters *viz*., type of blade, rake angle and forward speed on draft of ginger harvester is given in Table 1.From the table, it is evident that, as the rake angle increased from 15 to 25 degree, the draft also increased for all the types of blades and forward speeds. For inverted V blade, the minimum draft was noticed as compared to straight and crescent type blades for all the forward speeds. The minimum draft requirement (2431.57 N) was recorded in inverted V type blade at 15º rake angle followed by 20º rake angle (2615.79 N) for 2.0 km h^{-1} forward speed. Inverted V blade resulted in 33.75 per cent lesser draft as compared to straight blade at the rake angle of 15 degree and forward speed of 2.0 km h^{-1}. Similar trend was noticed for both the forward speed of 2.5 and 3.0 km h^{-1}. This might be due to different regime of soil failure due to different rake angles as different forces acting on the soil and also due to varied tool geometry parameters.

Table 1: Effect of different variables on draft requirement of ginger harvester cum elevator

SI. No.	Type of blade	Rake angle (degree)	Draft (N) Forward speed (km. h^{-1})		
			2.0	**2.5**	**3.0**
1	Straight	15	3411.20	3415.50	3420.10
		20	3539.02	3544.44	3551.23
		25	3658.74	3665.84	3670.84
2	Inverted V	15	2431.57	2460.68	2467.78
		20	2615.79	2625.82	2630.92
		25	2800.31	2814.14	2987.08
3	Crescent	15	3110.53	3122.23	3140.56
		20	3237.59	3268.87	3275.50
		25	3431.08	3434.04	3451.18

Similar findings were reported by Khura *et al.* (2011) [16] for inverted V shape blade with minimum draft for onion digger. Osman (1964) [22] studied the behavior of wider cutting blades and observed that, the draft was minimum at a lift angle of 20 deg. Hettiaratchi *et al.* (1966) [12] developed a two dimensional model for soil failure in front of a wider tool cutting the soil. Gill and Vanden Berg (1967) [8] reported that, the draft force was minimum at 20 deg lift angle for inclined tools which are operating at shallow depth. Godwin and Spoor (1977) [9] and Grisso *et al.* (1980) [10] reported that, the performance of a soil working tool depends on its shape, orientation during movement and initial soil conditions. It was concluded that the draft force of a soil working tool is directly proportional to the tool width and increases exponentially with the operating width. Yumnam and Pratap (1991) [29] recommended the optimum values of rake angle in between 10 and 30 degree for minimum energy requirement for root crops, since the blade rake angle affects the energy consumption in cutting and digging the soil.

b) Effect of type of blade, rake angle and forward speed on digging efficiency of ginger harvester

Effect of blade, rake angle and forward speed on digging efficiency of ginger harvester is depicted in Table 2. From the table it is observed that, the digging efficiency increased as the rake angle increased from 15 to 25 for all the types of blades. But, the digging efficiency increased initially as the speed of operation increased from 2 to 2.5 km h^{-1} and decreased on further increase of speed of operation from 2.5 to 3.0 km h^{-1}.

Table 2: Effect of different variables on digging efficiency of ginger harvester cum elevator

SI. No.	Type of blade	Rake angle (degree)	Digging efficiency (%) Forward speed (km h^{-1})		
			2.0	**2.5**	**3.0**
1	Straight	15	80.60	82.85	82.70
		20	83.13	85.38	85.23
		25	84.90	87.15	87.00
2	Inverted V	15	93.70	95.95	95.80
		20	96.93	99.18	99.03
		25	96.95	99.20	99.05
3	Crescent	15	83.30	85.55	85.40
		20	87.70	89.95	89.80
		25	88.00	90.25	90.10

The digging efficiency was the maximum at the rake angle of 20 degree for all combinations of variables. The highest digging efficiency (99.2%) was recorded with 25º rake angle for inverted V blade type at 2.5 km h^{-1} forward speed and it is on par with 2.0 km h^{-1} forward speed.

The lower digging efficiency at lower rake angle and lower forward speed might be due to insufficient depth of cut. At higher forward speed (3.0 km h^{-1}) also digging efficiency reduced, because of higher soil disturbance and lesser blade penetration. At optimum rake angle (20°) and forward speed (2.5 km h^{-1}), the higher digging efficiency was obtained. This might be due to optimum depth of cut and optimum soil loosening effect. Similar findings were reported by Vasta *et al.*, (1993) on harvesting of root crops by inverted V blade with maximum tuber recovery with minimum damage.

c) Effect of type of blade, rake angle and forward speed on per cent damage of ginger rhizome

The effect of type of blade, rake angle and forward speed on the per cent damage of ginger rhizome for developed ginger harvester is presented in Table 3.
It is observed that, the as the rake angle increased from 15 to 25 degree, there was a reduction in per cent damage to ginger rhizome for all blade types and forward speeds. The least damage (1%) was observed for inverted V type blade at 25º rake angle and 2.5 km h^{-1} forward speed.

Table 3: Effect of different variables on per cent damage of ginger rhizome

SL. No.	Type of blade	Rake angle (degree)	Per cent damage (%) Forward speed (km h^{-1})		
			2.0	2.5	3.0
1	Straight	15	7.68	7.30	7.55
		20	5.17	4.50	4.73
		25	5.03	4.50	4.72
2	Inverted V	15	4.10	2.15	2.37
		20	3.15	1.06	2.03
		25	3.01	1.00	2.00
3	Crescent	15	8.12	7.60	8.09
		20	5.27	4.80	5.13
		25	4.98	4.60	4.87

The higher damage to ginger rhizome at lesser rake angle might be due to lesser penetration, hence caused more damage to the rhizome. Again the forward speed also had considerable effect on percentage damage of rhizome. At optimum speed (2.5 km h^{-1}), there was sufficient depth of cut and optimum soil loosening effect, hence less damage to the rhizome was found. Further increase in forward speed (3.0 km h^{-1}) resulted in slightly reduced rhizome damage but the results are on par with the results of 2.5 km h^{-1} forward speed. Similar findings were reported by Vatsa *et al.*, (1993) [27] who conducted experiment on potato crop using inverted V blade type harvester.

d) Effect of type of blade, rake angle and forward speed on fuel consumption for ginger harvesting

The effect of operational parameters of ginger harvester cum elevator *viz.*, type of blade, rake angle and forward speed on fuel consumption was studied and the results are presented in the Table 4.
From the table it could be analyzed that, the fuel consumption increased as the rake angle and the forward speed increased for different blades attached to the digging unit. In case of inverted V blade, the average fuel consumption of 4.97 L h^{-1} was recorded which is 16.70 per cent lesser than the straight blade type. The maximum fuel consumption (5.18 L h^{-1}) was observed at the rake angle of 25 degree during the forward speed of 3.0 km h^{-1}. The minimum fuel consumption (4.72 L h^{-1}) was noticed at the rake angle of 15 degree during the forward speed of 2.0 km h^{-1}.

Table 4: Effect of different variables on fuel consumption for ginger harvester cum elevator

SI. No.	Type of blade	Rake angle (degree)	Fuel consumption (L h^{-1}) Forward speed (km h^{-1})		
			2.0	2.5	3.0
1	Straight	15	5.53	5.56	5.59
		20	5.83	5.87	5.93
		25	5.92	5.96	6.04
2	Inverted V	15	4.72	4.78	4.83
		20	4.94	5.03	5.10
		25	5.04	5.11	5.18
3	Crescent	15	5.20	5.25	5.29
		20	5.33	5.39	5.45
		25	5.42	5.46	5.49

For crescent blade, the average fuel consumption of 5.36 L h^{-1} was recorded which 7.28% is more than the inverted V blade. This blade has got maximum fuel consumption of 5.49 L h^{-1} for the rake angle of 25 degree and at the forward speed of 3.0 km h^{-1} whereas minimum fuel consumption of 5.20 L h^{-1} was noticed at rake angle of 15 degree and the forward speed of 2.0 km h^{-1}. The similar trend was obtained for all the combinations of types of blades and forward speed of tractor. Similar findings were reported by Gulsoylu *et al.* (2012) [11] during similar experiments for tillage operations.

e. Optimization of operational parameters for digging unit of ginger harvester cum elevator

Numerical optimization technique was adopted to get optimum independent variables for the best operation of ginger harvester cum elevator and tested using Design Expert 10.0.4 version software. Optimization constraints of experiment are presented in Table 5. The highest desirability index of 0.879 was observed at a forward speed of 2.5 km h^{-1} with 20 degree rake angle for inverted V type blade. Hence, this variable combination was chosen as optimum operational parameters for further performance evaluation of conveyor unit.

Table 5: Numerical optimization constraints on digging unit

Name	Goal	Lower Limit	Upper Limit	Importance	Highest Desirability
Type of blade	In the range	Straight	Crescent	3	0.879 at 2.5 km h^{-1} with 20 degree rake angle for inverted V type blade
Rake angle	In the range	15	25	3	
Forward speed	In the range	2.0	3.0	3	
Draft	Minimize	2336.43	3924.6	3	
Digging efficiency	Maximize	78.18	99.78	3	
Damage of rhizome	Minimize	0.98	8.19	3	
Fuel consumption	Minimize	4.58	6.28	3	

3.2 Performance evaluation of elevator unit of developed ginger harvester cum elevator

The performance evaluation of elevator unit attached to the ginger harvester for effective separation of soil mass from the ginger rhizome digged from the digging unit. Two variables were considered for performance evaluation of elevator unit *viz.*, angle of elevator (15, 20, 25 degree) and speed ratio of elevator (1:1, 1.25:1 and 1.5:1 km/h) by fixing optimum parameters for digging unit. The performance of elevator unit was tested in terms of performance parameter *viz.*, soil separation index and conveying efficiency. The results of the performance evaluation are explained here under.

a) Effect of angle of elevator and speed ratio of elevator on soil separation index of elevator unit

The data on the effect of different variables on soil separation index of elevator unit is given in Table 6. It is seen from the tables that, the average soil separation index was found
to be 79.33 per cent from different speed ratios and angle of elevator. The soil separation index increased as the angle of elevator and speed ratio of elevator increased for a particular value and decreased on further increase of the same. The maximum soil separation index was observed at 20^o angle of elevator and 1.25:1 speed ratio.

Table 6: Effect of different variables on soil separation index of elevator unit

SI. No.	Type of digging tool	Angle of elevator (Degree)	Soil separation Index,%		
			Speed ratio of elevator unit		
			1:1	1.25:1	1.5:1
1	Inverted V	15	76.59	79.10	78.02
		20	82.54	85.38	84.62
		25	75.06	76.90	75.72

This might be due to soil mass attached rhizome digged from the digging unit has tendency to move downward towards the blade of the elevator as it is in motion having optimum angle and creates optimum vibration as well. Further increase in angle of elevator (20 to 25^0) and speed ratio (1.25:1 to 1.5:1) resulted in decreased soil separation index. This might be due to reduced residence time and more inclination resulted in sudden movement of material without separation.

The separating index was less even for lower angle of elevator (15^0) and speed ratio (1:1) also. This might be due to accumulation of soil with the rhizomes on conveyor because of insufficient slope and less vibration due to lesser speed ratio. Similar findings were reported by Verma (1977) [28] on potato crops and Khura *et al.* (2011) [16] for onion crop.

b) Effect of angle of elevator and speed ratio of elevator on conveying efficiency of elevator unit

The effect of angle of elevator and speed ratio of elevator on conveying efficiency of elevator unit is recorded in the table 7. As indicated in the table, the conveying efficiency of elevator unit increases as the angle of elevator and speed ratio increased up to particular limit and then decreased on further increase of angle of elevator and speed ratio. It was observed that, the average conveying efficiency of 93.67 per cent was resulted from different combinations of angle of elevator and speed ratio of elevator.

Table 7: Effect of different variables on conveying efficiency of elevator

SI. No.	Type of digging tool	Angle of elevator (degree)	Conveying efficiency,%		
			Speed ratio		
			1:1	1.25:1	1.5:1
1	Inverted V	15	90.93	93.44	92.36
		20	96.88	99.72	98.96
		25	89.40	91.24	90.06

The maximum conveying efficiency of 99.72 per cent was noticed at 1.25:1 speed ratio of elevator and at 20 degree angle of elevator. The least conveying efficiency of
89.40 per cent was noticed at angle of elevator 25 degree and at the speed ratio of elevator 1:1. The increase of conveying efficiency by 8.81 per cent and decreased by 11.54 per cent was found as the angle of elevator increased from 15^o to 20^o and from 20^o to 25^o, respectively.

This might be due to a higher angle of elevator and speed ratio, the soil and rhizome have tendency to move downward towards the blade of the elevator as it is in motion and creates more vibration. Further increase in angle of elevator (20 to 25^0) and speed ratio (1.25:1 to 1.5:1) decreased soil separation index which results choking of vegetative matter at the windrower and hence reduced the conveying efficiency. This might be due to reduced residence time and more inclination resulted in sudden movement of material without separation.

The conveying efficiency was less even for lower angle of elevator (15°) and speed ratio (1:1). This might be due to accumulation of soil with the rhizomes on conveyor because of insufficient slope and less vibration due to lesser speed ratio. Similar findings were reported by Suryawanshi *et al.* (2008) [25] on groundnut crops.

c) Optimization of operation parameters for conveyor unit

The conveyor unit of the ginger harvester cum elevator was evaluated based on the optimized parameters obtained for digging unit. Further the conveyor unit was tested with different treatment combinations *viz.*, angle of elevator (15, 20 and 25 degree) and speed ratio of elevator (1.0, 1.25 and 1.5). The operational parameters of the conveyor unit were optimized based on the performance parameters of the conveyor unit such as soil separation index and conveying efficiency.

Numerical optimization technique was adopted to get optimum levels of independent variables for the designed and tested models using Design Expert 10.0.4 version software. Optimization constraints of experiments are presented in Table 8 and two best optimal solutions were presented in the Table 9. The highest desirability index of 0.947 (Fig.2) was observed at a speed ratio of 1.25 with angle of elevator of 20 degree. Hence, this treatment combination of 20 degree angle of elevator and speed ratio of 1.25 was chosen as the optimum for further field performance evaluation of ginger harvester cum elevator.

Table 8: Numerical optimization constraints conveying efficiency

Name	Goal	Lower Limit	Upper Limit	Importance
Angle of elevator	Is in range	15	25	3
Speed ratio of elevator	Is in range	1:1	1.5:1	3
Soil separation	Maximize	72.69	86.09	3
Conveying	Maximize	88.08	98.69	3

Table 9: Optimal solutions of conveyor unit

SI. No.	Variables	Optimal Values	The highest desirability index
1	Tool geometry	Inverted V	0.947 observed at a speed ratio of 1.25 with an angle of elevator of 20 degree.
2	Angle of elevator	20^0	
3	Speed ratio	1.25:1	

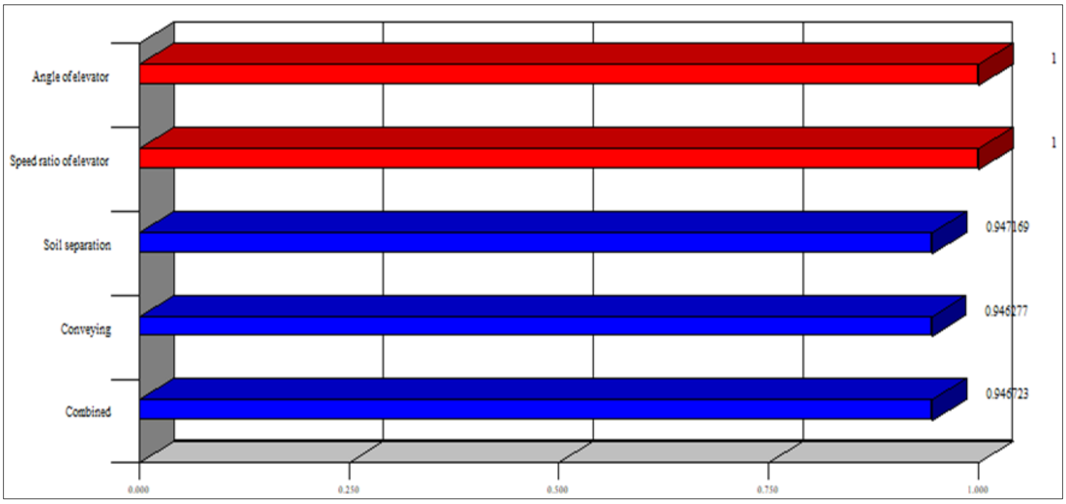

Fig 2: Desirability index of conveyor unit

4. Conclusion

The harvesting of ginger crop is very crucial for getting economic returns. At present no promising mechanized harvesting methods are available for efficient harvesting of ginger crop. The present manual method of digging the rhizome from spike spade and then soil removal results in more damage during harvesting as well as more post-harvest losses along with less shelf life during storage. Hence, the present study on design and development of ginger harvester cum elevator was taken up and based on the above results the following conclusions are made.

Among different blades of digging units tested for ginger harvester, the inverted V blade at the rake angle of 20^0 and operating speed at 2.5 km h^{-1} resulted with better digging unit performance in terms of minimum draft (2431.57 N), maximum digging efficiency (99.20%), least damage to ginger rhizome (1.0%) and less fuel consumption (4.72 L h^{-1}). These optimum combination parameters resulted in maximum desirability index (0.879).

Also the conveyor unit tested with two variables, the best combination of 20 degree angle of elevator and 1.25:1 elevator speed ratio was found to be optimum with best results in term of maximum soil separation index (85.38), maximum conveying efficiency (99.72%) and the highest desirability index (0.947). Hence, the inverted V type digging blade at 20° rake angle and at 2.5 km h^{-1}operating speed along with 20° angle of elevator and 1.25:1 elevator speed ratio was found to be the best for efficient ginger harvesting at 12.50 per cent soil moisture content.

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