International Journal of Environment and Climate Change

Volume 13, Issue 8, Page 304-311, 2023; Article no.IJECC.99009
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Development and Performance Evaluation of Maize Stalk Harvester

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i81954

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/99009

Original Research Article

Received: 20/02/2023
Accepted: 23/04/2023
Published: 24/05/2023

ABSTRACT

A power operated maize stalk harvester was designed and developed in the Dept. of Farm Machinery and Power Engineering, MPUAT, Udaipur, Rajasthan during 2018-19. The objective of this study is to optimize the operational parameters of the maize stalk harvesting by using the RSM techniques. The effects of independent parameters i.e., blade speed (2000, 4000 and 6000 rpm) and stalk moisture content (38, 42 and 46%) on cutting efficiency (%) and fuel consumption (l/h) were studied. To correlate the independent parameters with the dependent parameters, the central composite rotatable design (CCRD) method with a quadratic model was used. The findings indicated that the variations in blade speed and stalk moisture content affected the cutting efficiency (%) and fuel consumption (l/h). To assess the statistical significance of the model, an analysis of variance (ANOVA) was performed, which showed good agreement between the experimental data and data predicted by the model. The blade speed of 4000 rpm and stalk moisture content of 46.0% was found to be the optimum for power operated maize stalk harvester with the 96.52% cutting efficiency and 0.72 l/h fuel consumption.

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Keywords: Stalk harvester; blade speed; stalk moisture content; cutting efficiency; fuel consumption.

1. INTRODUCTION

Maize is a native crop of America. It was introduced to India by the Portuguese during the 17th century. It is grown in many parts of the country throughout the year. Kharif (monsoon) season is the main growing season in northern India. Maize is the third most important food grain in India after wheat and rice, with around 9.86 million ha area under this crop in the year 2020-21and 31.51 million tonnes annual production and 3195 kg/ha productivity [1]. In India, about 28 per cent of produced maize is used for food purposes, about 11 per cent as livestock feed, 48 per cent as poultry feed, 12 per cent in the wet milling industry (for example starch and oil production) and 1 per cent as seed [2]. Maize extensive use is for livestock feeds: cattle poultry and piggery both in the form of seed and fodder. In most of the developing countries maize is consumed directly as food. In India, over 85 per cent of the maize production is used as food. The green fodder can be fed to milch cattle to boost the milk production of a considerable extent. The maize has to be harvested when the grains are in milky stage and is supposed to have lactogenic effect hence, especially suited for milch cattle. The digestibility of maize fodder is higher than sorghum, bajra and other non-leguminous forage crops. Livestock production is the backbone of Indian agriculture contributing 7 per cent to National GDP and a source of employment and ultimate livelihood for 70 per cent of the population in rural areas. In India, to cut and chop the fodder crop different types of self-propelled and tractor-mounted forage harvesters are available in the market which is fully mechanized. The major issue regarding the self-propelled machines is the very high cost. Their design is limited to a specific task. Hence these machines being so costly cannot be used for any other productive work. The high degree of automation in such machines makes it unpopular among the farmers. Proper training has to be given to the operator for precise work. The self-propelled machines thus are sophisticated considering the current scenario of a typical Indian farmer. Tractor-mounted harvesters are popular among a handful of rich farmers. However, due to their overall size and the requirement of tractors, they are not used on small farms [3-5]. The power requirement is high and a tractor above 40 hp is needed. Tractors are available for rent and a skilled operator is also available but our Indian farmers cannot even afford that, leading to their dependency on the traditional method of fodder harvesting by sickle resulting in the drudgery of labour, time-consuming, low work capacity and high labour cost. There is no appropriate small harvester to cut the stalk of maize after the cob is removed from the plant. Therefore, a small-size stalk harvester is an essential machine to reduce the cost of harvesting and reduce drudgery. To overcome these drawbacks a manually pushing type power operated small size maize stalk harvester was developed and its performance was evaluated under field conditions.

2. MATERIALS AND METHODS

The maize stalk harvester was developed to cut the stalks by a circular serrated blade with the principle of shear or impact. The construction and functional components of the maize stalk harvester has been discussed in this section. The maize stalk harvester consists of main frame engine, blade & flexible shaft, handle and transportation wheels as shown in Fig. 1 (a) and (b). The functions of each part and the materials of construction, along with the specification are as follows.

2.1 Main Frame

The main frame was made up of 25.4×25.4 mm square M.S. pipe. The components engine, handle, blade, flexible shaft, windrower, row crop divider and handle are mounted on it. The frame was rigid and strong enough to bear the load of all components mentioned above.

2.2 Engine

A 1.8 kW petrol engine was selected as the source of power to operate the cutting unit of the developed maize stalk harvester. Technical specifications of the engine are shown in Table 1.

(a)

(b)

Fig. 1. Developed maize stalk harvester

Table 1. Specifications of the engine

Sl. no.	Particulars	Specifications
1.	Number of strokes	2 strokes
2.	Type of cooling system	Air-cooling system
3.	Maximum output (kW @rpm)	1.8 @3600
4.	Displacement (cc)	52
5.	Method of start	Recoil type
6.	Fuel type	Petrol mixed with lubrication oil (25:1)
7.	Fuel tank capacity	1.1 litre
8.	Weight	4 kg

2.3 Cutting Blade

A circular rotating blade of 250 mm diameter having 120 serrated teeth on the periphery was used for cutting. It was fixed on bevel gear casing by holders and reverse screws. The blades were made up of carbon steel with 2.5 mm thickness teeth.

2.4 Power Transmission Shaft

The power from the engine to the blade was transmitted by the shaft connected to the clutch. The power transmission shaft consists of flexible shaft and solid shaft. The length of flexible and solid shaft were 810 mm and 175 mm, respectively with the diameter of 8 mm. The flexibility of shaft helps in easy adjustment of cutting blade position on the frame for efficiently cutting of the crop during different field conditions.

2.5 Bevel Gear Casing

Bevel gear casing was fixed in between the flexible shaft and the cutting blade unit. The casing consists of a spiral bevel gear of 1:1 ratio which transmits the power from the shaft to the blade at 90°.

2.6 Windrower

Two windrower one is at top and another at the bottom for windrowing of harvested maize stalk to the field at left side of harvester. The bottom windrowing unit was placed just above the cutting blade for easy windrowing of harvested stalks. The windrowers are made of M.S. flat of cross section 12.5×3 mm.

2.7 Crop Row Divider

The crop row divider was made up of 18 gauge G.I. sheet and mounted at the front of the main frame. It helps in dividing the rows of crop.

2.8 Handle

A handle was attached to the frame, made up of 25.4 mm diameter round pipe and was designed on the basis of anthropometric data of Indian agricultural workers. The handle was used to guide and push the harvester during the operation. Hand grip was provided on handle for easy handling. It also prevented vibration to the operator developed during the operation in the field.

2.9 Experimental Procedure

The effect of blade speed (2000, 4000 and 6000 rpm) and stalk moisture content (38, 42, 46%) on cutting efficiency and fuel consumption were investigated in the experimental field of Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, Rajasthan. The detailed experimental parameters and their levels has been shown in Table 2.

The cutting blade with 60 teeth was mounted on the frame and fixed at 2000 rpm. The maize stalk harvester was run for 20 meters at a forward speed of 1.5 km/h. The machine was initially run at no load to ensure that each component of the machine was working properly. The data on cutting efficiency and fuel consumption were recorded during the performance evaluation of the harvester. The experiment was replicated at all three levels of blade speed and number of teeth on blade.

2.10 Data Analysis and Statistical Modelling

Data analysis and statistical modelling was conducted by response surface method (RSM). It is a technique that is most suitable for optimizing the experimental parameters with the fewer number of experiments and analysing the interactions among the parameters [6]. It is one of the economic tools used for statistical analysis of the data, studying the effect of parameters and constructing an empirical model [7]. To reduce the number of experiments and to optimize the parameters studied, the central composite rotatable design (CCRD) with quadratic model was used in this study.

To understand and explain the effect of blade speed and stalk moisture content on the cutting efficiency and fuel consumption a regression analysis of the experimental data was performed. The design expert software package (Version 13.0, Stat–Ease, Statistics Made Easy, Minneapolis, MN, USA) was used for the regression analysis of experimental data,

Table 2. Experimental design with dependent and independent parameters

Independent parameters	Levels	Dependent parameters
Blade speed, rpm	2000, 4000, 6000	Cutting efficiency, %
Stalk moisture content, %	38, 42, 46	Fuel consumption, l/h

plotting of response surfaces and contour graphs at the optimized conditions. The validation of the suggested models was done using ANOVA. The coefficient of determination (R^2) was used to measure the accuracy of the fitted model and the statistical significance of the parameters was tested using the probability value (P–value).

2.11 Numerical Optimization of Independent Parameters

To find the best combination of operational parameters of the digging blades of apower tiller operated groundnut harvester, efforts were made to optimize the independent parameters (soil moisture content and rake angle). Numerically, the optimum value of the experimental parameters was described through the desirability function technique [8]. It employs the transformation of dependent parameters on a scale of 0 (completely undesirable) to 1 (most desirable) for desirability function analysis. The criteria for selecting the independent parameters viz. blade speed and stalk moisture content were set in the experimental range with maximum cutting efficiency and minimum fuel consumption.

3. RESULTS AND DISCUSSION

The power operated maize stalk harvester was evaluated in the field with respect to cutting efficiency, field capacity and fuel consumption at the different levels of independent parameters.

3.1 Effect of Blade Speed and Stalk Moisture Content on Cutting Efficiency

Effect of blade speed and stalk moisture content on cutting efficiency of power operated maize stalk harvester has been shown in Fig. 2. The response surface plot shows the interaction of cutting efficiency with blade speed and stalk moisture content. It was observed that the cutting efficiency was found to be 91.43, 92.32 and 94.76 at the blade speed of 2000, 4000 and 6000 rpm, respectively at a stalk moisture content of 38%. It was also observed that at a stalk moisture content of 42% and 46%, the cutting efficiency was found to be 93.21, 94.12 & 96.72% and 95.15, 96.81 & 98.92% at the blade speed of 2000, 4000 & 6000 rpm, respectively.

From Fig. 2, It is observed that the cutting efficiency of the maize stalk harvester increased with the increase in blade speed. The reason may be due to less time is required to cut the plant at higher blade speed. The result was supported by Yiljep and Mohammed [9] for cutting of sorghum stalk.

It is also seen that the cutting efficiency of the maize stalk harvester increased with the increase in stalk moisture content in all the combinations studied. The reason may be due to fact that the less hardness of the pith of the plant at higher stalk moisture content. Similar result was obtained by Kumar [10].

3.2 Effect of Blade Speed and Stalk Moisture Content on Fuel Consumption

Effect of blade speed and stalk moisture content on fuel consumption of power operated maize stalk harvester has been shown in Fig. 3. The response surface plot shows the interaction of fuel consumption with blade speed and stalk moisture content. It was observed that the fuel consumption was found to be 0.74, 0.78 and 0.84 l/h at the blade speed of 2000, 4000 and 6000 rpm, respectively at a stalk moisture content of 38%. It was also observed that at a stalk moisture content of 42% and 46%, the fuel consumptionwas found to be 0.69, 0.73&0.79 l/h and 0.67, 0.72 & 0.77 l/h at the blade speed of 2000, 4000 & 6000 rpm, respectively.

From Fig. 3, It is observed that the fuel consumption of the maize stalk harvester increased with the increase in blade speed. The reason may be due to fact that at higher blade speed the power requirement is more, causes more fuel consumption.

It is also seen that the cutting efficiency of the maize stalk harvester increased with the increase in stalk moisture content in all the combinations studied. The reason may be due to fact that at lower moisture content the pith hardness of the plant is more which requires more power and time to cut the stalk, resulting more fuel consumption. Similar result was obtained by Kumar [10].

3.3 Data Analysis and Statistical Modelling of Cutting Efficiency and Fuel Consumption

The analysis of variance (ANOVA) of the cutting efficiency and fuel consumption for fitting of quadratic model to experimental data was performed and is shown in Table 3. It was observed that the blade speed (A) and stalk moisture content (B) had significant effect, and their interaction had a significant effect on cutting efficiency and fuel consumption. The empirical model (Eq. 1 and Eq. 2) in terms of coded factors has been developed to express the relationship between the independent and dependent parameters.

Cutting efficiency (%),

$$\text{Cutting efficiency} = 94.14+1.77A + 2.06B + 0.11AB +0.69A^2+ 0.29B^2 \ldots.(1)$$

Fuel consumption (l/h),

$$\text{Fuel consumption} = 0.73+0.05A -0.03B - 0.00\,AB - 0.003A^2 +0.01B^2 \ldots.(2)$$

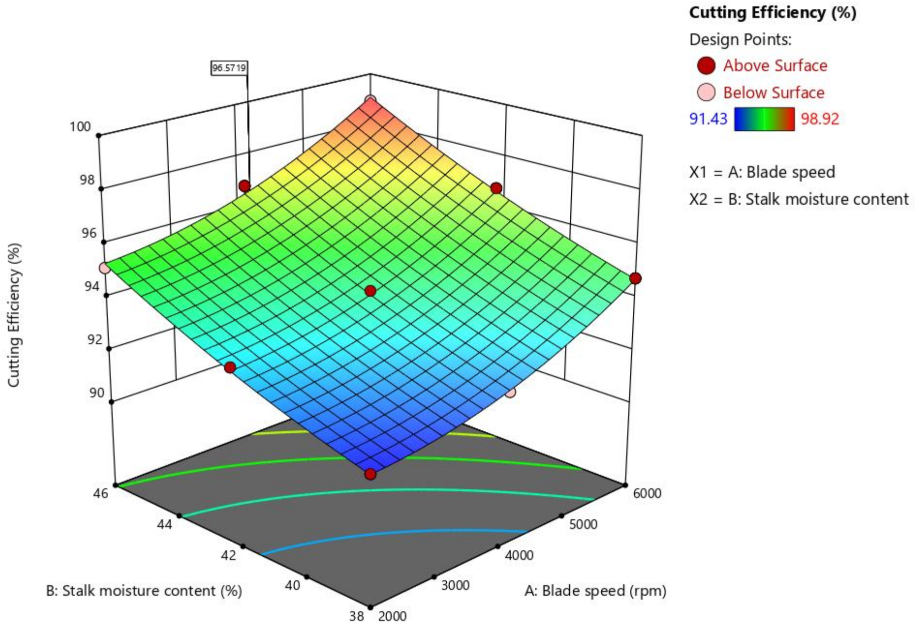

Fig. 2. Response surface and contour plots for the cutting efficiency with blade speed and stalk moisture content

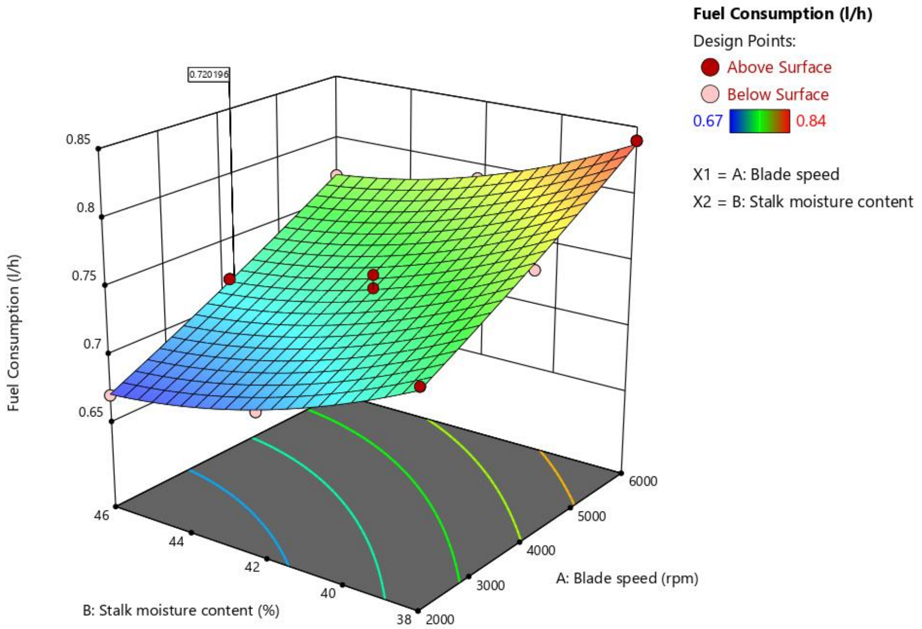

Fig. 3. Response surface and contour plots for the fuel consumption with blade speed and stalk moisture content

Table 3. ANOVA for the effect of parameters on draft for a quadratic model

Source	Cutting efficiency (%)			Fuel consumption (l/h)		
	F– value	P value	Regression coefficient	F– value	P value	Regression Coefficient
Model	130.7	< 0.0001		88.99	< 0.0001	
A	265.65	< 0.0001	1.77	301.06	< 0.0001	0.05
B	361.09	< 0.0001	2.06	133.8	< 0.0001	-0.0333
AB	0.6853	0.4455	0.11	0	1	0
A^2	17.25	0.0089	0.6934	0.3521	0.5787	0.0026
B^2	3.09	0.1392	0.2934	8.11	0.0359	0.0126
Lack of Fit	0.9407	0.552^{ns}		0.163	0.912^{ns}	
Statistical measures						
R^2	0.992			0.988		
Adjusted R^2	0.984			0.977		
Predicted R^2	0.955			0.963		
APR	39.02			31.97		
CV(%)	0.280			0.944		

Table 4. Optimized solutions for V–blade and straight blade geometries

Blade speed (rpm)	Stalk moisture content (%)	Cutting efficiency (%)	Fuel consumption (l/h)	Desirability
4077.85	46.00	96.52	0.72	0.851

3.4 Numerical Optimization of Independent Parameters

For optimization of parameters, the cutting efficiency was set to their possible maximum and fuel consumption was set to their minimum. The solution with maximum desirability (0.851) was considered as the optimum solution, as given in Table 4. The values were found to be 4077.85 rpm blade speed, 46.00 % stalk moisture content, 96.52% cutting efficiency and 0.72 l/h fuel consumption.

4. CONCLUSIONS

The following conclusions could be made based on the results of the study. The results revealed that the cutting efficiency and fuel consumption were significantly influenced by the blade speed and stalk moisture content. The cutting efficiency increased with the increase in blade speed (2000 to 6000 rpm) and soil moisture content (38% to 46%). The fuel consumption increased with the increase in blade speed (2000 to 6000 rpm) and decreased with increase in stalk moisture content (38% to 46%). The optimum values for using maize stalk harvester at 0.851 desirability were found to be 4077.85 rpm blade speed, 46.00% stalk moisture content, 96.52% cutting efficiency and 0.72 l/h fuel consumption.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/99009