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EDITORIAL

I felt that the 20th century wouldn't finish, but has found the 21 years already being about to pass in the 21st century. Time vanishes quicker than our actions and responses to the external stimuli. Now it is Covid-19 that annoys human being the most. Although it is still unclear how this coronavirus emerged, we are being busy sending people to another world. Therefore, people are wearing a face mask everywhere in the world when walking on the street.

Covid-19 is said to be spread by an airborne infection. That's why people are enforced to wear a face mask. This is probably the first scenery that the humankind encounter in the history. Has there been a world in the past decades where people all over the world are walking clad in face masks like this? Never. The fact that all the people in the world do the same thing at once must mean that the system of "living" for human beings has completely changed. In other words, this is caused by the well-developed networks of information and communications, resulting in quickly and easily connecting people in the world and that even a piece of information happened in remote area of the world has become easier to reach.

During the technological progress changing the human world, we always are face-to-face to the crops in the fields and look for new mechanization of agriculture. Agricultural mechanization is entering an era of using AI as well as mechanisms, ranging from large to small. Under this situation, Covid-19 could lead to inspire the creation of smarter and very small agricultural machinery. Once you would use these small machines, it may be able to catch all the coronaviruses around you.

Time goes by further, and more and more new technologies emerge. Under such circumstances, the most important thing is how to use it for happiness and wellbeing of the people. Many kind of techniques are often used (or abused) not only for people's happiness but also for killing them. Microbial technology, can also be known as microbial weapons, is used for both good and bad things. The time has come when we must re-think what we, as human-being, must do, what should be our ethics and roles, instead of blindly following the development of technology.

Yoshisuke Kishida
Chief Editor
August, 2021

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Effect of Some Process Conditions on Oil Recovery Efficiency from Palm Kernel Under Uniaxial Compression

by

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Abstract

Effect of some process conditions on oil recovery efficiency from palm kernel under uniaxial compression was studied. Palm kernel (Dura Variety) - obtained from the Nigerian Institute for Oil Palm Research (NIFOR), Benin, Nigeria, were dried to 4.5% (wb) moisture content. The palm kernels were crushed using a hammer mill and were further reduced using an attrition mill. The crushed samples were classified as fine and coarse based on particle size, using a set of laboratory Endocotts Test Sieves and Shaker. A model laboratory mechanical oil expeller with a temperature controller and a force measuring device was used to expel oil from the palm kernel under uniaxial compression using a 15 tones hydraulic press. Effects of heating temperature (70, 90, 110 and 130 °C) and applied pressure (6.0, 9.0, 12.0, and 15.0 MPa) on the oil recovery efficiency were studied for each of the particle size. The results obtained were subjected to statistical analysis using Analysis of Variance (ANOVA). Test results revealed that oil recovery efficiency increased with increasing heating temperature from 70 °C to 110 °C and later decreased when the heating temperature was further increased from 110 to 130 °C for each of the particle size investigated. The results also revealed that oil recovery efficiency increased proportionally as the applied pressure increased from 6 MPa to 15 MPa for both particle sizes. The results further revealed that the mean oil recovery efficiency for fine particle size is significantly higher than that of coarse particle sizes at 5% level of significance. In order to maximize oil recovery efficiency during mechanical expression of palm kernel oil under uniaxial compression, it is important to note that the process conditions (heating temperature and applied pressure) must be properly controlled.

Keywords: Palm Kernel Oil, Oil Recovery Efficiency, uniaxial compression

Introduction

The increase in world's population has undoubtedly increased the demand for fat and oil obtained from oil bearing crops. Oil bearing crops are classified into three groups, namely: Oil seeds and beans; Nuts; and Mesocarps or Fruits. The Oil Palm (Elaeisguineensis), gives both Palm Oil (PO) and Palm Kernel Oil (PKO) (Hartley, 1988). The PO, which is reddish in colour, is obtained from the Orange colour mesocarp, while the PKO is obtained from the hard-liquefied cell within the nut, called the kernel.

RMRDC (2004) reported that

palm kernel oil has a greater preponderance of saturated fatty acids than palm oil (80% compared to 60% for palm oil) with the major fatty acid being Lauric acid. According to Oil world Annual (2000), Lauric acid is the major fatty acid in the composition of Palm Kernel and Coconut oil at about 50%, while no other major oil contains more than about 1% (butter fat contains 3%). Because of their similarity in composition, and properties, palm kernel oil has similar uses to coconut oil in both food and non-food applications. Palm kernel oil and its hydrogenated and fractionated products are widely used either alone or in blends with other oils for the manufacture of cocoa butter substitutes and other confectionary fats, biscuit dough and filling creams, cake icings, ice cream, imitation whipping cream, sharp – melting creaming, table margarines and many other food products.

Modern processing of oil bearing crops (seeds or nuts) into edible or industrial oil is practiced using different methods, which according to Praven (1997) and Breadson (1983), may be categorized into three: a) one is the solvent extraction method in which a solvent, when brought in contact with the preconditioned oil seed or nut, dissolves the oil present in the oil bearing material and the separated mixture is later heated to evaporate the solvent and the oil is obtained; b) the second method is mechanical oil expression, in which, the preconditioned oil seed or nut is passed through a screw press, a hydraulic press or a ram press, where a combination of high temperature and pressure is used to crush the oil bearing material to release the oil; and c) the third method is the wet processing, in which, the oil bearing material is boiled in water leading to a partial separation of oil (clarification).

Mwthiga and Moriasi (2007); Olayanju et al. (2006) and Ajibola et al. (2000), reported that the parameters used before and during mechanical expression of oil from oil seeds affect oil pressing processes. These parameters, according to the researchers, include particle size, heating temperature, heating time, moisture content and applied pressure. Olaniyan (2010) investigated the effects of some process conditions like nature of bean, heating temperature and pressing time on the yield and quality of oil mechanically expressed from castor bean using a piston-cylinder rig in association with California Bearing Ratio Universal Testing Machine (CBR – UTM). Results showed that the process conditions and their interactions were significant on oil yield at 5% level of significance. However, only the pressing time was significant on the extraction pressure while oil yield increased with increased heating temperature and pressing time for the crushed, shelled and unshelled beans.

Bamigboye and Adejumo (2011) reported the effects of the processing parameters of Roselle Seed on its oil yield. The seeds were ground and classified into two particle sizes (fine and coarse). According to the researchers, the investigations showed that oil yield increases with an increase in the processing parameters of pressure up to 30 MPa, temperature of 100 °C and decreased beyond these points, while ground samples were found to have a higher yield than coarsely ground samples at the different processing parameters. They concluded by affirming that processing parameters affect the oil yield from Roselle Seeds. Olaniyan (2006) carried out an experiment with shear butter using the mechanical oil expression rig and reported that higher process loss was observed as a result of higher heating temperatures. According to him, this was so because at higher temperature, there was higher moisture evaporation and oil sublimation.

Although the need for increase in production and utilization of palm kernel oil continues to grow, not much can be found in the literature on studies undertaken on processing factors as related to its oil recovery efficiency using mechanical extraction method. Residues of reagents from chemical extraction of oil pose health risk to consumers, especially when used in the preparation of edibles. The use of mechanical method of oil expression, thus reduces to its barest minimum, the risk of chemical contamination as a result of chemical extraction. This study is therefore, aimed at investigating the effect of some process conditions such as pretreatment temperature, applied pressure and particle size on oil recovery efficiency during mechanical oil expression under uniaxial loading.

Materials and Method

All experimental investigations were carried out in the Engineering Materials Testing Laboratory (EMTL) located in the Engineering and Scientific Services (ESS) Department of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. The average room temperature of the laboratory throughout the duration of the experimental work was 30 °C.

Material Preparation

The palm kernel (Dura Variety) used in this experiment was obtained from the Nigerian Institute for Oil Palm Research (NIFOR), Benin, Nigeria. The moisture content of the palm kernel at the point of procurement was determined and found to be 11.5% (wb). The kernels were further dried to 4.5% (wb) moisture content using the sun drying method. The kernels were cleaned to remove stones and other foreign materials; after which they were packed into air tight containers and stored in the laboratory.

Size Reduction

Preliminary investigation revealed that it is difficult to mechanically extract oil from whole palm kernel using the hydraulic press and the mechanical oil expression rig. As a result of this, size reduction of these kernels was carried out. In order to reduce the size of the palm kernel to particle sizes of fine and coarse respectively; the palm kernels were first crushed with a hammer mill and further crushed for further size reduction using an attrition mill as reported by Olaniyan (2006). After size reduction, particle size analysis was carried out using a set of laboratory Endocotts Test Sieves and Shaker (model SW19 3BR, UK).

Particle size analysis was done in accordance with ASAE (1989): S319 Standard. In line with Adeeko and Ajibola (1989), samples that passed through the 5.6 mm sieve but got retained in the 2.36mm sieve were classified as coarse, while samples that passed through 2.36 mm sieve but got retained in the 0.6 mm sieve were classified as fine.

Experimental Machines and Instrumentation

In this study, a technique for heating oil seed sample before and during expression was adopted. A laboratory mechanical oil expressing piston-cylinder rig which is similar to the one used by Olaniyan (2006) and Mrema (1979) was used.

The model laboratory mechanical oil expeller is made up of three major components: the compression piston, the press cage cylinder and the supporting platform (Olaniyan, 2006). The press cage cylinder was made from a mild steel pipe with an inside diameter of 66 mm, 7 mm thickness and 140 mm long. A 600 W electric band heater was installed round the press cage cylinder to serve as a heating device for the expression process. A 5 mm hole was drilled on one side of the press cage cylinder at a height of 70 mm from the base; this hole is for the fixing of thermocouple probe for temperature monitoring. The rig was adequately instrumented with a temperature controller to control the expression temperature, while the pressure for oil expression was obtained from the hydraulic press via the instrumentation system (force measuring device). **Fig. 1** shows the exploded view of the model laboratory mechanical oil expression rig.

Experimental Design

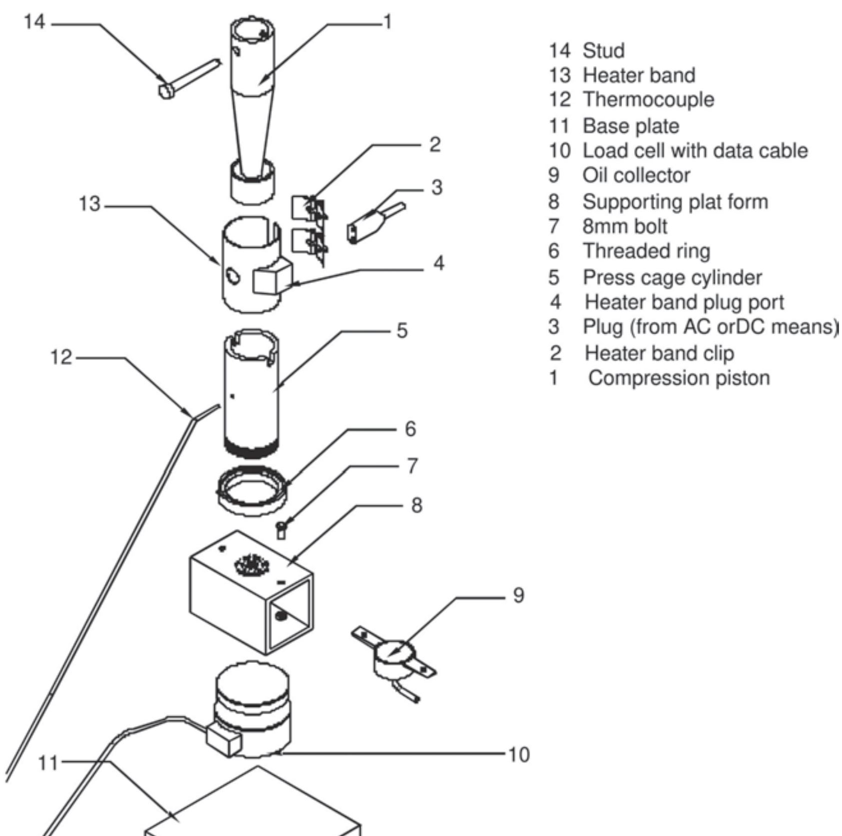
In order to study the effects of operative processing conditions like heating temperature, applied pressure and particle size respectively on oil recovery efficiency during mechanical expression of oil from palm kernel under uniaxial loading, a suitable experimental design that incorporated four levels of heating temperature (70 °C, 90 °C, 110 °C and 130 °C), four levels of applied pressure (6.0 MPa, 9.0 MPa, 12.0 MPa and 15.0 MPa) and two particle sizes (Fine and Coarse) was designed. A $4^2 \times 2$ factorial experimental design in a Randomized Complete Block Design (RCBD) was used. Each test was performed in three replicates at each level of the factors. The ranges of values of factors such as moisture content, heating time and pressing time were also obtained through preliminary investigations and were kept constant throughout the experiments in order to reduce the data to a reasonable size.

Experimental Investigation Procedures

Moisture Content Determination

Moisture content of the sample was determined by oven drying of 100g ground sample at 130 °C for 6 hours; as recommended for oil seeds by Young et al. (1982) and used by Tunde-Akintunde et al. (2001). The average moisture content of 4.5%

Fig. 1 Exploded view of the model laboratory mechanical oil expression rig



was adopted for all the samples used throughout the experiments in order to reduce the data to a reasonable size.

Heating of Ground Palm Kernel

Heating of the ground palm kernel was achieved by weighing 200g of the sample in line with Olaniyan (2006) and transfer the weighed sample into the press cage already encircled with the temperature controlled heater band. The samples in the press cage were heated to the temperatures of 70 °C, 90 °C, 110 °C and 130 °C, respectively for 30 minutes before expression begins. The lower limit of 70 °C and upper limit of 130 °C were selected based on preliminary laboratory investigation, which revealed that heating milled palm kernel sample below 70 °C did not give good oil yield during expression; while heating above 130 °C resulted in excessive burning and darkening of the oil. Also, the heating time of 30 minutes used in this study was based on preliminary investigations and also on the fact that the period allows for temperature uniformity and equilibration of the oil seed cake as reported by Hamzat and Clarke (1993).

Applied Pressure

Pressure was applied to the sample in the press cage cylinder through the compression piston attached to the spindle of the hydraulic press. Samples were subjected to applied pressures of 6.0 MPa, 9.0 MPa, 12.0 MPa, and 15.0 MPa, respectively, for 10 minutes. The lower limit of 6.0 MPa applied pressure was selected based on preliminary investigation which revealed that reasonable quantity of oil cannot be expressed from coarse palm kernel samples at applied pressure below 6.0 MPa, while the upper limit of 15.0 MPa applied pressure was selected based on the capacity of the existing UTM, which was used at the preliminary stage of this work.

Sequence of Mechanical Oil Expression

The complete assembly of the hydraulic press, the mechanical oil expression rig with the temperature regulator, and the compressive force measuring device used in this experiment is as shown in **Fig. 2**. Before coupling the mechanical oil expression rig, a stainless steel wire mesh was placed at the bottom of the cylinder guide in order to cover the drainage area and at the same time serve as a filter during the oil expression process.

After coupling, a sample of 200 g weight of ground palm kernel was poured into the press cage cylinder. The sample was then heated for 30 minutes at heating temperatures of 70°C. Using the actuating lever of the hydraulic press, the compression piston was moved down to touch the sample and pre-compact it to a height of 70 mm (Olaniyan, 2006) inside the press cage cylinder. After pre-compaction, the sample was further compressed by the hydraulic press through the compression piston to a pressure of 6.0 MPa for 10 minutes. The oil expressed drains into the oil collector and collected through the outlet pipe.

The same procedure was followed to carry out the experiment for three other heating temperature levels of 90 °C, 110 °C, and 130 °C with three other applied pressure levels of 9.0 MPa, 12.0 MPa, and 15.0 MPa for the coarse and fine particle sizes, respectively.

Determination of Oil Recovery Efficiency

Oil recovery efficiency was calculated as the ratio of the weight of oil expressed to the total weight of oil in the milled palm kernel sample before expression. It was mathematically expressed by Adeeko and

Fig. 2 Complete assembly of the force measuring device, mechanical oil expression rig with the temperature controller on hydraulic press (Legend: A- Mechanical Oil Expression Rig; B-Temperature Controller; C-Amplifier with display Unit (Force Measuring Device); and D-Load Cell)

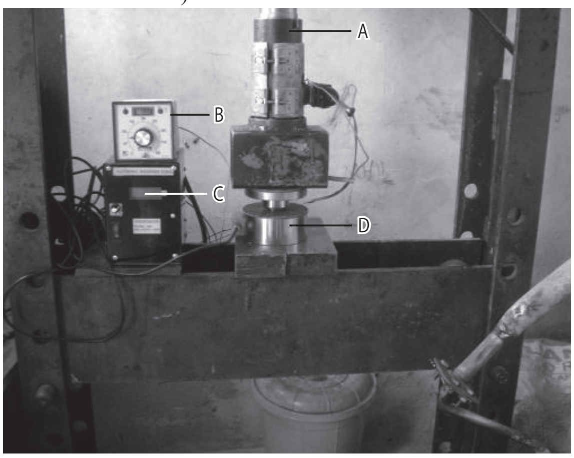


Table 1 Summary of the result of effect of process conditions on measured parameters

Parameter	Temperature (°C)	Particle size	Pressure (MPa)			
			6	9	12	15
Oil recovery efficiency (%)	70	Fine	14.69	16.75	18.61	17.10
		Coarse	2.95	3.71	8.18	4.67
	90	Fine	16.75	18.61	17.10	26.45
		Coarse	3.71	8.18	4.67	4.90
	110	Fine	18.61	17.10	26.45	36.57
		Coarse	8.18	4.67	4.90	8.09
	130	Fine	17.10	26.45	36.57	38.93
		Coarse	4.67	4.90	8.09	20.32

Ajibola (1989) as

RE = (WEO / XWs) × (100 / 1) ...(3.8)

Where,

RE = Oil Recovery Efficiency (%)

WEO = Weight of oil expressed (g)

Ws = Original Weight of sample before expression (g); and

X = Oil content of palm kernel (48%)

Results and Discussion

Table 1 summarizes the test results obtained for oil recovery efficiency at various operating conditions, while **Table 2** is the summary of the ANOVA results showing the effects of process conditions on oil recovery efficiency during mechanical expression of oil from palm kernel. It can be observed that the process conditions such as heating temperature, applied pressure and their interactions had significant effect on oil recovery efficiency at 1% level of significance for fine and coarse particle sizes respectively. Hence, the hypothesis of equality of mean treatment effect is rejected, and it can be implied that at least one of the mean treatment effect is significantly different from the other.

Effect of Heating Temperature on Oil Recovery Efficiency

In order to determine the differences in the mean treatment effect of heating temperature on oil recovery efficiency for both particle sizes, the New Duncan's Multiple Range Test (NDMRT) was used. The result of the comparison among the four levels of heating temperature for each of the particle size is presented in **Table 3**.

In comparing the means of oil recovery efficiency at the four levels of heating temperature, it can be observed from **Table 3** that the highest average oil recovery efficiency was obtained at 110 °C, while the lowest was at 70 °C for both fine and coarse particle size. The table also confirmed that an increase in temperature from 70 °C to 90 °C leads to a more increase in oil recovery efficiency in the case of coarse particle size when compared with increase in heating temperature from 90 °C to 110 °C for fine particle size. The results further confirm a decrease in oil recovery efficiency due to an increase in heating temperature from 110 °C to 130 °C. It was evident from the table that the average oil recovery efficiency at each of the four levels of heating temperature was significantly different from each other at 95% confidence level. This confirmed that increasing the heating temperature from one level to the next higher level contributed reasonably to changes in oil recovery efficiency at 5% level of significance considered in this study.

The effect of heating temperature on oil recovery efficiency at different pressures during mechanical expression of oil from palm kernel was also graphically investigated as shown in **Figs. 3A** to **3D**. From these figures, it can be deduced that oil recovery efficiency increased with increasing heating temperature from 70 °C to 110 °C and later decreased when the heating temperature was further increased from 110 °C to 130 °C for each of the particle size investigated.

This implies that in mechanical oil expression process, there is an

Table 3 Temperature comparison on oil recovery efficiency using New Duncan Multiple Range Test (NDMRT)

Particle Size	Temperature (°C)	Oil Recovery Eff. (%)
Fine	70	28.48[a]
	90	37.01[b]
	110	43.89[c]
	130	39.60[d]
Coarse	70	10.01[a]
	90	12.39[b]
	110	21.84[c]
	130	16.64[d]

Means with the same letters along the column are significantly different at p ≤ 0 .05

Table 2 Summary of Analysis of Variance (ANOVA) of the effects of temperature, pressure and particle size on oil recovery efficiency

Parameter	Particle size	Source of Variation	df	SS	MSS	F_{cal}	Prob.
Oil recovery efficiency (%)	Fine	Temperature (A)	3	1522.290	507.430	56.207	0.001
		Pressure (B)	3	9246.183	3082.061	341.395	0.001
		A × B	9	625.671	69.519	7.701	0.001
		Error	32	288.891	9.028		
		Total	47	11683.035			
	Coarse	Temperature (A)	3	972.323	324.108	371.225	0.001
		Pressure (B)	3	2707.013	902.338	1.034E3	0.001
		A × B	9	263.510	29.279	33.535	0.001
		Error	32	27.938	0.873		
		Total	47	3970.784			

optimum temperature beyond which there will be a reduction in the oil recovery efficiency of the expression process.

Furthermore, it was also observed that at lower applied pressures (6.0 MPa and 9 MPa) an increase in heating temperature from 70 °C to 90 °C resulted in minimal increase in oil recovery efficiency lower than when the heating temperature was increased from 90 °C to 110 °C. This is indicated in the nearly parallel nature of the curve from 70 °C to 90 °C followed by a steep slope from 90 °C to 110 °C after which a reduction in oil recovery efficiency as shown by a negative gentle slope from 110 °C to 130 °C. This trend is the same for the fine and coarse particle size of palm kernel. Meanwhile, at higher applied pressures (12 MPa and 15 MPa), the increase in oil recovery efficiency was consistent and progressive with an increase in the heating temperature from 70 °C to 110 °C for fine particle sizes (**Figs. 3C-3D**), but took a different trend for the coarse particle size at 15 MPa (**Fig. 3D**).

It appears that an increase in the heating temperature from 70 °C to 110 °C resulted in some vital processes within the oil bearing material that induced higher oil recovery efficiency. This no doubt resulted in the sharp increase in oil recovery efficiency within this temperature range. In the same manner, an increase in the heating temperature from 110 °C to 130 °C induced some processes in the oil bearing material that do not enhance oil recovery efficiency. Such induced processes are 'surface' or 'case' hardening, oil seed cake consolidation, depolymerization of the oil seed material (Praven, 1997; Lehinger, 1987), burning of the cake and sublimation of the oil in the oil capillaries (Olaniyan, 2006). All these either collectively or individually was responsible for the reduction in the oil recovery efficiency at temperatures beyond 110 °C as observed in this study.

Table 4 Pressure comparison on measured parameters using New Duncan Multiple Range Test

Particle Size	Temperature (°C)	Oil Recovery Eff. (%)
Fine	70	16.78[a]
	90	34.44[b]
	110	42.85[c]
	130	54.92[d]
Coarse	70	4.87[a]
	90	12.11[b]
	110	18.94[c]
	130	24.97[d]

Means with the same letters along the column are not significantly different at p ≤ 0.05 using the DNMRT

Furthermore, high oil recovery efficiency was obtained from samples heated at 110 °C. This result is an improvement when compared to Akinoso et al. (2006) that obtained the maximum oil recovery at 130 °C using a screw press.

Effect of Applied Pressure on Oil Recovery Efficiency

To determine the differences in the treatment effect of applied pressure that contributed more to the changes in the oil yield, the New Duncan Multiple Range Test (NDMRT) was used and the result of the comparison is presented in **Table 4**.

Results clearly show that at all levels of applied pressure, the means of oil recovery efficiency obtained for each of the particle size was significantly different from each other at 95% confident level. This implies that increasing the pressure from one level to the next higher level resulted to a reasonable increase in oil recovery efficiency during mechanical expression of oil from palm kernel under uniaxial loading. The table also shows that the lowest mean value of oil recovery efficiency was achieved at 6.0 MPa, while the highest mean value was at 15 MPa. Generally, the trend of increasing oil recovery efficiency as a result of increasing the applied pressure from 6.0 MPa to 15 MPa was also confirmed using the NDMTR table for each of the particle size investigated.

Figs. 4A to **4D** show the effect of applied pressure on oil recovery efficiency at different heating tempera-

Fig. 3A-3D Effect of temperature on oil recovery efficiency at various pressures

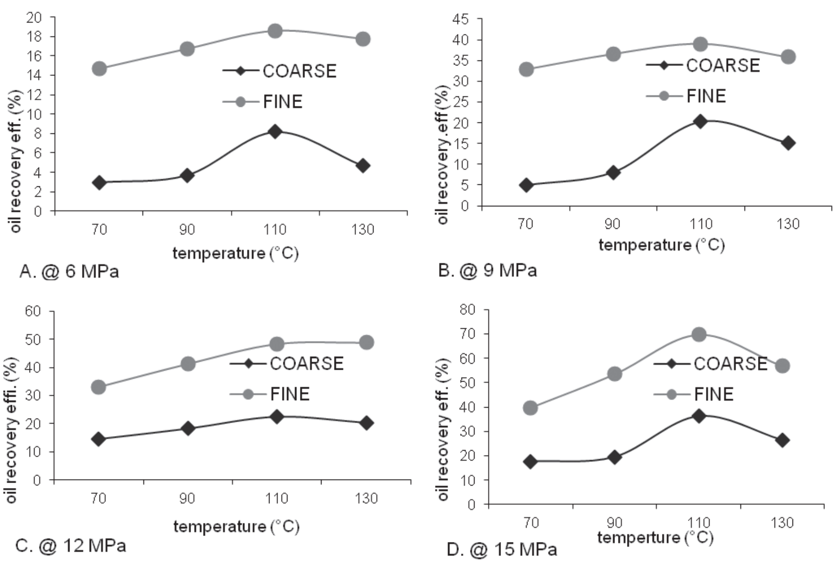


Table 5 Effect of particle size on measured parameters

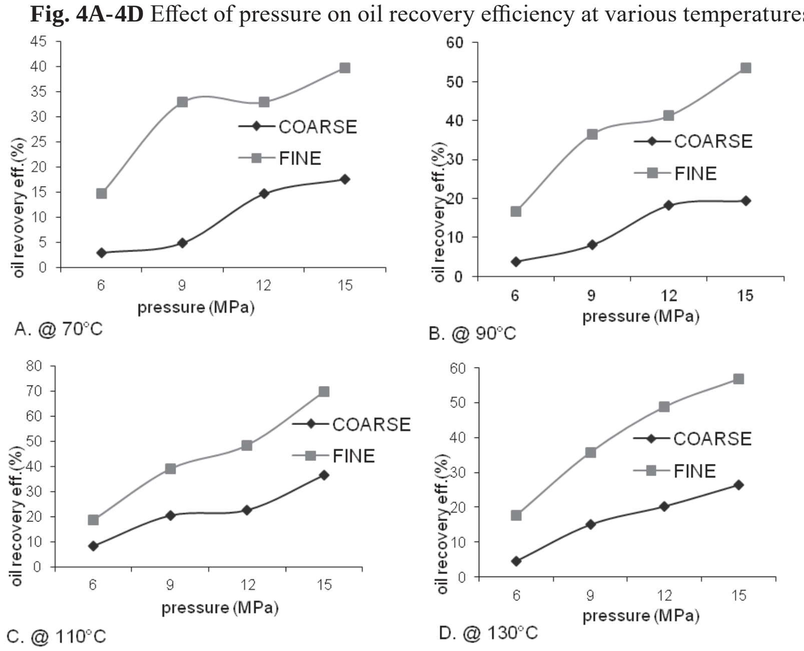
Parameter	Size	T	Df	Sig.	MD.	SE (MD)
Oil Yield	Fine	8.771	94	0.001	11.66	1.33
	Coarse	8.771	72.37	0.001	11.66	1.33
Oil Recovery Efficiency	Fine	8.363	94	0.001	22.030	2.634
	Coarse	8.363	75.64	0.001	22.030	2.634
Process Loss	Fine	1.731	94	0.087	0.503	0.291
	Coarse	1.731	91.2	0.087	0.503	0.291

MD is mean difference, SE is standard error

tures during mechanical expression of oil from fine and coarse particle size of palm kernel under uniaxial loading. From these figures, it can be deduced that oil recovery efficiency increased proportionally as the applied pressure increased from 6 MPa to 15 MPa for both fine and coarse particle size. However, the figures also showed that increasing the applied pressure from 6 MPa to 12 MPa produced a higher increase in the amount of oil recovery efficiency when compared to increasing the applied pressure from 12 MPa to 15 MPa.

It can therefore be deduced from this study that with a progressive increase in applied pressure during mechanical oil expression, adequate rupturing of oil capillaries results in the flow of oil out of the cells. This can be attributed to the sharp initial increase in oil recovery efficiency recorded when the applied pressure increased from 6 MPa to 12 MPa. Meanwhile, as the applied pressure was increased from 12 MPa to 15 MPa, there was a reasonable sealing of oil capillaries as a result of which the sample behave like a consolidated oil seed cake (as reported by (Faborode and Favie, 1997; Mrema and McNulty, 1985). These consolidation effects have been reported to reduce the flow of oil during mechanical oil expression process. Thus, the increase in oil recovery efficiency at applied pressure beyond 12 MPa was reduced. This trend was also observed by Ajibol et al. (1998) while studying mechanical expression of oil from Castor seeds, Adeeko and Ajibola (1989) in the mechanical expression of groundnut oil and Tunde-Akintunde et al. (2001) while studying mechanical expression of Soybean oil.

Fig. 4A-4D Effect of pressure on oil recovery efficiency at various temperatures



Effect of Particle Size on Oil Recovery Efficiency

The independent t-test was used to compare the means of fine and coarse particle sizes for each of the parameters measured. The result is presented in **Table 5**.

From **Table 5**, the mean of oil recovery efficiency from fine particle size is significantly higher than that of coarse particle size at 5% level of significance. The t-test statistics confirms that the differences observed in the mean values of oil recovery efficiency between the fine and coarse particle sizes was not due to random occurrence alone (i.e. by chance). This significant difference in the oil recovery efficiency is also evident in **Figs. 4A-4D**. From these figures, it is clear that irrespective of the pressure and temperature range, the oil recovery efficiency from fine particle size was consistently higher than those from the coarse particle size. This can be attributed to higher surface area of the fine particle sizes subjected to applied pressure, temperature, and weakening of more oil cells that readily expels oil on any slight increase in applied pressure and heating temperature.

Conclusion

The study revealed that increasing heating temperature from 70 °C to 110 °C irrespective of the applied pressure, results to a corresponding increase in oil recovery efficiency for both fine and coarse particle size. Further increase in heating temperature from 110 °C to 130 °C results in decrease in oil recovery efficiency for both particle sizes.

The study also reveals that oil recovery efficiency increase as the applied pressure increases from 6 MPa to 15 MPa at any heating temperature for both fine and coarse particle size. The highest oil recovery efficiency was recorded at applied pressure of 15 MPa while the minimum was obtained at 6 MPa.

It was established from this study that oil recovery efficiency from fine particle size are higher and significantly different from those obtained from coarse particle size.

This implies that, In order to maximize oil recovery efficiency during mechanical expression of Palm Kernel oil under uniaxial loading, the process conditions (i.e. heating temperature and applied pressure) must be properly controlled.

REFERENCES

Adeeko, K. A. and O. O. Ajibola. 1989. Processing Factors Affecting Yield and Quality of Mechanically Expressed Groundnut Oil. Journal of Agricultural Engineering Research. 5: 31-43.

Ajibola, O. O., Adetunji, S. O. and O. K. Owolarafe. 2000. Oil Point Pressure of Sesame seeds. IFE Journal of Technology 9: 57-62.

Akinoso, R., Igbeka, J. C., Olayanju, T. M. A. and L. K. Bankole. 2006. Modeling of Oil Expression from Palm Kernel. Agricultural Engineering International: the CIGR E-journal Vol. VIII, October.

ASAE. 1989. Methods of Determining and Expressing Fineness of Feed Materials by Sieving. ASAE Standards: ASAE S319. Agricultural Engineers' Handbook. Pp. 325-327.

Bamgboye, I. A. and O. I. Adejumo. 2011. Effects of Processing Parameters of Roselle Seed on its Oil Yield. Int. J. Agric and Biol. Eng. Vol.4(9): 82-86.

Breadson, D. K. 1983. Mechanical Extraction. Journal of American Oil Chemists Society. 60(2): 211-213.

Faborode, M. O. and Favier, J. F. 1997. New Insight into the Mechanics of Seed-Oil Expression. Journal of Agricultural Engineering and Technology (JAET) Vol. 5: 9-24.

Hamzat, K. O. and Clerke, A. O. 1993. Prediction of Oil Yield from groundnut using the concept of Quasi-Equilibrium Oil Yield. Journal of Agricultural Engineering Research. Vol. 55(1): 79-87.

Hartley, C. W. S. 1988. The Oil Palm. Third edition. John Wiley and Sons Inc. New York. Pp. 19-21.

Lehinger, A. L. 1987. Principles of Biochemistry. CBS Publishers and Distributors, India.

Mrema, G. C. 1979. Mechanisms of Mechanical Oil Expression from Rapeseed and Cashew- Unpublished PhD Thesis, National University of Ireland, Dublin, Ireland.

Mrema, G. C. and P. B. McNulty. 1985. Mathematical Model of Mechanical Oil Expression from Oil Seeds. Journal of Agricultural Engineering Research. 31: 361-370.

Mwithiga, G. and L. Moriasi. 2007. A study of Yield Characteristics during Mechanical Oil Extraction of Preheated and Ground Soybeans. Journal of Applied Sciences Research 3(10): 1146-1151.

Oil World Annual, 2000. ISTA Mielke GmbH; Hamburg, Germany.

Olaniyan, A. M. 2006. Development of Dry Extraction Process for Recovering Shea Butter from Shea Kernel. Unpublished Ph.D thesis, Department of Agricultural Engineering, University of Ilorin, Nigeria.

Olaniyan, A. M. 2010. Effect of Extraction Conditions on the Yield and Quality of Oil from Castor Bean. Journal of Cereals and Oil Seeds Vol. 1(2): 24-33.

Olayanju, T. M. A., Akinoso, R. and M. O. Oresanya. 2006. Effect of Worm shaft Speed, Moisture Content and Variety on Oil Recovery from Expelled Beniseed. Agricultural Engineering International: the CIGR Ejournal 8: 1-7.

Praven, C. B. 1997. Mechanical Oil Expression from Selected Oil seeds Under Uniaxial Compression. Unpublished Ph.D. thesis submitted to the College of Graduate Studies and Research, Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Canada.

RMRDC. 2004. Report on Survey of Agro Raw Materials in Nigeria on Oil Palm. Maiden Edition. Published by Raw Materials Research and Development Council (RMRDC), Abuja, Nigeria.

Tunde-Akintunde, T. Y., Akintunde, B. O. and J. C. Igbeka. 2001. Effects of Processing Factors in Yield and Quality of Mechanically Expressed Soybean Oil. Journal of Agriculture Engineering and Technology. 9: 39-45.

Young, J. H., Whitaker, T. B., Blankenshy, P. D., Brusewitz, G. H. and J. C. Steele. 1982. Effect of Oven-Drying Time on Peanut Moisture Content Determination. Transactions of the American Society of Agricultural Engineers. 25(2): 4-9.

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An Assessment of the Current Status of Postharvest Management of Major Agricultural Commodities in the Republic of Mozambique

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Abstract

This article presents a brief analysis of the current status of postharvest management of important agricultural commodities in the Republic of Mozambique, brings overall information to allow policy makers to make suitable strategic plans in order to boast postharvest management sector, so that the country will not fail to meet the target Sustainable Development Goals (SDGs), which is to secure food and end the poverty all over the world by 2030. Based on our analysis, we identify key issues related to postharvest management and losses for these commodities. We also discussed government programs introduced to support stakeholders engaged in postharvest management and marketing of food crops. We obtained relevant information from the Ministry of Agriculture and Food Security (MASA) through postharvest management sector as well as Ministry of Industry and Trade (MIC).

We analyzed the value chain for cash crops as well as exports, results indicates that, during the 1990-1991 years the cashew crop was valued at 15000 US Dollars, accounting for 2.8% of the total exports, 78.6% of household farmers are engaged in maize production, with less than 20% of the maize total production being sold. The general knowledge regarding postharvest management among stakeholders is inadequate contributing for losses ranging from 20% to 40% depending on crops and geographical location in the country. Moreover, Mozambique does not produce enough to feed its population, self-sufficiency in crop production cannot be achieved solely by increasing production, prevention or reduction of postharvest losses of cereal as well as cash crops are also necessary. This means that, the losses occur between the field and the consumer as a result of inadequate harvesting, threshing, dry-

ing, transport, storage and milling should be minimized.

Keywords: postharvest, Mozambique, agro-processing, agro-industry, commodity, storage facilities

Introduction

The agricultural sector within Sub-Saharan Africa (SSA) is characterized by poor postharvest management practices, leading to the highest postharvest losses between (26-36%) globally. These losses amount to an annual loss in food production of 120-170 kg/capita. Poor postharvest management practices are linked to financial, technical, and managerial limitations of predominantly smallholder farmers in this region. Postharvest losses contribute significantly to food insecurity in most SSA countries. Specifically, in Mozambique, the high level of food insecurity can be partly attributed to postharvest losses that are estimated to exceed 30%. Most smallholder farmers store the food products that they grow in their households. However, these products only last for three months because of the poor postharvest handling practices and unsuitable storage conditions, subsequently deteriorating and going waste. Poor storage conditions compel farmers to sell their surplus during the harvesting period at low prices, which reduces their incomes. Consequently, they are unable to purchase processed foods in the lean season, which increases their food insecurity. Therefore, strategies for securing food throughout the year in Mozambique's rural communities are essential (Food Agriculture and Natural Resources Policy Analysis Network, 2017).

Commencing from the time of the crop harvest, the postharvest marketing chain entails a series of interconnected activities, which include sales of live animals at farm gates and freshly obtained milk or fish catches that are delivered to consumers. A number of factors may cause losses as a product moves along this chain. These losses can be divided into three main categories: (1) quantitative or physical losses that cause a reduction in the weight of the product, (2) loss of quality leading to changes in the product's appearance, taste, texture, or nutritional value, and (3) loss of opportunities for value added to products (FAO, 2011).

The objectives of this study were to assess the current postharvest management situation in Mozambique, and to examine the main governmental programs aimed at preventing postharvest losses implemented by the Ministry of Agriculture and Food Security. We focus on the main commodities produced in Mozambique and examine their value chains, storage, and processing.

Materials and Methods

Mozambique, which is located in southeastern Africa, covers a total area of 801590 square kilometers (309493 square miles) (**Fig. 1**). The country's coastline extends over a distance of 2470 km (1535 miles) along the entire eastern frontier, bounded by the Mozambique Channel and the Indian Ocean. Tanzania is located to the north of Mozambique, Malawi and Zambia are to the northwest, and Zimbabwe is to the west. Below Mozambique, in a southwesterly direction are South Africa and Swaziland. Mozambique's capital, Maputo, is located at the country's southernmost tip, close to the borders with South Africa and Swaziland. The data for this study were obtained from the Ministry of Agriculture and Food Security, and the analysis drew on a review of relevant literature on Mozambique, including FAO publications and World Bank reports.

Results and Discussion

3.1. Broader Issues Affecting the Postharvest Situation

3.1.1. Investment Climate

Mozambique's investment climate has undoubtedly improved in recent decades. Political uncertainty has greatly diminished with the advent of peace following the civil war and the holding of six successful national elections. Economic reforms have led to enhanced monetary and price stability and have deepened economic integration with world markets, strengthened financial markets, and reduced state involvement in production. However, even with such changes, business operations in Mozambique remain difficult, and the country's business environment continues to lag well behind those of most of its direct competitors in the region. Companies still complain about administrative, regulatory, and legal obstacles, and surveyed investors reported that Mozambique is still considered an extremely risky investment location. The World Economic Forum's African Competitiveness Report for 2004 ranked Mozambique's business environment 20^{th} among 25 SSA countries. Even by regional standards, the country ranks low for the "contracts and law" and "macroeco-

Fig. 1 Map of Mozambique (*Source: https://www.worldatlas.com/af/mz/where-is-mozambique.html, 2017*)

nomic environment" indices. Small- and medium-sized enterprises have been especially disadvantaged by the complex and bureaucratic system of approvals, licenses, and special levies that impede market entry and raise the costs of doing business (USAID, 2004). Consequently, the World Bank (2006) identified the following key factors constraining investments in Mozambique:

a) An uncertain policy and regulatory environment,
b) Lack of a reliable system for settling disputes fairly and speedily,
c) A weak tax administration system entailing frequent delays in tax refunds,
d) A lengthy and costly business registration process, and
e) A difficult and costly process of acquiring land.

3.1.2. Rural Finance

a) In Mozambique, there is a pervasive lack of rural financial services as a result of several structural factors, including:
b) The predominance of low-input/low-output subsistence farming,
c) Extensive poverty and very low rural population densities in many parts of the country,
d) Frequent droughts and floods,
e) High and volatile real interest rates, and
f) Many years of civil war.

The government's attempts over two decades to provide rural finance at subsidized rates through the previously state-owned People's Development Bank have failed consistently. Although microfinance operations first emerged in the 1990s, they remain concentrated in urban centers and largely inaccessible to rural populations, located far from the reach of operators within the financial sector. Almost all rural districts lack formal banking facilities, and community-based financial arrangements and development credit institutions have very limited outreach in rural areas.

The limited financial services available in rural areas are directed only at large-scale farmers, large traders, and processors. Although a few organizations are beginning to offer large, wholesale loans to well-organized farmers' associations, such associations are rare and the minimum loan amounts are often too high. Consequently, almost all available smallholder agricultural finance in Mozambique is provided by agribusiness companies and traders in the form of input credit and short-term crop advances (FAO, 2011).

3.1.3. Systems of Quality Control

Mozambique's national regulatory system comprises multiple governmental institutions within various ministries, including those concerning agriculture, health, and trade. Constraints militating against compliance with official and non-official standards mainly relate to traceability, hygiene requirements, standards prevailing in certain markets, appropriate use of pesticides and the presence of residues in produce, and concerns regarding international transmission of pests. The national capacity for implementing regulatory techniques, training personnel for effective implementation of specific measures, and strengthening surveillance programs is weak. The official system for regulating and certifying exports of certain commodities is not in compliance with the requirements of export markets. Moreover, there are several deficiencies in the implementation of official auditing, approval, inspection, sampling, and certification procedures. All of these factors contribute to significant annual losses resulting from damage by pests and lead to restricted access to foreign markets. The standards of the Instituto Nacional de Normalização e Qualidade (INNOQ) do not cover all products. Thus, local trade is based on subjective perceptions of quality. Standards are lacking and, where present, their divergence from the standards used in neighboring countries, such as South Africa and other foreign markets, reduces the capacity of traders to tap into various market opportunities (FAO, 2011).

3.1.4. Issues Related to Primary Production

Various issues affecting primary production increase the propensity for high postharvest losses. These issues include shortages of improved seed varieties, inappropriate farming practices, and very limited use of fertilizers, irrigation, and mechanization. The use of commercial inputs is at a rudimentary stage. All of the basic food crops are produced within rain-fed and zero-input agricultural systems, an exception being maize, which is sometimes interspersed crop with tobacco and may receive some leftover fertilizer. In addition, apart from rice, all food crops are produced in association with other crops, which usually results in low yields. During the period 2001-2002, only about 5% of rural households used fertilizer and pesticides. Moreover, agricultural research and extension services are of low quality and provide limited coverage, with only about 13% of rural households having access to extension services. Similar issues apply to commercial crops, leading to low yields (FAO, 2011). Smallholders lack skills relating to production and marketing techniques and business practices. Moreover, the lack of effective producers' associations constitutes a key gap in crop production. Only 3.7% of farmers are organized within associations, with the rest operating independently. Consequently, these farmers do not benefit from economies of scale in areas such as input supplies, technology transfer, value addition, transport, logistics and storage, produce marketing, and access to financial services (FAO, 2011).

3.1.5. Transport and Other Logistic Infrastructure

Mozambique's transport infrastructure, which has long been regionally focused, is oriented to its landlocked neighbors and South Africa. Its ports, namely Maputo, Beira, and Nacala, make it an important transit route for South African, Swazi, Zimbabwean, Malawian, and Zambian imports and exports. However, commercialization of Mozambique's agricultural produce is difficult and expensive because of high freight transport costs, unpredictable railway operations, and a paucity of linkages between the country's rural economy and its main transport infrastructure. Consequently, prospects for competing in international markets are weak for producers and exporters (USAID, 2004). Only 5685 km of the country's 30400 km of roads are paved, although there are good connections to neighboring countries.

Density of the road network is the lowest in Southern Africa at 32 km per 1000 km^2 compared with a median value of 90 km per 1000 km^2 as standard in the world. If only rural areas are considered, the density is even lower at 20 km per 1000 km^2. Only 50% of the road network is in good or fair condition. In rural areas, roads are poorly maintained, and many are impassable during the rainy season. The rail system covers 2983 km and its gauge is compatible with that of neighboring rail systems. However, it is not evenly distributed across the country. The main railway network transects the country from east to west, as do the main roads. Many sections of the railways require renovation. Because of the poor infrastructure, transport costs are high, which in turn contributes to the weak market integration of smallholders, exacerbated by the lack of farmers' organizations. The development of power and telecommunications infrastructure in rural areas is at a nascent stage. Overall, access of households to electricity increased from 4% to 7% between 2004 to 2005 but remains highly unequal. In rural areas, only about 1% of households have access to power and less than 10% have access to telecommunications infrastructure (World Bank, 2006).

3.1.6. Agro-processing

In Mozambique, small-scale agro-processing is carried out for flour milling (mainly hammer milling), oil extraction, and rice milling. Numerous constraints affect these operations, including the following listed by the European Union (EU) and the Food and Agricultural Organization (FAO) (2007).

a) Lack of reliable supplies of suitable high quality raw materials,
b) Lack of adequate processing technologies because of limited research and development support that impedes technology generation, transfer, management, and absorption,
c) Lack of access to adequate processing equipment because of inadequate finance and unreliable maintenance support and spare parts supplies,
d) Inadequate knowledge regarding processing and marketing techniques and management of business operations,
e) Inadequate market information, and
f) Absence of updated national food laws, standards, and specifications for food products and quality control.

Cash crops, such as cotton, sugar, and cashews, are processed using large-scale agro-processing facilities. These operations are limited mostly to primary processing, with further value addition through secondary processing and utilization of by-products being negligible. For example, copra and unrefined coconut oil rather than higher-value coconut products are exported. Molasses is not processed further despite existing opportunities relating to alcohol production for export markets. Cotton is processed solely into lint for export, and raw cotton seeds are exported at low prices, despite the potential for producing vegetable oil, soap cakes, and animal feed. Most cashew exports are raw and unprocessed, while tobacco is not processed beyond the burley and flue-cured stages (FAO, 2011).

3.2. Main Commodities

The selection of commodities assessed in this report was based on

Fig. 2 Cultivated areas and yields for maize in Mozambique (*Source: World Bank, 2007*)

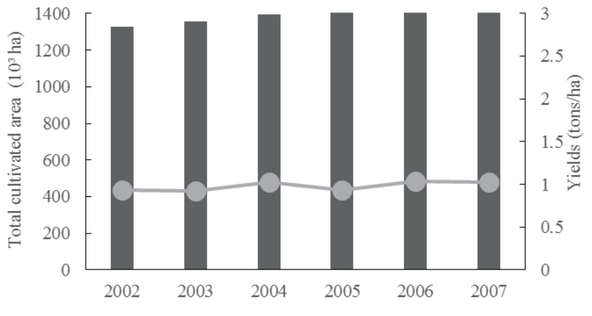
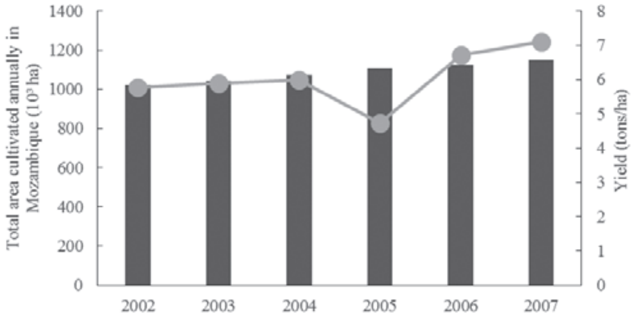


Fig. 3 Cultivated areas and yields for cassava in Mozambique (*Source: World Bank, 2007*)



two main considerations: (1) their national economic importance, (2) the potential for reducing quantitative and qualitative postharvest losses.

3.2.1. Maize

Maize is a key staple in rural and urban areas and is the most widely cultivated crop in Mozambique. It occupies more than 50% of cultivated land in the regions of Niassa, Tete, Manica, and Sofala (**Fig. 2**). An estimated 78.6% of households, comprising mostly smallholder farmers, are engaged in maize production using rudimentary technology. Like most other basic food crops, maize is grown primarily for household consumption, with less than 20% of the total amount produced being sold. Postharvest losses within the maize value chain are considered high, and there is scope for reducing them (FAO, 2011).

3.2.2. Cassava

Cassava is the second most widely cultivated crop in Mozambique. It is produced throughout the country and is a major staple for achieving food security (**Fig. 3**). An estimated 63.2% of households cultivate cassava. Although maize is considered Mozambique's most important staple food, cassava surpasses maize in terms of total calories and market value based on annual quantities produced. Apart from the tubers, cassava leaves are consumed as a vegetable in most parts of the country, constituting a highly significant source of dietary protein, minerals, and vitamins. There are substantial opportunities for reducing the high levels of qualitative and quantitative postharvest losses through value addition and processing. Mozambique currently imports more than 330000 tons of wheat annually. It is estimated that high quality cassava flour can be used as a substitute for up to 15% of wheat imports in the baked goods industry, resulting in annual savings of at least 15 million US dollars. In addition, there are considerable opportunities for the production of starch given the vibrant market and attractive margins for this product in South Africa, where rising maize prices have led starch producers to change their raw material from maize to cassava in recent years (FAO, 2011).

3.2.3. Rice

Rice is an important cereal in Mozambique, which is produced by an estimated 26% of households (**Fig. 4**). Like other basic food crops, most of the rice produced is for household consumption. The popularity of rice is growing in urban areas (USAID, 2004).

3.3 Agro-Industry in the Republic of Mozambique

Agro-industry, entailing processing that adds value to agricultural commodities before they reach consumers, can play a key role in agricultural development, especially when it is rurally based. In developing countries, including Mozambique, agro-industrialization is increasingly driven by globalization, as evidenced by direct foreign investments and trade (Benfica et al., 2002).

3.3.1. Trends and Patterns in Agro-Industrial Investments in Mozambique

Following the signing of the peace accord in 1992 and the holding of the first democratic election in the country in 1994, there has been significant capital inflow to support investments in Mozambique. Some general and subsector-specific patterns are evident. First, during the period from 1985 to mid-2001, agro-industrial investments constituted, on average, almost 60% of all investments in rural-based projects. Second, the total value of investments in agro-industry increased about fivefold from 33.4 million US dollars for the period 1985-1990 to over 161 US million US dollars for the period 1991-1996. Subsequently, their value more than doubled from that period to 1997-2001. Third, over the entire period, the focus of investments shifted from cotton and tobacco (1985-1990) to a more balanced diversification of investments in sectors such as maize, cotton, and cashew in the first half of the 1990s. Beginning in the late 1990s (1997-2001), significant investments have been made in the sugar sector, with some investments also made in tea. More recently, several tobacco

Fig. 4 Cultivated areas and yields for rice in Mozambique (*Source: World Bank, 2007*)

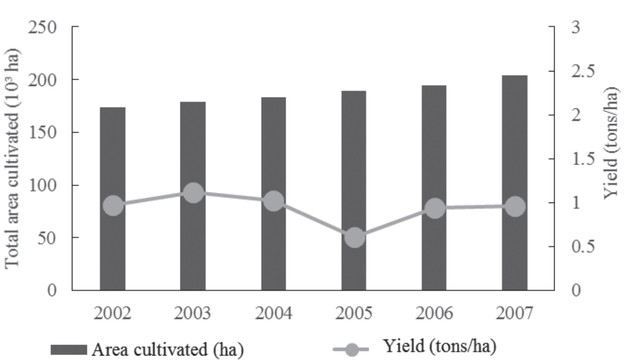
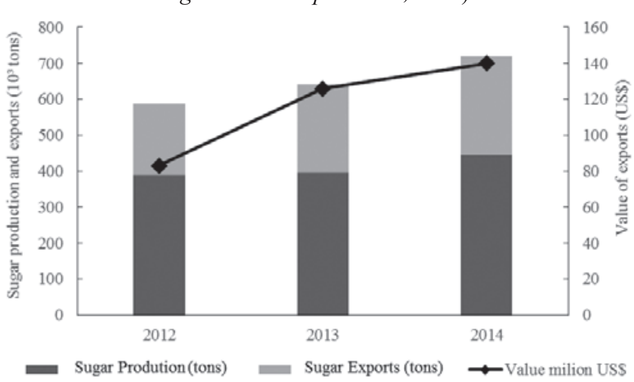


Fig. 5 Sugar production, exports, and export values (*Source: United States Agriculture Department, 2013*)



companies have invested in contract farming and processing operations in the central and northern parts of the country, leading to a significant increase in production (Benfica et al., 2002).

3.3.2. Sugarcane

Among the agricultural subsectors, sugar ranks second in terms of the export revenues it generates. After the civil war ended in 1992, the Mozambican government began to upgrade and modernize the sugar industry. Given its high quality soils, regular rainfall, and favorable climatic conditions, Mozambique has a comparative advantage in sugar production (United States Agriculture Department, 2013). Mozambique's sugar production for the 2013 season showed an increase of 2% at 396719 tons compared with the production quantity for the previous season (**Fig. 5**).

3.3.3. Cashew Nuts

During the 1960s and 1970s, Mozambique was a major cashew producer. The Portuguese actively promoted cashew cultivation during the colonial period, and in the 1960s, Mozambique produced half of the global supply of cashew nuts. In 1968, there were 45 million cashew trees in Mozambique, and at its peak, cashew production in the country exceeded 200000 tons of raw cashew nuts.

During the 1980s, Mozambique's cashew production and exports collapsed because of the civil war, nationalization of processing facilities, very low producer prices as a result of a ban imposed on raw cashew exports, and minimal non-price support extended to producers. During the period 1990-1991, Mozambique's cashew exports were valued at 15 million US dollars, accounting for just 2.8% of global exports. A very contentious reform process was initiated during the early 1990s to restore production in this sector to pre-independence levels and to maintain the processing industry (**Fig. 6**).

Table 1 Network Storage Capacity

Provinces	State sector capacity		Private sector capacity	
	Silos Capacity (tons)	Warehouses Capacity (tons)	Silos Capacity (tons)	Warehouses Capacity (tons)
Maputo	45,000	6,140	0	80,000
Gaza	0	20,580	0	5,000
Inhambane	0	6,700	0	5,000
Manica	2,000	13,900	13,000	8,900
Sofala	0	7,400	28,000	60,000
Tete	0	23,100	0	6,000
Zambézia	0	43,520	0	0
Nampula	0	35,427	43.000	56,000
Cabo Delgado	0	24,338	0	0
Niassa	0	20,730	0	7,000
Total	47,000	201,835	84,000	227,900

Source: FAO/Ministry of Industry and Trade of the Republic of Mozambique, 2008

3.3.4. Industrial Restructuring of Processors

Processors, including those who remained private throughout the independence period and, more importantly, those who had purchased capital-intensive factories in the early 1990s, were among the most proactive and important groups. They argued, then and now, that they required more time to restructure and that the ban on exporting raw cashews should be retained in some form for an extended period. Conversely, the World Bank has consistently argued that labor-intensive production methods are more appropriate than capital-intensive factories that actually lose value because of their highly inefficient processing methods (World Bank, 2012).

3.3.5. Warehouse and Storage Facilities

Large commercial companies engaged in domestic marketing of cereals own warehouses, most of which are not equipped properly to ensure optimal conditions for handling and storing cereals (**Fig. 7**). Most of the warehouses belong-

Fig. 6 Mozambique's Cashew production and exports (*Source: World Bank, 2012*)

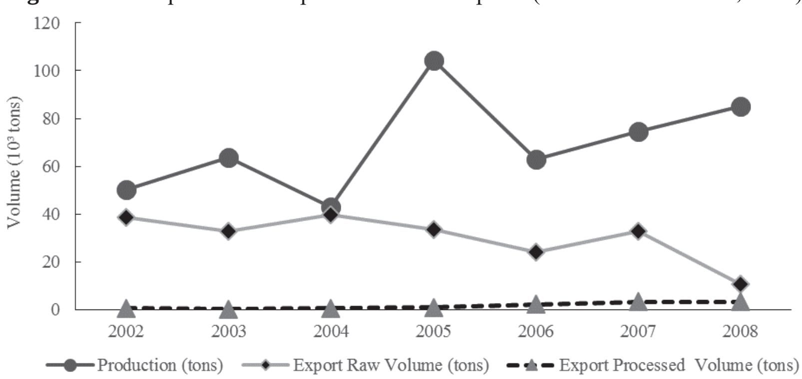


Fig. 6 Metal silos for postharvest maize storage (*Source: Ministry of Agriculture and Food Security, 2015*)

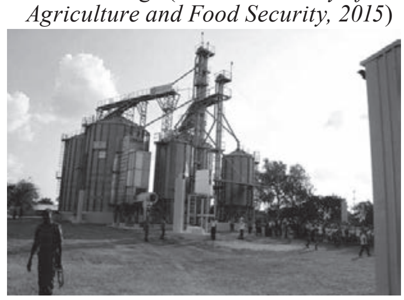


Table 2 Overall budget for the postharvest and marketing program

Provinces	Implementation years (10^3 US$)				
	2012	2013	2014	2015	2016
Competitive linkages forged within the value chain and market	34.4	616	616	609	384
Commodity exchanges	96	345	514	471	381
Enhancement of the quality and scale of the market	41.2	281	201.6	148.4	107.8
Promotion of an environment conducive to agrobusiness and market access	14.7	100	85.9	76.6	31.3
Total	186.3	1,342	1,417.5	1,305	904.1

Source: Ministry of Agriculture and Food Security, 2017

ing to the Instituto de Cereais de Moçambique (ICM), located in northern and central Mozambique, are currently rented out to organizations that use them as storage facilities (**Fig. 8**). There seems to be little transparency within ICM regarding its rental contracts. Some of the warehouses are in need of repairs, and ICM's staff have little experience in warehouse management and bulk grain storage of cereals. Moreover, ownership of some of the ICM warehouses is contested, usually by other state institutions, while information on existing warehousing is scattered, outdated, and sometimes inadequate (**Table 1**). Apart from inadequate funding available for its operations, another key constraint faced by ICM is the lack of a clear policy on the use of its warehouses for marketing cereals and on collaborations initiated with the private sector for this purpose (FAO, 2011).

3.4. Postharvest Management and Marketing Program

The Postharvest Management and Marketing Program comprises the following four subprograms: (1) support for developing competitive links within the value chain and market, (2) support for establishing commodity exchanges, (3) enhancement of the quality and scale of the market, and (4) the creation of an enabling environment for agribusiness and market access (**Table 2**).

3.4.1. The Subprogram for Supporting the Development of Competitive Links within the Value Chain and the Market

Activities in this subprogram focus on the following areas: (1) infrastructure and supply markets, (2) access to financial services, and (3) development of the capacities of market operators. In regard to infrastructure, the focus is on public investment in postharvest infrastructure, particularly facilities for preserving and marketing nutrient-rich foods. Other focal areas include the construction of agro-processing units, the development and upgrading of rural and urban markets, and the establishment of markets for the supply of livestock and fish products. In the area of financial services, the goal of the subprogram is to expand financial services relating to savings, credit, and insurance for processors, exporters, and other entrepreneurs within the sector. The total costs of implementing this subprogram are estimated to be 2.3 million USD (Ministry of Agriculture and Food Security, 2017).

Fig. 7 A Local silo in Gorongosa for postharvest maize storage (*Source: FAO, 2017*)

3.4.2. The Subprogram for Promoting Commodity Exchanges

Currently, agricultural market operations in Mozambique incur high transaction costs because of the limited availability of market information and comprehensive agricultural statistics indicating supply and demand trends, a lack of transparency among market operators, non-compliance with contracts, and an absence of quality standards for products. These constraints limit the activities of producers, processors, and traders in the agricultural sector, resulting in low investments and consequently low trading volumes. This subprogram is aimed at introducing order, efficiency, transparency, and integrity within agricultural markets. Its component activities include the establishment of the following facilities and systems:

a) A trading floor where agents (brokers) of sellers and buyers can be physically present to negotiate the purchase and sale quantities of products,
b) A certified storage management and cold chain system, with units located in production areas, near import trading centers, or in centers close to major import and export terminals, established to maintain high technical and financial performance levels, authorize storage of third-party products, and issue storage certificates, Financial institutions accept storage certificates as collateral because of their confidence in the high liquidity levels of the deposited goods, and
c) A surveillance system for generating market information along with support technology that includes a quality control system with laboratories for verifying the quality and safety

of products entering exchanges. The total estimated cost of this subprogram is 1.8 million USD (Ministry of Agriculture and Food Security, 2017).

3.4.3. Subprogram for Enhancing the Quality and Scale of the Market

This subprogram has the following objectives:

Developing the market for products and inputs and increasing value addition through public private partnerships,

Establishing properly equipped laboratories for conducting analyses of soils, pesticides, pesticide fibers, and residues in food,

a) Promoting internal product trade and exports through producer contracts and organizations, market studies, participation in fairs, and collective marketing actions,
b) Enforcing quality standards packaging by improving the services provided by national laboratories and quality certification and inspection institutes, and
c) Providing training for increasing knowledge about standards and quality control among producers, traders, and service providers. The total estimated cost of this subprogram is 1 million USD (Ministry of Agriculture and Food Security, 2017).

3.4.4. Subprogram for the Creation of an Enabling Environment for Agrobusinesses and Market Access

The main initiatives under this subprogram are as follows:

Training provided in the following areas: entrepreneurship in agriculture, fisheries, and the production of nutritious food for farmers, fishermen, traders, and service providers; postharvest management; marketing and commercialization; and agro-processing aimed at reducing crop losses,

a) Support provided to small- and medium-scale enterprises to market nutritious foods,
b) Provision of non-financial services to agrobusinesses (market information and business plan development and facilitating links between suppliers and buyers), and
c) Removal of barriers to the free movement of agricultural, fish, and animal products. The total estimated cost of this subprogram is 0.3 million US dollars (Ministry of Agriculture and Food Security, 2017).

Conclusions

The Mozambique Strategic Plan for the Development of the Agricultural Sector, 2011-2020 includes a postharvest management strategy. However, institutional collaborations in this area are constrained by the lack of a stand-alone policy on postharvest management.

Studies on postharvest management are lacking, and there is a general paucity of postharvest management service providers in the SSA region. Specifically, in Mozambique, postharvest management is constrained by the lack of infrastructure, transportation, and locally-oriented food industries as well as policy gaps, a lack of training institutions, and farmers' inability to access funding.

Knowledge of postharvest management among stakeholders is generally inadequate, with storage losses ranging from 20% to 40%, depending on crops and geographical locations. Storage losses compel farmers to sell their produce early to avoid physical losses, thereby reducing opportunities to sell at favorable prices.

Significant investments have been made to support the efforts of Mozambican smallholder farmers to improve their production and market linkages. Evidently, all projects aimed at improving value chains, with a view to promoting economic growth are being prioritized, and strategies for reducing postharvest losses are being formulated. However, because many of these activities are decentralized and implemented at provincial and district levels where institutional capacities are weak, their impacts on communities have been limited.

Acknowledgments

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Bibliography

Benfica R., Tschirley, D. and L. Sambo. 2002. Agro-industry and smallholder agriculture: Institutional arrangements and rural poverty reduction in Mozambique. http://purl.umn.edu/55231.

European Union/Food and Agricultural Organization [FAO]. 2007. Cassava development strategy for Mozambique. www.ipcinfo.org/fileadmin/user.../eufao.../cassava strategy.pdf.

FAO/Ministry of Industry and Trade. 2008. Study of grain storage in Mozambique. http://www.mic.gov.mz.

FAO. 2011. Continental programme on postharvest losses (PHL) reduction. Rapport No: 09/020 FAO/AfDB-MOZ. Rome. Italy.

Food Agriculture and Natural Resources Policy Analysis Network. 2017. Cost benefit analysis of postharvest management innovations in Mozambique.

FAO. 2011. UN Joint Programme Building commodity value chains and market linkages for farmer's associations. Project Document UNJP/MOZ/093/UNJ. Rome. Italy. http://www.fao.org/in-action/improved-post-harvest-handling-raises-incomes-for-mozambique-

farmers. 2017.
Ministry of Agriculture and Food Security (MASA). 2015. Economic and Social Plan http://www.masa.gov.mz.
Ministry of Agriculture and Food Security (MASA). 2017. National agriculture investment plan. http://www.masa.gov.mz.
United States Agriculture Department. 2013. Global agriculture information network.
USAID. 2004. Mozambique Diagnostic Trade Integration Study. Volume 2. Main Report. Removing Obstacles to Economic Growth in Mozambique. Crop Subsector Analyses. Results of Trade Transport Facilitation Audit. Available at: http://ww.integratedframework.org/files/english/Mozambique dtisvol2-dec04.pdf.
World Bank. 2006. Mozambique agricultural development strategy stimulating smallholder agricultural growth. Report No. 32416-MZ. Available at: http://siteresources.worldbank.org/MOZAMBIQUEEXTN/Resources/Moz-AG-Strat egy.pdf.
World Bank. 2007. Competitive commercial agriculture in Africa. Mozambique country case of study. Available at: World Bank. 2012. Mozambique cashew reforms revisited. Policy Research Working Paper 5939. documents.worldbank.org/curated/en

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News

Peter Pickel

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John Deere GmbH & Co. KG European Technology Innovation Center, Kaiserslautern
Chairman of the German Max-Eyth-Society for Agricultural Engineering (VDI-MEG)
GERMAN

Prof. Pickel new Chairman of the VDI Society Technologies of Life Sciences

Prof. Dr.-Ing. Peter Pickel has taken over the chairmanship of the VDI Society Technologies of Life Sciences (TLS) as of January 1, 2021.
He succeeds Prof. Dr.-Ing. Marc Kraft (TU Berlin), who had held the position since 2015 and could not take over another term in accordance with the VDI statutes.

The VDI has about 140.000 members and the TLS is an important part of it. Prof. Pickel is responsible for five VDI divisions under the common TLS umbrella: “Max Eyth Society of Agricultural Engineering”, “Bionics”, “Biotechnology”, “Biodiversity, GMO Monitoring & Risk Management”, and “Medical Technology”.

Pickel is Manager External Relations of the John Deere European Technology Innovation Center in Kaiserslautern. Previously, he was Director of the Institute of Agricultural Engineering and Land Cultivation and Dean of the Faculty of Agriculture at Martin Luther University Halle-Wittenberg, also dealing as a Board Member of the Club of Bologna since 2016.

He is a member of the European Commission's Bioeconomy Panel, which was founded in 2013. As spokesman for the Agricultural Engineering and Technologies (AET) Group, Pickel is involved in the field of European research funding and research coordination

Computer Aided Design and Development of a Tractor Operated Cotton Header

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Abstract

Cotton is an important commercial crop of India, having 12.81 M ha cultivated area that is the largest in the World. In India 100% of the cotton is harvested manually. Cotton can be harvested mechanically by commercially available cotton pickers (the most commonly used) or cotton strippers, which remove all the cotton bolls. A conceptual design of 3 row finger type cotton header was done by keeping in view the harvesting of local cotton varieties and agronomic practices. Based upon review, important design and operational parameters such as finger type cotton header such as finger length, finger spacing, finger angle and forward speed were selected for the study. All the sub-assemblies like header frame, finger, reel, auger and power transmission were created using NX-8 CAD software at Mahindra Applitrac, Mohali. Based upon 2D drawings and bill of material (BOM), a tractor operated three row cotton header was developed and fabricated. The location of center of gravity of the developed machine was 186 mm nearer from the rear axle (longitudinal) than the normal tractor, 123 mm offset from the left side of rear axle (lateral) instead of at the center as for normal tractor and 400 mm above than the normal tractor from the ground (height).

Keywords: Cotton header, CAD, Cotton stripper, 3D modeling, Center of gravity

Introduction

It is estimated that the world requirement for all fibres is expected to rise from 74 million tonnes in 2010 to 95 million tonnes in 2020. Current split of various fibers namely cotton, cellulosics, jute and other natural fibers, wool and synthetics is 40.0, 50.0, 5.0 and 2.0 and 3.0 %, respectively (Barik, 2010). Cotton is an important commercial crop of India, having approximate 12.81 million ha cultivated area that is the largest in the world. Although, India is the largest producer of cotton in the world yet its yield is much less as compared to the world average yield. The average yield of cotton is only 540 kg/ha as compared to 2151 kg/ha in Australia as against the world average of 766 kg/ha (Anon, 2014).

In the world, approximate 30% of seed cotton harvesting is done by mechanical harvester. USA, Australia and the Israel are one of the countries where 100% seed cotton is picked by mechanical harvesters. In terms of percentage, a significant amount of cotton is harvested by machines in Bulgaria, Greece and Spain. In Tajikistan, Uzbekistan, Turkmenistan and Azerbaijan, it is approximated that 60-70% of the total area is hand-picked. India, China, Turkey and Pakistan are major cotton producing countries in the world where almost 100% picking is done manually (Chaudhry, 1997).

Due to impending shortage of man power, mechanization of cotton harvesting is considered to be of critical importance. But, there are some reasons due to which cotton harvesters are not popular in India. Cotton varieties grown in India are determinate and bushy type. The holdings of farmer are small and disjointed. High initial cost of the spindle type pickers and their higher capacity have made their use uneconomical or impossible for small or medium-size farms. Finger type stripper was more efficient than a spindle type picker due to higher harvesting speed. Cotton stripper is having lower initial cost and maintenance cost with higher picking efficiency. The development of improved cotton varieties is better adapted to stripping (Kohli et al., 2015).

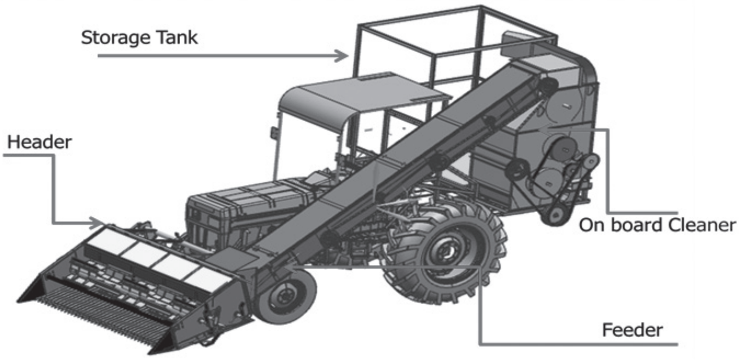
Several researchers have used the CAD software for the design and development of their machines that helps them to determine the typical dimensions of various components of machine. Modak (2010) developed computer aided solid model of tractor operated three row rotary weeder by using CATIA V5 R19. Desai (2012) also developed a solid model of axial flow thresher in his research study by using CATIA. Singh (2007) developed a wheel hand hoe mounted twin disc fertilizer broadcaster CAD model using PRO-E design software. Therefore keeping in view the above facts, the present study focused on development of a new model of tractor operated cotton header with the help of CAD tool NX-8 for local varieties grown in India to provide a useful intput to manufacturers.

Material and Methods

Conceptual Design of Finger Type Cotton Stripper Header

The conceptual design of tractor operated finger type stripper header was done to harvest the locally grown cotton varieties at high density planting system. The idea of conceptual design for finger type cotton header was derived from the study conducted by Tupper (1966). The designed cotton header works on the principle that when finger type header will move through the cotton field due to its forward motion, inclined fingers will strip the cotton bolls with burs from the plants and rest of the plant will remain in its position in the field. Cotton bolls with shells/burs will be stripped from the plants with the help of a series of stationery inclined fingers having a narrow gap among the fingers. The stripped materials will move upward to the inclined fingers with the force of next group of plants being stripped. A reel/paddle/kicker mounted at the rear-side of the fingers will help to convey the stripped materials to the conveying auger. The will helps to convey the material to feeder for further processing. Conceptual view of the cotton stripper is shown in the **Fig. 1**.

Fig. 1 Conceptual view of the finger type cotton stripper



Selection of Design Parameters

The conceptual design of cotton stripper header and selection of the various components for different assemblies was done on the basis of various design parameters. Various design parameters such as finger spacing, finger length, finger angle, finger dimension, finger material and perforated slot dimensionswere selected and reviewed as shown in **Table 1**.

Finger spacing depends upon the plant stem diameter. As plant stem diameter is increased the finger spacing also increased. It is reviewed in the ranges of 16 to 24 mm. For the study, three finger spacings i.e. 16, 20 and 24 mm were selected. Finger length is reviewed in the range of 610 to 900 mm. For the study, 600 and 700 length were selected. Finger angle helps finger to access the lower boll of cotton plant. It is reviewed in the ranges of 12 to 18 degree. For the study, three finger angles i.e. 12, 15 and 18 degree were selected. For finger material, spring steel and mild steel angle with the finger dimension of 25 × 25 × 4 mm were reviewed. For the study, mild steel angle with the finger dimension of 25 × 25 × 4 mm was selected. Perforated slots help to clean the seed cotton by removing of trash. The dimension of perforated slot was 13 × 76 mm as reviewed. The force exerted to limb to pull the boll was 13-22 N as reviewed. The selected design parameter is depicted on **Table 2**.

Theoretical Considerations

Theoretical throughput capacity of the header, rotational speed of the reel, pitch of the reel and conveying auger capacity are important parameters for the development of cotton stripper header. These parameters were calculated by using different relationship and formulas.

Theoretical Throughput Capacity of the Header

Stripper header has been designed to harvest 3 rows of cotton sown at 675 mm spacing as recommended by the PAU, Ludhiana. Theoretical throughput capacity of the header helps to avoid the choking of stripped material. It was calculated at different forward speed such as 5.0, 4.0, 3.0, 2.0 and 1.0 km/h as shown in the **Table 3**. On an average 2000 kg/acre stripped material including seed cotton, trash etc was considered for design calculations. Working width of the machine was considered 2.05 m to harvest three rows of cotton crop. The material flow was maximum i.e. 1.41 kg/s at maximum forward speed of 5 km/h.

Rotational Speed of the Reel/ Paddle/Kicker of Header

The influence of forward speed and the rotational speed of the reel on material flow during harvesting is subjected to reel index. Reel index is the ratio of the rotational speed of the reel to forward speed of machine. The rotational speed of the reel is always higher than forward speed. For reel design, 1.25 reel index (I_r) is generally considered. Reel tip speed (V_r), Reel rpm (N_r) and Reel pitch (pr) were calculated by using following relationships (Varshney et al. 2004). Reel pitch was calculated for 3 and 4 number of paddle/bats mounted on the periphery of the reel as more number of paddle/bats will convey more material to the auger. Reel peripheral speed, reel rpm and pitch for 3 numbers of paddles/bats are shown in **Table 4**.

$$V_r = (50 / 3) \times V_s \times I_r \quad \cdots(1)$$

$$N_r = V_r / (\pi \times D_r) \quad \cdots(2)$$

$$p_r = V_r / (b_r \times N_r) \quad \cdots(3)$$

Where

N_r = Reel rpm

Table 1 Important design parameters of header based upon review

Parameter	Range of parameters reviewed	References
Finger spacing	16 mm	Tupper, 1966; Kepner et al., 1979; Kepner et al., 1987
	16-24 mm	Parish and Shelby, 1974; Smith, 1964; Kirk et al., 1964
Finger length	660 mm	Tupper, 1966
	610 mm	Parish and Shelby, 1974
	700 mm	Smith, 1964; Kirk et al., 1964
Finger angle	12-18 degree	Kepner et al., 1979; Kepner et al., 1987
	15 degree	Tupper, 1966
	12-15 degree	Smith, 1964; Parish and Shelby, 1974
Finger dimension	25 × 25 × 4 mm	Kepner et al., 1979; Kepner et al., 1987
Finger material	Spring steel	Tupper, 1966
	Mild steel Angle	Kepner et al., 1979; Kepner et al., 1987
Perforated slot dimension	13 × 76 mm	Smith, 1964; Tupper, 1966; Kepner et al., 1979; Kirk et al., 1964
Force exerted to limb to pull the ball	13-22 N	Smith, 1964
Auger diameter	120-240 mm	Smith, 1964; Tupper, 1966; Kepner et al., 1979
Reel	Kicker type	Tupper, 1966; Kepner et al., 1979
	Paddle type	Smith, 1964; Kirk et al., 1964

Table 2 Selected design parameters

Parameter	Details
Finger spacing (mm)	16, 20 and 24
Finger length (mm)	600 and 700
Finger angle (degree)	12, 15 and 18 degree
Finger dimension (mm)	25 × 25 × 4
Finger material	Mild steel Angle
Perforated slot dimension (mm)	13 × 76
Auger diameter (mm)	220
Reel	Paddle type

Table 3 Throughput capacity of the header at different forward speeds

Working width (m)	Forward Speed (km/h)	Field capacity (ha/h)	Time for harvesting (ha/h)	Total material harvested (kg/ha)	Throughput capacity	
					kg/h	kg/s
2.05	5	1.03	0.98	5000.00	5125.00	1.42
2.05	4	0.82	1.22	5000.00	4100.00	1.14
2.05	3	0.62	1.63	5000.00	3075.00	0.85
2.05	2	0.41	2.44	5000.00	2050.00	0.57
2.05	1	0.21	4.88	5000.00	1025.00	0.28

V_r = Reel Tip speed m/min
V_s = forward speed km/h
I_r = Reel Index (1.25)
b_r = Number of reel bat
D_r = Diameter of reel in m (0.43 m)

The reel rpm was maximum i.e. 77.86 at maximum forward speed of 5 km/h and minimum i.e. 15.57 at minimum forward speed of 1 km/h. The pitch of reel for 3 and 4 numbers of bats was 0.45 and 0.33 m respectively.

Theoretical Capacity of the Conveying Auger

Function of the conveying auger is to convey the stripped material towards feeder for further cleaning and storage. Theoretical capacity of the auger (Q) was calculated by using following relationship (Varshney et al., 2004). The throughput capacity of auger is depicted in **Table 5**.

$$Q = (2.832 / 60) \times (D^2 - d^2) \times p \times N \times P \times C \quad \cdots(4)$$

Where
Q = Material Flow rate kg/s
p = Seed cotton density kg/m^3
D = Diameter of worm in m
d = Diameter of auger pipe in m
N = rpm
P = Pitch in m
C = Inclination factor; consider 1 for this case

$$v = (P \times N) / 60 \quad \cdots(5)$$

Where
v = Conveying Velocity, m/s

The throughput capacity of auger for 250 mm pitch is 5.70 kg/sec with 0.68 m/s conveying velocity. For the 200 mm pitch the throughput capacity of auger is 9.59 kg/s with 0.54 m/s conveying velocity.

Development of the Tractor Operated Cotton Stripper

The functional requirements of the machine for 3 row cotton header were identified and kept in mind during its development. Three important design parameters i.e. finger spacing, finger angle and finger length were selected to evaluate the performance of cotton header in the field. Hence different functional requirements of the first prototype were considered as follows:

a) Simplicity in fabrication and ease of use.
b) Arrangement for adjustment of finger spacing.
c) Arrangement for adjustment of finger angle.
d) Arrangement for adjustment effective finger length.
e) Controlled and adjustable header height from the ground
f) Vibrations should be minimum.

Computer-aided 3D Modelling of the Header

The NX-8 CAD software (Make: Siemens PLM Software) was used for the study. It provides modules for design, simulation and manufacturing with high-definition 3D (HD-3D) environment, to enable rich visual interaction and information delivery for validation, product templates and other applications reporting and analytics tools. The CAD was done at Research and Development Department, Mahindra Applitrac, Mohali. There are five major sub-assemblies of finger type stripper header. Different sub-assemblies of header are categorized below;

1. Header frame sub-assembly
2. Finger sub-assembly
3. Reel/Paddle sub-assembly
4. Auger sub-assembly
5. Power transmission

Header Fame Sub Assembly

All the sub-assemblies like finger, reel/paddle, auger and power transmission were mounted in this assembly. This assembly consists of left & right sheet, back sheet, auger bottom sheet, header frame chassis and feeder mouth etc are explained below.

Left and right side sheets of 2 mm thickness were used for fastening the finger, reel/paddle and auger subassemblies. Initially left sheet was created in CAD software then

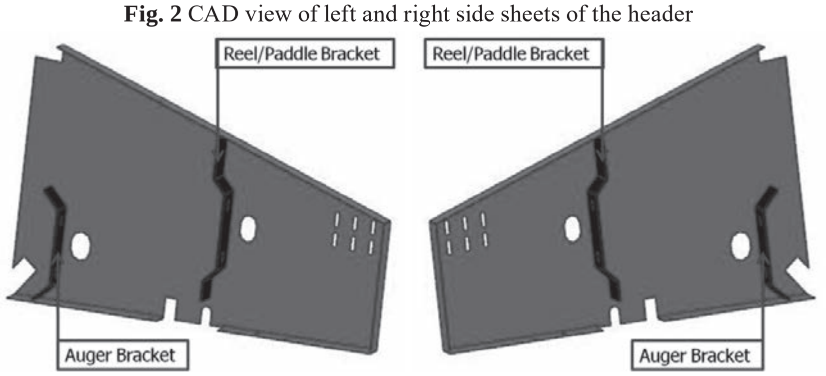
Table 4 Reel speeds and pitch for 3 number of paddles/bats

Speed (km/h)	Reel Tip Speed (m/min)	Reel rpm	Pitch of Reel (m)
1	20.83	15.57	0.45
2	41.67	31.14	0.45
3	62.50	46.71	0.45
4	83.33	62.28	0.45
5	104.17	77.86	0.45

Table 5 Throughput capacity of auger

S. No.	Pitch (mm)	Diameter of worm (mm)	Diameter of pipe (mm)	RPM	Cotton density (kg/m^3)	Material Flow (kg/s)	Conveying velocity (m/s)
1	250	220	76.1	162	70	5.70	0.68

Fig. 2 CAD view of left and right side sheets of the header



using mirror command right sheet was generated. For mounting the auger and reel/paddle assembly, brackets using flat having dimensions of 5 mm thickness and 50 mm width were created. Mild steel material was selected for the sheet and flat. These brackets were attached to the MS sheet. For strengthening the side sheet 40 mm bend provided to all sides. This bend will act as supporting rib. CAD views of left and right side sheets are shown in **Fig. 2**.

The auger bottom perforated sheet was half round curved sheet which helps the auger worm to convey the material. MS sheet of thickness 2 mm was selected for generating the sheet. The sheet was supported with 3 mm MS sheet rib and was having perforations of 13 × 76 mm slot, which helps to partially cleaning of seed cotton. These perforations help to clean seed cotton by removing 5% of trash (Smith, 1997). CAD view of auger bottom sheet is shown in **Fig. 3**.

Feeder mouth sheet supports the feeder sub assembly attached with the header frame assembly. It was generated using 3 mm thick MS Sheet attached in rectangular pattern in such manner to create a hollow box. CAD view of feeder mouth is shown in **Fig. 4**

Header frame chassis was generated using MS square box, angle, flat, rectangular box, round pipe, sheet etc. For making the chassis 40 × 40 × 4 mm MS square box was arranged in rectangular pattern. This rectangular pattern was attached with MS angle to give more strength. MS flat was used for mounting hitch point of the tractor. MS round pipe having 60.3 outer diameter was selected for the casing of header drive shaft. This pipe was attached on chassis with the help of 45 × 25 × 4 mm MS rectangular box. For back sheet, 2 mm MS sheet was selected and attached with chassis. The back sheet was also provided to strengthen the header frame chassis. CAD view of header frame chassis is shown in **Fig. 5**.

Cover sheet is provided to reduce ground losses of material from the header. The cover sheet made of using MS angle, sheet, hinge and wired mesh. For making the cover sheet, 25 × 25 × 4 mm MS angle and 1 mm thick MS sheet were selected. The sheet was supported with 4 rectangular ribs which were made using 3 mm thick MS sheet. The coversheet was mounted with the header using 4 inch hinges. CAD view of cover sheet is shown in **Fig. 6**.

All the above mentioned components of headed frame assembly were assembled using assembly command of the software. CAD view of header frame assembly is shown in **Fig. 7**.

Finger Sub Assembly

The finger sub assembly consists of finger unit, stalk walker and plant stopper are explained below. A set of fingers was created to give combing action to separate the cotton bolls from the plants. Finger unit was generated using MS angle, square box section, sheets and square bar. For making finger 25 × 25 × 4 mm MS angle having 700 mm (600 mm straight +100 mm bend) length was selected. The front tip finger was pointed and 10 degree bend was provided to avoid its damage when header is in rest position. The finger was attached with 35 mm long 40 × 40 × 4 MS square box and supported with 4 mm thick MS sheet rib. The 39 number of fingers having 16 mm spacing were selected for coverage of three rows. All fingers were mounted on 2030 mm long MS square box (32 × 32 × 4) with the help of fasteners. The spacing between two fingers were adjustable and can be increased or decreased with the help of fasteners. The two MS square bars were used as finger locking shaft to the locking finger assembly on right and left side of frame of the header. The angle between finger and horizontal known as finger angle was also adjustable and can be increased or decreased with the help of finger locking shaft. CAD view of finger unit is shown in **Fig. 8**.

Fig. 3 CAD view of auger bottom sheet

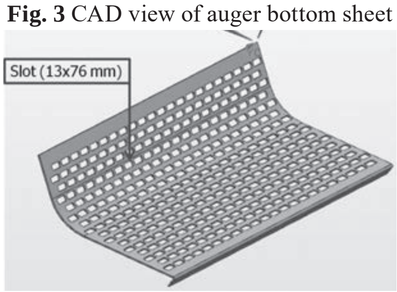


Fig. 4 CAD view of feeder mouth

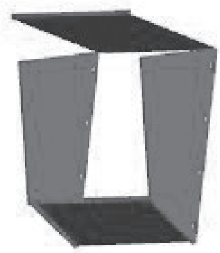


Fig. 5 CAD view of header frame chassis

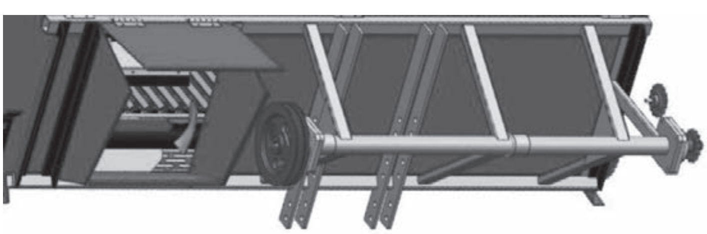
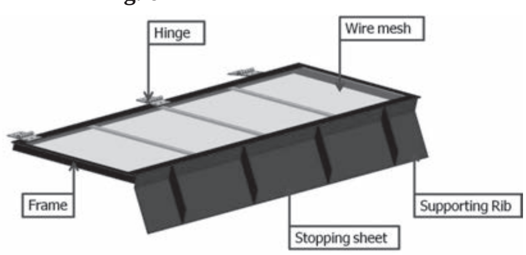


Fig. 6 CAD view of cover sheet



Stalk walker was used to bent down the cotton stalk under finger unit during picking time. It helps to stop the uprooting of the cotton stalk which will be avoided the unnecessary choking of the material on header. Stalk walker was generated using MS sheet, round pipe and round bar. For making stalk walker profile3 mm thick MS sheet was selected which was similar to the cycloid curve. Three profiles were created at 120 degree on round pipe having outer diameter of 42.3 mm and 2030 mm long. To give rotary motion to the pipe, two 30 mm MS round bar shaft were created on each end of the pipe. CAD view of stalk walker is shown in **Fig. 9**.

Plant stopper is a non-rotating component that is used to bend down the cotton stalk above finger unit during harvesting. It helps to control the movement of the cotton canopy directly hitting on the reel/paddle assembly, which helps to reduce the trash content and header losses. It was generated using MS sheet and round pipe. A 2050 mm long, 43.3 mm outer diameter MS round pipe was selected. The pipe was locked between two locking brackets. For making, these two brackets of5 mm thick and 65x65 mm MS sheet were generated. A 43.3 diameter hole was provided on the sheet for locking the pipe. It also helps to increase or decrease the effective finger length. CAD view of plant stopper is shown in **Fig. 10**.

Reel/Paddle Sub-assembly

Reel/Paddle assembly was generated using MS round pipe, sheet, flat, round bar and rubber flaps. For making paddle, 3.15 mm thick MS sheet was used. The paddle was attached using two ribs made with 2.5 mm MS sheet. A rubber flap was attached on the top side of paddle with the help of reel strip and fasteners. This reel strip was made by MS flat. The rubber flaps helps to avoid the stuck of paddle without any damage during operation. The 18 (3 × 6) paddles were mounted on the MS round pipe with 76.1 outer diameter at 120 degree along the 2030 mm length. To give rotary motion two 35 mm MS round shafts were used. CAD view of reel assembly is shown in **Fig. 11**.

Auger Sub-assembly

Auger assembly was generated using MS sheet, round pipe and round bar. The purpose of auger assembly was to convey the material from the reel/paddle to the feeder. For making auger worm, 3.15 mm thick MS sheet was used and divided into two parts left and right side worm. The pitch of worm was selected 250mm and outer diameter 220 mm. These worms were mounted on 1830 mm long and 76.1 mm outer diameter MS round pipe. Right and left side worm will convey the material to the feeder. Three paddles were generated using 5 mm thick MS sheet to transfer the collected material to the feeder mouth. These three paddles were mounted on auger pipe at 120 degree. To provide rotary motion two 35 mm MS round shafts were created at each end of the auger pipe. CAD view of auger assembly is shown in **Fig. 12**.

Power Transmission (Drive Line)

The drive line is very important part of tractor operated header of cotton stripper. The power transmission of tractor operated cotton strip-

Fig. 7 CAD view of header frame sub assembly

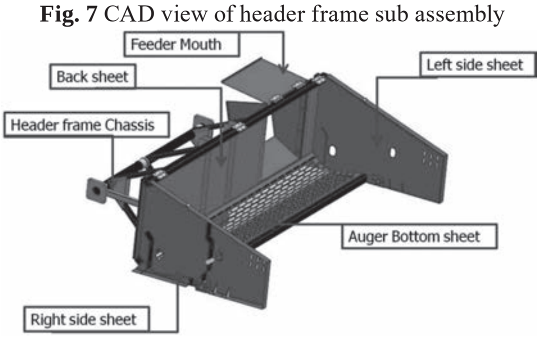


Fig. 9 CAD view of stalk walker

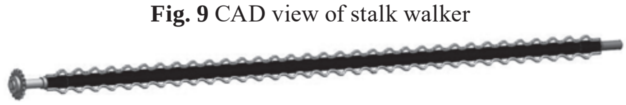
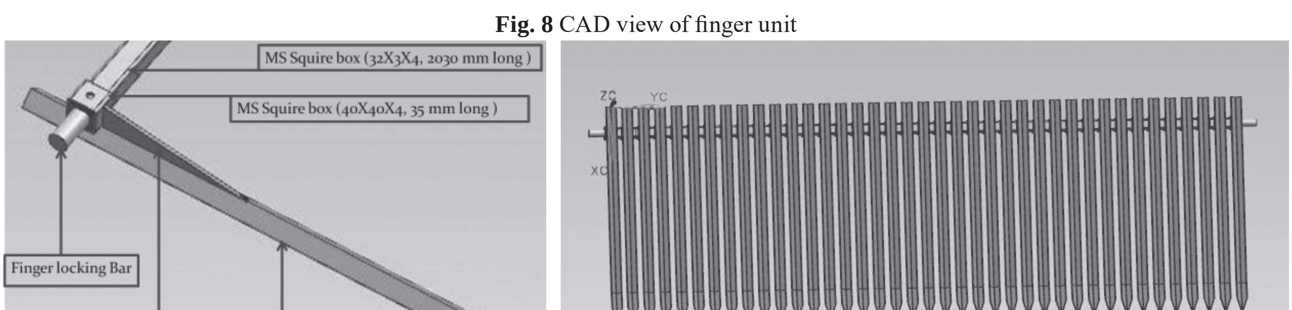


Fig. 10 CAD view of plant stopper

Fig. 8 CAD view of finger unit



per is shown in **Fig. 13**. The tractor PTO was used to drive the various assemblies of the cotton stripper. For Swaraj 855 Tractor selected for the study was having PTO power of 46 hp with 540 rpm. PTO power transmitted to the gearbox designed by Mahindra & Mahindra with an efficiency of 90% and 745 rpm output was selected for the study.

Different type of sprockets and pulleys used for power transmission system are shown in **Tables 6** and **7** respectively. The power was transmitted from gearbox output shaft to main drive shaft with the help of chain and sprockets. Two double groove sprockets (S1 and S2) of size 12B2 having 26 and 23 teeth were mounted to gearbox shaft and main drive shaft respectively to transmit the power from gearbox to main drive shaft. The main drive shaft rotates at 840 rpm. The power is then transmitted from main drive shaft to intermediate shaft and on-board cleaner shaft with the help of V-belt and pulley. A 280 mm diameter, double groove 2C-type, standard pulley was selected and mounted on the other end of main drive shaft. Similarly, a 280 mm diameter, C-type, standard pulley was selected and mounted on intermediate shaft. The intermediate shaft was also rotated at 840 rpm. For the rotation of on-board cleaner shaft, a 200 mm diameter, C-type, standard pulley was selected which rotates at 1176 rpm.

The power is transmitted from intermediate shaft to feeder shaft with the help of chain and sprocket drive. 21 teeth, 12B1 type, standard sprocket was selected and mounted on the intermediate shaft. Similarly 31 teeth, 12B1 type, standard sprocket (S4) was selected and mounted on the feeder shaft which rotated at 569 rpm. In the feeder unit, power is transmitted from feeder shaft pulley (P2) to header drive shaft pulley (P6) through three pulleys (P3, P4 and P5) which rotated at 569 rpm.

Table 6 Different types and teeth of sprockets used for power transmission

Name	Mounted	Assembly	RPM	Teeth	PCD (mm)	Type
S1	Gearbox shaft	Main Drive	743	26	158	12/B2
S2	Main drive shaft	Main Drive	840	23	140	12/B2
S3	Intermediate shaft	Main Drive	840	21	128	12/B1
S4	Feeder shaft	Feeder	569	31	188	12/B1
S5	Header drive shaft	Header	443	15	92	12/B1
S6	Auger shat	Header	162	41	249	12/B1
S7	Auger shat	Header	162	17	86	10/B1
S8	Reel shaft	Header	42	65	329	10/B1
S9	Stalk walker shaft	Header	162	17	86	10/B1

The header drive shaft rotates at 443 rpm. The power is transmitted from header drive shaft to auger shaft with the help of chain and sprocket drive. Fifteen teeth, 12B1 type, standard sprocket (S5) was selected and mounted on the other end of header drive shaft. Similarly, 41 teeth, 12B1 type, standard sprocket (S6) was selected and mounted on the auger shaft which rotates at 162 rpm. The auger shaft rotates at 162 rpm. The power is then transmitted from auger shaft to reel shaft and stalk walker shaft with the help of chain and sprocket drive. Seventeen teeth, 10B1 type, standard sprocket (S7) was selected and mounted on the auger shaft. Similarly, 65 teeth, 10B1 type, standard sprocket (S8) was selected and mounted on the reel shaft which rotated at 42 rpm. For the rotating the stalk walker shaft, 17 teeth, 10B1 type, standard sprocket (S9) was selected which rotates at 162 rpm.

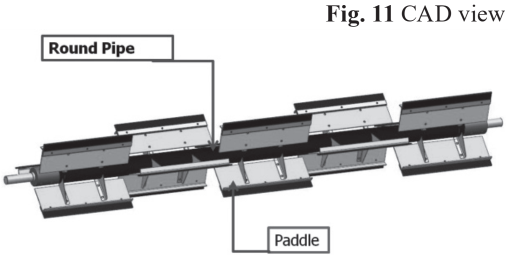
Computer Aided Modelling of Header

All the sub-assemblies like header frame, finger, reel, auger and power transmission were assembled using assembly domain of NX-8 CAD software. Isometric, side-rear and top views generated by CAD software of finger type stripper header are shown in **Fig. 14a**, **b** & **c** respectively.

Development and Fabrication of Cotton Stripper

Computer aided 2D drawings of all the components were generated from 3D models. Based upon 2D drawings and bill of material (BOM), a tractor operated three row cotton header

Fig. 11 CAD view of reel/paddle sub-assembly



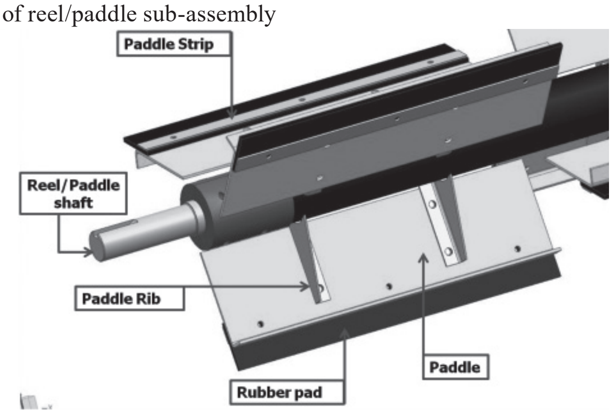


Fig. 12 CAD view of auger sub-assembly

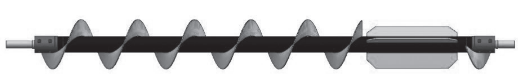


Table 7 Different types of pulleys used for power transmission

Name	Mounted	RPM	Diameter (mm)	Face width (mm)	Type
P0	Main drive shaft	840	280	59	2C
P1	Intermediate shaft	840	280	34	C
P2	Intermediate shaft	569	210	34	C
P3	Feeder shaft	569	210	34	C
P4	Feeder shaft	569	210	59	2C
P5	Feeder shaft	569	210	34	C
P6	Header drive shaft	472	253	48	C
PCI	On board cleaner shaft	1176	200	34	C

was developed and fabricated.

Determination of the Centre of Gravity (CG)

The total weight of cotton stripper was 3666.7 kg. The major weight contributing components are tractor, header, feeder, on board cleaner, main frame chassis and storage and their weight are 2031, 342, 196, 800, 172 and 115 kg respectively. **Fig. 15** shows the weight distribution of cotton stripper. The center of gravity is calculated for the stability and safety of cotton stripper.

The Center of gravity of tractor operated cotton stripper was calculated by weighing method (John et al., 1989). The centre of gravity is the point at which total mass of the body may be considered to act. Its position depends on the disposition of the different masses that involve of the machine. The location of the centre of gravity in the longitudinal (x_2) direction may be found by recording the reaction on the front (R_f) and rear (R_r) wheels. Total weight, reaction on front axle and rear axle of the vehicle was measured by using computerizes weighing force pad made by Mechanica System, Pune (**Fig. 17**). All 4 wheel of tractor place on force pad with the help supporting ramp. After that the front axle of the vehicle was uplifted 200 mm and reaction on front axle (R_f') was again measured (**Fig. 16**). The reaction measurement of all wheels was done in two cases; with and without adding counter weight (270 kg). On the basis of measured reactions, the centre of gravity (CG) was calculated as follow.

Case 1: Center of gravity of developed machine

R_{fL} = 491.4 kg
R_{rL} = 1814 kg
R_{fR} = 471.3 kg
R_{rR} = 884 kg
Front reaction R_f = 962.7 kg
Rear reaction R_r = 2698 kg
Total weight W = 3660.7 kg
Wheel base x_1 = 2098 mm
Left reaction R_L = 2305.4 kg
Right reaction R_R = 1355.3 kg
Track width TW = 1305 mm

Fig. 13 View of drive line of tractor operated cotton stripper

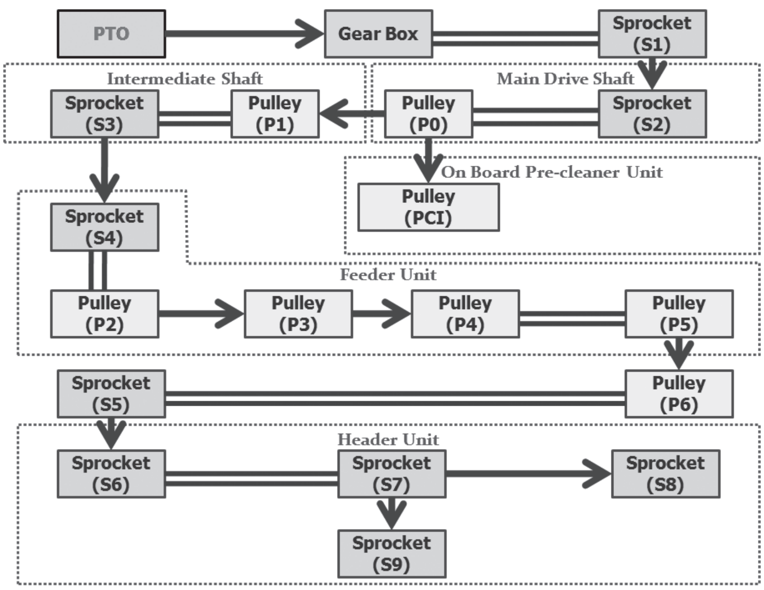


Fig. 14a Isometric view of header assembly

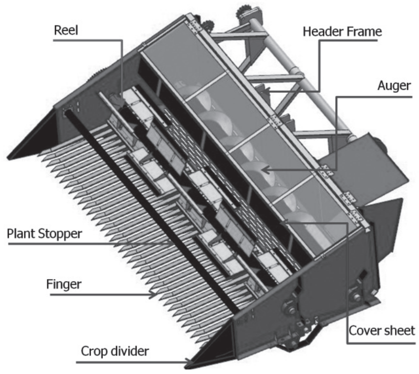


Fig. 14b Side-rear view of header assembly

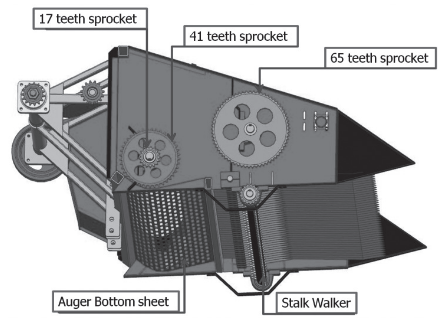
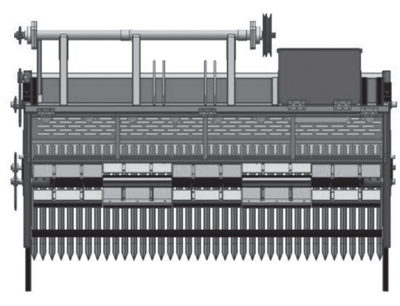


Fig. 14c Top view of Header assembly



$R_f = R_{fL} + R_{fR}$ ···(6)

$W = R_{f1} + R_{f2} + R_{r1} + R_{r2}$ ···(7)

$R_L = R_{fL} + R_{rL}$ ···(8)

$R_R = R_{fR} + R_{rR}$ ···(9)

Longitudinal location of the center of gravity from the rear axle

$x_2 = (R_f \times x_1) / W$ ···(10)

$= 551.73 \approx 552$ mm

Lateral location of the center of gravity from the left side

$z_L = (R_R \times TW) / W$ ···(11)

$= 499.81 \approx 500$ mm

For the calculation of height of the center of gravity from the ground, the front axle of the vehicle was uplifted 200 mm.

$R_{fL}' = 446.6$ kg

$R_{fR}' = 399.2$ kg

Front reaction $R_f' = 845.8$ kg

Up lift height $y = 200$ mm

Diameter of rear wheel $d_r = 1250$ mm

From Fig.3.22

$\beta_1 = \sin^{-1} (y / x_1)$ ···(12)

$= 5.47$ degree

$x_1' = x_1 \times \cos \beta_1$ ···(13)

$= 2088$ mm

$R_f' = R_{fL}' + R_{fR}'$ ···(14)

$= 845.8$ kg

$x_2' = (R_f' \times x_1') / W$ ···(15)

$= 482.43$ mm

$y_3 = [x_2 - (x_2' / \cos \beta_1)] / \tan \beta_1$ ···(16)

$= 700.63$ mm

Height of the center of gravity from the ground

$h = (d_r / 2) + y_3$ ···(17)

$= 1325.63 \approx 1325$ mm

The location of center of gravity for developed tractor operated cotton stripper is shown in Table 8. The location of center of gravity of the developed machine was 98 mm nearer from the rear axle (longitudinal) than the normal tractor, 153 mm offset from the left side of rear axle (lateral) instead of at the center as for normal tractor and 451 mm above than the normal tractor from the ground (height). The left side position (lateral) of center of gravity is shifted due to weight of feeder and on-board cleaner. To balance left side position (lateral) of center of gravity, 270 kg of counter weight was added on the right side of the machine.

Case 2: Adding counter weight of 270 kg

$R_{fL} = 433$ kg

$R_{rL} = 1953$ kg

$R_{fR} = 436$ kg

$R_{rR} = 1107$ kg

Front reaction $R_f = 869$ kg

Rear reaction $R_r = 3060$ kg

Total weight $W = 3929$ kg

Wheel base $x_1 = 2098$ mm

Left reaction $R_L = 2386$ kg

Right reaction $R_R = 1543$ kg

Track width $TW = 1305$ mm

$R_f = R_{fL} + R_{fR}$ ···(18)

$W = R_{f1} + R_{f2} + R_{r1} + R_{r2}$ ···(19)

$R_L = R_{fL} + R_{rL}$ ···(20)

$R_R = R_{fR} + R_{rR}$ ···(21)

Longitudinal location of the center of gravity from the rear axle

$x_2 = (R_f \times x_1) / W$ ···(22)

$= 464.03 \approx 464$ mm

Lateral location of the center of gravity from the left side

$z_L = (R_R \times TW) / W$ ···(23)

$= 530.17 \approx 530$ mm

For the calculation of height of the center of gravity from the ground, the front axle of the vehicle was uplifted 200 mm.

$R_{fL}' = 392.5$ kg

$R_{fR}' = 359.3$ kg

Front reaction $R_f' = 751.8$ kg

Up lift height $y = 200$ mm

Diameter of rear wheel dr = 1250 mm

From Fig.3.22

$\beta_1 = \sin^{-1} (y / x_1)$ ···(24)

$= 5.47$ degree

$x_1' = x_1 \times \cos \beta_1$ ···(25)

$= 2088$ mm

$R_f' = R_{fL}' + R_{fR}'$ ···(26)

Fig. 15 Weight distribution of tractor operated cotton stripper

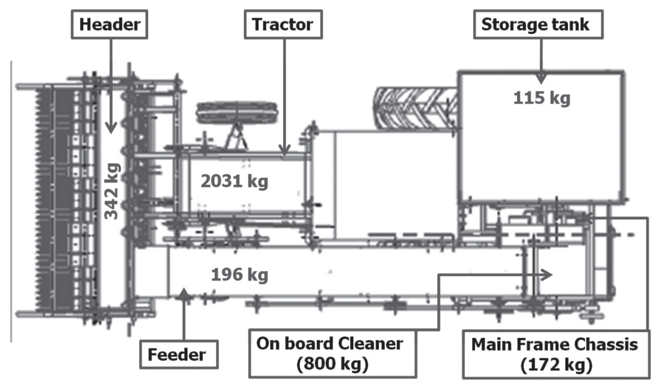


Fig. 16 Machine in (i) Horizontal Position (ii) Raised Position

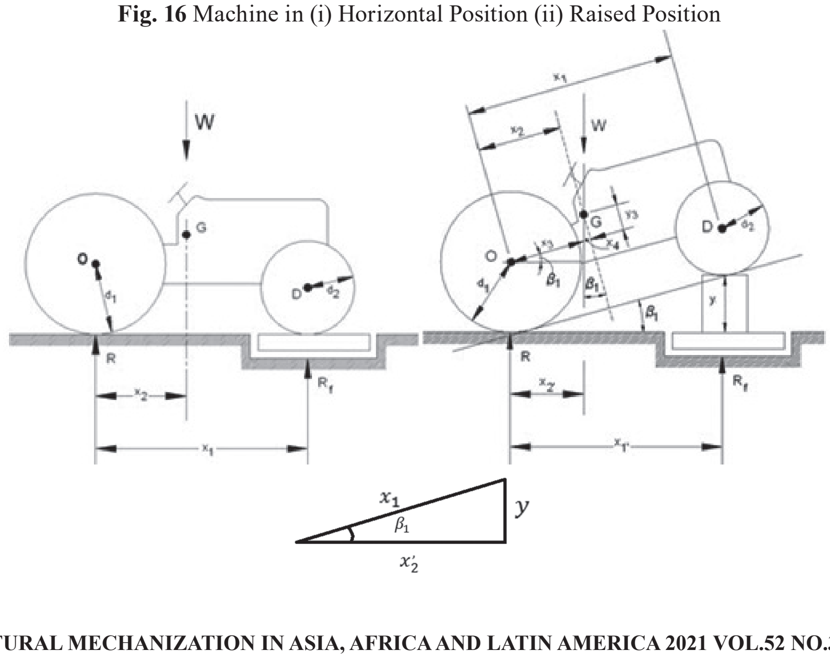


Table 8 Center of gravity of tractor operated cotton stripper

Position center of gravity	Location	Normal Tractor	Tractor operated cotton stripper	With adding counter weight
Longitudinal (mm)	From the rear axle	650	552	464
Lateral (mm)	From the left the rear axle	653	500	530
Height (mm)	From the ground	874	1325	1274

= 751.8 kg

$x_2' = (R_f' \times x_1') / W$ ···(27)

= 400 mm

$y_3 = [x_2 - (x_2' / \cos \beta_1)] / \tan \beta_1$ ···(28)

= 649.4 mm

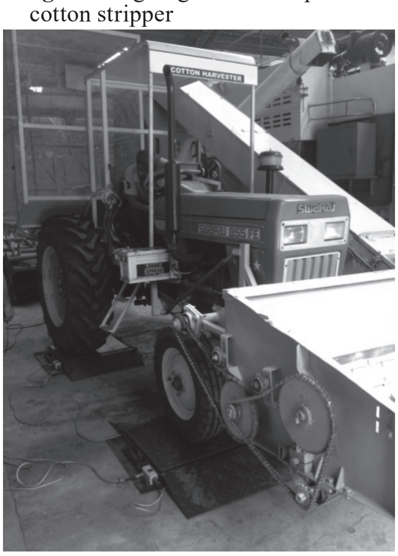
Height of the center of gravity from the ground

$h = (d_r / 2) + y_3$ ···(29)

= 1274.4 ≈ 1274 mm

The location of center of gravity of tractor operated cotton stripper is shown in **Table 8**. The center of gravity of the developed machine by adding weight of 270 kg were shifted longitudinally from 552 to 464 mm from the rear axle, laterally from 500 to 530 mm from the left of the rear axle and height wise from 1325 to 1274 mm from the ground. The location of center of gravity of the developed machine was 186 mm nearer from the rear axle (longitudinal) than the normal tractor, 123 mm offset from the left side of rear axle (lateral) instead of at the center as for normal tractor and 400 mm above than the normal tractor from the ground (height).

Fig. 17 Weighing of tractor operated cotton stripper



Stability of Tractor Operated Cotton Stripper While Turning

The assumptions for calculation are as follows:

i.) Forward movement is consistent; this assumes steady force and no acceleration.

ii.) Lines of forces on wheel are moreover tangential or radial or may be determine as such wheel sinkage and tyre distortion (but not normal tyre deflection) are neglected.

iii.) Other forces, such as the change in place of the fuel and oil in the tractor on sloping ground, air resistance and other slight forces are neglected.

Taking moments about rear wheel contact the ground (Singh 2015)

$[(W \times v^2) / r] \times h = (W \times TW) / 2$ ...(30)

Where

W = weight of tractor, kg

v = velocity of the tractor, m/s

r = turning radius of the tractor, mm

h = height of the CG from the ground, mm

TW = track width of the tractor, mm

Based on this equation 30 the velocity ratio is calculated for cotton stripper to normal tractor.

$v_{cs} / v_n = \sqrt{(r_{cs} \times h_n) / (r_n \times h_{cs})}$ ...(31)

Where

v_{cs} = velocity of the cotton stripper, m/s

v_n = velocity of the normal tractor, m/s

r_{cs} = turning radius of the cotton stripper, mm

h_n = turning radius of the normal tractor, mm

r_n = height of the CG from the ground of cotton stripper, mm

h_{cs} = height of the CG from the ground of normal tractor, mm

Put the value of height of the CG from the ground of cotton stripper from the **Table 8** for both cases i.e. developed machine and adding of counter weight

For developed machine

$v_{cs} / v_n = 0.81 \times \sqrt{(r_{cs} / r_n)}$ ···(32)

For adding of counter weight

$v_{cs} / v_n = 0.83 \times \sqrt{(r_{cs} / r_n)}$ ···(33)

For normal condition the steering system should be adjusted to increase the turning radius $r_{cs} > r_n$. But In the field operation turning radius was fixed due to plot size and field constrain hence $r_{cs} = r_n$. Therefore as per equation 32 and 33, there is need to reduce the forward speed to maintain same turning radius for dynamic stability of the machine. The reduction of forward speed is 0.81 and 0.83 times of the speed of normal tractor for developed machine without and with weight respectively.

Conclusions

In present study, CAD tool NX-8 was used for designing of tractor operated cotton header, which offered superior visual effect to assess the improvement. A computer aided model helped in better understanding of the concept and also saved the time of designing the machine. It reduced human efforts, prevented loss of material and helped to find out the distinctive dimensions of various components of machine with great accuracy in small time. Developed cotton header was fabricated based on the 2D drawing and BOM. The location of center of gravity of the developed machine was 186 mm nearer from the rear axle (longitudinal) than the normal tractor, 123 mm offset from the left side of rear axle (lateral) instead of at the center as for normal tractor and 400 mm above than the normal tractor from the ground (height).

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REFERENCES

Anonymous. 2014. Production, yield and area of cotton. www.indiastat.com. A site registered with main library, Punjab Agricultural University, Ludhiana (Date of visit: 28th December, 2014).

Barik, A. 2010. Cotton statistics at a glance, Tech Bull, Pp 1-42. Directorate of Cotton Development, Ministry of Agriculture, GOI, Mumbai, Maharashtra.

Chaudhry, M. R. 1997. Harvesting and ginning of cotton in the world. Proc. 7th Beltwide Cotton Conference pp16-18. New Orleans, USA.

Desai, K. W. 2012. Studies on the performance of modified axial flow thresher at different louver angles. M. Tech. thesis, Punjab Agricultural University, Ludhiana, India.

John, B. L., Paul, K. T., David, W. S. and M. Hoki. 1989. Tractor and their power units. Pp. 272-13. The AVI publishing company, Inc. New York.

Kepnar, R. A., Bainer, R. and E. L. Barger. 1987. Principle of Farm Machinery. Pp. 195-08. The A VI publishing company, Inc., USA.

Kepner, R. A., Curley, R. G., Brooks, C. R. and V. T. Walhood. 1979. A Brush-Type Stripper for Double-Row Cotton. Trans. ASAE 22(6): 1234-37.

Kirk, I. W., Hudspeth, E. B. Jr. and D. E. Wanjura. 1964. A broadcast and narrowrow cotton harvester. Texas Agricultural Experiment Station Progress Report (No. 2311, May 7). College Station: Agricultural Communications, The Texas A & M University System Agriculture Program.

Kohli, S. S., Sharma, K., Singh, M., Sharma, A. and P. Mishra. 2015. Attribute based coding, review and gap analysis of cotton harvesting processes and machines. Int. Comm. of Agricultural and Biosystems Engg., CIGR J 17(3): 120-127

Modak, S. P. 2011. Computer aided design and development of a tractor operated three row rotary weeder. M. Tech. thesis, Punjab Agricultural University, Ludhiana, India.

Parish, L. Richard and Shelby R. Kenneth. 1974. Design of a Cotton Brush Harvester for Four Narrow Rows. Trans. ASAE. 17(6): 1076-77.

Singh, M. 2015. Design and development of tractor operated seeder for wheat as relay crop in cotton. PhD thesis, Punjab Agricultural University, Ludhiana.

Singh, P. 2007. Use of CAD in development of prototype of wheel hand hoe mounted twin disc fertilizer broadcaster. B. Tech. project report, Punjab Agricultural University, Ludhiana, India.

Smith, H. P. 1950. Harvesting cotton. In W. B. Andrews (Ed.), Cotton production marketing and utilization (pp. 206-240). Richmond, VA: Wm. Byrd Press.

Smith, H. P. 1964. Farm machinery and equipment. New York: McGraw-Hill.

Tupper, G. R. 1966. New Concept of Stripper Harvesting of Cotton in Arkansas. Trans. ASAE (9): 110-111, 113.

Varshney, A. C., Tiwari, P. S., Narang, S. and C. R. Mehta. 2004. Data book for Agricultural Machinery Design. Pp 374-77.

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Development and Evaluation of a Tractor Operated Cotton Header

by

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Abstract

In India, cotton is mostly picked manually. Though, commercially available cotton harvesters were tried for Indian varieties, their high initial cost and their higher capacity made their use uneconomical for small or medium-size farms. Keeping in mind the conditions of Indian farms, a tractor operated cotton header has been developed. The developed machine was evaluated on RCH-773 and F-2383 cotton varieties. The forward speed significantly affected the picking capacity of both varieties i.e. RCH-773 and F-2383. Maximum picking capacity was 1865.01 and 559.50 kg/h, found at FL2, FS1, A1 and S2 combination for both varieties respectively. There was a significant effect of finger spacing observed on picking efficiency, ground loss and stalk loss for both varieties. The maximum picking efficiency was 95.56 and 94.89%, found at FL1, FS1, A2 and S1 combination for both varieties, respectively. The optimum combination of machine was found with 700 mm finger length (FL1), 16 mm finger spacing (FS1), 15 degree finger angle (A2) and 4.5 km/h forward speed (S2).

Keywords: Cotton header, cotton harvesting, picking efficiency, finger length, ground loss

Introduction

Cotton fabric alone accounts for half of the fiber worn in the world. The world demand for all fibers is expected to rise, in volume terms, from 74 million tons in 2010 to 95 million tons in 2020 (Barik, 2010). Cotton is an important commercial crop of India, having a cultivated area of 11.7 M ha, the largest in the world. Though, India is the largest producer of cotton in the world, but the yield is much less as compared to the average yield of the world. The average yield of cotton in the world is 766 kg ha^{-1}. Australia has the highest average yield of cotton as 2151 kg ha^{-1} while the average yield of cotton in India is only 540 kg ha^{-1} (Anon, 2014).

In the world, approximately 30% of seed cotton harvesting is done by mechanical harvesters. In some countries like USA, Australia and Israel, nearly 100% seed cotton is picked by mechanical harvesters. In terms of percentage, a significant amount of cotton is harvested by machines in Bulgaria, Greece and Spain. In Tajikistan, Uzbekistan, Turkmenistan and Azerbaijan, approximately 60-70% of the total area is hand-picked. India, China, Turkey and Pakistan are major cotton producing countries in the world, where nearly 100% picking is done manually. Cotton pickers with different mechanisms such as Drum type spindle and Chain belt type spindle; and cotton strippers with different mechanisms like finger type and brush type are adopted successfully in developed countries (Sharma et al., 2015).

In the cotton stripper, all cotton bolls, whether opened or closed are removed along with burs and sticks from the plant in a single operation. Brush and finger type mechanism is used in strippers. Cotton strippers are mostly used after the application of a defoliant. However, the undesirable dry leaves and sticks are collected, along with the seed cotton, during harvesting. Studies confirmed that defoliation was often needed to maintain fibre quality and to improve picker-harvester efficiency; whereas desiccation was a prerequisite in preparing cotton for stripping (Walhood and Addicott, 1968; Williamson and Riley, 1961).

Cotton stripper needs additional cleaning in order to get good quality lint. Once the seed cotton is harvested (either mechanically or manually), it is transported to cotton ginneries, where the cotton fibers (lint) are separated from the cottonseeds. Strippers are most successful in the areas where plants are small and the fibers are rather short (Wanjura and Baker 1978). For researchers, scientist and manufacturers, it is a difficult task to select and design a cotton harvester. The main reason for this is the design constraint due to various planting systems and different varieties of cotton in different zones of the countries like India. Singh and Buttar (2012) suggested that in order to select and design a cotton harvester, variety or hybrid with short height, less symopodial and synchronous blooming can be developed. These can be evaluated at a different spacing pattern such as high density planting system (HDPS). Brown and Ware (1958) reported that, in 1914, an unrevealed farmer used a sled-type stripper (prepared by attaching a part of a picket hedge to a luge) in the 1st attempt to strip cotton on the Texas High Plains. Consequently, farmers and local shops developed horse-drawn cotton sleds. Simultaneously, ginning machine manufacturers developed extracting and cleaning machinery, that enabled sledded cotton to be ginned and cleaned (Hudspeth, 1977; Sutton, 1984). Both finger and roll strippers are once-over, non-selective harvesters, that remove seed cotton as well as burs, remaining leaves, and portions of stems and branches from the plants. These machines were better suited, than were the spindle pickers, for harvesting the dry land, short-stature cotton typically produced in the Southwest. Although, many refinements were made in finger and roller strippers after their introduction (Kirk et al., 1964; Schroeder and Porterfield, 1954; Smith et al., 1935); low cotton prices, abundant hand labor, harvest losses with the machines, insufficient gin cleaning equipment, and lack of effective harvest aids (primarily desiccants) deferred their extensive recognition, until after World War II.

Due to impending scarcity of labor, mechanization of cotton harvesting is being considered to be of a vital importance. However, there are some reasons due to which cotton harvesters are not popular in India. Cotton varieties grown in India are determinate and bushy type; the holdings are small and fragmented; the initial cost of cotton pickers is high and its capacity is higher making its use uneconomical or impossible for small or medium-size farms. Keeping all these factors in view, a tractor operated cotton stripper has been developed in collaboration with PAU, Ludhiana and Mahindra Applitrac, Mohali.

Material and Methods

Working Principle of Tractor Operated Cotton Header

The idea of development for finger type cotton header was derived from the study conducted by Tupper

Fig. 1 Developed finger sub-assembly

Fig. 2 Developed stripper header

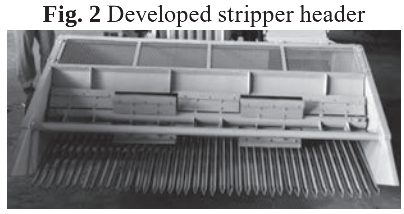


Fig. 3 View of developed feeder assembly

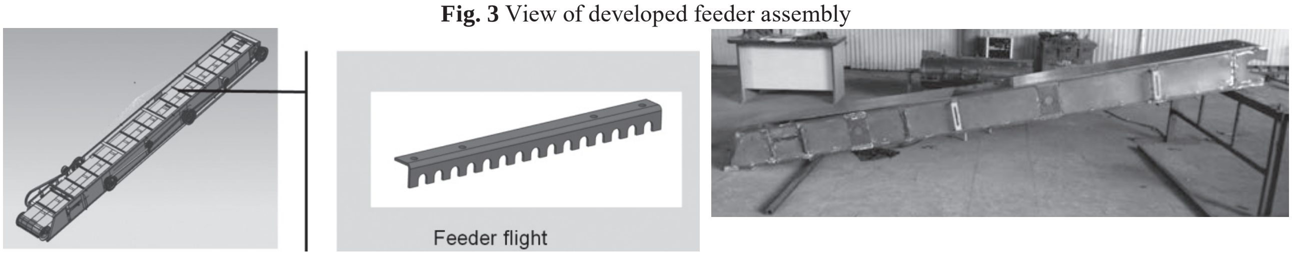


Fig. 4 Tractor operated cotton stripper

(1966). The designed cotton header works on the principle that when finger type header moves through the cotton field, due to its forward motion inclined fingers will strip the cotton bolls with burs from the plants and the remaining plant will maintain its position in the field. Cotton bolls with shells/burs will be stripped from the plants with the help of a series of stationery inclined fingers having a narrow gap. Due to the pushing force of next group of plants being stripped, the stripped material will move upward, towards the inclined fingers. A reel/paddle/kicker mounted at the rear-side of the fingers will help to convey the stripped materials to the conveying auger. The conveying auger will further help to convey the material to feeder for further processing. The material will be conveyed through feeder to the cleaning unit. The cleaner will remove burs, including green bolls, sticks and leaves. After cleaning, the storage tank will receive the seed cotton.

Development and Fabrication of Stripper Header

During its development the functional requirements of the machine for 3 row cotton header were identified and insured. The cotton stripper having four major assemblies, namely; header unit, feeder unit, cleaning unit and storage unit was mounted on a Swaraj 855 tractor (55 hp). Header assembly was mounted in front of the tractor with the help of a mounting frame. A standard hydraulic ram cylinder was used to increase or decrease the header height from the ground. This ram cylinder was connected with the auxiliary valve of a tractor hydraulic duct. The Direction Control Valve (DCV) was used for controlling the direction of hydraulic ram cylinder flow, which was installed at the right side nearer to the driver seat. The developed finger sub-assembly and stripper header are shown in **Figs. 1** and **2**, respectively.

Development and Fabrication of Feeder Assembly

Feeder was used to convey the material, conveyed by auger through header mouth to the cleaning unit. Flat belt with combing flight type mechanism was used to convey the material by the feeder. Flat belt was made of double ply nylon cloth. The combing flights were made using 3 mm thick MS sheet. Total 32 numbers of combing flights were bolted on 8160 mm long flat belt. The provision for tightening and loosening of the belt was also provided. Material flow was by the combing flights mounted at the underside of the feeder belt. Total length of the feeder was 4080 mm. View of developed feeder assembly is shown in **Fig. 3**.

Fabrication of Main Frame Chassis

Main frame chassis of the tractor operated cotton stripper was used to mount the storage tank, On-board cleaner and the drive line. It was fabricated to bear the load of 2000 kg weight. This was done using 40 × 60 × 4 mm MS rectangular pipe, 40 × 40 × 4 mm MS square pipe, 5 mm thick MS sheet and 40 × 40 × 4 mm MS angle etc. All the components were welded with the help of MIG welding, as per drawing.

Fabrication of Storage Tank

Storage tank of 300 kg capacity was provided for the collection of harvested seed cotton. To develop the storage tank, density of seed cotton was assumed 70 kg m^{-3} (Anthony and Mayfield, 1997). It was fabricated using 40 × 25 × 4 mm MS rectangular pipe, 25 × 25 × 4

Table 1 Main specifications of the developed tractor operated cotton stripper

S. No.	Description	Specification
1	**Tractor power, hp**	55
2	**No of rows**	3
3	**Picking mechanism and header unit**	
	Type	Finger type stripper
	Number of fingers	39
	Harvesting width, mm	2050
4	**Reel/Paddle**	
	Type	Paddle type
	Number of paddle	18
	Rotational speed, rpm	40
5	**Conveying mechanism**	
	Type	Auger type (Screw conveyor)
	Rotational speed, rpm	162
6	**Feeder unit**	
	Type	Belt and flight type
	Length, mm	4080
7	**Storage tank**	
	Type	Perforated sheet and nest type
	Capacity, kg	300
8	**Power transmission**	Chain-sprockets and V-Belts
9	**Overall dimensions, mm**	2050 × 2530 × 6235
10	**Cleaning unit**	
	Type	Chanel saw band cylinder type
	Capacity, kg/h	2000

mm MS square pipe, 1.6 mm thick MS sheet and MS wired mesh etc. All the components were welded with the help of MIG welding, as per drawing. View of storage tank for cotton stripper is shown in **Fig. 4**.

Field Evaluation Protocol

Field evaluation of the developed machine was conducted at the Research Farm, Department of Farm Machinery and Power Engineering, PAU, Ludhiana (30.9028° N, 75.8086° E), and at Regional Research Station, Bathinda (30.283333° N, 74.966667° E). Crop variety RCH-773 was sown at 675 × 675 mm plant to plant and row to spacing at PAU Ludhiana farm. While at Bathinda farm, Crop variety F-2383 was sown at a high density planting system, which had 67.5 × 10 cm spacing. After sowing, the various field operations such as irrigation, weeding fertilizer application and spraying etc. were been done. After sowing for about 170-190 days, the crop was harvested. **Table 2** shows the cotton crop characteristics for RCH-773 and F-2383 cotton varieties, sown at different plant spacing.

On an average plant height of 926.8 mm was observed for variety RCH-773 sown at PAU, Ludhiana. While, on an average plant height of 852 mm was observed for variety F-2383 sown at RRS, Bathinda. The plant width (canopy) was significantly lesser i.e. 513 mm for F-2383 sown at RRS, Bathinda than the plant canopy of 677 mm for variety RCH-773 sown at PAU, Ludhiana. The change in plant canopy was due to the soil and climatic difference observed at different locations. The number of opened bolls of 38 was observed for variety RCH-773 sown at PAU, Ludhiana. While, number of opened bolls of 6 was observed for variety F-2383 sown at RRS, Bathinda. The number of open boll of both varieties sown at RRS, Bathinda was significantly less than the number of opened bolls at PAU, Ludhiana. The number of green bolls of 2 was observed for variety RCH-773 sown at PAU, Ludhiana. There were no green bolls observed in the varieties F-2383 sown at RSS, Bathinda. The main reason of this observation was that an extreme attack of whitefly affected the cotton crop of the West Punjab region. This attack affected all the parameters of the cotton crop, like the number of open bolls, the number of green bolls etc. It was found that the heights of lower and upper boll of 225 and 847 mm for RCH-773 sown at PAU, Ludhiana respectively. While the heights of lower and upper boll 274 and 694 mm were observed for variety F-2383 sown at RRS, Bathinda, respectively.

Dependent and Independent Parameters

Important design and operational parameters, like; finger angle, finger spacing, finger length and forward speeds as independent parameters were selected for the present study. Dependent parameters, namely; picking capacity, field capacity, picking efficiency and losses were selected to evaluate the performance of tractor operated stripper header. The dependent and independent variables with their levels are given in **Table 3**.

Fig. 5 Operation view of tractor operated cotton header

Picking capacity, field capacity, picking efficiency and loss were measured, as per standard procedure. Picking capacity was the mass of the seed cotton harvested by the header per unit time, expressed in kg/h. Field capacity was measured as area harvested by the machine per unit time. Total losses were measured as the sum of ground and stalk loss. Ground loss was calculated as the ratio of the weight of seed cotton fallen through the machine on the ground to the average yield of the plot picked manually. Similarly, stalk loss was calculated as the ratio of the weight of seed cotton left on the plant (stalk) to the average yield of the plot picked manually. Picking efficiency was measured as the percentage of cotton

Table 2 Cotton crop characteristics

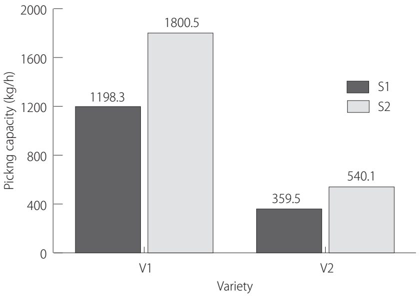
S. No.	Attribute	Average values of observed data	
1	Field location	PAU, Ludhiana	RRS, Bathinda
2	Cotton variety	RCH-773	F-2383
3	Plant spacing (cm)	675 × 675	675 × 100
4	Plant height (cm)	926	852
5	Plant canopy across row (cm)	677	513
6	Height of lower boll (cm)	225	274
7	Height of upper boll (cm)	847	694
8	No. of opened bolls	38	10
9	No. of green/unopened bolls	2	1

Table 3 Dependent and independent variables with their levels

Independent variables	Levels	Details	Dependent variables
Crop variety	2	RCH-773 and F-2383	• Picking capacity, kg/h
Finger angle, degree	3	12, 15 and 18	• Field capacity, ha/h
Speed, km/h	2	2.63 and 4.50	• Picking efficiency, % age
Finger spacing, mm	3	16, 20 and 24	• Losses, % age
Finger length, mm	2	600 and 700	

Number of replication: 3

Fig. 6 Effect of independent parameters on picking capacity



picked by the machine to the total seed cotton. The operational view of the tractor operated cotton header is shown in **Fig. 5**. The factorial experiment was conducted using randomized block design. With the help of SAS 9.3 software, General Linear Model (GLM) procedure was used for statistical analysis.

Results and Discussion

Picking Capacity

The effects of variety, forward speed, finger angle, finger length and finger spacing on picking capacity were calculated. The combined effect of all these parameters was also calculated. ANOVA table for picking capacity is depicted in **Table 4**. The picking capacities are also shown graphically in **Fig. 6**. Among all the treatments, the mean value of picking capacity varied from 337.61 to 1865.01 kg/h and the differences were statistically significant (p value = 0.0001), at a 5% level of significance.

Picking capacity of a tractor operated cotton header was statistically at par for finger length, finger spacing and finger angle and varied between 970.94 to 978.24, 969.26 to 979.12 and 968.03 to 982.28 kg/h respectively. At a 5% level of significance, the combined effect of finger length, finger spacing, finger angle and forward speed was not statistically significant on the picking capacity. However, variety, forward speed and combination of variety, finger length, finger spacing, finger angle and forward speed significantly affected the picking capacity as shown in **Table 4**.

Mean value of picking capacity of 1499.4 and 449.8 kg/h was observed for variety RCH-773 (V1) and F-2383 (V2) respectively. At a 5% level of significance, there was statistically significant effect of forward speed was observed on the picking capacity (p value =0.0001). Picking capacity for variety RCH-773 (V1) was 69.99 % higher than for variety F-2383 (V2). The main reason for this result may be the yield difference between both the varieties.

On an average, picking capacity for S1 and S2 forward speed was observed 778.9 and 1170.3 kg/h, respectively. This was found to be statistically different (p value = 0.0001) at a 5% level of significance. Picking capacity at S2 forward speed was 33.44 % higher than the picking capacity at S1 speed. The main reason for this result was that as the forward speed was increased the feed rate of material was also increased. On an average, maximum picking capacity of 1800.5 kg/h was observed for RCH-773 (V1) variety with S2 forward speed. The minimum picking capacity of 359.5 kg/h was observed for F-2383 (V2) variety with S1 forward speed.

The interaction among various independent variables such as variety, forward speed, finger angle, finger length and finger spacing was found statistically different at a 5% level of significance. The maximum picking capacity of 1865.01 kg/h was found for variety RCH-773 at a combination of FL2, FS1, A1 and S2. The minimum picking capacity of 1125.37 kg/h was found for variety RCH-773 at a combination of FL1, FS3, A1 and S1. The maximum picking capacity of 559.50 kg/h was found for variety F-2383 at a combination of FL2, FS1, A1 and S2. The minimum picking capacity of 337.61 kg/h was found for variety F-2383 at a combination of FL1, FS3, A1 and S1.

Table 4 ANOVA table for picking capacity

Factors mean (kg/h)			
Variety (V)	1499.4 (V1)	449.8 (V2)	
Forward speed (S)	778.9 (S1)	1170.3 (S2)	
Finger angle (A)	982.28 (A1)	968.03 (A2)	973.48 (A3)
Finger length (FL)	970.94 (FL1)	978.24 (FL2)	
Finger spacing (FS)	969.26 (FS1)	975.41 (FS2)	979.12 (FS3)

AVOVA table

Source	DF	Mean square	F Value	p value	Significant (S)/ Non-significant (NS)
V	1	59485607.75	46370.4	<.0001	S
S	1	8272446.44	6448.57	<.0001	S
A	2	3718.22	2.90	0.0584	NS
FL	1	2879.34	2.24	0.1363	NS
FS	2	1784.15	1.39	0.2522	NS
S*A	2	335.25	0.26	0.7704	NS
S*FL	1	1048.92	0.82	0.3674	NS
S*FS	2	1085.11	0.85	0.4313	NS
A*FL	2	3863.74	3.01	0.0674	NS
A*FS	4	4077.35	3.17	0.0513	NS
FL*FS	2	679.48	0.53	0.5900	NS
S*A*FL	2	409.07	0.32	0.7275	NS
A*FL*FS	4	4092.315	3.19	0.0502	NS
S*FL*FS	2	2066.88	1.61	0.2033	NS
S*A*FS	4	1066.08	0.83	0.5075	NS
S*A*FL*FS	4	801.46	0.62	0.6456	NS
V*S*A*FL*FS	35	69552.44	54.22	<.0001	S

Picking Efficiency

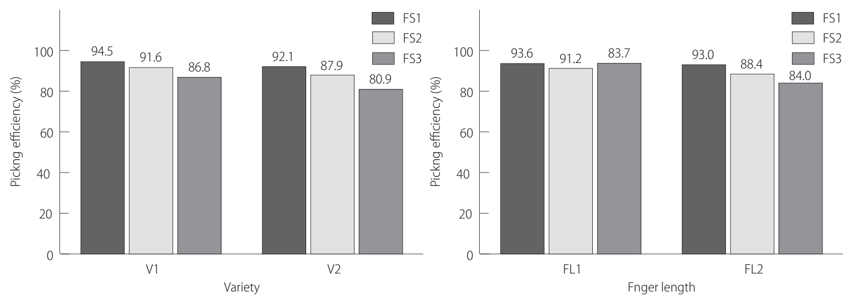
The effects of variety, forward speed, finger angle, finger length and finger spacing on picking efficiency (%) are presented in **Table 5**. The combined effect of all these parameters was also calculated. The picking efficiency is also shown graphically in **Fig. 7**. Among all the treatments, the mean value of picking efficiency varied from 75.45 to 96.5% and the differences were statistically significant (p value = 0.0001), at a 5% level of significance.

Picking efficiency of a tractor operated cotton header was statistically at par for finger length, forward speed and finger angle and varied between 89.5 to 88.5, 88.9 to 89.1 and 89.4 to 88.9% respectively. At a 5% level of significance, the combined effects of finger length, finger spacing, finger angle and forward speed were not statistically significant on the picking efficiency. However, variety, finger spacing and combination of finger length and finger spacing significantly affected the picking efficiency as shown in **Table 5**.

Mean value of picking efficiency of 91.0 and 87.0% was observed for varieties RCH-773 (V1) and F-2383 (V2) respectively. At a 5% level of significance, the effect of forward speed was observed statistically significant on the picking efficiency (p value = 0.0001). Picking efficiency for variety RCH-773 (V1) was 4.4% higher than for variety F-2383 (V2). On an average, picking efficiency of 93.3, 89.8 and 83.9% was observed for FS1, FS2 and FS3 finger spacing respectively. This was found statistically different (p value = 0.0001) at a 5% level of significance. With an increase in finger spacing from FS1 to FS3, picking efficiency decreased. The reason for this may be that an increased spacing between fingers leaves more seed cotton on the stalks.

On an average, maximum picking efficiency of 94.5% was observed for RCH-773 (V1) variety and with FS1 finger spacing. The minimum picking efficiency of 80.9% was observed for F-2383 (V2) variety and with FS3 finger spacing. At a 5% level of significance, the interaction between the finger length and finger spacing was found statistically different (p value = 0.0195). On an average, maximum picking efficiency of 93.6% was observed for FS1 finger spacing and with FL1 finger length. Similarly, on an average, minimum picking efficiency of 83.7% was observed for FS3 finger spacing and with FL1 finger length.

Fig. 7 Effect of independent parameters on picking efficiency



The maximum picking efficiency of 96.45% was found for variety RCH-773 at a combination of FL1, FS1, A2 and S1. The minimum picking efficiency of 82.97% was found for variety RCH-773 at a combination of FL1, FS3, A3 and S1. The maximum picking efficiency of 94.89% was found for variety F-2383 at a combination of FL1, FS1, A2 and S1. The minimum picking efficiency of 75.45% was found for variety F-2383 at a combination of FL1, FS3, A3 and S1.

Mean value of picking efficiency of 91.0 and 87.0% was observed for

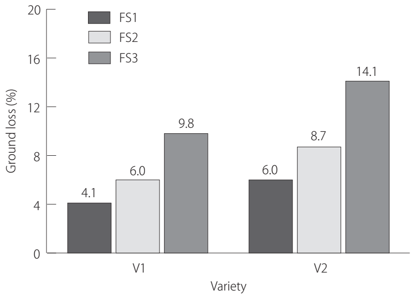
Table 5 ANOVA table for picking efficiency

Factors mean (%)			
Variety (V)	91.0 (V1)	87.0 (V2)	
Forward speed (S)	88.9 (S1)	89.1 (S2)	
Finger angle (A)	89.4 (A1)	88.6 (A2)	88.9 (A3)
Finger length (FL)	89.5 (FL1)	88.5 (FL2)	
Finger spacing (FS)	93.3 (FS1)	89.8 (FS2)	83.9 (FS3)

AVOVA Table

Source	DF	Mean Square	F Value	p value	Significant (S)/ Non-significant (NS)
V	1	858.927467	73.49	0.0001	S
S	1	2.956356	0.25	0.6158	NS
A	2	10.958464	0.94	0.3940	NS
FL	1	38.88205	3.328942	0.05132	NS
FS	2	1638.989189	140.24	0.0001	S
S*A	2	19.64506	1.68194	0.2737	NS
S*FL	1	36.2335	3.10	0.0743	NS
S*FS	2	25.905459	2.22	0.1127	NS
A*FL	2	38.16302	3.26	0.0574	NS
A*FS	4	10.184375	0.87	0.4828	NS
FL*FS	2	47.327379	4.05	0.0195	S
S*A*FL	2	29.556070	2.53	0.0833	NS
A*FL*FS	4	4.040566	0.35	0.8466	NS
S*FL*FS	2	29.602362	2.53	0.0830	NS
S*A*FS	4	19.220151	1.64	0.1664	NS
S*A*FL*FS	4	18.674664	1.60	0.1781	NS
V*S*A*FL*FS	35	3.883116	0.33	0.9998	NS

Fig. 8 Effect of independent parameters on ground loss



varieties RCH-773 (V1) and F-2383 (V2) respectively. At a 5% level of significance, the effect of forward speed was observed statistically significant on the picking efficiency (p value =0.0001). Picking efficiency for variety RCH-773 (V1) was 4.4% higher than for variety F-2383 (V2). On an average, picking efficiency of 93.3, 89.8 and 83.9% was observed for FS1, FS2 and FS3 finger spacing respectively. This was found statistically different (p value = 0.0001) at a 5% level of significance. With an increase in finger spacing from FS1 to FS3, picking efficiency decreased. The reason for this may be that an increased spacing between fingers leaves more seed cotton on the stalks.

On an average, maximum picking efficiency of 94.5% was observed for RCH-773 (V1) variety and with FS1 finger spacing. The minimum picking efficiency of 80.9% was observed for F-2383 (V2) variety and with FS3 finger spacing. At a 5% level of significance, the interaction between the finger length and finger spacing was found statistically different (p value = 0.0195). On an average, maximum picking efficiency of 93.6% was observed for FS1 finger spacing and with FL1 finger length. Similarly, on an average, minimum picking efficiency of 83.7% was observed for FS3 finger spacing and with FL1 finger length.

The maximum picking efficiency of 96.45% was found for variety RCH-773 at a combination of FL1, FS1, A2 and S1. The minimum picking efficiency of 82.97% was found for variety RCH-773 at a combination of FL1, FS3, A3 and S1. The maximum picking efficiency of 94.89 % was found for variety F-2383 at a combination of FL1, FS1, A2 and S1. The minimum picking efficiency of 75.45% was found for variety F-2383 at a combination of FL1, FS3, A3 and S1.

Table 6 ANOVA table for ground loss

Factors mean (%)			
Variety (V)	6.6 (V1)	9.6 (V2)	
Forward speed (S)	8.3 (S1)	7.9 (S2)	
Finger angle (A)	8.2 (A1)	8.1 (A2)	8.0 (A3)
Finger length (FL)	6.3 (FL1)	7.0 (FL2)	
Finger spacing (FS)	5.0 (FS1)	7.3 (FS2)	11.9 (FS3)

AVOVA Table

Source	DF	Mean Square	F Value	p value	Significant (S)/ Non-significant (NS)
V	1	463.936267	68.59	0.0001	S
S	1	10.613400	1.57	0.2124	NS
A	2	0.717202	0.11	0.8995	NS
FL	1	22.44977	3.31	0.0512	NS
FS	2	881.528363	130.33	0.0001	S
S*A	2	20.64618	3.05	0.0762	NS
S*FL	1	18.58349	2.75	0.1076	NS
S*FS	2	19.265150	2.85	0.0613	NS
A*FL	2	16.4237	2.43	0.1445	NS
A*FS	4	4.625616	0.68	0.6043	NS
FL*FS	2	13.060652	1.93	0.1488	NS
S*A*FL	2	10.679524	1.58	0.2098	NS
A*FL*FS	4	0.699709	0.10	0.9811	NS
S*FL*FS	2	16.64526	2.46	0.1405	NS
S*A*FS	4	19.6475	2.90	0.091	NS
S*A*FL*FS	4	22.28492	3.29	0.0534	NS
V*S*A*FL*FS	35	2.192452	0.32	0.9999	NS

Ground Loss

The effects of variety, forward speed, finger angle, finger length and finger spacing on ground loss (%) are depicted in **Table 6**. The combined effect of all these parameters was also calculated. The ground loss is also shown graphically in **Fig. 8**. Among all the treatments, the mean value of ground loss varied from 2.8 to 17.8% and the differences were statistically significant (p value = 0.0001), at a 5% level of significance.

Ground loss of a tractor operated cotton header was statistically at par for finger length, forward speed and finger angle and varied between 6.3 to 7.0, 8.3 to 7.9 and 8.2 to 8.0% respectively. At a 5% level of significance, the combined effect of finger length, finger spacing, finger angle and forward speed was not statistically significant on the ground loss.

Mean value of ground loss of 6.6 and 9.6% was observed for varieties RCH-773 (V1) and F-2383 (V2) respectively. At a 5% level of significance, the effect of forward speed was observed statistically significant on the ground loss (p value = 0.0001). Ground loss for variety F-2383 (V2) was 31.3 % higher than for variety RCH-773 (V1). On an average, ground loss of 5.04, 7.33 and 11.91% was observed for FS1, FS2 and FS3 finger spacing respectively, which was found to be statistically different (p value = 0.0001), at a 5% level of significance.

With an increase in finger spacing ground loss increased. The reason for this may be that more spacing between fingers contributed to a cotton fall on the ground. On an average, maximum ground loss of

14.1% was observed for F-2383 (V2) variety and with FS3 finger spacing. The minimum ground loss of 4.1% was observed for RCH-773 (V1) variety and FS1 finger spacing.

The maximum ground loss of 2.38% was found for variety RCH-773 at a combination of FL1, FS3, A1 and S1.The minimum ground loss of 2.86% was found for variety RCH-773 at a combination of FL1, FS1, A2 and S1. The maximum ground loss of 17.85% was found for variety F-2383 at a combination of FL1, FS3, A1 and S1.The minimum ground loss of 4.12% was found for variety F-2383 at combination of FL1, FS1, A2 and S1.

Stalk Loss

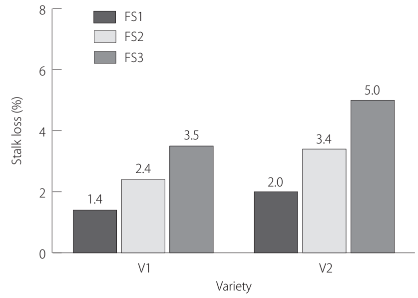
The effects of variety, forward speed, finger angle, finger length and finger spacing on stalk loss are depicted in **Table 7**. The combined effect of all these parameters was also calculated. The stalk loss is also shown graphically in **Fig. 9**. Among all the treatments, the mean value of stalk loss varied from 0.69 to 7.01% and the differences were statistically significant (p value = 0.0001), at a 5% level of significance. Stalk loss of tractor operated cotton header was statistically at par for finger length, forward speed and finger angle and varied between 2.3 to 2.4, 2.8 to 3.0 and 2.4 to 3.2% respectively. At a 5% level of significance, the combined effect of finger length, finger spacing, finger angle and forward speed was not statistically significant on the stalk loss.

Mean value of stalk loss of 2.4 and 3.4% was observed for varieties RCH-773 (V1) and F-2383 (V2) respectively. At a 5% level of significance, the effect of finger spacing was observed statistically significant on the stalk loss (p value = 0.0001). Stalk loss for variety F-2383 (V2) was 30.7% higher than for variety RCH-773 (V1). On an average, stalk loss of 1.7, 2.9 and 4.2% was observed for FS1, FS2 and FS3 finger spacing respectively, which was found statistically different (p value = 0.0001), at a 5% level of significance.

With an increase in finger spacing, stalk loss increased. The reason for this may be that more spacing between fingers contributed to more cotton left over on the stalks. On an average, maximum stalk loss of 5.0% was observed for F-2383 (V2) variety and with FS3 finger spacing. The minimum stalk loss of 1.4% was observed for RCH-773 (V1) variety and with FS1 finger spacing.

The maximum stalk loss of 4.86% was found for variety RCH-773 at a combination of FL1, FS3, A3 and S1. The minimum stalk loss of 0.69% was found for varieties RCH-773 at a combination of FL1, FS1, A2 and S1. The maximum ground loss of 7.01% was found for varieties F-2383 at a combination of FL1, FS3, A3 and S1.The minimum ground loss of 1.0% was found for varieties F-2383 at a combination of FL1, FS1, A2 and S1.

Fig. 9 Effect of independent parameters on stalk loss



Field Capacity

The effects of variety, forward speed, finger angle, finger length and finger spacing on field capacity were calculated. The combined effect of all these parameters was also calculated. ANOVA table for field capacity is depicted in Table 8. The field capacities are also shown graphically in **Fig. 10**. The mean value of field capacity varied from 0.37 to 0.72 ha/h among all the treatments and the differences were statistically significant (p value = 0.0001), at a 5% level of significance. Field capacity of tractor operated cotton header was statistically

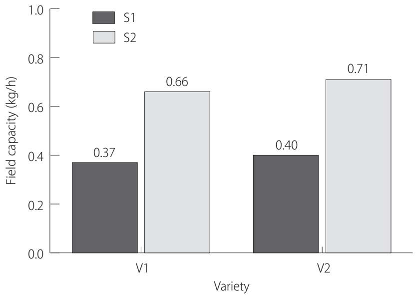
Table 7 ANOVA table for stalk loss

Factors mean (%)			
Variety (V)	2.4 (V1)	3.4 (V2)	
Forward speed (S)	2.8 (S1)	3.0 (S2)	
Finger angle (A)	3.2 (A1)	2.4 (A2)	3.1 (A3)
Finger length (FL)	2.3 (FL1)	2.4 (FL2)	
Finger spacing (FS)	1.7 (FS1)	2.9 (FS2)	4.2 (FS3)

AVOVA Table

Source	DF	Mean Square	F Value	p value	Significant (S)/ Non-significant (NS)
V	1	60.3991130	18.91	0.0001	S
S	1	2.3604463	0.74	0.3915	NS
A	2	12.11451	3.79	0.0642	NS
FL	1	0.7537852	0.24	0.6279	NS
FS	2	118.8232727	37.20	0.0001	S
S*A	2	2.3545338	0.74	0.4803	NS
S*FL	1	8.836182	2.77	0.1425	NS
S*FS	2	0.5586282	0.17	0.8397	NS
A*FL	2	5.1678394	1.62	0.2020	NS
A*FS	4	11.54725	3.61	0.0761	NS
FL*FS	2	12.77125	4.00	0.0511	NS
S*A*FL	2	9.401948	2.94	0.1271	NS
A*FL*FS	4	3.1877949	1.00	0.4109	NS
S*FL*FS	2	2.8587597	0.89	0.4109	NS
S*A*FS	4	1.7639782	0.55	0.6977	NS
S*A*FL*FS	4	3.1738111	0.99	0.4132	NS
V*S*A*FL*FS	35	0.4206053	0.13	1.0000	NS

Fig. 10 Effect of independent parameters on field capacity



at par for finger length, finger spacing and finger angle and varied between 0.535 to 0.540, 0.535 to 0.541 and 0.535 to 0.541 ha/h respectively. At a 5% level of significance, the combined effect of variety, finger length, finger spacing, finger angle and forward speed was not statistically significant on the field capacity as shown in **Table 8**.

Mean value of field capacity of 0.51 and 0.56 ha/h was observed for varieties RCH-773 (V1) and F-2383 (V2) respectively. At a 5% level of significance, the effect of forward speed was observed statistically significant on the field capacity (p value = 0.0001). Field capacity for variety F-2383 (V2) was 7.5% higher than for variety RCH-773 (V1). On an average, field capacity of 0.39 and 0.68 ha/h was observed for S1 and S2 forward speeds respectively, which was found to be statistically different (p value =0.0001), at a 5% level of significance. Field capacity at S2 forward speed was 42.98% higher than at S1 speed.

With an increase in forward speed, field capacity was increased, because field capacity is drawn through the forward speed of machine. On an average, maximum field capacity of 0.71 ha/h was observed for F-2383 (V2) variety and with S2 forward speed. The minimum field capacity of 0.37 ha/h was observed for RCH-773 (V1) variety and with S1 forward speed.

The maximum field capacity of 0.67 ha/h was found for variety RCH-773 at a combination of FL1, FS2, A2 and S2. The minimum field capacity of 0.37 ha/h was found for variety RCH-773 at a combination of FL2, FS2, A3 and S1. The maximum field capacity of 0.72 ha/h was found for variety F-2383 at a combination of FL1, FS2, A2 and S2. The minimum field capacity of 0.40 ha/h was found for variety F-2383 at a combination of FL2, FS2, A3 and S1.

Table 8 ANOVA table for field capacity

Factors mean (%)			
Variety (V)	0.51 (V1)	0.56 (V2)	
Forward speed (S)	0.39 (S1)	0.68 (S2)	
Finger angle (A)	0.535 (A1)	0.541 (A2)	0.538 (A3)
Finger length (FL)	0.540 (FL1)	0.535 (FL2)	
Finger spacing (FS)	0.541 (FS1)	0.537 (FS2)	0.535 (FS3)

AVOVA Table

Source	DF	Mean Square	F Value	p value	Significant (S)/ Non-significant (NS)
V	1	0.57453519	781.65	0.0001	S
S	1	28.3402667	38556.7	0.0001	S
A	2	0.00015046	0.2	0.8151	NS
FL	1	0.00026667	0.36	0.5479	NS
FS	2	0.00008935	0.12	0.8856	NS
S*A	2	0.00065972	0.9	0.4099	NS
S*FL	1	0.00155741	2.12	0.1477	NS
S*FS	2	0.00123472	1.68	0.1901	NS
A*FL	2	0.00008472	0.12	0.8912	NS
A*FS	4	0.0001956	0.27	0.8993	NS
FL*FS	2	0.0001125	0.15	0.8582	NS
S*A*FL	2	0.00001435	0.02	0.9807	NS
A*FL*FS	4	0.00022847	0.31	0.8704	NS
S*FL*FS	2	0.00058935	0.8	0.4505	NS
S*A*FS	4	0.00017569	0.24	0.9159	NS
S*A*FL*FS	4	0.00049838	0.68	0.6083	NS
V*S*A*FL*FS	35	0.00000242	0.01	0.9999	S

Best Combination of Independent Parameters for Cotton Header

All the independent parameters clearly depicted the picking capacity, picking efficiency, ground loss, stalk loss and field capacity of tractor operated cotton header. The optimum values of the various levels of independent variables, arrived from the results of the field evaluation of developed tractor operated cotton header, have been summarized in **Table 9**. The optimum combination for dependent parameters, such as, picking capacity, picking efficiency, ground loss, stalk loss and field capacity for both the varieties i.e. RCH-77 and F-2383 is also summarized in the **Table 8**. The optimum combinations of independent parameters were selected based on maximum picking capacity, picking efficiency and field capacity, but with minimum losses.

The best combination of independent parameters like finger length, finger spacing, finger angle and forward speed and their values for both of varieties i.e. RCH-77 and F-2383 is summarized in the **Table 9**. The best combination of machine was found with 700 mm finger length (FL1), 16 mm finger spacing (FS1), 15 degree finger angle (A2) and with 4.5 km/h forward speed (S2).

Conclusions

There was a significant effect of forward speed on picking capacity and field capacity for both varieties i.e. RCH-773 and F-2383. For both varieties, maximum picking capacity was found to be 1865.01 and 559.50 kg/h at a combination of 600 mm (FL2), 16 mm (FS1), 12 degree (A1) and 4.5 km/h (S2) respectively. For both varieties, maximum field capacity was found to be 0.67 and 0.72 ha/h at a combination of 700 mm (FL1), 20 mm (FS2), 15 degree (A2) and 4.5 km/h (S2) respectively. There was a significant effect of finger spacing on picking efficiency and losses for both varieties i.e. RCH-773 and F-2383. For both varieties, maximum picking efficiency was found to be 96.45 and 94.89% at a combination of 700 mm (FL1), 16 mm (FS1), 15 degree (A2) and 2.63 km/h (S1) respectively. Minimum ground loss was found to be 2.86 and 4.12% at a combination of 700 mm (FL1), 16 mm (FS1), 15 degree (A2) and 2.63 km/h (S1) for both varieties respectively. The minimum stalk loss of 0.68 and 0.99% was found at a combination of 700 mm (FL1), 16 mm (FS1), 15 degree (A2) and 2.63 km/h (S1) for both varieties respectively. The best combination of independent parameters for the machine was found with 700 mm finger length (FL1), 16 mm finger spacing (FS1), 15 degree finger angle (A2) and with 4.5 km/h forward speed (S2).

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REFERENCES

Anonymous. 2014. Production, yield and area of cotton. www.indiastat.com. A site registered with main library, Punjab Agricultural University, Ludhiana (Date of visit: 28th December, 2014).

Anthony, W. S. and D. W. Mayfield. 1997. Cotton Ginners Handbook. Pp; 157-168. United State Dept. of agriculture.

Barik, A. 2010. Cotton statistics at a glance, Tech Bull, Pp 1-42. Directorate of Cotton Development, Ministry of Agriculture, GOI, Mumbai, Maharashtra.

Brown, H. B. and J. O. Ware. 1958. Cotton (3rd ed.). New York: McGraw Hill.

Hudspeth, E. B. Jr. 1977. Status of once-over harvest machinery development. Summary Proceedings Western Cotton Production Conference, 58-59.

Kirk, L. W., Hudspeth, E. B. Jr. and D. E. Wanjura. 1964. A broadcast and narrow row cotton harvester. Texas Agricultural Experiment Station Progress Report (No. 2311, May 7). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Schroeder, E. W. and J. G. Porterfield. 1954. The development of the Oklahoma brush-type cotton stripper. Oklahoma Agricultural Experiment Station Bulletin (B-422, April). Stillwater: Agricultural Communications Services, Division of Agricultural Sciences and Natural Resources, Oklahoma State University.

Sharma, K., Singh, M., Kohli, S. S., Mishra. P. and A. Sharma. 2015. Design and Development of Self Propelled Walk Behind Finger Type Cotton Stripper. Sci. J. Agric. Engg. 40(4), 35-46.

Singh, S. and G. S. Buttar. 2012. High density planting system for mechanical picking and sustainable cotton productivity, Crop Improv Spec Issue, ICSA-2012:763-764.

Smith, H. P., Killough, D. T., Jones, D. L. and M. H. Byrom. 1935. Progress in the study of the mechanical harvesting of cotton. Texas Agricultural Experiment Station Bulletin (511, September). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Sutton, R. M. 1984. The importance of multi-stage lint cleaning in the cotton ginning industry. Company Handout. Lubbock, TX: Horn & Gladden Lint Cleaner Co.

Tupper, G. R. 1966. New Concept of Stripper Harvesting of Cotton in Arkansas. Trans. ASAE(9), 110-111, 113.

Walhood, V. T. and F. T Addicott. 1968. Harvest aid programs: Principles and practices. In F. C. Elliot, M. Hoover & W. K. Porter, Jr. (Eds.), Advances in production and utilization of quality cotton: principles and practices (pp. 407- 431). Ames: Iowa State University Press.

Warjura, D. E. and R. V. Baker. 1978. Stick and bark relationship in the mechanical stripper harvester and seed cotton cleaning system. Trans. ASAE. 22(2): 273-278 & 282.

Williamson, E. B. and L. A. Riley. 1961. Interrelated effects of defoliation, weather and mechanical picking on cotton quality. Transactions of the American Society of Agricultural Engineers, 4(2).

■■

Table 9 Optimum levels of independent parameters

Dependent variable	Independent variables					Combination of independent variables for both of varieties
	Variety	Forward speed	Finger angle	Finger length	Finger spacing	
Picking capacity	V1*	S2*	A1	FL2	FS3	FL2 FS1 A1 S2
Picking efficiency	V1*	S2	A1	FL1	FS1*	FL1 FS1 A2 S1
Ground loss	V1*	S2	A3	FL1	FS1*	FL1 FS1 A2 S1
Stalk loss	V1*	S1	A2	FL1	FS1*	FL1 FS1 A2 S1
Field capacity	V2*	S2*	A2	FL1	FS1	FL2 FS1 A1 S2
Best combination	FL1 FS1 A2 S2					

* *Significant effect*

Technical Performance and Benefit of Mini Combine Harvester in Southern Delta of Bangladesh

by

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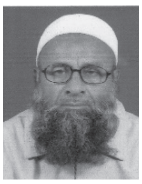

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Abstract

In Bangladesh rice harvesting operation has a major potential for increasing yield, labor productivity and reducing losses and production cost. Significant amount of field losses of rice occur every year due to natural calamities, shortage of time during harvesting period and following the traditional harvesting methods. The present study was conducted to identify rice harvesting practices in southern delta of Bangladesh, to assess the technical performance of mini combine harvester and benefit of mechanical harvesting systems. For comparison between mechanical and manual harvesting systems, several experiments were conducted. Mechanical harvesting of Aman-2016, Boro-2017 and Aman-2017 rice at Dumuria, Wazirpur, Subarnachar and Kalapara Upazilas of Khulna, Barisal, Noakhali and Patuakhali districts, respectively of Bangladesh were conducted using a mini-combine harvester. Manual harvesting of rice was also conducted at the same locations. Cost savings in mechanical harvesting of rice were found 55.86% for using mini-combine harvester over manual harvesting system. Similarly, labors saving using mini-combine harvester was found 65% over manual harvesting system. The total harvesting losses (including harvesting, threshing and cleaning) were also found 1.28% and 6.04% for using mini-combine and manual harvesting systems, respectively. The losses of rice can be reduced 4.76% using mini-combine harvester over manual harvesting system. The results indicated that manual harvesting is a labor and cost involving system. On the other hand mechanical harvester like mini-combine harvester is a labor and cost saving system along with reducing harvesting losses, human drudgery, harvesting time and increasing cropping intensity, crop productivity, economic emancipation.

Keywords: Rice, Manual harvesting, Rice losses, Mini-combine harvester, Cost saving.

Introduction

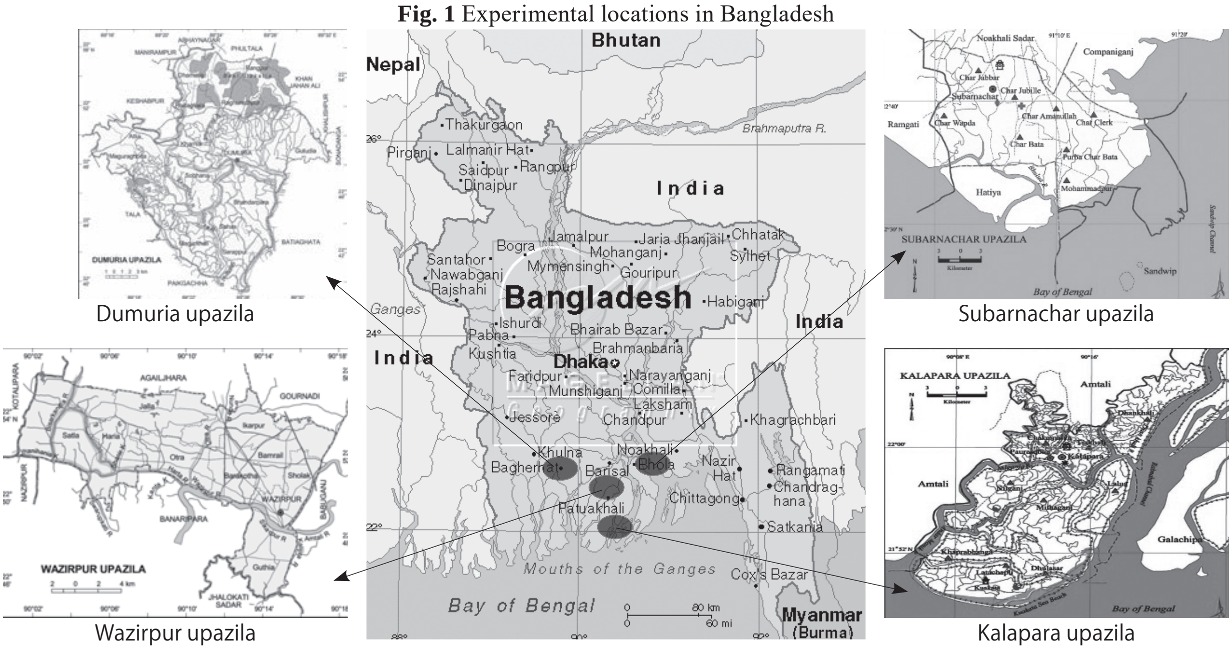
Rice farming is the most important livelihood activity in agriculture, and agriculture plays a key role in the overall livelihood status of Bangladesh in terms of its contribution to GDP. In 2015-16 fiscal year agriculture contributed 17% of GDP (BBS, 2016). Rice harvesting systems vary from region to region and include different methods for harvesting. Traditionally people of Bangladesh use different types of local made hand tools for harvesting; among them sickles are widely used for manual cutting and recently introduced reaper and mini combine harvester at very limited areas. Due to unavailability of mechanical harvesting system, significant amount of field losses of rice occur every year due to natural calamities and shortage of time during harvesting period (Noby et al., 2018). Post-harvest losses of rice at farm level were 9.49%, 10.51% and 10.59% for Aman, Boro and Aus seasons, respectively (Bala et al., 2010). During peak harvesting period there is scarcity of labor and harvesting is normally delayed resulting in-field losses of crops. Samon & Duff (1973) reported that 5, 7 and 10 days delayed harvest resulted in 3, 6 and 11% decrease in rice yield, respectively.

Bangladesh produced 34.4 million tonnes of clean rice in 10.61 million ha land (BRRI, 2014). Two millions of population is added annually, and expected to reach 215.4 million in 2050 when 44.6 million tonnes of cleaned rice will be required (Kabir et al., 2016); whereas, the estimated annual shrinkage of agricultural land is about 0.08 million ha due to various non-agricultural activities such as the construction of houses, offices, roads, mills, factories, etc (BRRI, 2009). Rice yield, therefore, needs to be increased from its present level of 2.74 to 3.74 t ha^{-1} (BRRI, 2013). Decreasing resources (e.g. land, labour, soil health and water) and increasing climate vulnerability (e.g. drought, salinity, flood, heat and cold) appeared as the great challenges to keep pace of food production in the background of increasing population. Sufficient rice production is the key to ensure food security in Bangladesh (Brolley, 2015).

The government has given the top priority to increase the availability of food in the country, while rice land is not expanding (MoA, 2013). Important task is to minimize the post-harvest losses. In that case suitable harvesting machinery is urgently needed to strengthen agricultural mechanization system to increase production with less drudgery and increased efficiency. Mechanical harvester like mini-combine harvester for harvesting of rice has a positive impact on livelihood status. Hossain et al. (2015) showed that average time, cost and grain saving by using combine harvester over manual methods were found to be 97.50, 35.00 and 2.75%, respectively. Appropriate farm mechanization has been emphasized as an important policy and development goal in Bangladesh (Mandal, 2002, 2014; Zhang et al., 2014). Miah et al. (2002) showed that farm mechanization has remarkable positive impacts in creating employment opportunities, higher income, increasing household assets and increasing the overall standard of living of rural laborers in Bangladesh.

Therefore, adoption of mechanical harvesting practices like mini-combine harvester is urgently needed to save cost, time and labor through reducing the human drudgery, labor involvement, harvesting losses and increase the cropping intensity, crop productivity, economic emancipation. Under this circumstance, the main objectives of the study were

Fig. 1 Experimental locations in Bangladesh



to assess the technical performance of mini combine harvester in southern region of Bangladesh, and to find out the benefit of mechanical harvesting over manual harvesting system.

Material and Methods

Experimental Locations

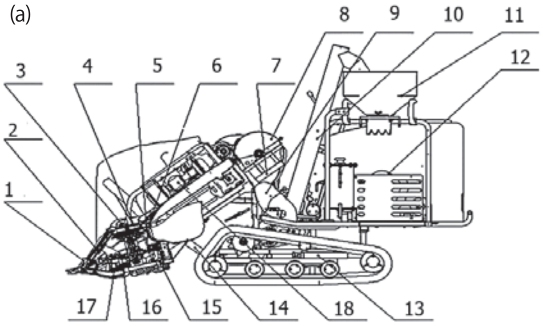
Four experimental locations in relation to mechanical vs. manual harvesting of rice using mini-combine harvester and manual system were chosen as: a) Dumuria (located in between 22°39’ and 22°56’ north latitudes and in between 89°15’ and 89°32’ east longitudes), b) Wazirpur (located in between 22°43’ and 22°56’ north latitudes and in between 90°01’ and 90°18’ east longitudes), c) Subarnachar (located in between 22°28’ and 22°44’ north latitudes and in between 90°59’ and 91°20’ east longitudes) and d) Kalapara (located in between 21°48’ and 22°05’ north latitudes and in between 90°05’ and 90°20’ east longitudes). Khulna, Barisal, Noakhali and Patuakhali districts, respectively of Southern Delta region of Bangladesh are shown in **Fig. 1**. Main sources of income in all selected locations are agriculture. Two villages in each upazila were selected for the study.

Table 1 Specifications of mini-combine harvester

Testing Item	Designed Value
Model	4LBZ-110
Overall dimension (L × W × H) mm	2590 × 1330 × 2010
Weight (kg)	950
Header width (mm)	1100
Structure form	Crawler propelled
Forward Speed (km/h)	1.6~2.8
Capacity (ha/h)	0.07~0.135
Fuel consumption (kg/ha)	12~20
Engine Power (hp)	20
Engine type	Diesel Engine
Engine Model	ZS1110
Engine Speed (rpm)	2200
Type of cutter	Reciprocating type
Tyre	Crawler
Transmission	Mechanical
Brake type	Internal Jaw
Grain collecting type	Manual grain collecting
Country of origin	China
Importer in Bangladesh	Glory Engineering Limited/ACI Motors Limited

Fig. 2 (a) Schematic diagram of mini-combine harvester and (b) Pictorial view of overall machine

(a)



(b)

1. Dividers, 2. Crop lifter, 3. Throwing wheel, 4. Crop conveyor chains, 5. Crop clips, 6. Threshing belt, 7. Grass discharge, 8. Second thresher drum, 9. Thresher grain screw, 10. Lifting auger, 11. Grain funnel, 12. Diesel Engine, 13. Chassis, 14. Oil elevator, 15. Header support, 16. Crop conveyor wheels, 17. Cutters, 18. Throwing device

Farm Households

Six farm households in each villages were considered for mechanical and manual harvesting of Aman rice (November-December 2016), Boro rice (April-May 2017) and Aman rice (November-December 2017) at same locations of Bangladesh.

Harvesting Types

Two types of harvesting are exist in Bangladesh. One is traditional or manual, and another is modern or mechanical harvesting system. These two methods of rice harvesting system were used at the experimental sites. These were: a) mechanical harvesting using mini-combine harvester and b) manual harvesting using hand sickle.

Selected Harvesting Machine

A mini-combine harvester (Model: 4LBZ-110) was used for harvesting of rice at the experimental sites. The harvester is manufactured by KYM Machinery Manufacturing Company Limited, Guangxi, China. Technical specifications of the harvester are presented in **Table 1**.

Machine Structure

The mini-combine harvester is made of key components including frame, table, cutter table, cutter head, transmission gear, diesel engine, control system, hydraulic system, electrical system, elevator device, and storage, as shown in **Fig. 2**.

Mechanical Harvesting Using Mini-combine Harvester

To determine mechanical harvesting time, cost, losses and labor requirement, selected plots were harvested using mini-combine harvester. Mini-combine harvester was used for rice harvesting as well cleaning tasks in a single operation as shown in **Fig. 3**.

Manual Harvesting Using Hand Sickle

To determine manual harvesting cost, losses and labor requirement; 3 (three) plots were selected in each villages and all plots were harvested manually. From harvesting to cleaning, all operations were done manually. Manual harvesting losses were estimated considering a) shatter loss, b) cutting loss, c) gathering loss, d) carrying loss, e) threshing loss, and f) cleaning loss; whereas combine harvester does all these operations in single pass. Harvesting to cleaning, all losses were estimated carefully as shown in **Fig. 4**.

Field Activities

Before field test of the machine, soil condition, crop condition, number of tiller/hill and yield conditions were recorded. For the field performance test, average plant height was also measured using measuring tape. The moisture content of soil was measured by digital moisture meter. The plot size was measured using measuring tape. Engine fuel and oil level were checked before operation. Fuel consumption was recorded after completing harvesting operation of each plot. The time was recorded from starting to end of reaping operation and time loss was also recorded. The field capacity was calculated using standard formula. The grain losses were also determined after completion of harvesting operation.

Performance Indicating Parameters

To assess technical and economic performances of the mini-combine harvester during harvesting of rice and also compare with manual harvesting system, the following performance indicators were identified: (i) operational time, (ii) labor requirement for harvesting, (iii) fuel consumption, (iv) field capacity, (v) working speed, (vi) effective time, (vii) grain yield and (viii) grain losses.

Field Capacity

For determination of field capacity and field efficiency the following data were taken during harvesting operation: (i) area of the plot; (ii) forward speed of the machine; (iii) cutting width of the machine; (iv) time required to harvest the specified area; (v) time loss due to refueling, cleaning/ clogging, machine adjustments, minor repair and turning.

Forward Speed

Forward speed was measured by dividing the distance with time required to travel the machine of that distance. Same procedure was considered five times in every plot for determining average forward speed. Following equation was used to determine forward speed of mini-combine harvester.

Forward speed (km/hr),

$$S = 3.6D / t \quad \cdots(1)$$

where, D = distance (m) and t = time (s).

Effective Field Capacity

The effective field capacity is the actual average rate of coverage by the harvester, based upon the total field time. The area covered divided by the total time is the effective field capacity. The effective field capacity was determined by measuring all the time elements involved while harvesting (Hunt, 1973).

Effective field capacity (ha/hr),

$$C_{eff} = A / T \quad \cdots(2)$$

where, T = total time for reaping operation (h) and A = area of land reaping at specified time.

Theoretical Field Capacity

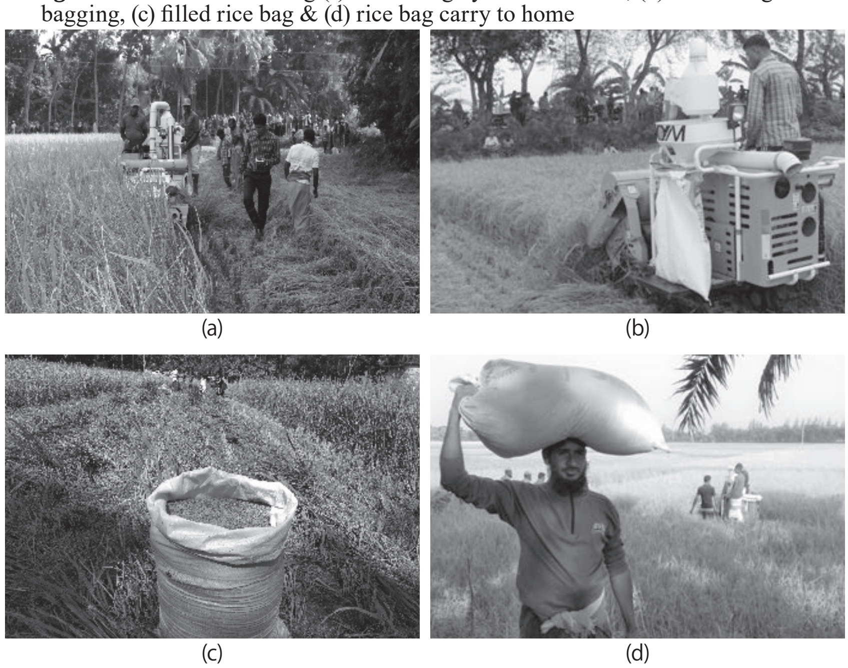
The theoretical field capacity of a harvester is the rate of harvesting that would be obtained if the harvester were performing its function 100% of the time at rated forward speed and always covered 100% of its cutting width. The theoretical field capacity was determined using following equation (Hunt, 1973).

Theoretical field capacity (ha/hr),

$$C_{th} = wS / 10 \quad \cdots(3)$$

where, S = rated forward speed of

Fig. 3 Mechanical harvesting (a) harvesting by mini-combine, (b) harvesting and bagging, (c) filled rice bag & (d) rice bag carry to home



the harvester (km/h) and w = rated width of the cutter bar (m).

Field Efficiency

The field efficiency was determined by the ratio of effective field capacity and theoretical field capacity. Following equation was used to determine it (Hunt, 1995).

Field efficiency,

$$C = (C_{eff} / C_{th}) \times 100 \quad \cdots(4)$$

where, C_{eff} = effective field capacity (ha/hr) and C_{th} = theoretical field capacity, (ha/h).

Fuel Consumption

Fuel consumption, especially for economic analysis was determined after harvesting each plot. Before starting the harvesting operation, the fuel tank of the mini-combine was fill up and at the end of the harvesting operation of each particular plot the required fuel to fill the tank was determined by using measuring flask. For determining fuel consumption per unit area, following equation was used (Hunt, 1995).

Fuel consumption (L/ha),

$$F = F_a / A \quad \cdots(5)$$

where, F_a = fuel used during operation (L), A = area of operation, (ha).

Grain Losses

For economic consideration, grain losses were measured during harvesting operation. In general there are four types of losses were considered during mechanical harvesting using mini-combine harvester. These are shatter loss, cutter bar loss, cylinder loss and separating loss. In addition to these losses gathering loss and carrying loss were also considered during manual harvesting operation. In the experiment following procedures were considered during harvesting operations.

Shatter Loss

Shatter losses in direct combining include heads, pods, or ears, and free seed, lost during cutting and conveying operations. The following equation was used to determine shatter loss (Hunt, 1995).

Shatter loss, kg/ha = (Average weight of dropped grain on the ground during cutting & conveying, kg) / (Area covered, ha) ···(6)

Cutter Bar Loss

Cutter bar loss indicates grains those are lost due to rough handling by the cutter bar. Following equation was used to determine cutter bar loss (Hunt, 1995).

Cutter bar loss, kg/ha = (Average weight of grain cutter bar, kg) / (Area covered, ha) ···(7)

Cylinder Loss

Grains lost out the rear of the mini-combine in the form of threshed heads indicate cylinder loss. Following equation was used to determine cylinder loss (Hunt, 1995).

Cylinder loss, kg/ha = (Average weight of unthreshed heads lost out the rear of min - combine, kg) / (Area covered, ha) ···(8)

Separating Loss

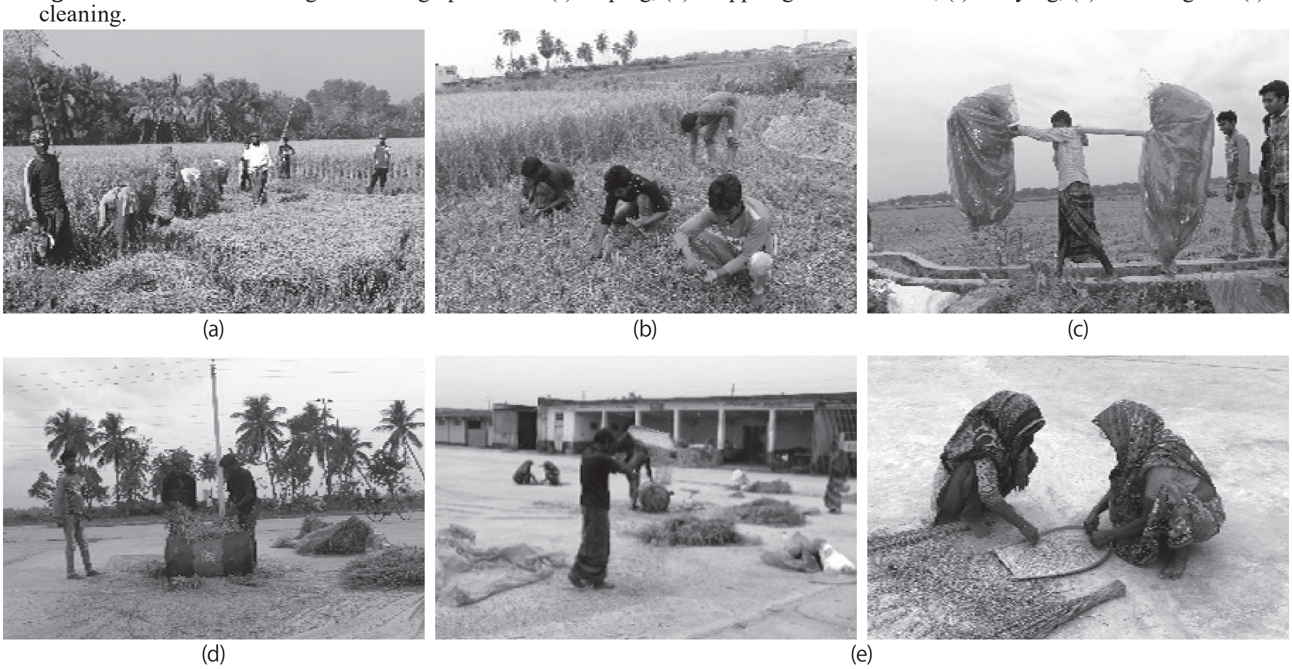
Separating loss means the grains lost out the rear of the min-combine in the form of threshed grain. The following equation was used to determine separating loss (Hunt, 1995).

Separating loss, kg/ha = (Average weight of threshed heads lost out the rear of min - combine, kg) / (Area covered, ha) ···(9)

Cost Analysis

Economic performance evaluation

Fig. 4 Manual rice harvesting to cleaning operations: (a) reaping, (b) dropped grain collection, (c) carrying, (d) threshing and (e) cleaning.



of mini-combine harvester for harvesting of rice was determined by calculating fixed cost and variable cost. Harvesting cost and time of mechanical harvesting system were also compared with manual harvesting.

Fixed Cost

The fixed cost is the cost which is involved irrespective of whether the harvester is used or not. These costs include i) depreciation cost, ii) interest on investment and iii) taxes, shelter and insurance.

i) Depreciation cost

Depreciation is the reduction in value of a harvester with the passes of time. Depreciation cost was calculated by straight line method (Hunt, 1995).

The annual depreciation,

D = (P − S) / L (BDT.₺/Yr) ···(10)

where, P = purchase price, BDT., S = selling price, BDT. and L = time between buying and selling, yr.

ii) Interest on investment

Interest on the investment of mini-combine is a legitimate cost, since money spent in buying a machine cannot be used for other productive enterprises, it was calculated by Straight Line Method (Hunt, 1995).

Interest on investment,

I = [(P + S) / 2] i ···(11)

where, P = purchase price, BDT; S = re-sale value, BDT; i = annual interest rate.

iii) Taxes, Shelter and Insurance

In the experiment, shelter, tax and insurance, STI = 2.5% of P was considered for calculating fixed cost of harvesting machine (Hunt, 1995).

Total Fixed Cost

Total fixed cost (BDT./yr) = D + I + STI ···(12)

Fixed cost (BDT./ha) = Total Fixed Cost (BDT./Yr) / Total Area Converage (ha/Yr) ···(13)

Variable Costs

Fuel cost, oil cost, labor cost and repair & maintenance cost were determined using following equations (Hunt, 1995).

Fuel cost, F (BDT./ha) = [Fuel consumed (L/day) × Price (BDT./L)] / Area covered (ha/day) ···(14)

Oil cost, O (BDT./ha) = 15% of Fuel cost, F ···(15)

Local cost, L (BDT./ha) = [Sum of wages of labor (BDT./day) / Area covered (ha/day)] ...(16)

Repair and maintenance cost, R&M (BDT./ha) = 0.025 % of purchase price, P ···(17)

Total variable cost = (F + O + L + R&M) BDT./ha ···(18)

Total cost of harvesting (BDT/ha) = Fixed cost (BDT./ha) + Variable cost (BDT./ha) ···(19)

Cost for Manual Harvesting, Threshing and Cleaning

Total cost (BDT./ha) = Wage of laborer (BDT./man) × No. of laborer (man/ha) ···(20)

Cost Saving Using Mini-combine Harvester

To determine the cost saving in using mechanical harvesting system, the costs of two different rice harvesting methods like mini-combine harvester and manual harvesting system were compared. The following equations were used to determine cost saving and percent of cost saving.

Cost saving for using mini combine (BDT./ha) = Manual harvesting cost (BDT./ha) - Mechanical harvesting cost (BDT./ha ···(21)

Results and Discussion

Technical Performance of Mini-combine Harvester

After using mechanical harvesting system in three seasons namely *Aman*/2016, *Boro*/2017 and *Aman*/2017 at *Wazirpur*-Barisal, *Dumuria*-Khulna, *Subarnachar*-Noakhali and *Kalapara*-Patuakhali of Bangladesh, average value along with standard deviations of forward speed, fuel consumption, theoretical field capacity, effective field capacity and field efficiency of mini-combine harvester were determined and presented in **Table 2**. The estimated field performances were varied due to variation of plot size, forward speed, operator's skill and soil condition.

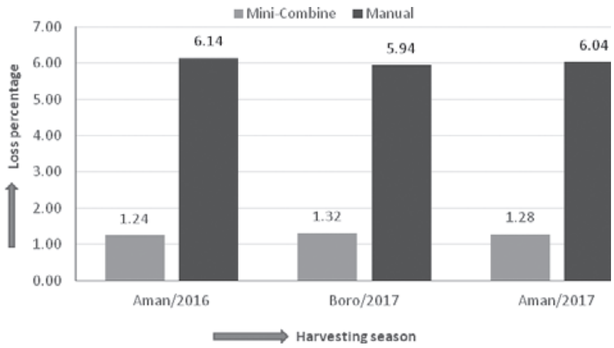
Table 3 Labor required for mechanical and manual harvesting systems

Item	Labors involvement (man-day/ha)	
	Mini-Combine	Manually
Harvesting	5	23
Rice bag carry from field to home	8	-
Threshed straw binding and carrying from field to home	8	-
Straw with rice carrying from field to home after reaping manually	-	15
Manual threshing	-	15
Cleaning	-	8
Total labor (from harvesting to cleaning)	21	61
Labor saved over manual system (%)	65	-

Table 2 Technical performance of mini-combine harvester

Rice Season	Forward speed (km/hr)	Fuel consumption (L/ha)	Theoretical field capacity (ha/h)	Effective field capacity (ha/h)	Field efficiency (%)
Aman/2016	1.85±0.05	16.83±0.54	0.2030±0.0060	0.1144±0.0040	56.38±1.59
Boro/2017	1.70±0.07	17.58±0.60	0.1868±0.0079	0.1032±0.0051	55.24±0.41
Aman/2017	1.59±0.03	18.82±1.20	0.1741±0.0037	0.0946±0.0056	54.32±2.74

Fig. 5 Grain losses in mechanical and manual harvesting



Labor Required for Harvesting of Rice

Labor requirement for rice harvesting by mini-combine harvester and manual system is shown in **Table 3**. Total labor required was found 21 man-day/ha and 61 man-day/ha for using mini-combine harvester and manual system, respectively. Labor could be saved 65% for using mini-combine harvester over manual harvesting.

Economic Performance of Mini-combine Harvester

Rice harvesting cost for using mini-combine harvester based on fixed cost and variable cost is shown in **Table 4**. There is minor variation of total operating cost of mini-combine harvester due to variation of fuel consumption and effective field capacity. From 3 (three) seasons harvesting, average mechanical harvesting cost was found 10769 BDT./ha.

Economic Performance of Manual Harvesting

Based on the field experiment on manual harvesting at *Wazirpur*-Barisal, *Dumuria*-Khulna, *Subarnachar*-Noakhali and *Kalapara*-Patuakhali of Bangladesh, average cost of manual reaping, straw binding and carry to home, threshing and cleaning of rice were estimated as shown in **Table 5**. Average manual harvesting to cleaning cost was found 24400 BDT./ha.

Comparison of Economic Performances

Rice harvesting cost using mini combine harvester and manual harvesting is shown in **Tables 4** & **5**. The harvesting costs were found BDT. 10769 and BDT. 24400 per ha, respectively for using mini-combine harvester and manual harvesting. Also percentage of cost save were found 55.86 % for using mini-combine harvester over manual harvesting. Khadr et al. (2009) obtained similar result, costs decreased in an average 58.3% for using Yanmar combine and 56.7% for using Kubota combine harvester. Cost savings depends on machine condition as fuel consumption, repair & maintenance cost increase and field capacity decreases day by day.

Grain Losses in Mechanical and Manual Harvesting Systems

Grain losses during rice harvesting using mini-combine harvester and manual harvesting are shown in **Fig. 5**. Average harvesting losses for using mini-combine harvester and manual harvesting were found a) 1.24%, 6.14%; b) 1.32%, 5.94% and c) 1.28%, 6.04%, respectively of a) Aman-2016, b) Boro-2017 and c) Aman-2017 rice harvesting. Average loss reduce over manual harvesting was found 4.76% using mini-combine harvester. Amponsah et al. (2017) mentioned grain loss using combine ranging from 1.43% to 4.43% and 1.85% to 5.6% for the IR841 and Nerica L20 rice varieties, respectively. Kannan et al. (2013) reported similar post-harvest loss of rice, estimated manual harvesting loss at 6.87%. Post-harvest loss was estimated highest for marginal farmers with 8.11% followed by medium farmers (7.69%) and small farmers (6.64%). Hossain et al. (2015) estimated average grain saving from loss reduction by combine harvester over manual methods was 2.75%. Harvesting loss might vary with the operator's skill, harvesting time, soil condition and agronomic characteristics of the rice. Generally early harvesting reduced pre-harvest and shattering loss in operation, on the other hand delayed harvesting

Table 4 Mechanical harvesting cost using mini-combine harvester

Rice Season	Cost item		Total operating cost (BDT./ha)
	Fixed cost (BDT./ha)*	Variable cost (BDT./ha)	
Aman/16	2228	7867	10095
Boro/17	2451	8264	10715
Aman/17	2723	8774	11497
Average operating cost			**10769**

BDT.: Bangladeshi Taka (Approximately 84 BDT. = 1 US $)

Table 5 Manual harvesting cost

Type of work	No of man-day/ha	*BDT./man-day	Total cost, BDT./ha
Rice reaping	23	400	9200
Straw binding & carry to home	15	400	6000
Threshing	15	400	6000
Cleaning	8	400	3200
Total cost of manual harvesting			**24400**

BDT.: Bangladeshi Taka (Approximately 84 BDT. = 1 US $)

caused more loss due to low moisture content.

Conclusions

Cost savings in mechanical harvesting of rice were found 55.86% for using mini-combine harvester over manual harvesting system. Similarly, labors savings using mini-combine harvester were found 65% over manual harvesting system. The total harvesting losses (including harvesting, threshing and cleaning) were also found 1.28% and 6.04% for using mini-combine and manual harvesting systems, respectively. The losses of rice can be reduced to 4.76% using mini-combine harvester over manual harvesting system. The results indicated that manual harvesting is a labor intensive and cost involving system. On the other hand mechanical harvesting using mini-combine harvester is less labor and less cost involving system along with increasing production through reduction of post-harvest losses. In addition important opportunity will be created for the unemployed skill people in the field operation of mini-combine harvester and repair & maintenance of new harvesting technologies. Based on technical and financial performances of mini-combine harvester, all identified factors have an impact on enhancing the agricultural growth and intensify the share of GDP in Bangladesh that will ultimately assist to strengthen livelihood status of Bangladesh along with satisfactory social status of literate farmer in future and maintaining good physical condition through reducing human drudgery.

Acknowledgement

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REFERENCES

Amponsah, S. K., Addo, A., Dzisi, K. A., Moreira, J. and S. A. Ndindeng. 2017. “Performance Evaluation and Field Characterization of The Sifang Mini Rice Combine Harvester”, Applied Engineering in Agriculture, Vol. 33(4): 479-489 © 2017 American Society of Agricultural and Biological Engineers.

BBS. 2016. Statistical Pocket book of Bangladesh. Bangladesh Bureau of statistics. Ministry of Planning, Bangladesh.

Bala, B. K., Hoque, M. A., Hossain, M. A. and S. Majumdar. 2010. Post-harvest loss and technical efficiency of rice, wheat and maize production system: assessment and measures for strengthening food security. Final Report (CF # 6/08) submitted to the National Food Policy Capacity Strengthening Programme (NFPCSP), Ministry of Food and Disaster Management, Dhaka, Bangladesh.

BRRI (Bangladesh Rice Research Institute). 2014. Annual Report 2013-14. Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh.

BRRI (Bangladesh Rice Research Institute). 2013. http://www.knowledgebank-brri.org /riceinban.php. Accessed on 2 Jan 2013.

BRRI (Bangladesh Rice Research Institute). 2009. Extension of agricultural machinery at union level. A paper presented by the Farm Machinery and Postharvest Technology Division of BRRI in The Institution of Engineers, Bangladesh, 51 Convention, 2009.

Brolley, M. 2015. Rice security is food security for much of the world. Rice Today, ISSN 1655-5422. Jan-Mar 2015, Vol. 14, No. 1. International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila, Philippines. PP. 30-32.

Hunt, D. 1995. Farm power and machinery management- 9th edition. Iowa State University Press, Ames, Iowa, USA.

Hossain, M. A., Hoque, M. A., Wohab, M. A., Miah, M. A. M. and M. S. Hassan. 2015. Technical and Economic Performance of Combined Harvester in Farmers’ Field. ISSN 0258-7122. Bangladesh J. Agril. Res. 40(2): 291-304, June 2015.

Kabir, M. S., Salam, M. U., Chowdhury, A., Rahman, N. M. F., Iftekharuddaula, K. M., Rahman, M. S., Rashid, M. H., Dipti, S. S., Islam, A., Latif, M. A., Islam, A. K. M. S., Hossain, M. M., Nessa, B., Ansari, T. H., Ali, M. A. and J. K. Biswas. 2015. Rice Vision for Bangladesh: 2050 and Beyond, Bangladesh Rice Journal, Vol. 19(2): 1-18.

Kannan, E., Kumar, P., Vishnu, K. and H. Abraham. 2013. “Assessment of Pre and Post-Harvest Losses of Rice and Red Gram in Karnataka”, Research Report: IX/ADRTC/153, Agricultural Development and Rural Transformation Centre (ADRTC), Institute for Social and Economic Change (ISEC), Bangalore.

Khadr, K. A. A., El-Bakhshwan, M. K. and H. M. Abou-nour. 2009. “Evaluation of the Japanese rice combine harvesters used after recommended salvage life”, Mansoura University Journal of Agricultural Sciences.

Mandal, M. A. S. 2014. Paper Presented at the NSD-IFPRI Workshop on “Mechanization and Agricultural Transformation in Asia and Africa: Sharing Development Experiences". June 18-19, Beijing, China. 2014. Agricultural mechanization in Bangladesh: role of policies and emerging private sector.http://www.slideshare.net/IF-PRIDSG/sattar-mandal?related=2 Available from URL: (accessed 14.05.15).

Mandal, M. A. S. 2002. Agricultural machinery manufacturing and farm mechanization: a case of rural non-farm economic development in Bangladesh. In: Paper Presented at International Workshop on Fostering Rural Economic Development through Agriculture-based Enterprises and Services. November 19-22, GTZ-Haus, Berlin, Germany.

Miah, M. A. M., Islam, M. S. and M. T. H. Miah. 2002. Socio-economic impact of farm mechanization on the livelihoods of rural labourers in Bangladesh. Paper presented at the Asian Regional Conference on Public-Private Sector Partnership for Promoting Rural Development held at BIAM Bhavan, New Eskaton, Dhaka, October 2-4, 2002.

MoA (Ministry of Agriculture). 2013. http://www.moa.gov.bd/. Accessed on 2 Oct 2013.

Noby, M. M., Hasan, M. K., Ali, M. R., Saha, C. K., Alam, M. M. and M. M. Hossain. 2018. Performance evaluation of modified BAU self-propelled reaper for paddy. Journal of Bangladesh Agricultural University, 16(2): 171-177.

Samon, B. and B. Duff. 1973. The Pattern and magnitude of field grain losses in rice production. IRRI Saturday Seminar Paper, July 7.

Zhang, X., Rashid, S., Ahmad, K. and A. Ahmed. 2014. Escalation of real wages in Bangladesh: is it the beginning of structural transformation? World Dev. 64, 273-285.

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ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

1821

Optimizing Field Performance of Axial Flow Rotary Combine with Single Rotor and Snap Roll Header for Maize Harvesting: Surinder Singh Thakura, Rupinder Chandel

A Maize combine with snap roll header was tested to study the effect of operational factors on combine performance. The combine was evaluated at different feed rates and different moisture contents (w.b.) for maize varieties PMH-2, Pioneer-1844 and DKC-9108. The feed rate and moisture content levels used for machine evaluationwere 69.94 Mg.h^{-1} (Mega gram per hour), 85.48Mg.h^{-1} and 124.33Mg.h^{-1} and 24.45%, 26.03% and 28.90% (wet basis, w.b.), respectively. Pre harvest losses increased from 1 to 4 % as the maize crop were sun dried from a grain moisture level of 28.90% to 24.45% because the ear shank became weak with decrease in moisture content. The shelling efficiency varied from 96.81% to 98.13%, cleaning efficiency varied from 95.20% to 95.80%, minimum grain damage obtainedwas 2.1% and minimum total losses obtained was 9.96%. The optimum values of feed rate and moisture content (w.b.) were 85.48 Mg.h^{-1} (forward speed of 1.10 km.h^{-1}) and 26.03%, respectively. With these independent variables, values obtained for shelling efficiency, cleaning efficiency, grain damage and total loss were 98.13%, 95.80%, 2.10% and 10.23%, respectively. The cost of drying at 26.03% moisture content was found to be 28.57% higher when compared with that of 24.45% moisture content. The saving in cost and time with maize combine with snap roll header in comparison to conventional treatment were 56.38% and 89.92%, respectively. The energy involved inmaize harvesting for maize dehusker cum sheller and maize combine with snap roll header were 2152.26 and2633.25 MJ ha^{-1},respectively.

1844

Development and Performance Evaluation of a Low Cost Maize Shelling Machine for Rural Farmers: Nwogu, Chukwunonso

A low cost maize shelling machine comprising mainly of frame, four feed hoppers, shelling tube, lever, beam and discharge chute was developed to reduce drudgery and other challenges associated with hand shelling of maize. The frame and other major components of the machine were constructed with mild steel bars, shafts and sheets which were sourced locally. The machine is manually operated and requires no prime mover (electric motor, IC engine, etc.), hence incurring minimal operational cost as well as finding use in areas without sufficient electricity supply. Test results revealed that shelling an average mass of 10 kg of maize, a maximum shelling efficiency of 82.03% and least grain damage of 0.60 kg was obtained for the machine during machine testing using maize sample having 13% moisture content. In conclusion, the developed maize sheller performed well using a maize sample of 13% moisture content.

Design Parameters of Tractor Drawn Pressurized Aqueous Fertilizer Drill

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Abstract

The present study investigated the design values of a pressurized pumping system. Moisture range required to sowing was first determined for different soil type. For loamy sand an application range of 0.15-092 liter aqueous fertilizer per meter is needed for raising moisture from 3 to 7% to germination moisture of 14 %. Whereas, for sandy loam, the range is 0.17-1.34 liter per meter for raising moisture from 4 to 12% to germination moisture of 20%; and for loam soil it is 0.23-1.59 liter per meter for raising moisture from 8 to 16% to germination moisture of 27%. Based on estimation, an aqueous fertilizer requirement of 5500 to 8000 l/ha was set in experimental field with clay loam soil. To optimize different pump variables for required discharge rate, five levels of pump rotational speeds i.e. 1998, 1665, 1332, 999 and 666 rpm, four levels of line pressure staring from fully opened valve i.e. gauge pressure of 0 kg/cm^2, by reducing valve opening area up to 2, 4 and 6 kg/cm^2, and three levels of nozzle sizes i.e. 8, 10 and 12 mm were taken. Pump rotational speed influenced discharge directly in a linear manner at fully opened valve for all pump speeds for each nozzle. As line pressure increased, the discharge rate decreased. Flow reduction of 2 to 6 times was obtained by creating the line pressure through control valve at rotational speed from1998 to 666 rpm. The selected design values for pressurized pumping system were found to be (a) pump rotational speed of 666, 999, 1332 and 1665 rpm, (b) line pressure of 0, 2 or 4 kg/cm^2 and (c) nozzle size of 10 mm.

Keywords: Aqueous Fertilizer, Pressure, Discharge, Nozzle size, Germination, Moisture content

Introduction

In India, the un-irrigated area was 63.30% of net sown area during 2014-2015 which shows above 60% of net sown area is without assured irrigation (Anonymous, 2015). The agricultural output, in this area depends on monsoon. In fact, crop cultivation is a difficult task due to uncertainty and deficit of soil moisture during sowing time, which causes the problem in germination of seed and good establishment. For proper germination and growth of plant, precise placement of seed with optimum soil moisture content, nutrients and other climatic conditions are required. Aqueous fertilizer drill plays a vital role in seedbed preparation as well as in seed placement along with aqua fertilizer (which also supplements the water) for healthy initial growth. Placements of aqua fertilizer also have greater significance for enhancing the agriculture production. But in moisture deficit areas the applied basal dose of fertilizer remains unavailable due to inadequate soil water to dissolve, dilute and convey it to root depth level in winter and summers.

This problem can be solved by using aqueous fertilizer, because these fertilizers are energy saving, economical and they can be applied uniformly with the flexibility in formation of different grades. This may facilitate successful germination and initial root and shoot development of the plants. Application of aqueous fertilizer at root zone depth can be achieved by using suitable aqua fertilizer seeding/planting machine. To supplement soil moisture and nutrient requirements of different crops, a continuous or intermittent supply of aqueous fertilizer may be needed. A suitable technology is required for application of aqueous fertilizer alongside of seed (Dey, 2004).

Pressurized metering system may prove useful for precision seeding of different crops in deficit moisture condition areas by controlled application of aqua-fertilizer according to the corresponding soil moisture.

Materials and Methods

Estimation of Aqueous Fertilizer Requirement for Selected Soil-moisture-crop Conditions

Determination of Available Soil Moisture (ASM)

Firstly, the available moisture at sowing depth was determined and based on which, subsequent estimation of aqueous fertilizer requirement in given area was made. The available soil moisture is the moisture that plant can use, which depends on soils texture also. The available soil moisture was calculated by using the equation (1):

$$ASM, (\%) = FC, (\%) - WP, (\%) \quad \cdots(1)$$

Where,

ASM = Available soil moisture, %;

FC = Field capacity, the upper limit of available moisture at which drainage ceases (Occurs at soil moisture tensions of 1/10 bar (10 centibar) for sandy soil and 1/3 bar (33 centibar) for other soils; and

WP = Wilting point or lower limit of the soil moisture at which plant wilt permanently (Permanent wilting point occurs at 15 bars of soil moisture tension).

Determination of Aqueous Fertilizer Requirement

The requirement of aqueous fertilizer in a given soil moisture environment depends on soil texture, field capacity, wilting point and available moisture in a particular soil. The first step in this direction was to estimate the requirement of additional soil moisture which is just sufficient to meet the moisture requirement for germination. It is not possible to provide extra moisture abundantly, because moisture applicator has its own limitations w.r.t. water carrying capacity and mode of aqueous fertilizer application. Also any excess volume of water would be a hindrance in proper sowing of seed alongside of aqueous fertilizer. The estimation of aqueous fertilizer was done by using the following equation:

$$V_1 = (FC - WP) \times \rho \times d \times w \times n \times W \quad \cdots(2)$$

Where,

V_1 = Amount of aqueous fertilizer, vol. l/ha;

FC = Field capacity, %;

WP = Wilting point, %;

ρ = Density of soil, g/cc;

d = Depth of seed placement, cm;

w = Width of root spread per meter row length, cm;

n = No. of turns of seed drill per hectare and

W = Width of seed drill, cm

Design Parameters of Seed Cum Pressurized Aqua Fertilizer Drill

Based on the information of obtained soil moisture requirements for different types of soil in dry-land and rain-fed areas, and placement depths, different components of the drill were developed. Apart from fertilizer metering system, the pressurized aqua fertilizer drill consisted of the critical components including: Main frame, Seed hopper, Seed metering mechanism, Tubes for seed and aqueous fertilizer, Furrow opener, and Ground wheel. Need based modifications were made for these components.

a. Main frame

Frame was subjected to torsion and bending due to induced draft. Design was based on the stresses produced in the frame, the following assumptions were taken.

Width of furrow opener = 6 cm

Depth of furrow opener = 8 cm

Soil resistance = 0.5 kg/cm^2

Cross-section of furrow = 6 cm × 8 cm

Cross-sectional area = 48 cm^2

Draft = soil resistance (kg/cm^2) × cross-sectional area of furrow (cm)

= 0.5 × 48

= 24 kg

Torque produced on toolbar (T) = 0.5 × 8 × 6 × 0.4 (clearance from ground) × 9 (no. of tynes) = 86.4 kg-cm

In addition to torque the bending moment is also produced in the toolbar. The toolbar can be assumed as simply supported frame. The maximum bending moment will be at the centre. The reactions at each of the two supports is = 24 × 9/2 = 108 kg

The maximum bending moment at the centre is calculated as:

$$M = 3.5P \times 2.5x - 3Px - 2Px - Px$$
$$= 9.15Px - 6Px = 3.15\ Px$$
$$= 3.15 \times 24 \times 45 = 3400 \text{ kg-cm}$$

$$T_e = (M^2 + T^2)^{1/2} \quad \cdots(3)$$
$$= [(3400)^2 + (8640)^2]^{1/2}$$
$$= 9284 \text{ kg-cm}$$

The maximum shear stress developed at the centre of toolbar is given by

$$S_s / y = T_e / I \quad \cdots(4)$$

Where,

S_s = shear stress at section

Y = distance of outermost fibre from neutral axis

T_e = equivalent torque

I = moment of inertia (bd^3 / 12 for rectangular section and for square section b = d)

Let $S_s = 500$ kg/cm^2

$I = bd^3 / 12$ ···(5)

$= d^4 / 12$

Therefore,

$I/Y = (d^4 / 12) / d / 2 = d^3 / 6$ ···(6)

$d^3 = 6\ T_e/S_s$

$= 9284 \times (6 / 500) = 111.4$ cm^3

d = 4.81 cm or 5 cm.

So, size of toolbar is 50 × 50 mm.

b. Tank for Liquid Fertilizer Storage

The aqueous fertilizer needs to be carried along with the pressurized aqua fertilizer seed drill for continuous application in the field. Dey et al. (2004) mounted the aqueous fertilizer tank of 500 litre capacity at the rear of the peristaltic pumping based aqua fertilizer seed drill. The machine during its operation in the field faced serious instability problem in vertical direction. To counter the challenge in the present design of the experimental setup, two tanks were mounted on a platform made of mild steel flat of size 40 × 10 mm on the both sides of aqueous fertilizer metering pumping system. Two cylindrical tanks of 200 litre capacity each with a vertical opening were mounted on the main frame

c. Seed Hopper

Considering physical and engineering properties of wheat and seedling requirement, a trapezoidal cross section hopper was fabricated with side wall slope of 15° with the horizontal. The vertical rollers were mounted at the bottom. The bottom of the box is flat and rounded at the corners. The location of box in seed drill was kept 145 mm above the ground, helps preventing the excessive bending of seed delivery tubes. The length and width of the rectangular cross section of seed flowing were kept as 70 and 25 mm, respectively.

d. Seed Metering Mechanism

Seed metering mechanism is an important component of a sowing machine and function of which is to distribute seed uniformity at desired application rate with minimum damage. To achieve uniform seed flow in rows, the metering device needs to draw seeds from bulk and deliver those to the seed tube. The commonly recommended metering system on seed drill are internal double run, stationary opening seed metering with agitator and fluted roller type.

e. Furrow Opener

The single shovel type furrow opener was used to apply the required amount of aqueous fertilizer in the furrow alongside of the seed.

f. Vertical Roller Metering Mechanism

Vertical roller metering mechanism consists of roller with spherical cells on the periphery of roller. The roller is made up of aluminum, mild steel and nylon of 5 cm diameter for laboratory study. The drive from ground wheel was transmitted through the main shaft using chain-sprockets with the transmission ratio of 0.5 (ground wheel to seed plate). The angle of metering device was kept as 15° with the horizontal.

g. Ground Wheel

The ground wheel was provided to drive the metering mechanism. The speed of metering was controlled by the ground wheel through power transmission system of chain and sprocket mounted on the shaft of ground wheel and metering mechanism. The specified range of diameter of ground wheel as per RNAM test code is 350-450 mm; keeping dimension of other components of machine particularly frame size and furrow opener height, ground wheel was taken as 360 mm which confirms the specified range. The wheel rim was made of mild steel flat with 100 mm width and 1.6 mm thicknesses. Lugs of 25 × 5 mm were provided, on the periphery of the wheel for better traction.

h. Drive Mechanism of the Pump

This seed cum pressurized aqua fertilizer drill is to be operated by a 45 hp tractor. Different moving component of the machine were supplied power from the tractor. The centrifugal pump used to supply aqueous fertilizer to the nozzles was powered by the PTO drive of the selected tractor with speed of 540±10 rpm. A suitable power transmission system was designed and fabricated to accomplish this task. The power transmission is designed taking universal coupling fitted to PTO, cone pulleys, two shafts of 32mm diameter, four bearings (P207), followed by two cone pulleys of cast iron of size 2016-1004 mm diameter and connected to another cone pulley of size 2540-762 mm through v-belt drive and further it is connected to the centrifugal pump.

i. Nozzles of Distributor Along with Plastic Tubes

Three different sizes of nozzles along with tubes of 8, 10 and 12 mm diameter were used for carrying aqueous fertilizer.

j. Fitting of the Pipes with Pressure-volume Control Valve

The designed aqueous fertilizer metering was continuously subjected to the pressurized flow under pump operation a 5 cm galvanized iron pipe was used instead of plastic for pumping flow through distributor from tank. The pressure and volume control valve was fitted in between the pump and the distributor for calibration of discharge in correspondence to the pressure.

Design of Experiments

Plan of experiments is summarized in **Table 1**.

Table 1 Plan of experiments

S. No.	Variables	Levels of variables	Measured parameter
1	Nozzle size	8, 10 and 12 mm	Discharge (l/ s)
2	Rotational speed of pump	1998, 1665, 1332, 999 and 666 rpm	
3	Line pressure	0, 2, 4 and 6 kg/cm^2	

Test Procedure

The instrumentation for measurement of rpm, time and discharge included tachometer, stopwatch, beaker and measuring cylinder. The study included determination of discharge rate from the all tubes for various levels of nozzle size, rpm and pressure.

Rotational Speed of Pump

Different levels of pump rotational speed 1998, 1665, 1332, 999 and 666 rpm (**Table 1**) were obtained by varying PTO rpm from 300, 250, 200, 150 and 100 with the help of throttle.

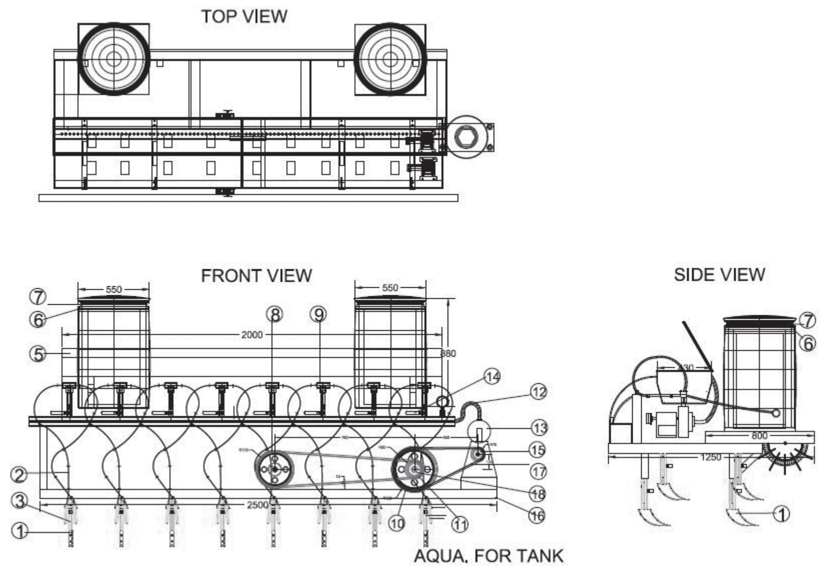
Pressure Levels

Provision of pressure-volume control valve was made to restrict flow of aqueous fertilizer, which creates relative pressure between pump and valve. Four levels of line pressure, staring from fully opened valve i.e. gauge pressure of 0 kg/cm^2, similarly 2, 4 and 6 kg/cm^2 (**Table 1**) were maintained in order to vary discharge rates for each level of pump speed.

Measurement of Discharge w.r.t Time

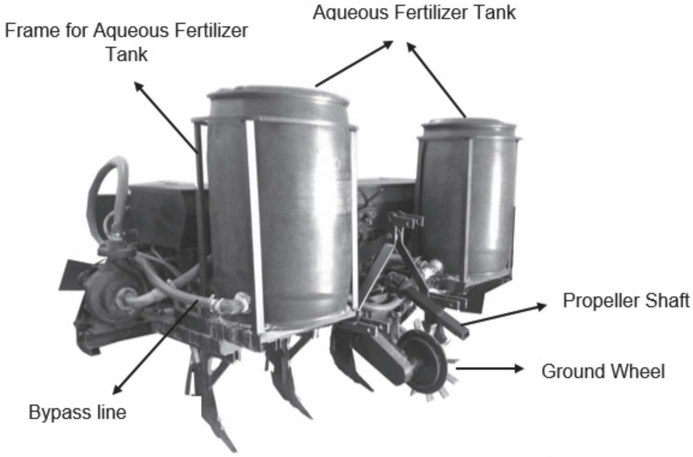
The discharge from tubes was measured with three replications to minimize error. Discharge from nine tubes was measured with 1000 ml beakers. But due to pressurized aqueous fertilizer it permitted less time to collect discharge from each tube. Therefore all nine tubes bind at one end of frame then discharge was measured w.r.t. time with help of bucket and measuring cylinder of 1000 ml of capacity. Precise measurement of time was done by stopwatch.

Fig. 1 Computer aided design of seed cum pressurized aqueous fertilizer drill



1. Tyne, 2. Aqual fertube, 3. Seed tube, 4. Seed metering, 5. Seed hopper, 6. Tank frame, 7. Aqua for tank, 8. Drive pulley, 9. Driven pulley, 10. Driven pulley, 11. Driven pulley, 12. Delevery pipe, 13. Central pump, 14. Control valve, 15. Driven pulley, 16. Frame, 17. "V" belt, 18. Bearing

Fig. 2 Developed seed cum pressurized aqueous fertilizer drill



Fabrication of Tractor Operated Nine Row Pressurized Aqua Fertilizer System

The final design values of different component were determined (**Fig. 1**). The fabrication of different component and their assembling was done in the workshop of College of Agricultural Engineering Jabalpur. Thus, the prototype was ready for test evaluation (**Fig. 2**).

Results and Discussion

Extra Water Requirement to Acquire Germination Soil Moisture

Different areas face different levels of moisture deficit. At the same time, there is possibility of crop germination and growth over a small range of soil moisture levels. With these facts in view, an analysis was done to evaluate water requirement for given initial soil moisture to obtain germination moisture for three different soil types namely, loamy sand, sandy loam and loam soil. A brief description in respect of above is presented below for different soils, separately.

Loamy Sand Soil

The water requirement was estimated for raising the soil moisture level to 14%, suitable for germination in loamy sand soil, from the assumed soil moisture of 3, 5 and 7 %.

The water requirement ranged from 0.15-0.23, 0.29-0.46, 0.44-0.69 and 0.44-0.92 liter per meter for depth of application of 2.5, 5, 7.5, and 10 cm, respectively for variation of initial moisture from 7 to 3%. The maximum water requirement observed was 0.92 liter per meter for depth of 10 cm and initial moisture content of 3% and minimum requirement was 0.15 liter per meter for 2.5 cm and initial moisture of 7%. It was noticed that for loamy sand soil an application range of aqueous fertilizer was 0.15-0.92 liter per meter (**Fig. 3**).

Sandy Loam Soil

The water requirement was estimated for raising the soil moisture level to 20%, suitable for germination in sandy loam soil, from the assumed soil moisture of 4, 8 and 12%. The water requirement ranged from 0.17-0.34, 0.34-0.64, 0.50-1.01 and 0.67-1.34 for depth of application of 2.5, 5, 7.5, and 10 cm, respectively for variation initial moisture from 12 to 4%. The maximum water requirement observed was 1.34 liter per meter for depth of 10 cm and initial moisture content of 3% and minimum requirement was 0.17 liter per meter for 2.5 cm and initial moisture 12%. It was noticed that for loamy sand soil an application range of aqueous fertilizer was 0.17-1.34 liter per meter (**Fig. 4**).

Clay Loam Soil

The water requirement was estimated for raising the soil moisture level to 27%, suitable for germination in loam soil, from the assumed soil moisture of 8, 12 and 16%. The water requirement ranged from and 0.23-0.40, 0.46-0.80, 0.69-1.20 and 0.92-1.59 liter per meter for depth of application e.g. 2.5, 5, 7.5 and 10 cm, respectively for variation initial moisture from 16 to 8 %. The maximum water requirement observed was 1.59 liter per meter for depth of 10 cm and initial moisture content of 8% and minimum requirement was 0.23 liter per meter for 2.5 cm and initial moisture 16%. It was noticed that for loam soil an application range of aqueous fertilizer was 0.23-1.59 liter per meter (**Fig. 5**).

Aqueous Fertilizer Requirement for Clay Loam Soil of Experimental Field

The proposed aqueous fertilizer applicator at the time of sowing is to provide maximum additional moisture to facilitate germination in soil. Thus, keeping in view the available moisture at about wilting point and minimum germination moisture of above 8% and also the limitations of seed drill to carry large volume of aqueous fertilizer, the aqueous fertilizer requirement with clay loam soil was finalized as 5500-7500 l/ha. Kant et al., (2007) estimated aqueous fertilizer requirement with sandy loam soil was 8000-10000 l/ha. Anonymous (1996) also estimated same requirement in their experiment at WTC, IARI, New Delhi.

Discharge v/s Pump Rotational Speed at Various Levels of Nozzles at Fully Open Valve

The influence of pump rotational speed on discharge rates was evaluated. The discharges from three levels of nozzle sizes i.e. 8, 10 and 12 mm were recorded for five levels of pump rotational speeds i.e. 666, 999, 1332, 1665 and 1998 rpm by keeping when pressure and volume control valve was fully open. It was observed that the pump rotational speed directly influenced the dis-

Fig. 3 Requirement of additional moisture for different depth of sowing (AGM, 14%)

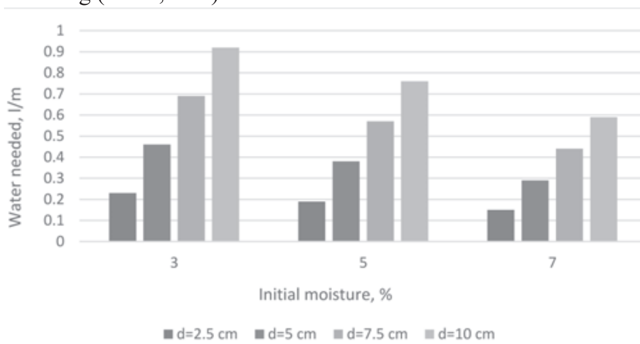


Fig. 4 Requirement of additional moisture for different depth of sowing (AGM, 20%)

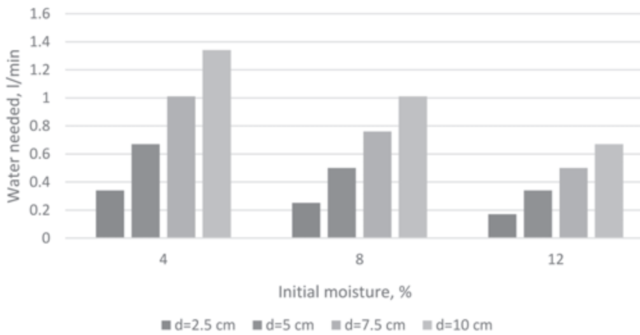
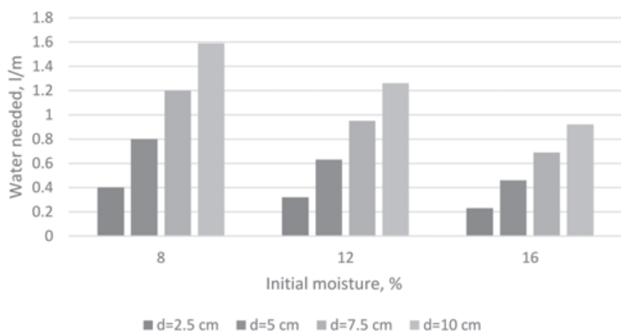


Fig. 5 Requirement of additional moisture for different depth of sowing (AGM, 27%)



charge in linear manner for different levels of nozzle sizes (**Figs. 6-9**). The similar trend was observed when nozzle sizes increased from 8 to 12 mm. Generally the discharge from nine different nozzles was same because nozzle openings were uniformly spaced. Minor variation noticed due to possible minute variation in nozzle sizes while fabricating.

The discharge from nozzle diameter of 8, 10 and 12 mm openings increased linearly with increase in pump rotational speed from 666 to 1998 rpm (**Fig. 6**). For 8 mm nozzle size, the range of discharge was 0.69 to 1.41 l/s for pump speeds range of 666 to 1998 rpm. For 10 mm nozzle size, the range of discharge was 0.74 to 1.53 l/s for pump speed range of 666 to 1998 rpm. For 12 mm nozzle, the range of discharge was 0.72 to 1.48 l/s for pump speeds range of 666 to 1998 rpm. At 1665 rpm the three nozzles sizes gave discharge of 1.13, 1.21, and 1.17 l/s. The discharge increased by 63.77, 69.44 and 49.25%, for increased rpm from 666 to 1665 for three nozzle sizes of 8, 10 and 12 mm, respectively.

Similarly, the observed increase in discharge due to speed changes from 1665 to 1998 rpm was 25.66, 28.57 and 45% for three nozzle sizes of 8, 10 and 12 mm. The results indicated that nearly uniform variation in discharge was obtained over speed range of 666 to 1998 rpm. This variation in discharge was as expected. More the pump speed of a centrifugal pump, which is positive displacement pump, more will be discharge. Thus, the pumping system used for metering aqueous fertilizer was capable to give a discharge variation of to 0.13 to 1.21 l/s for different nozzle sizes.

Statistical analysis was done to know the relative performance of the pressurized aqua fertilizer metering system for discharge rates at various pump rotational speed for different nozzle size. The discharge obtained at pump rotational speed of 666, 999, 1332, 1665 and 1998 was significantly at 1% level (**Table 2**).

Discharge vs. Nozzle Sizes at Pump Rotational Speed at Fully Open Valve

The discharge rate for various levels of nozzle sizes at pump rotational speeds levels i.e. 666, 999, 1332, 1665 and 1998 rpm at fully opened valve was recorded. It was observed that discharge rate is similar for each nozzle size i.e. 8, 10 and 12 mm for various levels of pump rotational speeds,

The experimental results showed that at 666 rpm the discharge from three nozzles i.e. 8, 10 and 12 mm were 0.69, 0.73 and 0.70 l/s, which confirmed the principle of mass conservation in the pipe flow. At 1998 rpm, the three nozzle sizes of 8, 10 and 12 mm gave discharge of

Fig. 6 Discharge at different nozzle sizes at various rotational speeds of pump at fully open valve

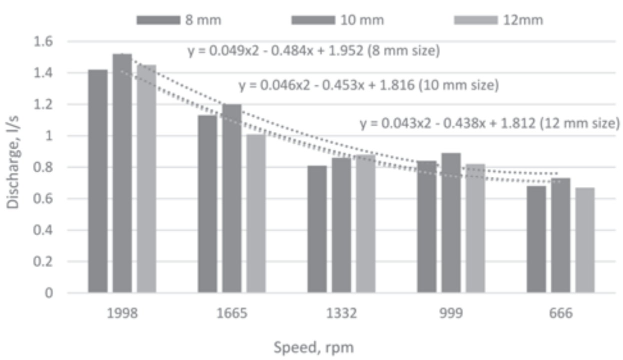


Fig. 7 Discharge vs rotational speed of pump for various levels of line pressure of aqueous fertilizer (8 mm nozzle)

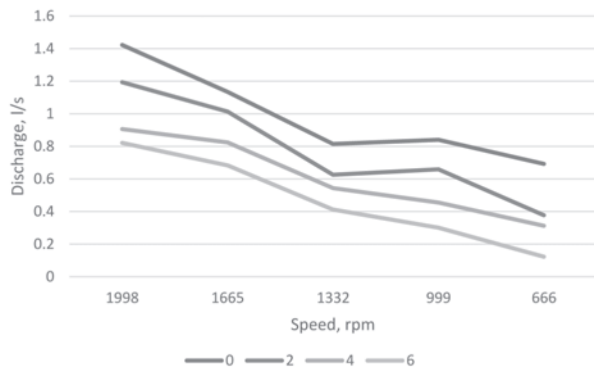


Fig. 8 Discharge vs rotational speed of pump for various levels of line pressure of aqueous fertilizer (10 mm nozzle)

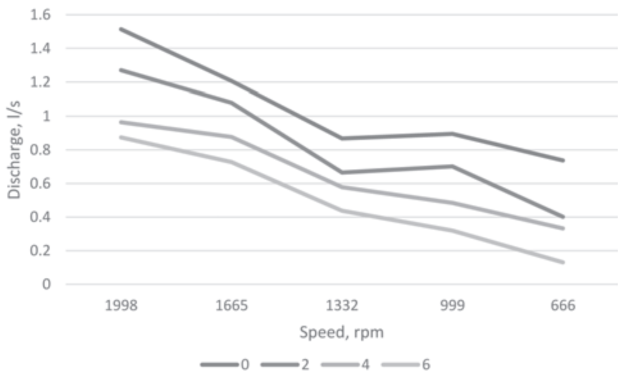
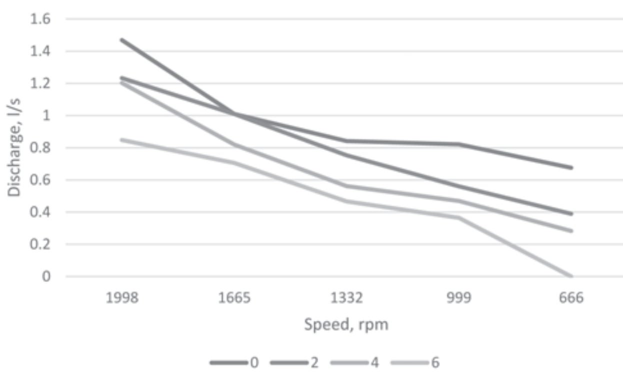


Fig. 9 Discharge vs rotational speed of pump for various levels of line pressure of aqueous fertilizer (12 mm nozzle)



1.42, 1.51 and 1.46 l/s. respectively, in the same order which showed relative higher value for 10 mm. As expected, the discharge from different nozzle sizes at same rotational speed of pump should almost be the same. The aqueous fertilizer was pumped by centrifugal pump and the latter being a positive displacement pump discharge should be same irrespective of nozzle sizes. However, minor variation in discharge may be witnessed due to deviation in nozzle size from design value caused while fabricating the same. At lower diameter, the line pressure will increase leading to variation in pump efficiency also. In addition, there could be possibility of slippage in belt pulley system of power transmission at lower size of nozzle due to development of higher line pressure. Having given scope for above variables, the discharge from different nozzle sizes at a given rpm should be same.

It was observed that the velocity of discharge increased for smaller nozzle size i.e. 8 mm than 10 mm and 12 mm. This causes the problem of seed and soil displacement. Hence nozzle size of 8 mm was not used for fabrication of pressurized aqueous fertilizer metering system.

Conclusions

The main design variables of pressurized aqua fertilizer metering system in the order of importance were rotational speed of pump, calibrated line pressure and nozzle size. Pump rotational speed influenced discharge directly in a linear manner at fully opened valve for all pump speeds for each nozzle size. A discharge range of 0.69 to 1.41, 0.74 to 1.531 and 0.72 to 1.48 l/s could be attained by varying the pump speed from 666 to 1998 rpm respectively, for three nozzle sizes of 8, 10 and 12 mm, respectively. For each pump rotation discharge from 8, 10 and 12 mm nozzle sizes was almost same, therefore, a positive displacement centrifugal pump was an appropriate selection and same output was obtained irrespective of nozzle sizes with minor variations. Keeping total discharge and pattern of aqueous fertilizer flow from nozzles, a 10 mm nozzle was found optimum. In pressurized aqueous fertilizer metering system, discharge rates decreased with increase in assumed forward speed for constant levels of pump rotational speed and line pressure. The developed pressurized system is capable of delivering a maximum 3600 l/h and minimum of 369 l/h of aqueous fertilizer with refilling time of 6.66 to 65 minute, respectively.

REFERENCES

Anonymous. 2015. Directorate of Economics and Statics: Agricultural Statics, http://eands.dacnet.nic.in/Agricultural_Statistics_At_Glance-2015%20E-book/book.swf.

Anonymous. 1996. Aqua ferti seed drill for rain-fed farming. A technical bulletin of Water Technology Centre, Indian Agricultural Research Institute, New Delhi, India.

Dey, A. K. 2004. Studies on design parameters of a tractor drawn aqua ferti seed drill. Ph.D. Thesis, IARI, New Delhi.

Gautam, A. K., Shrivastava, A., Samaiya, R. K. and A. Jha. 2018. Design and development of tractor drawn seed cum pressurized aqueous fertilizer drill. Indian Journal of Agricultural Research, 52(3), 257-263.

Gautam, A. K., Shrivastava, A. K. and R. K. Samaiya. 2017. Effect of aqueous fertilizer on soil moisture content depth of seeding and seedling emergence for wheat. International Journal of Agricultural Science and Research, 7(3), 241-246.

Kant, K. 2007. Studies on design parameters of aqueous fertilizer placement with seed drill. Ph.D. Thesis, IARI, New Delhi.

Ratliff, L. F. C., Ritchie, J. T. and K. K. Casel. 1983. Field measured limit of soil water availability as related to laboratory measured properties. Soil Science Society of America Journal, 47, 770-775.

RANM. 1995. Test codes and procedure for farm machinery. Technical series, No: 12.

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Table 2 Statistical analysis for discharge, pump speed and pressure

Source	DF	SS	MSS	Fcal	Ftab 5%	Ftab 1%
S	4	12.582	3.145	55419.38**	2.45	3.48
P	3	7.023	2.341	41245.02**	2.68	3.95
S × P	12	0.342	0.029	502.17**	1.83	2.34
D	2	0.062	0.031	545.02**	3.07	4.79
S × D	8	0.008	0.001	17.86**	2.02	2.66
P × D	6	0.005	0.001	13.29**	2.18	2.96
S × P × D	24	0.000	0.000	0.16ns	1.61	1.95
Error	120	0.007	0.000			
Total	179	20.028				

*SE = 0.025, CV% = 3.413, **(highly significant)*

Indices for Comparative Performance Evaluation of Seed Drills

by

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Abstract

The performance of a seed drill depends on manufacturing quality, precision and performance under field condition. In this study, an overall performance index was developed to compare performance of seed drills manufactured in different regions of Madhya Pradesh state of India for sowing of soybean and wheat crops. The test parameters of seed drills such as inter row variation of seed and fertilizer, seed damage, variation in seed placement, number of seeds dropped per meter, effective field capacity, field efficiency, fuel consumption, working width, type of furrow opener, hardness of furrow opener and weight of machine were selected to calculate precision, performance, machine quality and overall performance indices of seed drills. A completely randomized design was used to analyze test data of selected 90 seed drills. The average precision index of seed drills was 0.70 and 0.64 for wheat and soybean crops, respectively. The average performance index of seed drills was 0.72 and 0.73 for sowing of wheat and soybean crops, respectively. The machine quality index of the seed drills varied from 0.60 to 0.72. The overall performance index of the seed drills was 0.70 for wheat and 0.67 for soybean crops. The overall performance of seed drills manufactured in *Malwa* plateau of Madhya Pradesh was the best for sowing of wheat (0.74) and soybean (0.72) crops. Significant difference was observed among the seed drills manufactured in different regions of Madhya Pradesh based on precision, performance, machine quality and overall performance indices.

Keywords: Agro-climatic regions, performance index, precision index, machine quality, seed drill.

Introduction

Agriculture remains as principal means of livelihood for over 58% of the rural households. Over the year, number of people engaged in agricultural activities have decreased to 54% in 2011, which are further expected to go down to 40% in 2020 and 26% in 2050 (Mehta et al., 2018). This decline is accompanied by increase in daily wage rates from INR 87 in 2008-09 to INR 214 in 2012-13. Food grain productivity in India has increased from 522 kg/ha in 1950-51 to 2042 kg/ha in 2015-16 (Anonymous, 2017a). However, food grain production needs to be increased by about 40% by 2050 from 275 MT in 2017-18 to achieve food security to meet demand of growing population. The farm power availability has increased from 0.30 kW/ha in 1960-61 to 1.92 kW/ha in 2016-17. The overall mechanization level on Indian farms varies from 45 to 50% for different crops, as compared to 90% in developed countries (Mehta et al., 2014).

The availability of tractors has increased from one in 150 ha to one in 30 ha (Senthilkumar et al., 2017). However, similar growth rate was not reported for other farm machinery such as threshers, rotavators and power tillers (Anonymous, 2017b). Among different field operations, tillage and threshing are highly mechanized whereas sowing/planting is the least mechanized in India (Singh, 2015). More than 5000 farm machinery manufacturers produce 315,000-400,000 units of tillage and 63,500-79,000 units of threshing machineries every year in India. However, only around 2,500 farm machinery manufacturers are manufacturing 75,000?100,000 units of seeding/planting equipment (Singh, 2016). The number of manufacturers of sowing and planting machineries are low due to poor quality of manufacturing facilities, low workmanship, and small market as compared to other agricultural machineries. If manufacturing standards and quality norms are followed then the field performance of machinery will be enhanced (Mehta et al., 2014). The Food and Agriculture Division of BIS ensures manufacturing of agricultural products/equipment and their quality through its network of testing centres and laboratories through specific test codes. In addition, the government of India has also set up farm machinery testing centres to ensure manufacturing of quality farm machinery. The quality of farm equipment is ensured through performance evaluation under laboratory and field conditions at different farm machinery testing institutes and designated test centres (Anonymous, 2011).

The manufacturing of agricultural machinery in India is quite multifaceted and comprises of village artisans, tiny units, small-scale industries, State Agro-industrial Development Corporations and multinational companies. The quality of farm equipment manufactured at small scale industries is poor due to improper design, poor manufacturing facilities, and use of substandard and low quality materials (NAAS, 2016). Most of the farm machinery are not manufactured as per relevant BIS standards and their performance also do not conform the standards. However, there is still scope to improve the quality of agricultural implements, manufactured by small-scale manufacturers (Singh, 2015). It is necessary for a farm machinery to meet requirements of minimum performance standards (MPS) during testing of machinery. Singh et al. (2005) optimized design and operational parameters of pneumatic metering mechanism for cotton seed based on the miss index, multiple index, quality feed index and precision in spacing under laboratory and field conditions. Maleki et al. (2006) introduced a new index named coefficient of uniformity which was less sensitive for data outliers as compared to coefficient of variation for assessment of seed uniformity for seed drills.

The right selection of the agricultural machinery is a prerequisite for proper functioning for intended farm operation for sustainable agriculture (Cupiał et al., 2015). It will help in increase in productivity by 30% and reduce input costs by 20% (FICCI, 2015). The performance of tillage, sowing, and harvesting machinery is evaluated based on effective field capacity, field efficiency, fuel consumption, labour requirement, cost of operation etc. Among the tillage equipment, the performance index for moldboard plough is based on overall performance at a particular soil condition. It will also depend on the depth of operation, effective field capacity, soil inversion, pulverization, and draft requirement (BIS, 1999). Similarly, overall performance index developed by Behera et al. (1995) for seed

Table 1 Agro-climatic region wise details of major crops grown, soil type and rainfall pattern of Madhya Pradesh

Sl. No.	Agro-climatic region	Major crops grown	Soil type	Rainfall, mm	Ftab 5%	Ftab 1%
1	Gird Region	Wheat, soybean, Jowar	Alluvial (Light)	800-1000	891	3555
2	Bundelkhand	Wheat, soybean, Jowar	Mixed red and black (Medium)	800-1400	895	2611
3	Satpura Plateau	Wheat, soybean, Jowar	Shallow black (Medium)	1000-1200	995	2569
4	Nimar Plains	Wheat, soybean, cotton	Medium black (Medium)	800-1000	946	3148
5	Jhabua Hills	Wheat, soybean, cotton	Medium black skeletal (Light/Medium)	800-1000	977	2760
6	Kymore Plateau and Satpura hills	Rice, wheat, soybean	Mixed red and black soils (Medium)	1000-1400	901	2227
7	Vindhya Plateau	Wheat, soybean, rice	Medium black and deep black (Medium/Heavy)	1200-1400	959	2622
8	Central Narmada Valley	Wheat, soybean,	Deep black (deep)	1200-1600	925	3595
9	Malwa Plateau	Wheat, soybean, cotton	Medium black (Medium)	800-1200	1025	3309
10	Chhattisgarh plains	Rice	Red and yellow (Medium)	1200-1600	834	1331
11	Northern Hill Region of Chhattisgarh	Rice, wheat	Red and yellow medium black and skeltal (Medium/light)	1200-1600	632	1820

Source: http://www.mp.gov.in/en/web/guest/mp-krishi/arg-st/landuse-ir-pop/argo-climatic (accessed on 16/06/2018)
http://mpkrishi.mp.gov.in/Compendium/APY1_12_05_2017.xls (accessed on 16/06/2018)

drills was based on their evaluation under field condition only. In addition, precision index is based on direct impact on quality and field performances of agricultural machinery. Precision index proposed by NAAS (2016) covered different attributes of seed drills such as inter row variation of seed and fertilizer, seed damage and seeding depth for seed cum fertilizer drill.

Thus, the majority of indices developed for comparative evaluation of seed drills were based on the performance of metering mechanism or furrow opener of the seed drills under laboratory and field conditions. However, few studies have been carried out for assessment of manufacturing quality of equipment and their impact on performance and precision. The study focuses on development of an overall performance index of seed drills based on precision, performance and manufacturing quality indices of the machinery to help in selection of better quality machinery by farmers.

Material and Methods

Selection of Seed Drills

There are 11 agro-climatic regions in Madhya Pradesh (MP) state of India (**Table 1**). The region-wise details of major crops grown, soil type, rainfall and productivity of soybean and wheat crops are reported in **Table 1**. The seed drills with fluted roller type metering mechanism having shoe or shovel type furrow opener are commonly manufactured in Madhya Pradesh state of India and are used for sowing of wheat, soybean, gram, lentil and maize crops.

Ten number of seed drills were selected from each of nine agro-climatic regions of Madhya Pradesh state except Chhattisgarh plains and Northern hill region of Chhattisgarh. Test data of 90 seed drills tested at Farm Machinery Testing Centre of ICAR-Central Institute of Agricultural Engineering, Bhopal in Madhya Pradesh state of India were compiled for the study. The general specifications of selected seed drills tested at the centre for soybean (cv. JS 9305) and wheat (cv. HI 1544) seeds are given in **Table 2**. The selected seed drills are having category II type three point hitch meeting the requirements of IS 4468, part1 (BIS, 1997). The parameters of seed drills such as inter row variation of seed and fertilizer, seed damage, variation in seed placement depth, number of seeds per meter row length, field capacity, field efficiency, fuel consumption, working width, type of furrow opener, hardness of furrow opener, conformity of hitching with BIS and weight of machine were taken for development of precision, performance and machine quality indices.

Development of Indices

Indices were developed to assess the precision, performance and manufacturing quality of seed drill using 13 parameters. To assign the rating, parameters were arranged in order depending on whether a higher value was considered ‘good’ or ‘bad’ in terms of machine quality, performance and precision. A weight to each parameter was as-

Table 2 General specifications of seed drills manufactured in Madhya Pradesh

Components	Constructional details	Material	Specifications
Overall dimensions	Length, mm Width, mm Height, mm	- - -	1800-2800 1300-1700 1200-1550
Weight of machine	Seed drill Seed-cum-fertilizer drill	-	371±50 kg 406±65 kg
Frame	Square box, C-Channel, square box Channel	Mild steel	Adjustable row spacing
Tyne	7/9/11/13 Nos	Mild steel	Straight/ curved
Furrow opener	Shoe or shovel	High carbon steel	Hardness, HB Shoe type: 230±46 Shovel type: 286±75
Metering mechanism	Fluted roller	Cast iron, Aluminium, plastic	Cup type with 7-10 flutes
Hopper	Trapezoidal shape	Galvanised iron sheet	Capacity: 100-150 kg Sheet thickness: 1.5-2.0 mm
Hitch	Three point hitch	Mild steel	Category II
Seed and Fertilizer tubes	Transparent, flexible	Plastic tubes	25-30 mm diameter
Ground wheel	Front or rear mounted (lug type)	Mild steel	Diameter, m Front: 0.40±0.03 Rear: 0.75±0.05
Power transmission system	Chain and sprocket	Carbon and alloy steel Mild steel	2 Nos for chain 4 Nos for sprocket

signed based on its contribution in achieving the higher precision, performance and better quality of machine. The recommended range, rating and weightage assigned to different parameters for calculation of different indices are given in **Table 3**. The values were transformed using a linear scoring technique (Andrews et al., 2002). The indices for comparative evaluation of seed drills were developed on the basis of weightage and rating assigned to the selected parameters.

The range for different parameters for precision index i.e. inter-row variation of seed (0-7.5%), inter-row variation of fertilizer (0-12%) and seed damage (0-0.5%) were selected as per recommendation of IS 6813 (BIS, 2000). Their ratings were selected based on recommendations of NAAS (2016). Each parameter was given a rating depending on their importance within the recommended range. Precision in sowing depends on inter-row variation of seed and fertilizer, seed damage, variation in seed placement depth and number of seeds per meter row length (NAAS, 2016). These attributes were selected for calculation of precision index.

Effective field capacity, field efficiency, fuel consumption and working width of seed drills were considered for calculation of the performance index. The ratings of different parameters for calculation of performance index were taken from Senapati et al. (1992).

The manufacturing quality of seed drills is an important parameter for proper functionality of the machine. The type of furrow opener, hardness of furrow opener, conformity of hitching pyramid with BIS and weight of machine were selected for calculation of manufacturing quality index. The recommended range for hardness of cutting edge of furrow opener of seed drills is 350- 450 HB (BIS, 1983). Therefore, higher rating of 1 was assigned for hardness more than 350 HB and lower value of 0.6 for hardness less than 250 HB. The dimensions of hitching system of seed drill (12 parameters) should be as per IS 4468, part1 (BIS, 1997). The machine that con-

Table 3 Rating and weightage assigned to different parameters of seed drills for calculation of precision, performance and machine quality indices

Parameters	Recommended values	Range	Rating (R)	Weightage (W)
Precision Index				
Inter row variation of seed, %	0-7	≤1.00	1.0	0.3
		1.01-3.00	0.8	
		3.01-5.00	0.6	
		5.01-7.00	0.4	
		≥7.01	0.2	
Inter row variation of fertilizer, %	0-12.5	0-2.50	1.0	0.2
		2.51-5.00	0.9	
		5.01-7.50	0.8	
		7.51-10.00	0.7	
		10.01-12.00	0.6	
		≥12.01	0.5	
Seed damage, %	0-0.5	0-0.25	1.0	0.1
		0.26-0.50	0.8	
		>0.5	0.6	
Variation in seed placement depth, %	0-20	0-5.0	1.0	0.1
		5.1-10.0	0.8	
		10.1-15.0	0.6	
		15.1-20.0	0.4	
		>20.0	0.2	
Seeds per meter row length, no	25-40 (Wheat) 18-27 (Soybean)	>40 >27	1.0	0.3
		36-40 25-27	0.9	
		31-35 22-24	0.8	
		26-30 19-21	0.7	
		≤25 ≤18	0.6	
Performance Index				
Effective field capacity, ha/h	0.4-0.8	>0.80	1.0	0.3
		0.71-0.80	0.9	
		0.61-0.70	0.8	
		0.51-0.60	0.7	
		≤0.5	0.6	
Field efficiency, %	70-90	>90.0	1.0	0.3
		80.1-90	0.9	
		70.1-80.0	0.8	
		≤70.0	0.7	
Fuel consumption, l/h	1.5-3.5	≤1.5	1.0	0.3
		1.6-2.5	0.8	
		2.6-3.5	0.6	
		>3.5	0.4	
Working width, m	1.5-3.0	>2.25	1.0	0.1
		2.01-2.25	0.9	
		1.76-2.00	0.8	
		1.51-1.75	0.7	
		≤1.50	0.6	
Machine Quality Index				
Hardness of furrow opener, HB	350-450	>350	1.0	0.3
		251-350	0.8	
		≤250	0.6	
Hitching pyramid	12	12	1.0	0.2
		9-11	0.9	
		6-8	0.8	
		3-5	0.7	
		<3	0.6	
Weight of machine, kg	300-400	>400	1.0	0.2
		350-400	0.9	

forms all 12 parameters for hitching was assigned the highest rating of 1 and lower value of 0.7 was assigned which conform to less than 4 parameters. The shoe type furrow opener performs better than shovel type of furrow opener. Therefore, rating values of 1 and 0.8 are assigned to shoe and shovel type furrow openers, respectively (Damora and Pandey, 1995; Chaudhuri, 2001).

The precision, performance and machine quality indices were determined by following equation (Senapati et al., 1992; Afzalinia et al., 2006):

$$I = \sum_{i=1}^{n} R_i W_i$$

Where,

I = Precision or performance or machine quality index

R_i = Rating of i^{th} parameter considered for corresponding index

W_i = Fractional weightage of i^{th} parameter considered for the index

n = Number of parameters considered for the index

An overall performance index was calculated by considering precision, performance and manufacturing quality indices. Overall performance index (OPI) was calculated by assigning weightage of 0.4, 0.3 and 0.3 for precision, performance and machine quality indices, respectively.

$$OPI = \sum_{i=1}^{n} I_i W_i$$

Where,

OPI = Overall performance index,

I_i = Value of each index,

W_i = Fractional weighting of each index, and

n = Number of indices.

Statistical Analysis of Data

The analysis of test data of 90 seed drills was done by SPSS statistical program (v.10) and values were arranged according to Duncan's multiple range test. The means at 5% level of significance ($P < 0.05$) was calculated to test the significance of differences between parameters.

Results and Discussion

Precision Parameters

The results of ANOVA of different parameters selected for development of precision index of the selected seed drills are given in **Table 4**.

Seed Placement Depth

There was no significant difference in seed placement depth for wheat and soybean seeds among seed drills of different regions. The variation in seed placement depth for wheat and soybean seeds varied from 1.87 to 5.08% and 5.38 to 23.46%, respectively (**Table 4**). The higher variation in seed placement depth in soybean was due to more depth of seed bed prepared after summer ploughing and followed by sowing under high soil moisture content during rainy season. Seed placement depth also depends on the type of furrow opener. It was observed that the shoe type furrow opener performed better as compared to the shovel type furrow opener in vertisol.

Inter Row Variation in Seed

There was significant difference ($p < 0.0001$) in inter row variation in seed placement for wheat and soybean seeds by the selected seed drills. The maximum variation in inter row placement of seeds was found in seed drills of Vindhya Plateau (6.50%) and followed by Bundelkhand (6.11%), Jhabua Hills

Table 4 ANOVA of different parameters used for precision index

Agroclimatic regions	Wheat					Soybean				
	Variation in seed placement depth, %	Inter row variation in seed, %	Inter row variation in fertilizer, %	Seed damage, %	Number of seeds per meter, No.	Variation in seed placement depth, %	Inter row variation in seed, %	Inter row variation in fertilizer, %	Seed damage, %	Number of seeds per meter, No.
Gird	4.17	5.76^AB^	8.07^A^	0.32^C^	30	6.37	5.49^ABC^	8.26^A^	0.41	26
Bundelkhand	3.33	6.11^AB^	6.10^AB^	0.33^BC^	30	5.38	4.12^CD^	6.40^AB^	0.39	22
Satpura Plateau	2.50	5.25^ABC^	7.96^A^	0.49^A^	30	10.42	5.18^ABC^	7.80^AB^	0.49	22
Nimar Valley	5.08	5.02^BC^	6.09^AB^	0.44^AB^	30	14.85	4.25^C^	6.01^AB^	0.50	25
Jhabua Hills	1.87	5.92^AB^	5.67^AB^	0.39^ABC^	32	18.04	4.47^BC^	5.33^B^	0.46	25
Kymore Plateau & Satpura Hills	8.33	5.90^AB^	7.21^AB^	0.45^ABC^	35	23.46	5.95^A^	7.93^AB^	0.49	23
Vindhya Plateau	2.08	6.50^A^	7.23^AB^	0.43^ABC^	24	7.83	5.71^AB^	8.28^A^	0.51	21
Central Narmada Valley	7.71	4.40^CD^	7.20^AB^	0.36^ABC^	32	21.04	5.15^ABC^	8.43^A^	0.43	23
Malwa Plateau	4.51	3.75^D^	5.71^B^	0.37^BC^	30	10.88	2.94^D^	5.56^B^	0.44	20
Mean	4.45	5.14	6.60	0.40	30	12.91	4.50	6.82	0.46	23
p-value	0.2245	<.0001	0.0345	0.0160	0.0682	0.2146	<.0001	0.0041	0.1796	0.3379
CV (%)	75.45	11.55	17.19	15.22	11.9	73.25	14.26	18.59	13.52	17.2
	NS	**	*	*	NS	NS	**	**	NS	NS

*** Significant at 1% (P < 0.01), * Significant at 5% (P < 0.05), NS - Non Significant*
A, B, C and D - Means within a column followed by the same letters are not significantly different.

(5.92%), Gird (5.76%), Kymore Plateau & Satpura hills (5.90%) and Satpura Plateau (5.25%) regions of Madhya Pradesh. The inter row variation in placement of seeds by the seed drills manufactured in different regions of Madhya Pradesh was within the recommended limit of less than 7% (IS 6813, 2000). Among the different agro-climatic regions, seed drills manufactured in Malwa plateau had the lowest inter row variation in placement of wheat (3.75%) and soybean (2.94%) seeds.

Inter Row Variation in Fertilizer

There was a significant difference in inter row variation in fertilizer placement by the seed drills manufactured in different agro-climatic regions for wheat and soybean crops (**Table 4**). It varied from 5.7 to 8.07% and from 5.56 to 8.43% for wheat and soybean crops, respectively. The inter row variation in fertilizer placement was due to seasonal variability and seed bed conditions during sowing of wheat and soybean seeds. Hygroscopic nature of fertilizer also increased the variability. The variability was also due to different sizes of flute diameter used in the seed drills manufactured in different regions. The inter row variation in fertilizer placement for the selected seed drills from different regions was within IS 6813 recommended limit of less than 12.5% (BIS, 2000).

Seed Damage

It was observed that there was significant difference ($p < 0.05$) in seed damage for wheat seeds and no significant difference for soybean seeds for seed drills manufactured in different regions of Madhya Pradesh. Seed damage varied from 0.32% (Gird) to 0.49% (Satpura plateau) for wheat seeds and from 0.39% (Bundelkhand) to 0.51% (Vindhya Plateau) for soybean seeds. The seed damage was more in soybean as compared to wheat seeds. This might be due to difference in seed size, moisture content, and breakage of soybean seed coat during drilling.

Number of Seeds per Meter

There was no significant difference in number of seeds dropped per meter length for wheat as well as soybean crops by seed drills manufactured in different agro-climatic regions. The average number of seeds dropped per meter for wheat and soybean seeds were 30 and 23, respectively.

Performance Parameters

The results of statistical analysis of different variables considered for development of performance index of seed drills of different agro-climatic regions of Madhya Pradesh are given in **Table 5**.

Width of Operation

For wheat crop, there was no significant difference in width of operation for sowing of seeds by seed drills manufactured in different agro-climatic regions. The average width of operation of seed drills was 2.18 m. The seed drills manufactured in Vindhya plateau had the maximum (2.63 m) width of operation and Jhabua Hills and Bundelkhand regions had minimum (2.03 m) width of operation. In Madhya Pradesh, the wheat seeds are commonly sown in close row to row spacing. Farmers of the region do not follow weeding or intercultural operations after sow-

Table 5 ANOVA of different parameters used for performance index

Agroclimatic regions	Wheat				Soybean			
	Width of operation, m	Effective field capacity, ha/h	Field efficiency, %	Fuel consumption, l/h	Width of operation, m	Effective field capacity, ha/h	Field efficiency, %	Fuel consumption, l/h
Gird	2.18	0.49^{H}	69.44^{CD}	3.13	1.58^{AB}	0.53^{AB}	67.40^{CD}	4.40
Bundelkhand	2.03	0.55^{G}	74.87^{ABC}	3.54	1.58^{AB}	0.46^{B}	68.30^{BC}	4.61
Satpura Plateau	2.18	0.57^{FG}	67.31^{D}	3.58	1.58^{AB}	0.59^{AB}	63.93^{D}	4.62
Nimar Valley	2.12	0.64^{CD}	79.70^{A}	3.63	1.53^{ABC}	0.53^{AB}	71.59^{AB}	4.62
Jhabua Hills	2.03	0.61^{DE}	72.45^{BCD}	3.58	1.30^{C}	0.61^{AB}	70.85^{ABC}	4.24
Kymore Plateau & Satpura Hills	2.18	0.60^{EF}	74.98^{ABC}	3.64	1.50^{BC}	0.50^{AB}	69.25^{ABC}	4.34
Vindhya Plateau	2.63	0.67^{BC}	75.54^{ABC}	3.52	1.73^{A}	0.68^{A}	69.83^{ABC}	4.74
Central Narmada Valley	2.33	0.69^{AB}	72.62^{BCD}	3.85	1.58^{AB}	0.58^{AB}	68.70^{ABC}	5.07
Malwa Plateau	2.14	0.71^{A}	75.52^{AB}	3.73	1.58^{AB}	0.65^{A}	71.79A	4.50
General mean	2.18	0.63	74.24	3.60	1.55	0.58	69.62	4.56
p-value	0.15	<0.0001	0.0001	0.5033	0.0018	0.0300	<.0001	0.4959
CV (%)	11.39	2.72	3.63	10.30	6.00	15.00	2.44	9.69
	NS	**	**	NS	**	*	**	NS

*** Significant at 1% (P < 0.01), * Significant at 5% (P < 0.05), NS - Non Significant*
A, B, C, D, E, F, G and H - Means within a column followed by the same letters are not significantly different

ing. Therefore, sowing of wheat in 9 to 11 rows by the seed drill is the most common practice for utilizing the maximum width of operation of machine. The width of operation of seed drills varied significantly ($p < 0.05$) across agro-climatic regions for sowing soybean crop. The seed drills manufactured in Jhabua hill region had the lowest (1.30 m) width of operation and in Vindhya plateau had the highest (1.73 m) with an average value of 1.55 m across the regions. This might be due to the variation in soybean cultivation practices (flat bed, ridge furrow and raised bed) among different agro-climatic regions leading to different width of operation. Lowest width of operation in the Jhabua hill region may be due to small size and irregular shape of hilly and stony fields. In this hilly region, there is a scope for utilizing high capacity machinery for timeliness of farm operations.

Effective Field Capacity

The effective field capacity of seed drills manufactured in different agro-climatic regions varied significantly for sowing of wheat as well as soybean crops. The seed drills manufactured in MP had an average effective field capacity of 0.63 ha/h for wheat and 0.58 ha/h for soybean crops. The effective field capacity of seed drills was maximum of 0.71 ha/h for wheat and 0.65 ha/h for soybean crops for machineries manufactured in Malwa plateau. However, it was minimum of 0.46 ha/h for soybean crop in Bundelkhand region and 0.49 ha/h for wheat crop in Gird region.

Field Efficiency

The field efficiency of machineries manufactured in different agro-climatic regions varied significantly ($p < 0.05$) for sowing of wheat as well as soybean crops. The average field efficiency of the seed drills was 74 and 70% for wheat and soybean crops, respectively. The maximum field efficiency of 80% was observed for sowing of wheat crop for machineries manufactured in Nimar valley whereas minimum of 67% was in Satpura plateau.

Fuel Consumption

There was no significant difference in fuel consumption of machineries manufactured across different agro-climatic regions for sowing of wheat as well as soybean crops. However, an average fuel consumption of tractor operated seed drills was 3.6 l/h for wheat crop as compared to 4.56 l/h for soybean crop. The fuel consumption was higher for sowing of soybean seeds due to difficulty in sowing during rainy season.

Table 6 ANOVA of different parameters used for machine quality index

Agro-climatic regions	Hardness, HB	Weight of machine, kg	Hitch pyramid, No.
Gird	251^{ABC}	383^{AB}	6
Bundelkhand	242^{ABC}	368^{AB}	5
Satpura Plateau	231^{BC}	375^{AB}	6
Nimar Valley	297^{AB}	325^{B}	5
Jhabua Hills	295^{ABC}	355^{AB}	6
Kymore Plateau & Satpura Hills	205^{C}	318^{B}	6
Vindhya Plateau	323^{A}	388^{AB}	5
Central Narmada Valley	225^{BC}	403^{A}	5
Malwa Plateau	289^{AB}	401^{A}	5
General mean	268	371	6
p-value	0.009	0.019	0.776
CV (%)	14.9	9.9	21.7
	**	*	NS

*** Significant at 1% (P < 0.01), * Significant at 5% (P < 0.05), NS - Non Significant*
A, B and C - Means within a column followed by the same letters are not significantly different.

Manufacturing Quality Parameters

The results of ANOVA of different parameters selected for development of manufacturing quality index of seed drills are given in **Table 6**.

Hardness of Furrow Opener

There was significant difference in the hardness of furrow openers of seed drills manufactured in different agro-climatic regions of Madhya Pradesh (**Table 6**). The higher value of hardness was observed for machineries manufactured in Vindhya plateau (323 HB) and followed in Nimar Valley (297 HB). These regions have medium black soils which lead to more wear in working component of agricultural machinery. In addition, better manufacturing facilities, availability of quality materials and competitiveness among manufacturers in these regions aid in fabrication of better quality of machinery. However, the lowest hardness of furrow opener of 205 HB was observed in machineries of Kymore Plateau and Satpura hills regions. The hardness of soil working component also varied based on type of furrow opener. Among the tested machines, 67% of seed drills had shovel type furrow opener (**Table 1**). The hardness of shoe type of furrow opener was higher (286 ±75 HB) as compared to shovel type (230 ±46 HB) furrow opener (**Table 1**). Overall, hardness of 38.5% furrow openers conformed to IS 10691 (BIS, 1983).

Machine Weight

The weight of seed drills varied significantly ($p < 0.05$) among different agro-climatic regions. It varied from 305 to 515 kg with an average value of 371 kg (**Table 6**). The average weight of seed drills was the highest (403 kg) for machineries manufactured in Central Narmada

Valley and the lowest weight of 318 kg in Kymore Plateau & Satpura hills region. The variation in weight of seed drills was recorded due to type of seed drill, number of tynes and frame section. The weight of seed drills manufactured in Central Narmada Valley and Malwa plateau regions was higher as compared to machinery manufactured in other regions due to sale of seed-cum-fertilizer drills in the regions. The average weight of seed-cum-fertilizer drills was higher (406 ±65 kg) as compared to that of seed drills (371 ±50 kg) manufactured in Madhya Pradesh. The weight of seed drills was also higher due to more numbers of furrow openers (11 or 13) used in the seed drills of Central Narmada Valley and Malwa Plateau regions. The average weight of seed drills manufactured in Madhya Pradesh state increased from 366 ±44 kg to 473 ±25 kg with increase in number of tynes from 9 to 13. The variation in the weight of machine was also due to type of frame section of seed drill. The average machine weight for frame sections of square box, C-channel and square box channel was 387, 393 and 420 kg, respectively.

Hitch Pyramid

The seed drills manufactured in different agro-climatic regions had no significant difference in hitch pyramid. Among 12 parameters of hitch pyramid, an average of 6 parameters of the selected seed drills conform to IS 4468, part1 (BIS, 1997). However, all the seed drills conform to two parameters of hitch pyramid viz., diameter of lower and upper linch pin hole (12 mm).

Indices for Seed Drills

The calculated values of precision, performance, machine quality and overall performance indices of the seed drills of different agro-climatic regions of Madhya Pradesh are reported in **Table 7**.

Precision Index

There was significant difference in precision indices of seed drills manufactured in different agro-climatic regions for both the crops. The precision index of the seed drills varied from 0.59 to 0.74 for sowing of wheat and soybean seeds with an average values of 0.70 and 0.64 for wheat and soybean crops, respectively (**Table 7**). The precision indices of seed drills manufactured in Vindhya plateau and Malwa plateau regions were the highest for sowing of wheat and soybean seeds, respectively due to less variation in seed placement, inter-row variations in seed and fertilizer and seed damage. The parameters affecting precision index mainly depend on types of metering mechanism and furrow opener. The higher precision index of seed drills manufactured in Malwa Plateau for soybean seeds was mainly due to use of shoe type of furrow opener. Chaudhuri (2001) also reported that the shoe type furrow opener performed better in black soil and had less lateral and vertical variations of seed and fertilizer placement as compared to other types of furrow openers. The seed drills selected for the study have fluted roller type metering mechanism. The flute diameter of seed drills manufactured in Malwa plateau was more as compared to those manufactured in Vindhya plateau region. Therefore, the precision indices of the seed drills of Malwa plateau and Vindhya plateau regions were higher for sowing of soybean and wheat crops, respectively. The ground wheel size and position are other important parameters that influenced the precision of seed drills. Among the selected

Table 7 Precision, performance, machine quality and overall performance indices of seed drill manufactured in different agro-climatic regions of Madhya Pradesh

Agroclimatic regions	Precision Index		Performance Index		Machine Quality Index	Overall Performance Index	
	Wheat	Soybean	Wheat	Soybean		Wheat	Soybean
Gird	0.67^{BC}	0.60^{B}	0.69^{AB}	0.73^{AB}	0.64^{BC}	0.67^{BC}	0.65^{CD}
Bundelkhand	0.71^{AB}	0.59^{B}	0.71^{A}	0.77^{A}	0.61^{C}	0.68^{BC}	0.65^{CD}
Satpura Plateau	0.63^{C}	0.62^{B}	0.70^{AB}	0.66^{AB}	0.60^{C}	0.64^{C}	0.63^{D}
Nimar Valley	0.71^{AB}	0.62^{B}	0.74^{A}	0.76^{A}	0.68^{ABC}	0.71^{AB}	0.68^{BC}
Jhabua Hills	0.67^{BC}	0.65^{AB}	0.74^{A}	0.76^{AB}	0.71^{AB}	0.70^{AB}	0.70^{AB}
Kymore Plateau & Satpura Hills	0.70^{ABC}	0.60^{B}	0.71^{A}	0.64^{B}	0.60^{C}	0.67^{BC}	0.61^{D}
Vindhya Plateau	0.74^{A}	0.69^{A}	0.61^{B}	0.68^{AB}	0.69^{ABC}	0.68^{BC}	0.69^{ABC}
Central Narmada Valley	0.73^{AB}	0.65^{AB}	0.75^{A}	0.70^{AB}	0.63^{BC}	0.70^{AB}	0.66^{BCD}
Malwa Plateau	0.73^{A}	0.70^{A}	0.77^{A}	0.76^{A}	0.72^{A}	0.74^{A}	0.72^{A}
General mean	0.70	0.64	0.72	0.73	0.66	0.70	0.67
p-value	0.0014	0.0229	0.0008	0.0001	0.0003	0.0001	<.0001
CV (%)	4.27	4.85	5.84	7.70	5.92	3.29	3.27

*** Significant at 1% (P < 0.01), * Significant at 5% (P < 0.05), NS - Non Significant*
A, B, C and D - Means within a column followed by the same letters are not significantly different.

seed drills, 79% had front mounted ground wheel. The front mounted ground wheel resulted in better maneuverability and ease of operation. However, machines manufactured in Malwa plateau region have ground wheel mounted at the rear side. The average diameter of rear mounted ground wheel was higher (0.75 ±0.05 m) as compared to front mounted ground wheel (0.40 ±0.03 m) (**Table 1**). The higher diameter of wheel minimized skid of ground wheel and thus maintained uniform seed rate and resulted in higher precision.

Performance Index

The performance index of a machinery mainly depends on effective field capacity and field efficiency of the machine. The performance indices of seed drills for sowing of wheat and soybean seeds were significantly influenced by machinery manufactured in different agro-climatic regions. The average performance index of 0.72 and 0.73 was observed for sowing of wheat and soybean seeds, respectively (Table 7). Machineries manufactured in Malwa plateau and Bundelkhand region had the highest (0.77) performance index for wheat and soybean seeds, respectively. The lowest performance index was recorded for machineries manufactured in Vindhya plateau for sowing of wheat (0.61) and in Kymore plateau and Satpura hills region for soybean (0.64) seeds. These performance parameters were higher for seed drills manufactured in Malwa plateau. In addition, better maneuverability, ease of operation, no breakdown during operation and less number of turns aided in higher performance index. The seed drills of this region also had large size of seed box that avoided frequent refilling.

Machine Quality Index

Among the different agro-climatic regions, the machine quality indices were significantly higher for machinery manufactured in Malwa plateau (0.72) and followed in Jhabua hills (0.71) and Vindhya plateau (0.69) (**Table 7**). The machine quality index was found lower (0.60) in Satpura plateau and Kymore plateau & Satpura hills. The machine quality parameters i.e. hardness of furrow opener and weight of machine were higher in Malwa plateau, Jhabua hills and Vindhya plateau as compared to other regions of Madhya Pradesh. The major farm machinery manufacturing clusters are located at Indore (Malwa plateau) and Bhopal (Vindhya plateau) in Madhya Pradesh state. This may be due to better infrastructure, manufacturing facilities and availability of skilled man power in these regions. The farmer's awareness towards mechanization and higher sale volume of agricultural machinery in these regions also created competitiveness among manufacturers for maintaining quality of machinery. The variation in manufacturing quality of seed drills manufactured by different manufactures was also reported by NAAS (2016). It was due to variation in design, manufacturing processes involved, materials of construction and lack of standardization of various components of the equipment.

Overall Performance Index

The overall performance index of seed drills manufactured in Madhya Pradesh varied significantly among different agro-climatic regions. The overall performance index varied from 0.64 to 0.74 with an average value of 0.70 for wheat and from 0.61 to 0.72 with an average value of 0.67 for soybean seeds (**Table 7**). The findings of the study are consistent with the results reported by Senapati et al. (1992); and Behera et al. (1995). They observed overall performance index of 0.49 -0.57 for finger millet and 0.75-0.88 for dryland paddy. The overall performance index of seed drills manufactured in Malwa plateau was the highest (0.74) and followed in Nimar valley (0.71) for sowing of wheat. For soybean crop, the overall performance index was the highest (0.72) for machinery manufactured in Malwa plateau. The higher overall performance index of seed drills manufactured in Malwa plateau has a direct correlation with the yield of soybean and wheat crops in the region. The yield of both the crops in the region was higher as compared to other regions of MP (**Table 2**). The overall performance indices of seed drills manufactured in Satpura (for wheat) and Kymore plateau & Satpura hills regions (for soybean) were minimum among the selected agro-climatic regions.

Conclusions

An overall performance index based on precision, performance and manufacturing quality was proposed and calculated for the selected seed drills manufactured in different agro-climatic regions of Madhya Pradesh. The following conclusions may be drawn from the study.

(a) The precision indices of seed drills manufactured in Vindhya plateau and Malwa plateau regions were the highest for sowing of wheat and soybean seeds, respectively.
(b) There was a significant difference in the effective field capacity and field efficiency among the seed drills manufactured in different agro-climatic regions affecting performance of seed drills.
(c) Among the manufacturing quality parameters, hardness of furrow opener conformed to BIS standards. However, on average 6 parameters of hitch pyramid conformed to BIS recommendations.
(d) The highest values of overall performance index were 0.74 and 0.72 for sowing of wheat and soybean crops, respectively for seed drills manufactured in Malwa plateau of Madhya Pradesh.

(e) The developed overall performance index will help in comparative performance evaluation for seed drills and selection of right seed drills.

REFERENCES

Adake, R. V., Mayande, V. M., Kumar, A. C. S., Thyagarj, C. R., Mandal, U. K., Srinivas, I., Reddy, B. S. and A. L. Pharande. 2010. Performance indices of farm implements for in-situ incorporation of biomass (green manural) in rainfed situations. Indian Journal of Dry land Agricultural Research and Development, 25(1), 61-69.

Afzalinia, S., Shaker, M. and E. Zare. 2006. Performance evaluation of common grain drills in Iran. Canadian Biosystems Engineering, 48(2), 39-43.

Andrews, S. S., Karlen, D. L. and J. P. Mitchell. 2002. A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agriculture, ecosystems & environment, 90(1), 25-45.

Anonymous. 1996. Report of the Sub-Group on Agricultural Implements and Machinery for Formulation of 9th Five Year Plan, Government of India.

Anonymous. 2011. Farm Machinery. National Portal Content Management Team, Available from https://archive.india.gov.in/citizen/agriculture/index.php?id=58 (accessed on 24.10.2017).

Anonymous. 2017a. Annual report 2016-17, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India, http://agricoop.nic.in/sites/default/files/Annual_rpt_201617_E.pdf (accessed on 25.09.2017)

Anonymous. 2017b. Online Agricultural Research Data Book 2017. Indian Agricultural Statistics Research Institute, New Delhi, India, http://iasri.res.in/agridata/17data/HOME_17.HTML (accessed on 24.10.2017).

Behera, B. K., Sahoo, P. K., Swain, S. and D. Behera 1995. Evaluation of Seeding Devices for Dryland Paddy. Agricultural Mechanization in Asia Africa And Latin America, 26, 17-21.

BIS. 1983. Share for Tractor-operated Mould board Ploughs, IS 10691: 1983. Bureau of Indian Standards, New Delhi, India.

BIS. 1997. Agricultural Wheeled Tractors - Rear-Mounted Three-Point Linkage Categories 1, 2, 3 and 4, IS 4468, Part1:1997. Bureau of Indian Standards, New Delhi, India.

BIS. 2000. Sowing equipment-seed-cum-fertilizer drill-specification (second revision), IS 6813, Bureau of Indian Standards, New Delhi, India.

Chaudhuri, D. 2001. PM -Power and Machinery: Performance Evaluation of Various Types of Furrow Openers on Seed Drills- a Review. Journal of agricultural engineering research, 79(2), 125-137.

Cupiał, M., Szeląg-Sikora, A. and M. Niemiec. 2015. Optimisation of the machinery park with the use of OTR-7 software in context of sustainable agriculture. Agriculture and Agricultural Science Procedia, 7, 64-69.

Maleki, M. R., Mouazen, A. M., De Ketelaere, B. and J. De Baerdemaeker. 2006. A new index for seed distribution uniformity evaluation of grain drills. Biosystems engineering, 94(3), 471-475.

Mehta, C. R., Chandel, N. S. and T. Senthilkumar. 2014. Status, challenges and strategies for farm mechanization in India. Agricultural Mechanization in Asia Africa and Latin America, 45(4), 43-50.

Mehta, C. R., Chandel, N. S., Senthilkumar, T. and K. K. Singh. 2014. Trends of agricultural mechanization in India. Economic and Social Commission for Asia and the Pacific (ESCAP) Policy Brief, 2.

Mehta, C. R., Singh, K. K., Gholap, B. S. and R. Patle. 2018. Status of Mechanization of Potato Cultivation in India. Agricultural Engineering Today, 42(2), 37-44.

NAAS. 2016. Practical and affordable approaches for precision in farm equipment and machinery, Policy Paper No. 84, National Academy of Agricultural Sciences, New Delhi,India, 16.

Senapati, P. C., Mohapatra, P. K. and U. N. Dikshit. 1992. Field evaluation of seeding devices for finger-millet. Agricultural Mechanization in Asia, Africa, and Latin America, 23(3), 21-24.

Senthilkumar, T., Chandel, N. S., Mehta, C. R. and B. S. Gholap. 2017. Trends of Tractorization in Indian Agriculture. Agricultural Mechanization in Asia Africa and Latin America, 48(2), 50-59.

Singh, G. 2015. Agricultural mechanisation development in India. Indian journal of agricultural economics, 70, 64-82.

Singh, R. C., Singh, G. and D. C. Saraswat. 2005. Optimisation of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. Biosystems engineering, 92(4), 429-438.

Singh, S. 2016. Data book on Agricultural Mechanization in India. Agricultural Machinery Manufacturers Association, India.

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Development of a Pelleting Machine for Hazelnut Residue Utilization

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Abstract

This study evaluates the technical and environmental aspects of hazelnut production wastes for energy utilization. A commercial- as well as a laboratory-scale pelleting machine were developed and tested for hazelnut residues utilization. The residues were pelleted at two different moisture contents (M10: 8%-10% and M12: 10%-12%) as referred to EU standards, and particle sizes (PS: 6 mm and 10 mm). Physical properties (bulk density, pellet density, mechanical duration and pellet firmness, and pellet moisture and equivalent humidity contents), and thermal properties (gas emission values after combustion, ash content and calorific values) of the pellets were measured. Pellet bulk densities varied between 541.2 kg/m^3 and 587.9 kg/m^3, while the pellet densities varied between 1,238.2 kg/m3 and 1,309.4 kg/m^3. Mechanical durability (MD) values varied from 89.6% to 93.3%. Firmness values changed from 1146 N to 1574.2 N. Ash content was 7.2% and heating value of the pellets was 18.4 MJ/kg. The effect of material moisture content and particle size on the parameters was found to be statistically significant. In conclusion, hazelnut husk agricultural residue was found to be suitable as a solid biofuel in the form of pellets, for both in environmental and in fuel properties aspects.

Keywords: Energy, measurement, nuts, physical properties, waste

Introduction

The continuous increase in oil and gas prices and climate change have boosted the demand for alternative energy sources like biomass. Utilizing agricultural residues for biomass purposes can be an attractive solution for sustainability. Effects of environmental, economic, social, political and technical factors have led to the rapid deployment of various sources of renewable energy based power generation. For example, biomass has been widely used for heating in Northern Europe districts, and is often used at combined heat and power (co-generation) plants (Bernotat and Sandberg, 2004). Energy consumption will continue to increase for long and at a high rate given the increasing demands by the developing economies, especially in Asia and South America. Therefore, a global society needs to sustainably develop large-scale alternatives for the use of fossil resources. There are many options, but not all of them are feasible. One potential option is the use of biomass from crops (Struik and Venturi, 2000). Plant biomass is available in large quantities, and can be utilized for sustainable heat and power production, when used as fuel (Smeets et al., 2007). Comprehensive studies have been performed by several authors regarding management of waste from agricultural production and technical, economic and environmental assessment of energy production from biomass wastes (Lychnaras and Rozakis, 2006; Ouaini et al., 2005) in different countries of all over the world.

Densification is one of the most popular ways of utilizing biomass. Densifying the agricultural residues can be done either in the form of briquettes or in pellets. Both methods increase the specific density (gravity) of biomass to more than 1,000 kg/m^3 (Lehtikangas, 2001; Mani et al., 2004). Pelleted biomass is low and uniform in moisture content. It can be handled and stored cheaply and safely using well developed handling systems for grains (Fasina and Sokhansanj, 1996).

Pelletized biomass made from agricultural residues are rapidly becoming an important renewable source for energy production for industrial and domestic purposes. Direct burning of unprocessed biomass for industrial applications is very inefficient. One of the strategies to overcome this is to densify them into pellets or briquettes, which also increases the higher volumetric energy content, reduces transportation cost and makes it available for a variety of applications (Tripathi et al., 1998; Demirbaş, 2001). Agricultural residues, accounts for approximately two-thirds of all potential sources of renewable energy in Turkey (Angın and Şensöz, 2006). Although there are crops with both high and low residue yields, it is reasonable to assume that about 25% of any dry agricultural feedstock is residue (Grover and Mishra, 1996). Turkey is the number-one producer of hazelnuts in the world (**Table 1**) (FAO, 2016). In Turkey's Black Sea region, hazelnut is the most commonly and most profitably cultivated agricultural product, and results in approximately 184,000 tons of residue annually. However, under current practice, this residue is randomly burnt in what amounts to a waste of potential alternative energy, whose incorporation into the economy could have great positive effects both locally and nationally.

When concerning the last 8 seasons, Turkey produced about 527,125 tons of hazelnuts per year (TCGTB, 2017), and that counts for 65.1% of world's production, on 658,356 ha (TUİK, 2017), representing 71% of the world's hazelnut plantations.

The present study examined utilization possibilities of hazelnut husk agricultural residue as biofuel in the form of pellets. Therefore, a pelleting machine was constructed for both commercial and laboratory purposes (**Fig. 1**). Then the residues were pelleted with two different moisture contents M10: 8%-10% and M12: 10%-12% and particle sizes (PS: 6 mm and 10 mm). Some physical, mechanical and thermal properties of pellets were also analyzed.

Materials and Methods

This study was conducted in Samsun Ondokuz Mayis University using hazelnut husk residue from agricultural production. The most recent EU standards (EN 14961-1, 2010; EN 14961-2, 2010; EN ISO 17225-6, 2015) were followed and all the tests and reference values were taken from these related standards.

Statistical Analyses and Trial Pattern

Data analysis was performed using the IBM SPSS Statistics 21 software. The normality analysis was performed with the Kolmogorov-Smirnov single sample test and the variance homogeneity was assessed by the Levene test and the variances were homogeneous ($P > 0.05$), with normal distribution of the data. In this case it has been understood that analysis of variance can produce reliable results. Duncan multiple comparison test was applied for the comparison of the averages. The experiment was done according to the design pattern of random factor (2 × 2) × 3 factorial trial composition.

Pelleting Process

Hazelnut residues were sun-dried under normal conditions until their moisture content was reduced to M10 and M12. The dried material was then ground in a 3 kW powered electric hammer mill consisting of 8 hammers rotating at a speed of 2,850 rpm. Once particles of the re-

Fig. 1 Constructed pelleting machine

Table 1 Hazelnut production (tons) in the world

Country	2010	2011	2012	2013	2014	2015	2016	2017
Turkey	500,000	600,000	430,000	660,000	549,000	412,000	646,000	420,000
Italy	120,000	107,000	140,000	84,000	132,000	100,000	125,000	130,000
USA	42,600	24,500	35,000	32,000	35,000	36,300	43,500	32,000
Azerbaijan	35,000	39,000	55,000	40,000	30,000	25,000	50,000	35,000
Georgia	32,000	40,000	30,000	28,000	35,000	35,000	40,000	40,000
Spain	18,000	20,000	22,000	16,000	19,500	19,500	20,000	21,000
Others	27,000	27,000	27,000	25,000	25,000	25,000	45,000	42,000
Total	774,600	857,500	739,000	885,000	825,500	660,773	969,500	720,000

quired sizes PS: 6 mm and 10 were obtained, moisture contents were re-measured and the particles were pelleted using a pelleting machine.

Particle Size Distribution

For particle size distribution a sieve set with seven different sieves with opening diameters ranging from 0.25 and 3.15 mm was used. The test was done according to standard (EN 15149-2, 2010).

Specific Energy Consumption

Pelleting capacity of the machine was determined as dividing the mass of produced pellets by time taken in pelleting that quantity. Then the specific electrical energy consumption of the machine was determined proportioning the consumed electrical energy to machine capacity (kWh/kg) for the certain amount of pellet production when the machine was in regular regime.

Particle Density

Particle densities of pellets were calculated according to standard (EN 15150, 2011). As defined in that standard the volume of the cylindrical properly shaped pellets was calculated by stereometric method and the averaged volume is proportioned to the average mass of the pellet (kg/m^3).

Bulk Density

This was calculated according to standard (EN 15103, 2009). Firstly, a container, which has a certain volume, is filled by pouring the produced pellets from a height of 200 mm to 300 mm above the upper rim until a cone of maximum possible height is formed. Then the filled container is shock exposed to allow settling by dropping it freely from 150 mm height onto a wooden board at least 3 times. Then the surplus material is removed by using a small scantling and the container is weighed. The bulk density is calculated as:

$$B_p = (m_2 - m_1) / V \quad \cdots(1)$$

where; B_p is pellet bulk density (kg/m^3), m_2 is mass of filled container (kg), m_1 is mass of empty container (kg) and V is net volume of the measuring container (m^3).

Mechanical Durability (Tumbler) Test

This is done according to standard (EN 15210-1, 2009). In this test 500 g of test portion is placed into this rotating chamber. It's rotated 500 times at 50 rpm speed and then the sample is removed and weighed again. The weight difference before and after the test gives us the mechanical durability of the pellets.

$$D_u = (M_A / M_E) \times 100 \quad \cdots(2)$$

where; D_u is mechanical durability (%), M_A is mass of sieved pellets after the tumbling treatment (g) and M_E is mass of pre-sieved pellets before the tumbling treatment (g).

Pellet Firmness

Pellet firmness is defined as the maximum force resistance of pellets before breaking up. This test is performed to calculate the pressures that the upper pellets apply to the underlying pellets during transport and storage. A special testing device is used for the firmness of pellets (**Fig. 2**).

Pellet Moisture Content

The moisture content of the pellets was determined according to European Union standard (EN 14774-1). Weights of empty containers were weighed with a digital precision scale and recorded before testing. Then randomly selected pellets were weighed and recorded (**Fig. 3**). Thereafter, the material was dried at 105 °C for 24 hours, and after drying, the samples were reweighed and recorded. Then the moisture content of pellets was calculated by the equation, below.

$$M_p = [(m_2 - m_1) - (m_3 - m_1) / (m_2 - m_1)] \times 100 \quad ...(3)$$

where; M_p is moisture content of pellet (%), m_1 is mass of empty container (g), m_2 is mass of sample with the container (g), m_3 is mass of sample with the container after drying (g).

Flue Gas Emissions

Flue gas emissions like O_2 (%), CO (ppm), CO (%), NO (ppm), NO_x (ppm) were measured and recorded with a gas analyzer (**Fig. 4**).

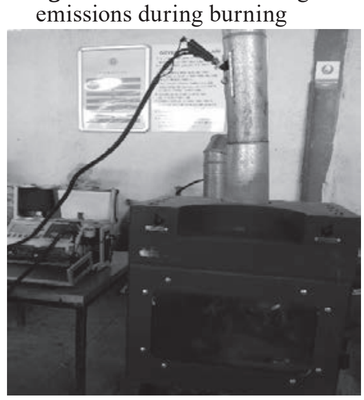
Heating Value of Pellets

Lower heating value of pellets

Fig. 2 Special testing device for pellet firmness

Fig. 3 Determination of moisture content of pellets

Fig. 4 Measurement of flue gas emissions during burning



was determined by a calorimeter according to the instructions given in standard (EN 14918, 2009). Before testing, the pellets were disintegrated in a shredder and kept at 105 °C for 24 hours to remove the moisture. Samples dried at a weight of 0.5-1 g were burned in oxygen atmosphere in a calorimeter bomb under standard conditions and the calorific value was automatically determined in MJ/kg according to the increase in the temperature of the water in the calorimeter chamber and the average actual heat capacity of the system (EN 14961-2, 2010).

Ash Content of Pellets

The ash contents of the pellets were determined using an ash furnace according to standard (EN 14775, 2009). The porcelain crucibles were kept at 575 ±25 °C for a minimum of 4 hours in the ash oven, then they were taken into desiccator, then cooled and weighed. They were again placed in the ash oven and kept until they reached to a fixed weight. When the porcelain crucibles reached to a constant weight, 0.5-2 g of sample was weighed and placed in the oven. Oven temperature has been raised according to a certain increase in the program. The oven temperature was raised from room temperature to 105 °C and waited for 12 minutes in that condition. Then the temperature was raised up to 250 °C with an increase of 10 C/min and kept there for 30 minutes. The temperature is raised again up to 575 °C with an increase of 20 °C/min and kept at that condition 180 minutes. Then the temperature is expected to drop down to 105 °C and the samples are weighed again.

Results and Discussion

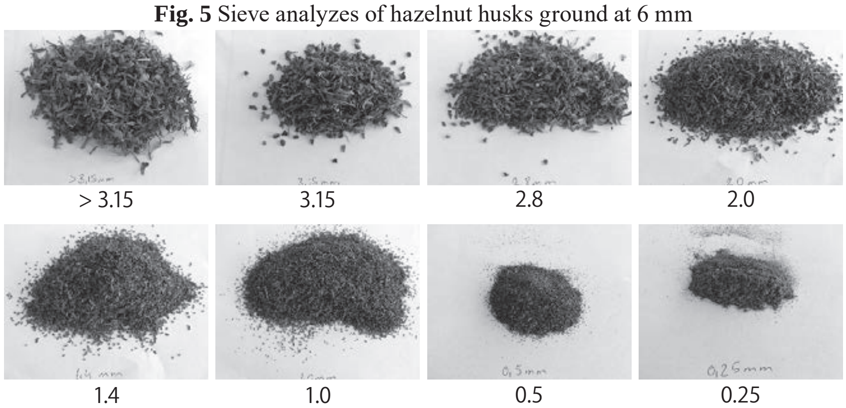
Particle Size Distribution

Particle size distribution of material grinded at 6 mm is given in **Table 2** and in **Fig. 5**. Particle size distribution of material grinded at 10 mm is given in **Table 3** and in **Fig. 6**.

Table 2 Particle size distribution of hazelnut husk (PS: 6 mm)

Sieve	Dimension (mm)	Sample weight (g)	Sample (%)	Cumulative ratio (%)
0-0.25	0.25	1.93	1.93	1.93
0.25-0.5	0.50	3.90	3.90	5.83
0.5-1.0	1.00	14.49	14.49	20.32
1.0-1.4	1.40	14.23	14.23	34.55
1.4-2.0	2.00	20.66	20.66	55.22
2.0-2.8	2.80	11.49	11.49	66.71
2.8-3.15	3.15	11.07	11.07	77.78
> 3.15	> 3.15	22.22	22.22	100

Fig. 5 Sieve analyzes of hazelnut husks ground at 6 mm



Pellet Particle and Bulk Densities

The effects of moisture content and particle size on pellet particle and bulk densities were found statistically significant (**Table 4**). As seen in the table, the highest pellet bulk density was found as 587.9 kg/m^3 at M10 moisture content and 10 mm particle size. The lowest value was achieved as 541.2 kg/m^3 at M12 moisture content and 6 mm particle size. Furthermore, the highest pellet density was found to be 1,309.4 kg/m^3 at M12 moisture content and 10 mm particle size, whereas the lowest was 1,238.2 kg/m^3 at M10 moisture content and 6 mm particle size. A study on switch grass done by (Colley, 2006) showed that the density of the pellets obtained ranged from 850 to 1,250 kg/m^3. But, another study done with wheat straw, barley straw, corn cob and switch grass showed that the decrease of the material particle size increases the pellet density, the increase of the moisture content decreases the pellet density (Mani et al., 2006). Although the difference between the bulk densities of the pellets obtained at 6 mm and 10 mm particle sizes with M10 moisture content is statistically insignificant but, the difference of bulk densities at M12 for the same particle sizes is found to

Table 4 Pellet density and bulk density

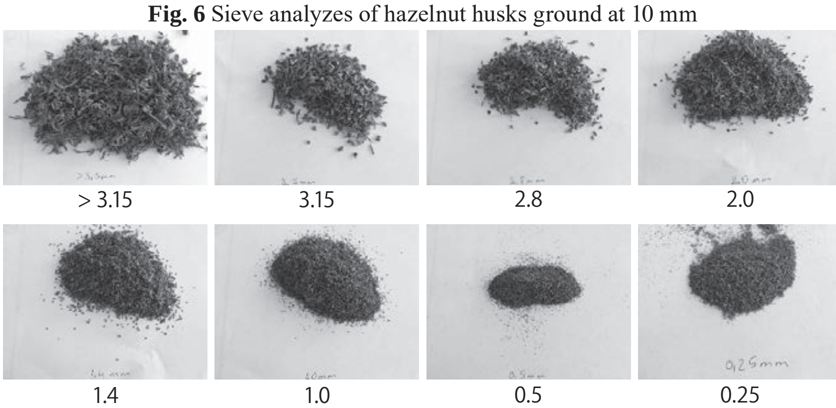
Moisture content (%)	Particle size (mm)	Pellet bulk density* (kg/m^3)	Pellet density* (kg/m^3)
M10	6 mm	584.44 ± 3.88a	1,238.20 ± 16.08b
	10 mm	587.91 ± 3.88a	1,288.87 ± 2.87a
M12	6 mm	541.23 ± 1.08c	1,305.89 ± 1.67a
	10 mm	552.40 ± 2.03b	1,309.38 ± 10.39a
Sig.		< 0.001	0.003

**The difference between the values in the columns carrying the same letter is insignificant*

Table 3 Particle size distribution of hazelnut husk (PS: 10 mm)

Sieve	Dimension (mm)	Sample weight (g)	Sample (%)	Cumulative ratio (%)
0-0.25	0.25	1.57	1.57	1.57
0.25-0.5	0.50	3.16	3.16	4.73
0.5-1.0	1.00	11.71	11.71	16.45
1.0-1.4	1.40	11.93	11.93	28.39
1.4-2.0	2.00	17.51	17.51	45.92
2.0-2.8	2.80	11.57	11.57	57.50
2.8-3.15	3.15	13.09	13.09	70.60
> 3.15	> 3.15	29.37	29.40	100

Fig. 6 Sieve analyzes of hazelnut husks ground at 10 mm



be statistically significant. Interestingly, this case was totally opposite for the pellet densities. Some studies showed that the effect of the material moisture content on pellet density and pellet bulk density is important (Colley, 2006; Mani et al., 2006; Liu et al., 2014). In a study pellets were obtained from materials of different moisture contents and highest pellet bulk density was achieved at the lowest moisture content (Larsson and Rudolfsson, 2012). Another study noted that that increasing the material moisture content reduced the pellet bulk density (Zamorano et al., 2011). The results for bulk densities of pellets are in line with the studies given in literature.

Mechanical Durability and Firmness of Pellets

The effect of pellet moisture content (MC) and particle size (PS) variations on pellet mechanical durability (MD) and firmness parameters has been found statistically significant (**Table 5**). The highest MD value was found as 93.3% (M10 and PS: 6) where the lowest was 89.6% (M12 and PS: 10). As for the firmness values they were 1,574.2 N and 1,146 N, respectively. A reverse relation has been found between the MD and firmness values for the hazelnut husk residue that the pellets having highest MD value had the lowest firmness and vice versa. It's also related with the MC of pellets that the pellets with higher MC values had the bigger firmness values, which can be also explained by resistance of water to compaction. Ironically, dryer pellets had bigger MD values. The MC values cause the material to slide more easily through the compaction holes, which greatly reduces the pellet quality (Lehtikangas, 2001). PS values played an important role here, that the pellets with smaller PS values had the higher MD values always. Which can be explained by the smaller particle sized material has a better compaction characteristic and has smoother surfaces. But, on the other hand as for the firmness values smaller particle sized pellets had lower firmness values because they are more prone to break downs under direct forces. After all, some researchers indicated that the pellet quality is high when the MD value is 80% and higher, medium when MD is ranging from 70 to 80% and low quality when MD ≤ 70% (Tabil and Sokhansnj, 1996; Tabil and Sokhansnj, 1997). Another study reported that the pellet with the highest firmness value is not regarded as in good quality (Celma et al., 2012).

Pellet Moisture Content

Materials loose some moisture from their structure during pelleting process. This is because the mold heats due to friction between the mold and the matrix, and some moisture is removed from the material itself when pelleting the material. The effect of material MC and PS on pellet's moisture content was found statistically significant (**Table 6**). As seen from the table the low-

Table 5 MC, PS, MD and firmness of pellets

MC (%)	PS (mm)	MD (%)	Firmness (N)
M10	6 mm	93.26 ± 0.13a	1,146.00 ± 34.08d
	10 mm	91.31 ± 0.09b	1,372.59 ± 15.74b
M12	6 mm	90.38 ± 0.05c	1,299.23 ± 11.07c
	10 mm	89.57 ± 0.03d	1,574.23 ± 9.67a
Sig.		< 0.001	< 0.001

**The difference between the values in the columns carrying the different letter is significant*

Table 6 Pellet moisture content

MC (%)	PS (mm)	Pellet moisture content (%)*
M10	6 mm	8.78 ± 0.04b
	10 mm	8.55 ± 0.06c
M12	6 mm	11.60 ± 0.03a
	10 mm	11.54 ± 0.01a
Sig.		< 0.001

**The difference between the values carrying the same letter is insignificant* est pellet moisture content was 8.6% whereas the highest was 11.6%. The difference between the moisture contents of pellets pelleted at M12 was not statistically significant. But, it was found significant in pellets at M10. The results were in line with the references given in standards (EN 14961-2, 2010; EN ISO 17225-6, 2015).

Ash Content and Heating Value of Pellets

Ash content of the pellets made from hazelnut husk agricultural residue was found as 7.2%, which is in line with the reference value (A10 ≤ 10%) given in standard (EN ISO 17225-6, 2015). Heating value of hazelnut husk pellets was found as 18.4 MJ/kg. That is also compatible with the value (Q14.5 ≥ 14.5 MJ/kg) indicated in the above mentioned standard. A comprehensive table is given below (**Table 7**) to understand the importance of hazelnut husk pellets as biofuel (Dok, 2014). As seen from the table, heating value of hazelnut husk pellets are higher than the pellets made from other types of agricultural residues especially it's higher than the heating capacity of wood.

Flue Gas Emission Value of Pellets

Flue gas emission values of fuel pellets are given in (**Table 8**). All the measured emission values were in the limits given in Regulations for Air Pollution Control (IKHKKY, 2014).

Specific Energy Consumption

This is rather a relative quantity because it's up to the properties of pelleting machine and conditions of material. But, for the energetically and economical points of view it needs to be measured to give an idea about the process whether it is cost effective or not. All the pelleting process was done by a laboratory type pelleting machine and specific energy consumptions were found as 0.29 kWh/kg and 0.32 kWh/kg for the PS 6 and PS 10, respectively.

Conclusions

The present study used a laboratory type pelleting machine to produce cylindrical pellets with varying parameters in order to determine the suitability of hazelnut husk agricultural residue as pellet fuel based on physical-mechanical and thermal parameters. The latest related European Union standards (EN) were taken into consideration while building up and carrying out the study. From an environmental point of view, the tested material presented above is based on the replacement of fossil fuels. Hazelnut husk residue gave promising results both in energetically and in environmentally aspects regarding their physical-mechanical and thermal properties. Besides, pelleting of unused agricultural residues for use as solid biofuel could be useful in meeting today's energy deficits and reducing global warming. In addition, the use of agricultural residues as an alternative energy source can contribute to employment in agricultural regions by promoting the establishment of new, agricultural-based industries. It is stated that the pellets are mostly obtained from wood chips and chips, and these materials are used to the maximum extent (Stahl and Berghel, 2011). However, it is emphasized that the demand for fuel pellets is going to increase in the future and the chips to be used in pellet production will be insufficient, so that other raw materials or their blends can be used. Last but not the least, additional research is important not only for enhancing the quality and quantity of scientific data, but also as a means of focusing public attention on the energy potential of agricultural residues.

Acknowledgment

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REFERENCES

Angın, D. and S. Şensöz. 2006. Effect of drifting gas (N2) flow on pyrolysis of safflower seed pulps and characterization of liquid product (In Turkish). Fırat University, Journal of Science and Engineering 18(4): 535-542.

Bernotat, K. and T. Sandberg. 2004. Biomass fired small-scale CHP in Sweden and the Baltic States: a case study on the potential of clustered dwellings. Biomass Bioenergy, 27(6):521-530.

Celma, A. R., Cuadros, F. and F. L. Rodriguez. 2012. Characterization of pellets from industrial tomato residues. Food and Bioproducts Processing, 90(4): 700-706.

Colley, Z. J. 2006. Compaction of switchgrass for value added utilization: MSc Thesis. Department of Chemical Engineering, The Graduate Faculty of Auburn University. Alabama USA. Website: https://etd.auburn.edu/handle/10415/483, accessed on March 29, 2018.

Table 7 Heating value of some fuel pellets made from agricultural residues

Category	Heating value (MJ/kg)
Wheat-barley stalk	18.07
Sunflower stem	16.90
Rice stem	15.18
Corn stalk	17.86
Tobacco stem	17.36
Kiwi pruning wastes	18.36
Rice husk	15.14
Ground tea	19.37
Wood	17.57
Hazelnut husk pellets	**18.40**

Table 8 Flue gas emissions of hazelnut husk pellets

Water content after burning (%)	NO_x (ppm)	CO_2 (%)	O_2 (%)	CO (ppm)	NO (ppm)
4.6	61.7	0.9	19.2	1,383.7	121

Demirbaş, A. 2001. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Conversion and Management, 42(11): 1357-1378.

Dok, M. 2014. Agricultural residue potential of black sea region and utilizing them as pellet fuel. (In Turkish). Enerji Tar?m? ve Biyoyakıtlar 4. Ulusal Çalıştayı Bildiriler Kitabı, p. 211-222.

EN 14774-1. 2009. Solid biofuels - determination of moisture content- oven dry method- Part 1: Total moisture - Reference method. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 14775. 2009. Solid biofuels - Determination of ash content. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 14918. 2009. Solid biofuels - Determination of calorific value. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 14961-1. 2010. Solid biofuels - Fuel specifications and classes - Part 1: General requirements. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 14961-2. 2010. Solid biofuels- Fuel specifications and classes- Part 2: Wood pellets for non-industrial use. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 15103. 2009. Solid biofuels - Determination of bulk density. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 15149-2. 2010. Solid biofuels - Determination of particle size distribution - Part 2: Vibrating screen method using sieve apertures of 3,15 mm and below. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 15150. 2011. Solid biofuels - Determination of particle density. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN 15210-1. 2009. Solid biofuels - Determination of mechanical durability of pellets and briquettes - Part 1: Pellets. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

EN ISO 17225-6. 2015. Solid biofuels - Fuel specifications and classes - Part 6: Graded non-woody pellets. European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.

FAO. 2016. Food and Agriculture Organization of the United Nations, FAO Statistics Division.

Fasina, O. O. and S. Sokhansanj. 1996. Storage and handling characteristics of alfalfa pellets. Powder Handling and Processing, 8(4): 361-365.

Grover, P. D. and S. K. Mishra. 1996. Biomass briquetting: technology and practices; regional wood energy development program in Asia. Food and Agriculture Organization of the United Nations. Field Document No. 46, Bangkok, Thailand.

IKHKKY. 2014. Isınmadan kaynaklanan hava kirliliğinin kontrolü yönetmeliği (Regulations for Air Pollution Control Caused by Burning). http://www.mevzuat.gov.tr/.

Larsson, S. H. and M. Rudolfsson. 2012. Temperature control in energy grass pellet production ? effects on process stability and pellet quality. Applied Energy, 97: 24-29.

Lehtikangas, P. 2001. Quality properties of pelletized sawdust, logging residues and bark. Biomass and Bioenergy, 20(5): 351-360.

Liu, Z., Quek, A. and R. Balasubramanian. 2014. Preparation and characterization of fuel pellets from woody biomass, agro-residues and their corresponding hydrochars. Applied Energy, 113: 1315-1322.

Lychnaras, V. and S. Rozakis. 2006. Economic analysis of perennial energy crop production in Greece under the light of the new CAP. New Medit, 5(3): 29-37.

Mani, S, Tabil, L. G. and S. Sokhansanj. 2004. Evaluation of compaction equations applied to four biomass species. Canadian Biosystems Engineering, 46(3): 55-61.

Mani, S., Tabil,l. G. and S. Sokhansanj. 2006. Effects of compressive force, particle size and moisture content on mechanical of biomass pellets from grasses. Biomass and Bioenergy, 30(7): 648-654.

Ouaini, N., Medawar, S., Daoud, R. , Ouaini, R., Chebib, H., Rutledge, D. and N. Estephan. 2005. Etat actuel des huileries d'olive au Liban: potentiel de production. New Medit, 4(4): 31-36.

Smeets, E. M. W., Faaij, A. P. C., Lewandowski, I. M. and W. C. Turkenburg. 2007. A bottom-up assessment and review of global bio-energy potentials to 2050. Progress in Energy and Combust Science, 33(1): 56-106.

Stahl, M. and J. Berghel. 2011. Energy efficient pilot-scale production of wood fuel pellets made from a raw material mix including sawdust and rapeseed cake. Biomass and Bioenergy, 35(12): 4849-4854.

Struik, P. C. and G. Venturi. 2000. An integrated approach in evaluation of production of energy from biomass. New Medit, 4(4):35?39.

Tabil, L. G. and S. Sokhansnj. 1996. Process conditions affecting the physical quality of alfalfa pellets. Applied Engineering in Agriculture, 12(3): 345-350.

Tabil, L. G. and S. Sokhansnj. 1997. Bulk properties of alfalfa grind in relation to its compaction charac-

teristics. Applied Engineering in Agriculture, 13(4): 499-505.
TCGTB. 2017. Hazelnut report http://koop.gtb.gov.tr/data/ 58e5f-49b1a79f54dd851b458/ 2016%20 F?nd?k%20Raporu.pdf
Tripathi, A. K., Iyer, P. V. R. and T. C. Kandpal. 1998. A Techno-economic evaluation of biomass briquetting in India. Biomass and Bioenergy, 14 (5-6): 479-488.
TUIK. 2017. Hazelnut production data (In Turkish). Turkish Statistical Institute. www.tuik.gov.tr
Zamorano, M., Popov, V., Rodriguez, M. L. and A. Garcia-Maraver. 2011. A comparative study of quality properties of pelletized agricultural and forestry lopping residues. Renewable Energy, 36 (11): 3133-3140.

ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

1848

Design of a Mechanical Planter for Coated Seeds: I. Yehia, Habiba E. Sabry, M. K. Abd El-Wahab, A. M. El-Shal

The aim of this research is to design a mechanical planter for coated seeds and determine the optimum factors affecting mechanical planting of coated basil seeds. The studied factors are five metering device speed and four forward speed levels. The main results of this study can be summarized as follows: The maximum basil seeding rate of 3.00 kg/fed was obtained at metering-device speed of 20 rpm. Meanwhile, the minimum seeding rate of 2.25 kg/fed was obtained at metering-device speed of 60 rpm. The maximum plant-emergency of 96.1 % was obtained at forward speed of 1.82 km/h. Meanwhile, the minimum plant-emergence of 85.6% was obtained at forward speed of 4.79 km/h. By increasing forward speed from 1.82 to 4.79 km/h, the total crop-yield decreased from 2500 to 2000 kg/fed. Also, the minimum production-cost of 31.21 LE/Mg was obtained using forward speed of 4.79 km/h.

1849

Comparative Performance Studies on Different Types of Marker for System of Rice Intensification (SRI): Ajay Kumar Verma

Five different types of SRI markers commonly used by the farmer's viz. 1 rope, 3 rope, 8 row bamboo and two developed markers viz. 8 rows rolling and 5- row rolling markers were chosen for the studies. Comparative performance evaluation studies were conducted in marking and transplanting of single seedlings by each SRI markers. The experiment fields were research farm of Indira Gandhi Agricultural University (IGAU), Raipur and in the farmer's fields. In puddle clay loam soil, 12 h settling time was observed for well visible marking. The performance of 8 row rolling SRI marker was found better than the rest of the markers in terms of visibility of marking, minimum time and minimum energy requirement. The minimum time and minimum energy requirement for marking with transplanting were found to be 126 man h/ha and 2824 MJ /ha respectively for 8 rows rolling SRI markers. The minimum cost for marking with transplanting was found to be Rs 4500/ha for 8 rows rolling SRI markers followed by Rs.5660/ha for 5 row rolling SRI markers. The study confirmed that rolling markers were energy efficient and cost effective for SRI Rice cultivation.

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Development and Evaluation of Pedal Operated Dehuller for Black Soybean: Gurupreet Singh, Khan Chand, N. C.Shahi

Black soybean is a food source which contains high quality protein and does not contain cholesterol and saturated fatty acids. It is rich in vitamin and minerals and has significant medicinal effect. In India, traditional method of dehusking the black soybean is hand operated grindstone (Chakki). In grindstone, main disadvantage is the incomplete dehulling of the beans. This method of dehusking is also tedious and time consuming process. Therefore post harvest management and processing of black soybean are very important and hence an effort has been made to develop a pedal operated dehuller for Uttarakhand women with the help of anthropometric data. Dehuller works on the principle of shearing force where black soybean passes through between the grind stone roller and concave surface of perforated mild steel sheet and power would be provided through pedal to the machine. The different components were designed and best dehulling efficiency of the machine was 72.08% at 10% moisture content and 25 kg/h feed rate with payback period of 1.67 year. This machine is basically designed for Uttarakhand small women farmers and can generate employment.

Design, Development and Performance Evaluation of an Intercrop Planter for Soybean-Pigeon pea, Chickpea

by

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Abstract

A tractor-drawn intercrop planter was designed and developed for intercropping of soybean - pigeon pea in Kharif (rainy) season followed by chickpea after harvesting of soybean in Rabi (winter) season. The developed intercrop planter facilitates to sow chickpea in the same harvested field of soybean in the presence of standing crop of pigeon pea. The developed intercrop planter was capable to sow 5 rows of soybean in the broad bed of 1.5 m width, make ridges in both the sides of the broad bed and sow one row of pigeon pea in both the outer sides of the ridge simultaneously. The machine consists of mainframe, inverted T-type furrow openers, ridger, ground wheel, power transmission system, inclined plate metering mechanism for seed and fluted roller metering mechanism for fertilizer and delivery tubes. Two separate detachable planters for the sowing of pigeon pea were attached to both ends of the main frame. The width of the intercrop planter was 4.2 m.

The experiment was laid out in a split plot design. The plant to plant spacing was maintained by the intercrop planter for soybean, pigeon pea and chickpea was 5 cm, 30 cm, 10 cm respectively. The speed of operation, actual field capacity, field efficiency and fuel consumption for intercropping of soybean -pigeon pea was 2.46 km/h, 0.56 ha/h, 77.2% and 4.7 l/h respectively. In intercropping seed yield of pigeon pea was found maximum for row spacing of 120 cm for pigeon pea. The maximum yield was found 10.7 q/ha, 13.6 q/ha and 8.2 q/ha for soybean, pigeon pea and chickpea respectively. The land equivalent ratio of pigeon pea was found 1.56 with soybean and 1.38 with chickpea. The per hectare cost of operation of intercropping was Rs. 1126.8.

Introduction

Water scarcity and water stagnation are the major problems for the cultivation of soybean under the rainfed situation. This significantly affects germination as well as the yield of the Soybean crop. To overcome these problems, farmers of Chhattisgarh adopted a 'Broad Bed Furrow' (BBF) seed drill for the sowing of soybean. Singh et al. (2011) developed a tractor-drawn broad bed machine for the sowing of soybean. The machine reduces plant mortality in the range of 14-19% as compared to flatbed under the vagaries of monsoon which subsequently resulted in yield enhancement. Reddy et al. (2012) informed that the seed rate for various rainfed crops varies from 4 to 140 kg/ha. So, the selection of a multi-crop planter with the replaceable metering rotor is crucial to meet the farm requirements and timeliness of operation. Verma et al. (2018) found that in comparison with flood irrigation, 40 to 50 % saving in irrigation water was recorded with BBF method of soybean.

Soybean and pigeon pea intercropping are one of the established cultivation practices in Chhattisgarh because soybean is a short duration crop of 100-110 days and pigeon pea is a drought tolerance and a long duration crop of 180-190 days. Both this crop is grown in Kharif season. The type of soil where it grows as well as the depth of sowing of this crop is similar. After harvesting of soybean in the first fortnight of October, chickpea can be sown up to the first fortnight of November. The water requirement for the growing of chickpea is also less. So, chickpea is found suitable crop for Rabi season. Therefore intercropping of Soybean-pigeon pea, chickpea well suited in the rainfed situation of Chhattisgarh. At present, sowing of pigeon pea as an intercrop with soybean is performed manually. It is a time consuming and a lot of drudgeries involved in this operation. Till now, there is no such machine available for intercropping of soybean - pigeon pea, as well as the sowing of chickpea in the same field after harvesting of soybean. To overcome this problem, there is a need to design a suitable intercrop planter that can be performing the above-said functions without damaging the standing pigeon pea crop. So, keeping the above points in view, the present study was planned.

Materials and Methods

On the basis of previous studies, the BBF soybean seed drill was found suitable for rainfed farming. Therefore, to design the intercrop machine for soybean and pigeon pea, the BBF seed drill technique was used to sow soybean in Kharif and chickpea in Rabi. Some modification made in the existing design of BBF seed drill viz. in place of fluted roller metering units and shovel type furrow openers, inclined plate metering units and Inverted - T type furrow openers were used. Separate seed box was provided for each inclined plate metering unit. For metering of fertilizer fluted rollers were used. Detachable planters were attached to both ends of the main frame for pigeon pea. Power was transmitted from ground wheel though chain-sprocket drive system to the bevel gear and finally to the inclined plate metering mechanism. The specifications of the intercrop planter are given in **Table 1**.

Brief Description of Machine

Mainframe

The mainframe of intercrop planter was made up of box section by joining two MS Angle 65 × 65 × 5 mm. The length and width of the mainframe for soybean or chickpea planting was 2200 mm and 600 mm respectively. Two detachable planters where fasten both sides for the sowing of pigeon pea of 1000 mm length and 600 mm wide. The overall length and width of the mainframe for the complete unit were 4200 mm and 600 mm, respectively.

Furrow Opener

Five numbers of Inverted-T- types furrow openers were fastened to the main frame by U-Clamps at an equidistance of 300 mm. They were attached to the lower portion of tynes which used to drill the soil. The seeds and fertilizers come into the furrow opener through delivery pipes and drop the seed and fertilizer in the soil through slits. The spacing between two furrow openers was adjusted as per the desired row spacing of crops. The cutting portion of furrow openers (point of share) was made of 8 mm thick high carbon steel. The front edges of the furrow openers had a piece of carbon steel (hardness 65 RHN) welded all around the nose, tip and sides to reduce wear and tear. The furrow opener was welded to the mild steel flat shank. The double boot was provided behind each furrow opener to receive a polyethylene tube of diameter of 25 mm each to host seed and fertilizer delivery pipes. The furrow openers were adjusted to make 30-50 mm wide slits.

Ridger

Ridger was attached on both sides of the mainframe after furrow openers of soybean. It was made up of cast iron. Ridger was used to make the drainage channel of 350-400 mm width and 250-300 mm height.

Seedbox

The seed box of intercrop planter was rectangular in shape with the semi-circular bottom made up with GI (Galvanized Iron) sheet with a 3 kg seed capacity. Total five seed box was attached on the frame and dimensions of hopper 240 × 220 × 207 mm. A circular bottom was welded to the bottom of the hopper which was used for controlling the seed flow and diverting the seed to the metering mechanism. The hopper was positioned in such a way that the circular bottom of hopper touches the cone on its outer surface for metering the seeds. The upright position of the hopper was adjustable to suit different crops.

Fertilizer Box

The fertilizer box was made of MS sheet of 20 gauges and the length, width and height of the fertilizer box were 1990, 220 and 200 mm respectively. The lower portion was made

Table 1 Specifications of intercrop planter

S. No.	Particular	Specification
1	Mainframe L × W (mm)	(1000 + 2200 + 1000) × 600
2	Working width (mm)	4200
3	Soil condition	Upland friable soil
4	Source of power	55 hp tractor
5	No. of rows	7 (1 row of pigeon pea + 5 rows of soybean + 1 row of pigeon pea) in Kharif (Rainy season)
6	Furrow opener	Inverted - T type
7	Seed Box, (Nos.)	7
8	Fertilizer box, (Nos.)	3
9	Seed metering	Inclined plates
10	Fertilizer metering	Fluted rollers
11	Ridger, (Nos.)	2
	Ground wheel MS flat 100 × 5mm	Wheel Diameter -380 mm, Width - 100 mm Nos. of lugs - 15, lugs height - 30 mm
13	Depth control	By tractor hydraulic
14	Power transmission	chain, and sprockets and set of bevel gear
15	Weight of machine kg	430 kg

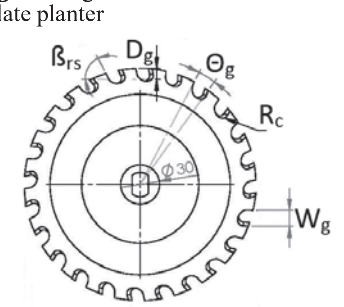
of trapezoidal in shape whereas the upper portion was rectangular. The adjustable lever was used for controlling the fertilizers rate. The fluted roller picks the fertilizer from the fertilizer box and then drops it on the flow control tongue. The flow control tongue drops the fertilizer uniformly into the boot attached in the furrow opener.

Inclined Metering Plate

An inclined plate was developed based on the design procedure adopted by Ryu and Kim (1998) and Ahmadi et al. (2007). Five design variables shown in **Fig. 1** are defined and used to determine the exact size of the cell.

Dg, depth of the cell should be slightly larger than the length of the seed, therefore 15 mm length of the cells were taken to accommodate 3-4, 2-3 and 1-2 seeds/cell for soybean, pigeon pea and chickpea respectively. Wg, the opening of the cell periphery of the plate should be 75-80 % the length of Dg, so Wg was taken 12 mm for these seeds, such that two to three seeds were loaded when the cell passes through the seed mass depending upon the orientation of seed. Θg, is the opening angle of the groove is defined as an angle between the two straight lines connecting the starting and final points of the cell and the center of the plate, respectively. It determines the loading process of the cell, 8° for all the seeds were taken under the present study. βrs, the right angle and the left angle of the cell were selected as 60° and 40° such that easy loading of the cell should be done and as well as the seed loaded in the cell should be related upon the release point. Rc, the bottom of the cell was kept around so that the seeds and foreign matter does not cling to the cell. The bottom of the cell had a radius of 2.0 mm. In addition to that, a brush was provided, which was always in contact with the seed plate after the point of release. The brush helps to remove any seed or foreign particle that gets stuck in the cell. This will ensure that the cell is empty when it moves through the seed mass again.

Fig. 1 Design variables of an inclined plate planter



The inclined plate metering was made up of plastic. The outer and inner diameter of the inclined plate was 170 mm and 120 mm respectively. There were two types of metering plate used of 24 cells and 12 cells over the outer periphery in the inclined plate. The 24 cells of the inclined plate were used for soybean and chickpea, whereas 12 cells inclined plate was used for pigeon pea. The drawing of the inclined plate with 24 cells and 12 cells are shown in **Fig. 2**.

Power Transmission Unit

The power transmission unit consists of drive wheel, shaft, idler, and sprocket and roller chain. The function of the power transmission unit is to transmit power from the drive wheel to the metering mechanism. Chain sprocket was connected with the drive wheel to the driving shaft. This shaft was connected to fertilizer and seed metering shafts with the help of the chain. Bevel gears were attached with the seed metering shaft for changing the vertical drive to horizontal drive. The idler gear was used to tighten or loosen the chain for its smooth operation.

Drive for the metering unit was taken from the ground wheel. The chain drive mechanism was used to transmit power from the drive wheel to the fluted rollers metering for metering of fertilizer and inclined plates for metering of seeds. The chain sprockets were selected based on the speed reduction ground wheel to the fluted rollers and inclined plates. An eighteen teeth chain sprocket was used at the ground wheel to transmit power to 14 teeth sprocket in one end on the first shaft and 11 teeth on another end. The power from the 11 teeth sprocket of the first shaft was transmitted to fertilizer metering shaft through a 30 teeth sprocket. From the fertilizer metering shaft, the power was distributed to the seed metering shaft having a set of sprockets (20, 25 and 30) were provided for changing the speed ratios to change the seed spacing and seed rate. Then power to the inclined plate was transmitted through a set of the bevel (S7) and pinion (S6) gear sprocket having 14 and 10 teeth, respectively, for each

Fig. 2 Inclined plate 24 cells for soybean & chickpea and 12 cells for pigeon pea

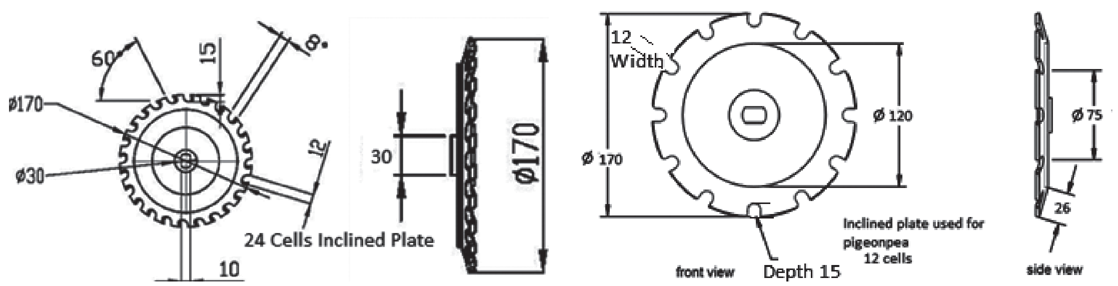


plate. The power transmission unit is shown in **Fig. 3**. Speed ratio to get desired seed spacing for soybean, chickpea and pigeon pea is given in **Table 2**.

Table 2 Speed ratios of the sprocket for 24 and 12 cells inclined plate for a seed spacing

No. of teeth, S_1 (drive sprocket)	No. of teeth, S_5 (intermediate sprocket)	No. of teeth, S_7 (driven sprocket)	Speed ratio of the sprocket, S_1: S_7	Seed spacing, cm
For soybean seed with 24 cells inclined plate				
18	10	14	1: 1	05
For chickpea seed with 24 cells inclined plate				
18	20	14	1: 0.51	10
For Pigeon pea seed with 12 cells inclined plate				
18	20	14	1: 0.51	20
18	25	14	1: 0.40	25
18	30	14	1: 0.34	30

Table 3 Treatment details of the experiment

Notation	Treatment
Split-plot design for the row to row and plant to plant spacing for pigeon pea	
M_1S_1	60 cm row to row and 20 cm plant to plant spacing
M_1S_2	60 cm row to row and 25 cm plant to plant spacing
M_1S_3	60 cm row to row and 30 cm plant to plant spacing
M_2S_1	90 cm row to row and 20 cm plant to plant spacing
M_2S_2	90 cm row to row and 25 cm plant to plant spacing
M_2S_3	90 cm row to row and 30 cm plant to plant spacing
M_3S_1	120 cm row to row and 20 cm plant to plant spacing
M_3S_2	120 cm row to row and 25 cm plant to plant spacing
M_3S_3	120 cm row to row and 30 cm plant to plant spacing
Randomized block design for different bed height for soybean-pigeon pea intercropping	
T_1	Flatbed for intercropping
T_2	15 cm height of raised bed for intercropping
T_3	25 cm height of raised bed for intercropping
T_4	Sole crop of soybean
T_5	Sole crop of pigeon pea
T_6	Sole crop of chickpea

The field experiments were conducted at the Research Farm of Indira Gandhi Krishi Vishwavidyalaya Raipur, during Kharif season of 2017 for intercropping of soybean - pigeon pea. Chickpea was intercropped in between the standing pigeon pea crop during Rabi season of 2017-18, in the same field from were soybean harvested. The soil depths of the entire experiment field were greater than 1 m. The experimental soil was clay in texture (Sand 18.0%, Silt 32.4%, Clay 49.6%) with a bulk density ranging from 1.34-1.42 Mg/m^3 at 16% moisture content (db). Field preparation was done by two passes of the tractor-drawn cultivator and one pass of rotavator to get the proper seedbed for the sowing of soybean - pigeon pea in Kharif season and chickpea was sown directly after harvesting of soybean as zero till drill to utilize the residual moisture in Rabi season. For comparison with intercropping the sole crop of soybean, pigeon pea and chickpea were also grown in similar field conditions. The experiment was laid out in Split-plot design for soybean-pigeon pea intercropping in which 3 main plot (different row to row spacing: 60, 90 and 120 cm) and 3 subplot (different plant to plant spacing: 20, 25 and 30 cm) for each main plot. Resulting in 9 different treatments with 3 replications were planned. The total number of sub-plot for each treatment were 27. The experiment was also laid out in RBD for comparison of soybean crop grown for different bed height viz. flatbed, 15 cm and 25 cm. The Treatment details of the experiment are given in **Table 3**.

Results and Discussion

Selection of crop variety, crop duration and yield potential were

Fig. 3 The power transmission system of intercrop planter for a different seed spacing

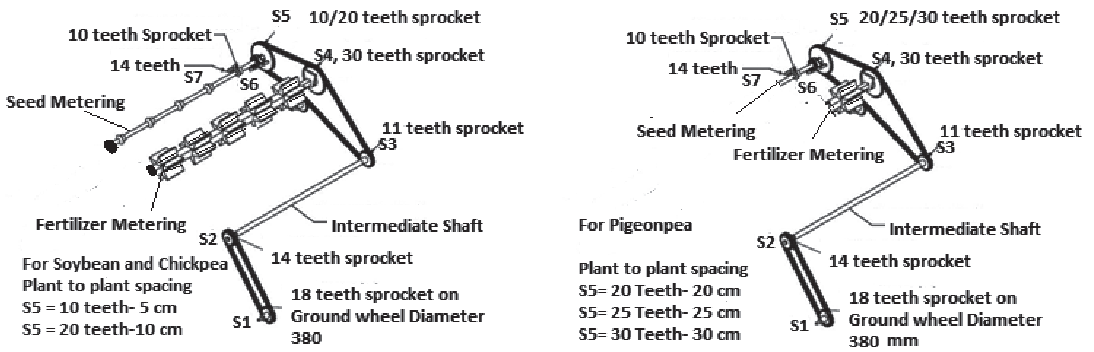


Table 4 Selected crop for the experiment

Particular	Soybean	Pigeon pea	Chickpea
Crop variety	JS-9752	Rajeev Lochan	JG130
Duration of the crop (days)	95-100	180-190	110-115
Average Productivity (q/ha)	20-25	18-20	15-20

important parameters for intercropping. Selected crop taken for the experiment is given in **Table 4** and important physical properties for the design and development of intercrop machine is shown in **Table 5**.

An intercrop planter was designed, developed and fabricated at IGKV, Raipur during the year 2017. The developed machine is shown in **Fig. 4**.

Evaluation of Developed Intercrop Planter

Laboratory Test

In intercrop planter for 5:2 (soybean-pigeon pea and chickpea- pigeon pea) for 30 cm row to row spacing for soybean and chickpea were calibrated. The seed rate obtained for intercropping for soybean was 28.14 kg/ha for 5 cm plant to plant spacing while it was 23.56 kg/ha for 10 cm plant to plant for chickpea. For same crop geometry for the sowing of the sole crop of soybean and chickpea the required seed rate was 62.22 kg/ha and 43.63 kg/ha respectively. Pigeon pea was calibrated for 120 cm row spacing and 20, 25 and 30 cm plant to plant spacing. The calibration results for the intercrop seed drill is given in **Table 6**.

Field Performance of Intercrop Planter

The width of the machine was 4.2

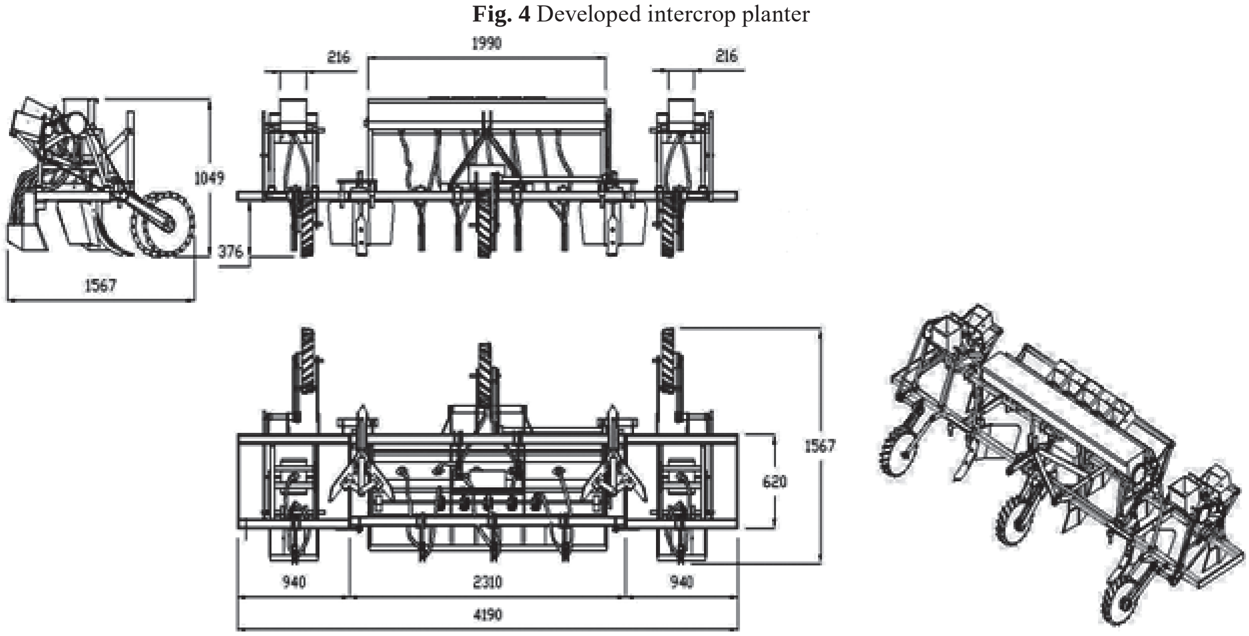
Table 5 Physical properties seeds selected for the study

Seed	Length (cm)	Width (cm)	Thickness (cm)	Moisture (%)	Geometric Mean Dia (mm)	Sphericity (%)	Bulk Density (kg/m^3)	The angle of repose (°)
Soybean	2.54	1.68	0.81	12.8	1.50	59	694	28.2
Pigeon pea	4.18	2.24	1.70	14.3	2.51	60	667	26.1
Chickpea	8.48	6.45	6.03	15.2	6.90	81	709	28.0

Table 6 Calibration of intercrop planter

Particulars	Sole crop, seed rate (kg/ha)		Intercrop 5:2, seed rate (kg/ha) (Soybean : pigeon pea) or (chickpea : pigeon pea)				
	Soybean	Chickpea	Soybean	Chickpea	Pigeon pea		
	Row to row spacing 30 cm		Row to row spacing 30 cm		Row to row spacing 120 cm		
	Plant to plant spacing		Plant to plant spacing		Plant to plant spacing		
	5 cm	10 cm	5 cm	10 cm	20 cm	25 cm	30 cm
Mean ($\bar{x}$)	62.22	43.63	28.14	23.56	7.21	5.59	4.28
SD	3.75	1.52	1.18	0.29	0.52	0.45	0.25
CV	0.05	0.03	0.04	0.03	2.20	3.17	2.86

Fig. 4 Developed intercrop planter



m while operating for intercropping of soybean and pigeon pea. Two detachable planters were fastened for the sowing of pigeon pea and two drainage channels were also made besides the broad bed. To maintain 5:2 rows spacing the path of movement of the tractor in the field is shown in **Fig. 5**.

Proper formation of channels and precision required for the sowing of intercrop in the BBF, the average operating speed was maintained about 2.5 km/h. The turning losses were more because of higher working width hence field efficiency was found 77%. The field performances of developed intercrop planter during Kharif season are given in **Table 7**.

For measurement of the draft, the digital load cell was placed in between two similar tractors and intercrop planter was hitched by the rear tractor. The average draft was observed during the intercropping was 3423 N with the forward speed of 2.43 km/h. The power requirement for intercropping planter was 30 kW.

After harvesting of soybean from the intercropped field of soybean ? pigeon pea, chickpea was sown in between standing crop of pigeon pea. Prior to the sowing of chickpea, detachable planters and ridgers were removed. The chickpea was sown under zero tillage condition during Rabi season. The actual field capacity and field efficiency was 0.37 ha/h and 68.4% respectively (**Table 8**). It was less as compare to Kharif season. This may be due to extra cares were needed while operating in between the standing crop of pigeon pea to reduce plant mortality. The depth of placement of seeds was adjusted by hydraulics. The complete cultivation of soybean-pigeon pea, chickpea is shown in **Fig. 6**

Table 7 Field performance of intercrop planter for soybean - pigeon pea during *Kharif*

Particulars	Speed (km/h)	Actual field capacity (ha/h)	Field efficiency (%)	Fuel consumption (l/h)
Mean ($\bar{x}$)	2.43	0.56	77.21	4.70
SD	0.13	0.03	3.60	0.29
CV	5.50	6.23	4.66	6.24

Table 8 Field performance of intercrop planter for chickpea during *Rabi*

Particulars	Speed (km/h)	Actual field capacity (ha/h)	Field efficiency (%)	Fuel consumption (l/h)
Mean ($\bar{x}$)	2.51	0.37	68.43	4.01
SD	0.11	0.01	6.22	0.36
CV	4.70	4.09	9.09	8.99

Crop Parameters

Plant population

The observations of plant population per m^2 of the paired row of pigeon pea were recorded at 20 DAS and at the time of harvest are presented in **Table 9**. The plant population of pigeon pea was recorded according to combinations of the row to row spacing (60, 90 and 120 cm) with the different plant to plant spacing (20, 25 and 30 cm). The results revealed that there was non-significant variation in the main plot of plant population at 20 DAS and at harvest due to row spacing but significant variation observed at subplot due to plant to plant spacing. At 30 cm plant to plant spacing, minimum plant population per meter row length was observed. The interaction effect was observed that the main plot does not affect the subplot.

Fig. 5 Path of movement of intercrop planter for 5:2 intercropping of soybean -pigeon pea

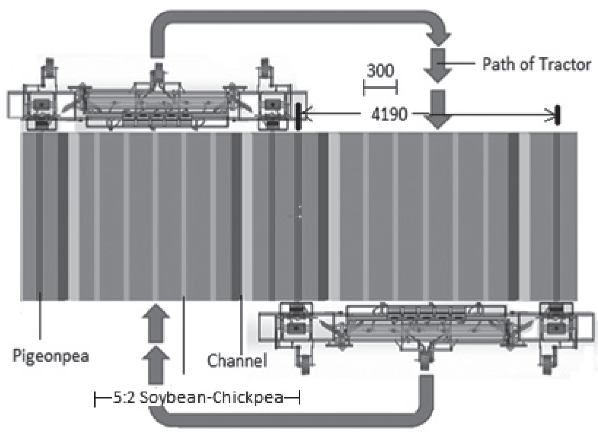


Fig. 6 The complete cultivation of soybean-pigeon pea, chickpea

Table 9 Plant population per m² at 20 DAS and at harvest of the paired row of pigeon pea

Main Plot	Sub Plot	20 DAS	Harvest
M_1 (60 cm row to row spacing)	S_1 (20 cm plant to plant spacing)	15.5	12.4
	S_2 (25 cm plant to plant spacing)	13.2	11.22
	S_3 (30 cm plant to plant spacing)	10.6	8.79
M_2 (90 cm row to row spacing)	S_1 (20 cm plant to plant spacing)	15.03	12.02
	S_2 (25 cm plant to plant spacing)	12.54	10.65
	S_3 (30 cm plant to plant spacing)	10.17	8.44
M_3 (120 cm row to row spacing)	S_1 (20 cm plant to plant spacing)	15.19	12.15
	S_2 (25 cm plant to plant spacing)	13.86	11.78
	S_3 (30 cm plant to plant spacing)	11.44	9.50
CD	Main Plot	NS	NS
	Sub Plot	0.49	0.21
CV	Main Plot	6.89	4.49
	Sub Plot	11.86	6.22

Table 10 Seed yield by different cropping system

Cropping system	Seed yield (kg/ha)		
	Soybean	Pigeon pea	Chickpea
Sole crop	14.7	16.27	15.04
Intercropping 5:2 (Soybean: pigeon pea)			
Flatbed	7.6	12.27	7.88
up to 15 cm bed	9.2	13.10	8.05
up to 25 cm bed	10.7	13.56	8.24

Table 11 Pigeon pea equivalent yield and LER at different intercropping system

Cropping system	LER S:P	LER P:C	Pigeon pea equivalent yield q/ha with soybean	Pigeon pea equivalent yield q/ha with chickpea
Sole pigeon pea	1	1	16.27	16.27
Intercropping system (S:P:C)				
Flatbed	1.27	1.28	16.52	18.63
Raised bed 15 cm	1.43	1.34	18.25	19.60
Raised bed 25 cm	1.56	1.38	19.55	20.21

Number of branches per plant

The number of branches of a paired row of pigeon pea was recorded at 30 DAS, 60 DAS and at harvest. The number of branches per plant of pigeon pea was recorded according to combinations of row spacing (60, 90 and 120 cm) with the different plant to plant spacing (20, 25 and 30 cm) at 30 DAS, 60 DAS and at harvest. The number of branches/plant was observed that it varies 4.75 to 5.83 at 30 DAS, 7.07 to 8.91 at 60 DAS and 10.53 to 12.54 at harvest. The data revealed that there was a significant effect on the number of branches per plant due to row spacing and plant spacing. From the result, it was observed that row spacing affect the branches as it increases the number of branches also increases. It may be due to the wider spacing between soybean and pigeon pea which causes plants having a favorable condition for growth.

Yield Attributes

Number of pods per plant

The number of pods/plant of pigeon pea was recorded according to combinations of the row to row spacing (60, 90 and 120 cm) with the different plant to plant spacing (20, 25 and 30 cm) and it varies from 170.9 to 222.8. The maximum number of the pod was found in the combination of 120 cm row to row spacing with 30 cm plant to plant spacing due to the wide spacing between pigeon pea which received the proper aeration, high nutrients for optimum plant growth for the higher number of pods/plant. The data revealed that there was a significant effect in the number of pods/plant due to row to row spacing and plant to plant spacing.

Number of seeds per pod

The number of seeds/pod of pigeon pea was recorded according to combinations of row spacing (60, 90 and 120 cm) with the different plant to plant spacing (20, 25 and 30 cm) and it varies from 1.98 to 3.08. The maximum number of seeds/pod was 3.08 in the combination of 120 cm row spacing with 30 cm, plant to plant. The data revealed that there was a significant effect on the number of seeds/pod due to row and plant spacing.

Seed yield

Seed yield is the most important character and superiority of the treatment was judged by its capacity to produce more seed yield. It was found that highest yield was 13.56 q/ha in the combination of 120 cm row to row, 30 cm plant to plant spacing and 25 m bed height. The data revealed that there was a significant effect on seed yield between sole and intercrop. The yield of soybean and chickpea was also found highest for 25 cm bed height. Table 10 shows the yield by different cropping system.

Land Equivalent Ratio (LER)

The data pertaining to LER of soybean and pigeon pea intercropping in Kharif season are given in **Table 11**. LER for intercropping of soybean- pigeon pea was highest in the combination of 120 cm row spacing with 30 cm plant spacing which was found most suitable and economical than other intercropping. Chickpea was taken after harvesting of soybean on standing pigeon pea during Rabi season. The maximum land equivalent ratio was found to be 1.38 at 25 cm bed height which followed by 1.34 at 15 cm bed height. Pigeon pea equivalent yield with soybean at different intercropping is given in **Table 11**.

Cost Economics of Different Cropping System

Highest output, net benefit and benefit-cost ratio cost were observed in the intercropping system as compared to sole crop of soybean, pigeon pea and chickpea (**Table 12**).

Cost of Cultivation

Cost of cultivation was calculated by the straight-line method on the basis of the cost of the machine and present cost on insurances, tax, fuel and wages charge. Fixed cost of the machine was Rs 89.60 per hour while operational cost Rs 352.50 per hour. The total cost of operation of intercropping was Rs 1126.85 per ha.

Conclusions

1. Soybean-pigeon pea and chickpea intercropping system showed the most parallel intercropping practice for a higher benefit. The intercrop planter was found to be the most suitable for obtaining desired spacing with soybean and pigeon pea and permits a second crop of chickpea which was not feasible in a traditional practice.
2. Speed of operation, actual field capacity, field efficiency and fuel consumption was recorded 2.46 km/h, 0.56 ha/h, 77.21% and 4.70 l/h for soybean and pigeon pea intercropping. Chickpea was intercropped after the harvesting of the soybean by detaching the pigeon pea. Speed of operation, actual field capacity, field efficiency and fuel consumption was recorded 2.46 km/h, 0.56 ha/h, 77.21% and 4.70 l/h for chickpea
3. Seed yield of pigeon pea was found 13.56 q/ha, that was maximum for 120 cm row to row and 30 cm plant to plant spacing as compared to 90 cm row to row and 25 cm plant to plant.
4. The land equivalent ratio of pigeon pea was observed a maximum of 1.56 with soybean followed by 1.38 with chickpea at 25 cm bed height. LER was found lowest in flatbed intercropping practice as compared to others. Maximum pigeon pea equivalent yield with chickpea was 20.21 q/ha at 25 cm followed by 19.60 q/ha at 15 cm bed height.
5. Maximum output, net benefit and the benefit-cost ratio was observed Rs 146698, Rs 90550 per ha and 2.62 respectively for intercropping by developed intercrop machine.

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REFERENCES

Ahmadi, E., Goudarz, A. and M. M. Jaberi. 2009. Evaluation of Various Planters on Seed Rate, Emergence, Sowing Depth and Seed Distribution Uniformity of Canola. Journal of Agricultural Science (University of Tabriz), Vol. 18(4): 211- 221.

Rau, H. I. and K. U. Kim. 1998. Design of roller type metering device for precision planting. Transaction of ASAE. 41: 923-30

Reddy, Sanjeeva B., Satyanarayana, Adke and M. Anantachar. 2012. Performance of seed planter metering mechanism under simulated conditions. Indian J. DrylandAgric Res. And Dev. 27(2): 36-42.

Singh, Devvrat, Vyas, A. K ., Gupta, G. K., Ramteke, R. and I. R. Khan. 2011. Tractor-drawn broad bed furrow seed drill machine to overcome moisture stress for soybean (Glycine max) in Vertisols. Indian J. Agril. Sci. 81(10): 941-4.

Verma, P. D, Parmanand, Jain V. and A. S. Rajpur. 2018. Evaluation of sowing methods of soybean in Bhatapara district of Chhattisgarh. J Krishi Vigyan. 6(2): 109-112.

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Table 12 Cost economics of intercropping system with sole crop

Cropping system	Input cost (Rs/ha)	Output cost (Rs/ha)	B:C
Sole crop soybean	29,068	47,063	1.62
Sole crop pigeon pea	47,155	93,777	1.99
Sole crop chickpea	34,544	67,621	1.96
Intercropping (120 × 30 cm at 25 cm bed height)	56,148	146,698	2.62

ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

1917

Influence of Operational Parameters of Cutting Blade on Torque and Cutting Index of Cassava Stem: Bikram Jyoti, K. Karthirvel, C. Divakar Durairaj, T. Senthil kumar

Cassava harvesting is highly labour intensive and a partially mechanized operation. A cassava stems harvester need to be developed as an attachment to existing cassava digger. The design of an efficient cassava stem harvester requires optimization of blade and operational parameters. To optimize the operational parameters, an experimental cassava stem harvester was developed to investigate the effect of forward speed and peripheral velocity of cutter blade on torque and cutting index of cutter blade. The forward speed and peripheral velocity of blade showed a profound effect on cutting performance of rotary blade. The treatment with combination of 2.0 kmh^{-1} forward speed and 30 ms^{-1} peripheral velocity yielded the minimum torque and best quality of cut cassava stem. The treatment combination of 2.0 kmh^{-1} forward speed and 30 ms^{-1} peripheral velocity which yielded the cutting torque value of 0.31 Nm and the corresponding to minimum value of cutting index was selected for the development of prototype tractor operated cassava stem harvester.

1918

Anthropometric Studies of Women Agricultural Workers of Chhattisgarh, India: Ajay Kumar Verma, Meera Patel

The Chhattisgarh State of India is rice growing mono-cropped area. Rice is a labour intensive crop. Women agricultural workers are involved in transplanting, weeding, harvesting and threshing operations of rice cultivation. Manual tools and animal-drawn implements are extensively used for different farm operations. These agricultural tools/implements are not designed ergonomically and this leads to an increase in accidents and health hazards to agricultural workers. Proper matching of machine requirements with operator’s capabilities is necessary to achieve better performance. Very little data are at present available on anthropometry of women agricultural workers of Chhattisgarh. Therefore, a survey on 22 basic anthropometric data necessary for the design of agricultural equipment was conducted. Total 250 women agricultural workers having five different age groups of 20-25, 25-30, 30-35, 35-40 and 40-45 years from five districts of Chhattisgarh were selected. From each age group, 50 women workers were chosen to collect anthropometric data. The collected data were analyzed statistically. A large variation was observed in the anthropometric data of women agricultural workers of different states of India and other countries. Mean stature and mean weight of the women agricultural workers of Chhattisgarh were 1508 (±53) and 50(±9) kg, respectively. The coefficient of variation was found highest for weight (17.6%) as compared to other body dimensions. The analysis of anthropometric data suggests that the majority of the selected body dimensions were linearly related to stature of the subjects. It was observed that most of the body dimensions increased considerably with an increase in percentile values of stature from 5^{th} to 95^{th}. The result revealed that the mean weight of the agricultural workers is gradually increasing as the age increases.

2002

Morphological and Colorimetric Descriptors for the Characterization of Mature Pads of *Opuntia ficus-indica* L.: Juan Arredondo-Valdez, Alejandro Isabel Luna-Maldonado, Ricardo Valdez-Cepeda, Humberto Rodríguez-Fuentes, Juan Antonio Vidales-Contreras, Juana Aranda- Ruiz

Mexico is the world's leading producer of *Opuntia ficus-indica* L. This kind of prickly pear is the most widespread and most commercially important cactus in Mexico. Morphological and colorimetric descriptors are among the most important agronomic traits because they affect yield. The acquisition and processing of images discovered interesting relationships between the *Opuntia ficus-indica* L. morphological characteristics, as well as colorimetric parameters of those cladodes. The non-linear data behaviors were fitted using deterministic models and CurveExpert software. Mean values of the L*, C, and H color parameters were displayed in a window of a computer program online.

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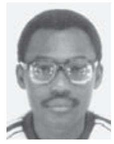
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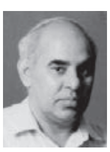
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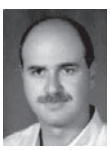
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