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AMA

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VOL.53, NO.4, AUTUMN 2022

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YOSHISUKE KISHIDA

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EDITORIAL

Last November, the world's population exceeded 8 billion. And it will continue to grow toward 10 billion. The amount of farmland per person on the planet is decreasing every year. Therefore, the biggest challenge for agricultural technology is to increase land productivity. In other words, to maximize the utilization of the decreasing farmland.

As I have mentioned many times, there are two important requirements for increasing land productivity. The first is to perform accurate agricultural work, and the second is timely operation. For example, when sowing wheat seeds or transplanting paddy rice, the timely operation for planting and sowing is different from region to region.

The most important tool of performing this work timely is agricultural machinery. Mechanization allows farmers to perform the work with limited labor and time. In developed countries, agricultural mechanization has made considerable progress, but looking around the world, there are still many areas in developing countries such as Africa, where agricultural mechanization has not been progressed sufficiently. Promotion and development of agricultural mechanization, including in developing countries, is indispensable in considering global food issues.

To increase land productivity, there is a third important factor. That is information on what kind of work should be done. For example, tillage operations vary depending on the nature of the soil. The method of tillage depends on the hardness, moisture content, and other conditions of the soil. Therefore, it is necessary to know the exact condition of the soil.

Also, even within a single field, the condition of the soil differs from place to place. Therefore, it is necessary to make a soil map by attaching a sensor to the front of the tractor, so the operator can determine the nature of the soil, and automatically control the work conditions.

Also, the method of fertilizer application depends on the conditions of the crop and the soil. Fertilizer composition in the field is not uniform. This also requires a map of soil fertility. Variable operations based on that map is necessary.

With the evolution of various sensors and computers that process information, it has become much easier to do this than in the past. New agricultural mechanization that combines this information is needed.

The war in Ukraine broke out at a time when the world's food production must be increased, and there is no sign of an end to the war even after one year.

After World War II, Japan created a new constitution. Japan established a new constitution after World War II, one in which all international problems are to be solved by discussion, not by military force. If all the countries of the world would create such a constitution, the earth would become a more peaceful place. By creating such an environment, food production will also become sufficient and a food crisis will be averted.

Yoshisuke Kishida
Chief Editor
Dec, 2022

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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Farm Mechanization Status of *Farmersin* Rainfed Area of Western Maharashtra in India

by
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Abstract

Farm mechanization implies the use of various power sources and improved farm tools and equipment in agriculture. A survey was conducted with 144 representative farmers selected from the rainfed areas of *Ahmednagar* and *Solapur* Districts of Western Maharashtra in India to study knowledge of the farmers and utilization of farm implements and machinery in the rainfed areas. The majority of farmers had medium knowledge and utilization of farm implements and machinery in the rainfed area. The farmers had comparatively more knowledge and utilization of hand tools, manually operated farm implements and animal drawn farm implements than power operated farm implements and machinery. This may be due to lesser complexity, lesser cost and more familiarity of hand tools than other implements. Few farmers were using highly technical, sophisticated and costly machinery like excavator, tractor drawn leveler, power operated weeder, power operated cultivator, and self-propelled combine harvester. This may be because of the poor knowledge and limited resources. Based on the findings, it has been established that attention of the extension agencies need to be diverted to this important aspect in order to enhance knowledge level of farmers about the farm implements and machinery. This brings forward the need for launching a massive publicity campaign about farm implements and farm machinery in the rainfed area.

Keywords: Farm Mechanization, rainfed, farm implements, farm machinery, knowledge, utilization, India

Introduction

Farm mechanization implies the use of various power sources and improved farm tools and equipment in agriculture. Farm mechanization increased the output with timely operations and precision in input application. It saves time and labour, cuts down production costs, reduces post-harvest losses and boosts output and farm income (Singh et al., 2011).

But as all farmers may not have sufficient knowledge/awareness about improved farm implements and machineries they may not utilize it at the same time and at the same rate. Such inadequacy of knowledge and utilization lead to wrong choice, make it uneconomical and risky too. Considering these aspects, the present study entitled, 'Farm Mechanization Status of farmers in Rainfed Area', was undertaken with the specific objectives to study were to assess the knowledge level and extent of utilization of the farmers about farm implements and machinery in rainfed area.

Methodology

The study was conducted in rainfed area of *Karjat* and *Pathardi tahsils* of Ahmednagar district; and at *Karmala* and *Mohol tahsils* of *Solapur* districts. A total of 144 representative farmers were selected from eight villages from these four tahsils by identifying 18 farmers from each village using proportionate random sampling procedure. The data were collected through a specially developed interview schedule. The data were analyzed, tabulated and interpreted with suitable statistical parameters like frequency, percentage and mean and standard deviation method (Patil, 2015).

Measurement of the Knowledge Level

The term knowledge in the present study was defined as factual information possessed by an individual about farm implements and machinery. Eleven knowledge-related parameters were finalized to ask the respondent farmers at the time of interviewing to work out the knowledge level (Patil, 2015).

Measurement of Utilization Level

In this study, the term utilization of farm implements and machinery was defined as the behavior of a farmer with regard to type and number, nature of ownership, experience in using, extent and type of use, maintenance and repairs and storage of farm implements developed and recommended by the MPKV, Rahuri for performing various agricultural operations. For measuring the utilization of farm implements and machinery, the responses of the respondents about utilization were collected and score was assigned as per the scale developed by Patil and Shinde (2016).

Results and Discussion

I. Knowledge of the Respondents About Farm Implements and Machineries

The awareness of the farmers about farm implement, equipment and machinery was ascertained and the findings in this regard are presented as knowledge level about the farm implements in **Table 1**.

Table 1 revealed that, in rainfed area, majority (63.89%) of the respondents had medium knowledge level of farm implements and machinery, followed by high knowledge level (22.22%), and low knowledge level of farm implements and machinery (13.89%).

It is seen that, there is a wide gap between the expected knowledge level and existing knowledge level of the respondent farmers about the farm implements and machinery. Therefore, attention of the extension agencies needs to be diverted to this important aspect in order to boost up the knowledge level of farmers about the farm implements and machinery. This brings forward the need of launching a massive publicity campaign about farm implements and machinery.

The findings of the study are in line with the findings of Aitwade (2012), Dhere (2012) and Nagaraj et al. (2013).

II. Utilization of Farm Implements and Machineries by the Respondents

Continued use of any practice or technology helps the farmers to improve production and productivity of crops by enhancing farm efficiency. Keeping that in view, the present investigation estimated the extent of utilization of farm implements and machinery by the respondents. The data pertaining to the level of farm implements and machinery utilization by respondents are presented in **Table 2**.

Table 2 reveals that in the case of rain-fed area majority (60.42%) of the respondents had medium level of utilization farm implements and machineries, followed by low level of utilization (20.14%), and high level of utilization (19.44%).

There is a wide gap between the expected utilization level and the existing utilization level of the farm implements and machinery by the respondents. Attention of the extension agencies therefore, needs to be diverted to this important aspect in order to boost the level of utilization by the farmers. This brings forward the need for launching a massive publicity campaign and increased

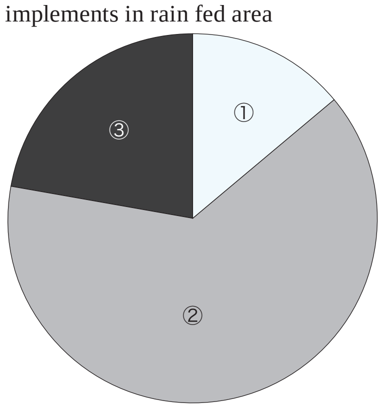
Table 1 Distribution of the respondents according to knowledge

Sl. No.	Knowledge level % (Score)	Rainfed (n= 144)	
		Frequency	Percent
1	Low (up to 79)	20	13.89
2	Medium (80 to 90)	92	63.89
3	High (91 and above)	32	22.22
	Total	144	100.00

Table 2 Distribution of respondents according to their utilization level

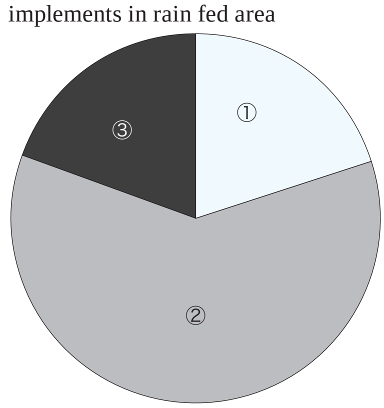
Sl. No.	Utilization level % (Score)	Rainfed (n= 144)	
		Frequency	Percent
1	Low (up to 67)	29	20.14
2	Medium (68 to 87)	87	60.42
3	High (88 and above)	28	19.44
	Total	144	100.00

Fig. 1 Percent knowledge of farm implements in rain fed area



① Low (up to 79): 20 (13.89%)
② Medium (80 to 90): 92 (63.89%)
③ High (91 and above): 32 (22.22 %)

Fig. 2 Percent utilization of farm implements in rain fed area



① Low (up to 67): 29 (20.14%)
② Medium (68 to 87): 87 (60.42%)
③ High (88 and above): 32 (22.22 %)

subsidy of farm implements in the irrigated as well as the rain-fed areas. The findings of the study are in line with the findings of Aitwade (2012).

Besides this level-wise distribution of knowledge and utilization, an attempt has been made to place the respondents as per the operation-wise knowledge and utilization of farm implements and machinery used.

III. Farm Operation-wise Knowledge and Utilization of Farm Implements and Farm Machineries by the Respondent

The operation-wise knowledge and utilization of farm implements and farm machinery by the respondent are presented in **Table 3**.

Farm operation-wise knowledge and utilization of farm implements and farm machinery used by the respondent

A. Farm Implements and Machinery Used for Land Development

Amongst the land preparation implements it is observed from **Table 3a** that knowledge and utilization of the animal drawn implements (soil bucket / keni) were 77.73% and 77.27%, respectively. In the case of power operated implements like JCB and tractor drawn leveler it was 54.09% and 32.49%, respectively. It is because very few farmers used the power operated back-hoe loader (JCB) and tractor drawn leveler.

B. Farm Implements and Machineries Used for Primary Tillage

Amongst the implements used for primary tillage it is observed that knowledge level of animal drawn wooden plough was the highest (85.00%) and utilization was 83.69%. **Table 3a** also showed that for primary tillage operations like ploughing and harrowing, the respondents were using power operated implements also. Knowledge and utilization levels of power operated or tractor drawn rotavator and mould board plough implements were 57.46% and 53.46%, respectively. The findings of the study are in line with the findings of Dhere (2012) and Nagaraj et al. (2013).

Table 3a Distribution of the respondents according farm operation-wise knowledge and utilization of farm implements and farm machineries

	Name of Farm implements / farm machineries	Farm implements and machineries in rainfed area (n = 144)				
		No. of farmers using	Farm implements / farm machinery ownership		Avg. knowledge	Avg. utilization
			Owned	Hired	(%)	(%)
A. Farm implements & machineries used for land development						
I	Animal drawn Soil bucket / Keni	84 (58.33)	37 (25.69)	47 (32.64)	77.73	77.27
II	Power operated Back-hoe loader (JCB) & Tractor drawn leveler	12 (8.33)	2 (1.39)	10 (6.94)	54.09	32.49
B. Farm implements & machinery used for primary tillage						
I	Animal drawn Wooden plough & Mould board plough	142 (98.61)	74 (51.39)	68 (47.22)	85.00	83.69
II	Power operated mould board plough or Tractor drawn rotavator	105 (72.92)	20 (19.05)	85 (80.95)	57.46	53.46
C. Farm implements & machinery used for primary tillage						
I	Animal drawn Blade harrow	138 (95.83)	77 (55.80)	62 (44.93)	87.88	86.31
II	Power operated					
1.	Rotovator	72 (50.00)	9 (12.50)	63 (87.50)	65.03	61.08
2.	Ridger	30 (20.83)	14 (46.67)	16 (53.33)	67.86	58.18
3.	Peg tooth harrow	36 (25.00)	10 (27.78)	26 (72.22)	64.39	59.08
4.	Cultivator	15 (10.42)	2 (13.33)	13 (86.67)	70.91	65.55
D. Farm implements & machinery used for primary tillage						
I	Manually operated seed drill	42 (29.17)	29 (69.05)	13 (30.95)	90.91	82.55
II	Animal drawn Two bowl Seed drill	101 (70.14)	52 (51.49)	49 (48.51)	82.20	81.05
III	Power operated Seed cum fertilizer drill	41 (28.47)	7 (4.86)	34 (23.61)	61.90	47.30

C. Farm Implements and Machineries Used for Secondary Tillage

Amongst the implements used for secondary tillage, it is observed from **Table 3a** that in the rain-fed area, knowledge level of animal drawn Blade harrow implements was 87.88% and utilization was 86.31%. **Table 3a** also shows that respondents were using power operated implements and machinery for secondary tillage operations up to some extent. The knowledge level of respondents about power drawn implements for secondary tillage ranges from 64.39% to 70.91% in the rain-fed areas. The findings of the study are in line with the findings of Dhere (2012) and Nagaraj et al. (2013).

D. Farm Implements and Machinery Used for Sowing

Farmers were using different manually operated, animal drawn and or power operated seed drill for sowing as per their capacity and availability. Amongst the manually operated implements used for sowing, it is observed from **Table 3a** that, manual seed drill was mostly used in the rain-fed areas (82.55%) and knowledge level of this amongst the respondents was also very good (90.91%).

The knowledge level of animal drawn seed drill was 82.20% and utilization was 81.05% amongst respondents. **Table 3a** also shows that power operated implements used by the respondents for sowing was 47.30%.

Table 3b Distribution of the respondents according farm operation-wise knowledge and utilization of farm implements and farm machineries

	Name of Farm implements / farm machineries	Farm implements and machineries in rainfed area (n= 144)				
		No. of farmers using	Farm implements / farm machinery ownership		Avg. knowledge	Avg. utilization
			Owned	Hired	(%)	(%)
E. Farm implements & machinery used for intercultural operations						
I	Manually operated					
1.	Khurpi	144 (100.00)	144 (100.00)	0 (0.00)	97.60	88.88
2.	Wheel hoe	85 (59.03)	74 (87.06)	11 (12.94)	92.73	69.46
3.	Weeder / Hand hoe	38 (26.39)	34 (89.47)	4 (10.53)	91.63	67.06
II	Animal drawn					
1.	Blade hoe	112 (77.78)	55 (49.11)	57 (50.89)	88.64	81.75
III	Manually operated					
1.	Power weeder	2 (1.39)	2 (100.00)	0 (0.00)	74.19	68.18
2.	Cultivator	10 (6.94)	3 (30.00)	7 (70.00)	72.73	59.16
F. Equipment & farm machinery used for Plant protection						
I	Manually operated Knapsack sprayer	135 (93.75)	96 (71.11)	39 (28.89)	89.36	69.49
II	Power operated Knapsack power sprayer & HT Pump	43 (29.86)	35 (24.31)	8 (5.56)	80.67	55.84
G. Farm implements & farm machinery used for Harvesting & threshing						
I	Manually operated					
1.	Local sickle	143 (99.31)	143 (100.00)	0 (0.00)	98.92	89.69
2.	Vaibhav sickle	88 (61.11)	88 (100.00)	0 (0.00)	99.17	71.91
3.	Cotton stalk puller	66 (45.83)	23 (34.85)	43 (65.15)	96.14	70.94
4.	Maize sheller	9 (9.25)	9 (100.00)	0 (0.00)	100.00	58.15
II	Self-Propelled					
1.	Multi crop thresher	139 (96.53)	7 (5.04)	132 (94.96)	82.88	57.10
2.	Combine harvester	13 (9.03)	0 (0.00)	13 (100.00)	47.37	39.16

E. Farm Implements and Machinery Used for Inter-culture Operations

Table 3b showed that the knowledge level of respondents is more about khurpi (97.60%), followed by wheel hoe (92.73%) and weeder/hand hoe (91.63%). This may be due to the design and make up of these hand tools for inter-culturing operations. These are very simple and familiar for many years. In the case of animal drawn farm implements, blade hoe was mostly used (81.75%) for inter-culturing operations.

Very few farmers were using the power operated weeder and cultivator. This may be due to availability the limited resources and poor cropping pattern.

Therefore, it is concluded that, the knowledge level of respondents towards farm implements for intercultural operations is more about hand tools (manually operated), followed by animal drawn and power drawn. This may due to less complexity and more familiarity of hand tools than other implements and machinery. The findings of the study are in line with the findings of Aitwade (2012) and Dhere (2012).

F. Farm Implements and Farm Machinery Used Plant Protection

Table 3b shows that, in manually operated plant protection equipment such as Knapsack sprayers were used by most (89.36%) of the farmers, followed by Power operated Knapsack power sprayers and HT Pumps (80.67%). From the table, it is concluded that utilization of the farmer with regard to plant protection equipment is quite good (55.84% to 69.49%). The findings of the study are in line with the findings of Dhere (2012).

G. Farm Implements and Machinery Used for Harvesting & Threshing

Table 3b reveals that the knowledge level of hand tools for harvesting and threshing ranges from 96.14% to 100%. **Table 3b** also shows that, in power operated harvesting and threshing implements or machinery, the knowledge level about multi crop thresher was the highest (82.88%). Very few farmers used the self-propelled combined harvester in their fields. The findings of the study are in line with the findings of Dhere (2012) and Nagaraj et al. (2013).

Conclusions

It can be concluded that majority of the farmers had medium knowledge and utilization of farm implements and machinery in the rain-fed areas. Farmers had comparatively more knowledge and utilization of hand tools, manually operated farm implements and animal drawn farm implements than power operated farm implements and machinery. Very few farmers were using the power operated back-hoe loader (JCB), tractor drawn leveler, power operated weeder, power operated cultivator, maize sheller and power operated combine harvester in their fields. This may be due to unavailability, limited resources and poor cropping pattern. Therefore, attention of the extension agencies needs to be diverted to this important aspect in order to boost the knowledge level of farmers about the farm implements and machineries. This brings forward the need for launching a massive publicity campaign about farm implements and farm machinery in rain-fed areas.

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Design and Development of a Two-Stage Evaporative Cooling Transportation System for Fruits and Vegetables

by

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Abstract

Cooling and storage of fruits and vegetables using evaporative system is a well establish technique. Many evaporative cooling storage structures have been designed and developed using different construction and pad materials to improve system cooling efficiency. But the limitation with evaporative cooling is that, cooling of air can be achieved up to wet bulb temperature only. It can be overcome with the two-stage indirect-direct evaporative cooling system consisting of indirect cooling system and direct evaporative cooling. Therefore, two-stage evaporative cooling system was designed, constructed to improve the efficiency of evaporative cooling in order to reduce losses of fresh fruits and vegetables during transport and increase its availability. The developed system was evaluated for its performance with respect to three different air supply velocities (11.11, 14.00, 16.70 m/s), three pad thicknesses (100, 150, 200 mm) and three water flow rates (3, 4, 5 lpm) in terms of temperature drop and increase in relative humidity..

Significantly overall higher temperature drop of 14 ±2.9 °C was obtained for combination of 16.7 m/s air velocity, 200 mm pad thickness and 5 lpm water flow rate. The overall cooling efficiency obtained varied from 54% to 100%. Maximum average relative humidity of 63% obtained for 14 m/s air velocity, 150 mm pad thickness and 3 lpm water flow rate.

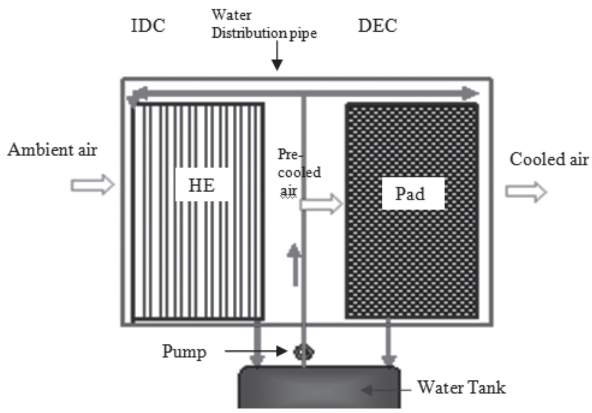
Keywords: Direct evaporative cooling, Indirect cooling, Two-stage evaporative cooling, Fruits and vegetables, PLW, Shelf-life

Introduction

Two principal methods of evaporative cooling are direct cooling and indirect cooling. In direct method of evaporative cooling, outside unsaturated air is allowed to pass through wet pad. Due to evaporation of water, air gets cooled and humidified. Whereas, in indirect method of evaporative cooling, the air is cooled as it flows outside the tubes of the heat exchanger in which cold water circulates. The indirect cooling process takes place at a constant absolute humidity. The effectiveness of either of these methods is below one. The efficiency of direct cooling is up to 90% with good quality rigid pad media, while efficiency of indirect cooling is in the range of 60-70% (Mohmmad, 2013). The direct evaporative cooling has got the limitation for drop in air temperature, i.e. the maximum up to the wet bulb temperature of ambient air. It may be overcome by combining direct and indirect cooling system known as two-stage indirect-direct (TSEC) evaporative cooling.

Two-stage indirect-direct evaporative cooling system combines

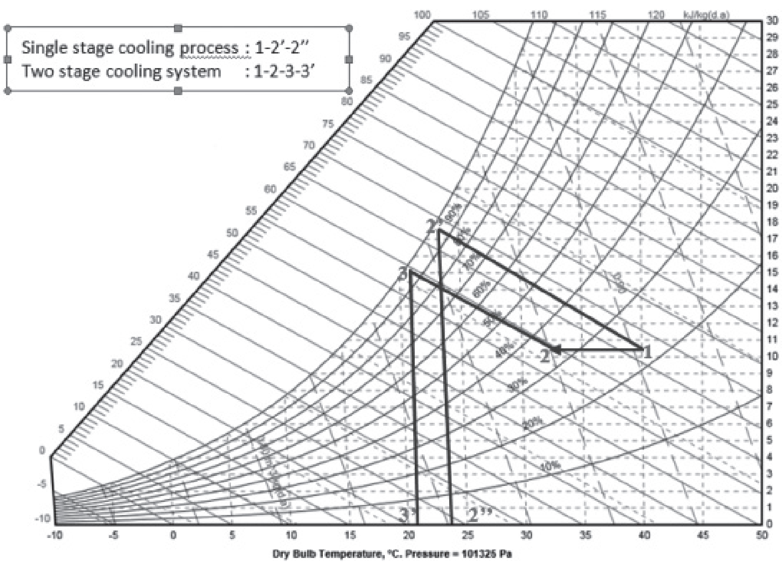
Fig. 1 Schematic of TSEC system



indirect evaporative cooling (IDC) unit in first-stage with direct evaporative cooling (DEC) unit in second-stage. In the two-stage evaporative cooling system, ambient air is passed over a heat exchanger cooling unit (first-stage) with circulating water coming out from the direct evaporative cooling unit as shown in **Fig. 1**. The heat exchange process in indirect cooling system reduces the dry bulb temperature of the entering air stream without changing its humidity. Thereafter, the air stream is introduced into the second stage i.e. direct evaporative cooling system. In the second stage, the pre-cooled air passes through a water-soaked pad. As a result, the air temperature approaches the wet bulb temperature of the pre-cooled air. This temperature is lower than the wet bulb temperature of the ambient air. The two-stage evaporative cooling provides air that is cooler than either a direct or indirect single-stage system can provide individually. The direct type evaporative cooling is simple but introduces moisture into the air stream while cooling it adiabatically. A promising way to increase the performance of evaporative cooling system is to decrease the dry bulb temperature of the air at constant absolute humidity. Such condition can achieve by combining both the indirect type and direct type of evaporative cooling system. The concept of the two-stage evaporative cooling system can be well explained on psychrometric chart as shown in **Fig. 2**. Point 1 on psychrometric chart represents initial condition of the ambient air. By using indirect cooling system or direct cooling system, the cooling of air at point 1 can be cooled up to 2'. This has been shown by process 1-2' on psychrometric chart. Now, by combining both indirect cooling system and direct cooling system, the cooling of air at point 1 can be cooled up to 3. This can be shown by process 1-2-3 on psychrometric chart.

The coefficient of performance (CoP) of the two-stage evaporative cooling system is at least 20% greater than those achieved when employing either the indirect cooling or direct evaporative cooling system alone (Bourhan et al., 2001). Different designs of two stage evaporative coolers have been also reported in literature for the preservation of fruits and vegetables. Datta et al., 1987 have fabricated indirect-direct evaporative cooling system and tested and compared its performance with a computer prediction. They reported that this system has scope for use in India and this system is also applicable in all zones where the wet bulb temperatures are below 24-26 °C for most of the hot season. Two-stage indirect-direct evaporative cooler showed higher effectiveness value varying between 0.8 and 1.1 than the single-stage evaporative cooling systems as reported by Al-Juwayhel et al., 2004. Single-stage direct evaporative cooling, single-stage indirect evaporative cooling, two-stage indirect direct evaporative cooling and three-stage system of evaporative cooling and mechanical vapour compression systems have been designed and developed by Al-Juwayhel et al., 2004 and reported that the two-stage indirect direct configuration achieved the best value of Energy Efficient Ratio among others. EI-Dessouky et al., 2004 designed and developed a two-stage indirect-direct evaporative cooling system and reported that high efficiency are obtained irrespective of the high intake air temperature. Two-stage evaporative cooler has been designed and tested by Jain 2007 for fruits and vegetable and reported that two-stage cooler can provide 20% better cooling when compared to single stage cooler and storage life of 14 days for tomato. Kulkarni and Rajput, 2011 designed and developed, a direct evaporative cooling system, an indirect evaporative cooling system and indirect-direct system (IDC/DEC) i.e. two-stage evaporative cooling system by placing indirect evaporative cooling in first stage followed by direct evaporative cooling in second stage and reported that two-stage evaporative cooling system was found more suitable in the climatic conditions of 39-46 °C and 37-46% RH. A regenerative type direct-indirect evaporative cooling system consisting of direct evaporative cooling in first stage and indirect evaporative cooling in downstream have been designed and developed by Jain and Hindoliya, 2012 and reported that this type of two-stage arrangement

Fig. 2 Representation of TSEC system on psychrometric chart



was more advantageous for providing thermal comfort in residential and commercial buildings. Kongre et al., 2015 have designed two-stage cooler cum cold storage and analyzed its performance in laboratory and reported drop in temperature from 36 to 23 °C in 195 min. They also reported that two-stage evaporative cooler provides overall good environment to store the perishable food and vegetables. In-house two-stage indirect-direct evaporative cooling system using plate heat exchanger in indirect section designed and cooling pad system (corrugated cellulose) in direct section have been developed and evaluated by Sadgir and Ghuge 2016, reported maximum temperature drop of 21.7 °C and maximum effectiveness of 92.5%. They also reported that indirect-direct evaporative cooling system gave best performance for hot and dry climate region in India. Earlier direct evaporative cooling type system was designed, developed and tested on commercial vehicle and maximum drop in temperature of 9.8 °C observed by Vala and Joshi, 2014. Hence to improve the efficiency of evaporative cooling system a systematic and scientific study was undertaken to design and develop a modified evaporative cooling system called two-stage evaporative cooling (TSEC) system in order to reduce losses of fresh fruits and vegetables during transport and increase its availability.

Concept and Design Considerations

The two-stage evaporative cooling system was particularly designed for fitting on commercial transport vehicle and to provide cooling environment to fruits & vegetables during distant transportation in order to minimize their post-harvest losses. Therefore, one of the popular commercial vehicle (EICHER, Model 10.9) considered for the design of the TSEC system. A laboratory simulation model was designed and fabricated using Theory of Model (Glenn, 1950). The two-stage evaporative cooling system has been designed considering the requirement of the total cooling load. The two-stage evaporative cooling model structure comprises of air supply duct and blower, cooling unit holder comprised of indirect cooling and direct cooling system, water distribution and circulation system, cooled air distribution duct, storage chamber, and other components. The indirect cooling (IDC) component is finned-tube type heat exchanger was fabricated as per calculated dimensions (643 × 547 × 80mm, 12FPS) using standard copper pipe and aluminum fins. The direct cooling unit (DEC) consists of wet-pad system and corrugated cellulose (CELdek, cross-fluted 45° × 15°) evaporating cooling pads (MUNTERS, Sweden).

Material and Methods

The two-stage evaporative cooling model structure designed as mentioned above has blower and air supply duct, cooling unit holder consists of indirect and direct cooling system, water distribution and circulation system, cooled air distribution duct, storage chamber, and other components. All the components of the TSEC structure have been fabricated using different mild steel sections and other materials. All the components were connected and fitted together to make a single unit. The water from a tank was circulated in indirect cooling (IDC) and sprayed over the evaporative cooling pad at a time through pump and pipelines. The various components and necessary arrangements to conduct the study are described as under.

Air Supply Duct and Blower

The shape of the supply duct is square at one end and circular at the other end as shown in **Fig. 3**. The dimension of supply duct is 350 × 643 × 547 mm with 500 mm circular opening at fan side. To supply air at different velocities, an axial fan (Make; Highcool, supply voltage: 230-50Hz/1.20A, power: 130-250W, RPM: 1380/8µF) was used. For regulation of speed of fan a Variable Frequency Drive (Make: Fuji electric, FRENIC-mini, Type: FRN0006C2S-7A0.5hp, single phase) was used.

Cooling Unit

For fitting of two cooling systems; heat exchanger and evaporative

Fig. 3 Schematic arrangement of two-stage evaporative cooling system

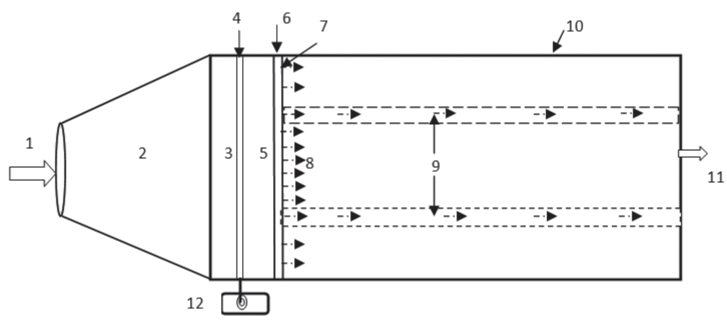


Fig. Top view

1. Entering outside air
2. Air Supply Duct
3. Indirect cooling system (IDC)
4. Primary cooled air
5. Direct Cooling System (DEC)
6. Cooled Air Carrying Duct
7. Perforated Plate
8. Cooled air entering in storage chamber
9. Channel
10. Closed Storage Chamber
11. Air outlet from top
12. Water Circulation System

cooling pad, a cooling unit was fabricated using mild steel material. The overall dimension of the cooling unit is 435 × 643 × 547mm. In this cooling unit heat exchanger is placed at first stage and evaporative cooling pad placed at the second stage. For placing & removing heat exchanger and EC pad, inside cooling unit, openable door was provided on both sides. This opening can be closed by placing plate with nut bolts and made air tight. At the top of the cooling unit holes were provided on either side for fitting of water spray pipe over the EC pad (**Fig. 3**).

The indirect cooling (heat exchanger) have inlet and outlet pipe for circulation of water. The average discharge from the outlet pipe measured and found 1.8 lpm. For holding pads of various sizes in the direct cooling unit after heat exchanger, supporting structure was provided for holding of pad of different thicknesses. For placing and removing pads, a plate type opening of 580 × 220 mm was kept to facilitate placing and removing of pad. Below the pad holder, water collection trough was provided to collect drain water from pad. An outlet pipe of 25 mm diameter was attached with trough at bottom and connected to water tank.

Storage Chamber

The size of the storage chamber was decided on the basis of simulation theory of model. On front side of the storage chamber, perforated vertical mild steel sheet was fixed and at the bottom, channel fabricated with necessary holes for entry of cooled air inside the storage chamber and on the back side, door was provided to facilitate loading and unloading. On the opposite side opening of 643 × 150mm having 25 × 25mm wire mesh provided for outgoing air. The overall dimensions of the storage chamber were 1476 × 643 × 547mm with a storage volume of 0.519 m^3 (**Figs. 3** and **4**).

Air Distribution Duct

For uniform distribution of cooled air inside the storage chamber a channel of dimension 180 × 110 × 40 mm at the bottom of the storage chamber was provided. Such two channels were provided inside the storage chamber (**Fig. 3**). Front side of the storage chamber is to be fitted with cooling unit. The arrangement for uniform distribution of cooled air was done on the basis of cooling whole material inside the storage chamber after loading. For outlet of cooled air from the bottom of storage chamber hole of 5mm were made at regular distance on both sides of it along the channel. Also holes of regular size were made on front side of the storage chamber. For outlet of air, wire mesh size of 25 × 25 mm was provided at the back of the storage chamber. Lowers were provided over outgoing air opening to check entry of outside air.

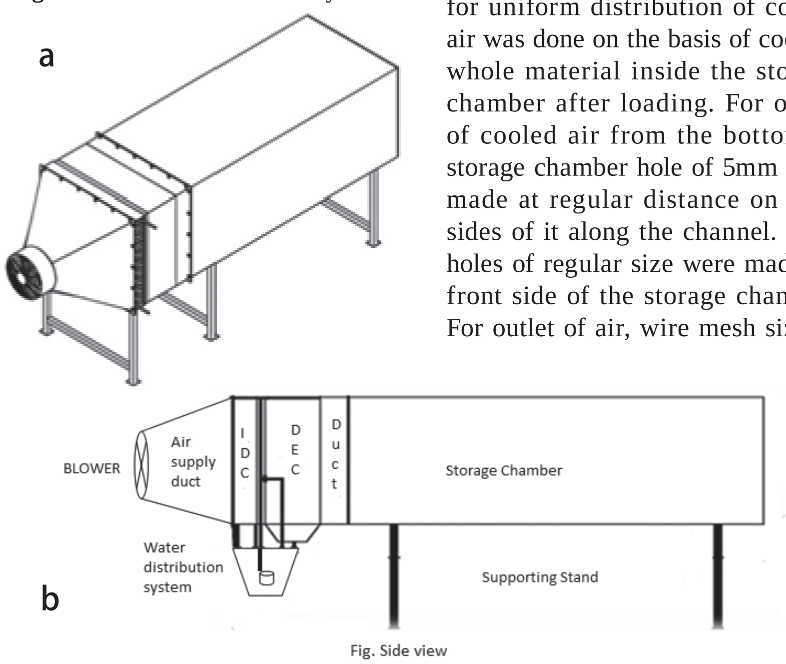
Water Distribution System

To supply and re-circulate water in HE and spray over EC pad, a water tank (capacity 25 liter) with submersible water pump (Voltage: 160-240/50 Hz, power: 12 W, head maximum: 1.65 m & discharge: 900 lph) was arranged. To regulate the flow of water over EC pad at the 3, 4 and 5 lpm water flow rate valves were kept in piping (**Fig. 4b**). Water coming out from IDC and DEC collected in water tank and re-circulated again.

Experimental Set Up

The storage chamber and cooling unit holder structure of developed TSEC system made close using mild steel sheet. Back side door was made air tight by fixing thermo-seal on the periphery of the frame and opening for outgoing air provided at the top. Also lowers fitted on the outgoing air screen to prevent back entry of outside air. The fan and supply air duct was fitted before cooling unit, cooling unit is placed before storage chamber. IDC system and pad fitted inside the cooling component. The water distribution system was arranged with a small submersible pump, necessary piping for circulation of water in IDC and spray system for evaporative cooling (DEC). For collection of water tank having 25 liter capacity was used and a small submersible water pump was used for circulation of water. The schematic arrangement of TSEC system is shown in **Fig. 3** as top view and side view. **Fig. 4a** is the isometric view of TSEC system. For performance evaluation of the developed TSEC system, water flow rate (discharge) was set to an average discharge of 3, 4 and 5 lpm. For supply of air at different velocities (40 kmph, 50 kmph, 60 kmph) an

Fig. 4 Isometric view of TSEC system



axial fan was used. The complete experimental set-up is shown in **Fig. 5**. The necessary arrangements for recording observations outside and inside the TSEC storage chamber were made. The data were analyzed with respect to effect of operating parameters on reduction in temperature, increase in relative humidity.

Results and Discussion

A. Performance Evaluation with No-loading

The two-stage evaporative cooling (TSEC) system as designed was evaluated for its performance with respect to three different air supply velocities (11.11, 14.00 and 16.70 m/s), three pad thicknesses (100, 150 and 200 mm) and three water flow rates (3, 4, and 5 lpm). The parameters which have been studied were drop in air temperature, relative humidity in the storage chamber, cooling efficiency of the system.

Effect of Operating Parameters on Temperature Drop

The overall highest temperature drop of 14 +2.9 °C was achieved for the 16.70 m/s supply air velocity, 200 mm pad thickness and 5 lpm water flow rate to direct cooling (DEC). On the other hand, the lowest air temperature drop of only 6 +1 °C was obtained for the operating set of 11.11 m/s air velocity, 100 mm thickness and 3 lpm water flow rate. The performance of the TSEC system is greatly affected by the variation in the air velocity, pad thickness and water flow rate.

Effect of Supply Air Velocity

Fig. 6 shows the drop in air temperature observed at different air velocities with respect to three pad thicknesses and water flow rates. It was observed that when air velocity was increased from 11.11 to 16.70 m/s, overall drop in air temperature increased with increased in pad thickness from 100 to 200 mm. The overall air temperature drop

Fig. 5 Fabricated TSEC system with set up

of 14 °C and 9 °C was observed as maximum and minimum for 16.70 and 11.11 m/s air velocity (**Fig. 6**). In general, among all test combinations significantly higher drop of temperature was achieved with 16.70 m/s air velocity as compared to other two air velocities tested for all the pad thicknesses and water flow rates. The difference in drop of air temperature for the 14.00 m/s and 11.11 m/s were significantly lower as compared to 16.70 m/s air velocity. Higher air velocity caused faster heat transfer with water coil

Fig. 6 Effect of air supply velocity on temperature drop

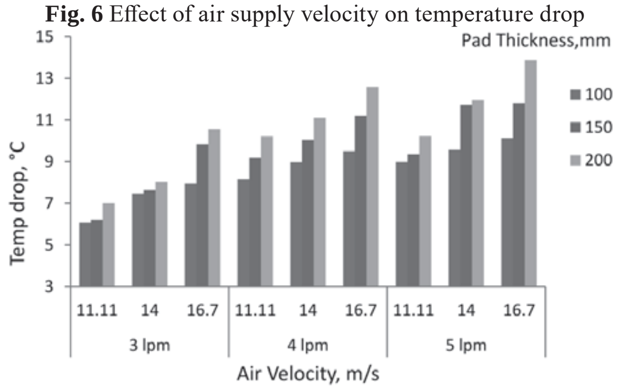


Fig. 7 Effect of pad thickness on air temperature drop

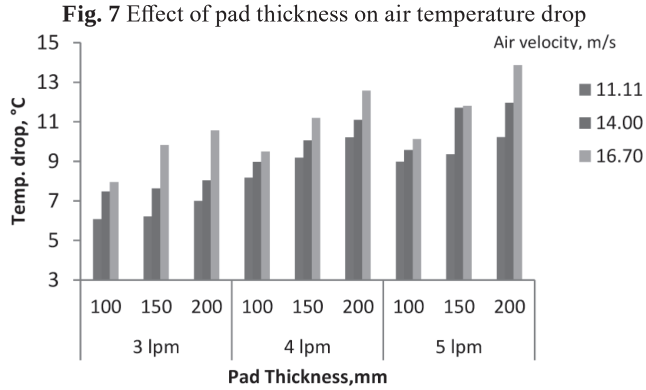


Fig. 8 Effect of water flow rates on temperature drop

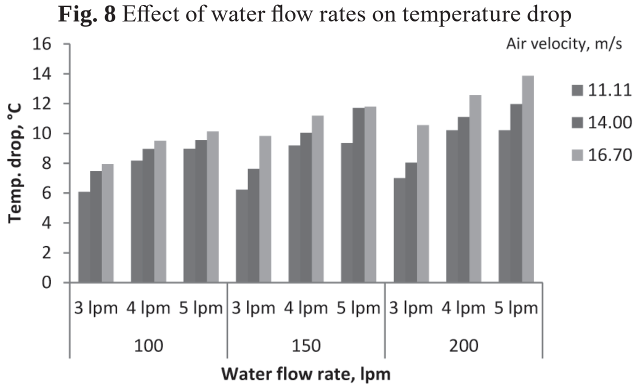
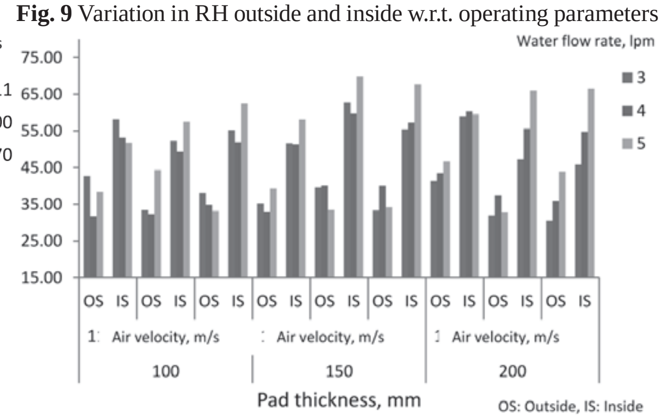


Fig. 9 Variation in RH outside and inside w.r.t. operating parameters



in IDC and more evaporation of water from thicker pad.

Effect of Pad Thickness

It was seen that when pad thickness was increased from 100 to 200 mm, the drop in air temperature also increased with increase in air velocity from 11.11 to 16.70 m/s (**Fig. 7**). The maximum drop of 11 °C achieved with 200 mm pad thickness, while the minimum of 6 °C drop of temperature was obtained for 100 mm pad thickness as shown in **Fig. 7**. In general, it was observed that when pad thickness was increased drop in air temperature increased for all the air velocities and water flow rates. The thick pad could have provided good air-water contact time within pad, resulted in higher drop in air temperature.

Effect of Water Flow Rate

When water flow rate was increased from 3 lpm to 5 lpm, drop in air temperature was increased with increase in pad thickness from 100 to 200 mm at 16.70 m/s air velocity (**Fig. 8**). Maximum drop of 14 °C was achieved for 5 lpm water flow rate, while the minimum of 8 °C drop in air temperature was obtained with 3 lpm water flow rate. In general, it was observed that when water flow rate was increased, drop in air temperature was increased with increase in pad thickness and air velocity for all the test combinations. Higher water flow may have kept wet pad fully saturated.

Effect of Operating Parameters on Increase in RH

The performance of the developed TSEC experimental unit was also evaluated for the increase in relative humidity of the air inside the storage chamber. Effect of three pad thicknesses, three air velocities and three water flow rates on variation in average relative humidity outside as well as inside the storage chamber is shown in **Fig. 9**.

The ambient average relative humidity was recorded between 31 and 47%, whereas, inside average relative humidity observed from 46% to 63%. Maximum average relative humidity of 63% obtained for 14.00 m/s air velocity with 150 mm pad thickness and 3 lpm water flow rate, whereas, the minimum average RH of 46% recorded for 16.70 m/s, 200 mm pad thickness and 3 lpm water flow rate. Also, from the statistical analysis it was found that the interaction effects of all test combinations of pad thicknesses, water flow rates and air velocities were found non-significant as far as increase in RH is concerned.

Cooling Efficiency of the System

The cooling efficiency of the system was computed by dividing the mean degree of cooling to wet-bulb depression of the supply air. The cooling efficiency of the TSEC system observed at three different air velocities, three pad thicknesses and three water flow rates shown in **Fig. 10**. The cooling efficiency of the system varied between 54% and 100% (**Fig. 10**). Among all test combinations significantly highest cooling efficiency was achieved with 11.11 m/s air velocity (with 200 mm pad thickness and 4 & 5 lpm) as compared to other two air velocities tested for all the pad thicknesses and water flow rates. However, the cooling efficiency for the 14.00 m/s and 16.70 m/s air velocity was significantly higher as compared to 11.11 m/s air velocity in most of the combinations.

The average cooling efficiency obtained at 3 lpm ranged from 54% to 81% for all the air velocities and pad thicknesses. At 4 lpm water flow rate, values of cooling efficiencies obtained between 63% and 96% with respect to all air velocities and pad thicknesses tested. Whereas at 5lpm water flow rate, cooling efficiencies observed between 73% and 100% during various combination of air velocities and pad thicknesses. In general higher cooling efficiency observed with higher air velocity and thicker pad.

B. Performance Evaluation of the System with Loading

The performance evaluation of the developed TSEC system was done with loading of different vegetables at the optimized combination of the operating parameters i.e. 16.70 m/s air velocity, 200 mm pad thickness

Fig. 10 Cooling efficiency of the TSEC w.r.t. operating parameters

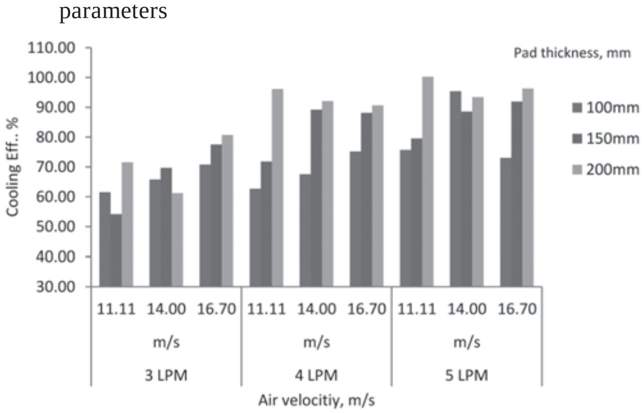
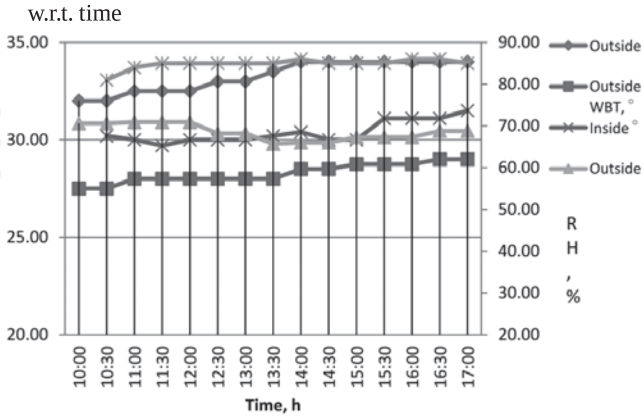


Fig. 11 Variation in temperature and RH inside storage chamber w.r.t. time



and 5 pm water flow rate. Five different vegetables viz; tomato, brinjal, bottle gourd, chilly and cucumber were selected. Vegetables were procured from the APMC, were sorted, cleaned and weighed. Two duplicate samples were prepared, one as control and other for loading inside the storage chamber. Before loading of the sample, the system was run for steady state condition and then vegetables were loaded inside the storage chamber and observations regarding variation in temperature and RH outside and inside the storage chamber were recorded. Air temperature and RH, inside the storage chamber was maintained 29 ±1 °C and 85 ±1.5 % respectively.

Variation in Temperature and Relative Humidity

The drop in air temperature inside the storage chamber initially decreased and then increased with advancement of time. The maximum and minimum drop in air temperature was observed 8.5 °C and 6.5 °C, respectively (**Fig. 11**) with average drop in air temperature of 7.8 ±1 °C. The relative humidity inside the storage chamber was initially decreased and then increased with advancement of time (**Fig. 11**). The maximum and the minimum percent increase in RH was observed as 71% and 25%, respectively, with average percent increase in RH of 48 ±15 above ambient air RH. The relative humidity inside the storage chamber was observed above 85% for most of the time. The statistical analysis (independent two sample t-test) for drop in air temperature and increase in RH showed significant at 5% level.

Physiological Loss in Weight

The initial weight of selected vegetable was recorded before and at the end of the day storage for both ambient and TSEC storage. The saving in physiological loss in weight (PLW) obtained with TSEC storage was compared with ambient and data are given in **Table 1**. The highest saving in PLW of 82% was observed for cucumber and least saving in PLW of 63% was observed for bottle gourd. The percent saving in PLW was observed higher for tomato, followed by cucumber, chilly, brinjal and bottlegourd. The percent saving in PLW was observed higher for tomato, followed by cucumber, chilly, brinjal and bottlegourd.

Shelf-life of Vegetables after TSEC

For study of shelf life, one set of vegetable was kept inside the room as control. Whereas the sample kept inside the TSEC storage chamber cooled for 18:00 h was immediately stored in incubator chamber set at 25 +2% °C and 85 +2% RH. Both the samples were physically observed daily till loss of their usefulness i.e. shriveling, colour change, spoilage. The observed shelf life of vegetables for control storage as well as incubator chamber is given in **Table 2**.

Shelf life of vegetables almost doubled with TSEC system as against control storage. The highest shelf life was achieved for bottle guard followed by tomato, cucumber, brinjal and chilly. Whereas, only 4 to 5 days of shelf-life was observed for ambient storage. The maximum percent gain in shelf life over control was observed with bottle gourd followed by cucumber, tomato, brinjal and chilly.

Conclusions

The drop in air temperature inside the two-stage evaporative cooling storage chamber was observed higher at the higher air velocities, higher pad thicknesses and higher water flow rates tested. The drop in temperature increased with the increase in air velocity, pad thickness and water flow rate. Based on research following conclusions can be drawn:

a) The two-stage evaporative cooling system can be used as an efficient unit for keeping the fruits and vegetables adequate cool during the transportation.
b) Operating parameters set of 16.70 m/s air velocity; 200 mm pad thickness and 5 lpm water flow rate gave highest temperature drop of 14 +3 °C as compared to others.
c) Maximum cooling efficiency (100%) was obtained at a combination of 11.11 m/s air velocity, 200 mm pad thickness and 5 lpm water flow rate while, minimum (54%) was obtained for 11.11 m/

Table 1 Saving in PLW with TSEC system

Produce	Physiological loss in weight (%)		% saving in PLW with TSEC over ambient/trip
	Ambient (control)	TSEC	
Tomato	10.0	3.0	70.5
Brinjal	3.5	1.2	65.0
Bottle Guard	2.0	0.7	63.0
Chilly	1.5	0.5	68.5
Cucumber	2.5	0.4	82.0

Table 2 Effect of TSEC on shelf-life of vegetables

Produce	Shelf life (days)		Gain in shelf life over control (%)
	Control (Ambient storage)	TSEC followed by control chamber storage	
Tomato	5	12	140
Brinjal	4	8	100
Bottle Guard	4	13	160
Chilly	4	8	100
Cucumber	5	10	150

s air velocity, 150 mm pad thickness and 3 lpm water flow rate.

d) The maximum relative humidity of 63% was obtained for a set of 14.00 m/s air velocity, 150 mm pad thickness and 3 lpm water flow rate, whereas, lowest RH of 46% was achieved for 16.70 m/s, 200 mm pad thickness and 3 lpm water flow rate.

e) The percent saving in PLW was observed higher for cucumber (82%), followed by tomato (70%), chilly (69%), brinjal (65%) and bottle gourd (63%).

f) The shelf life of vegetables TSEC storage over control was observed almost double, with bottle guard (160%) followed by cucumber (150%), tomato (140%), brinjal (100%) and chilly (100).

g) The developed TSEC systems can cool supply air below its wet bulb temperature, thus efficiency more than one.

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■■

Design and Development of an Indoor Soil Bin for Soil-engaging Tool Investigations

by
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Abstract

In this study, an indoor soil bin is developed for experimental soil-machine investigations. The soil bin was consisted of five main components, i.e., a fixed soil tank, a moving carriage, drive power transmission system, soil processing device, and control unit. The soil processing device consisted of a roller with variable weight for soil compaction. The moving carriage and the roller were driven by an electrical motor using a chain and sprocket system. The control unit included a load cell, inverter, and interface. For system performance evaluation, draft forces and power requirements of a plane blade were studied at several travel speeds. The blade was tested at a depth of 5 cm, rake angle of 90° and three travel speeds 1.8, 2.3 and 3.7 cm/s. The results obtained in this study showed that travel speed had considerable effects on draft force and power consumption. The results obtained by the developed soil bin was in accordance with the previous studies and it can be used as a reliable laboratory setup for further investigations on soil-engaging implements.

Keywords: soil bin, tillage, forces, draft, plane blade.

Introduction

The study of soil-machine interactions and soil dynamics can be conducted either in a soil bin or in real field. Soil bin is a laboratory setup useful in soil dynamics investigations, especially for agricultural soil-machine interaction studies (Clark and Liljedahl, 1968). Application of soil bin for soil-machine interaction studies was initially established by several research institutes, e.g., U.S. National Tillage and Machinery Laboratory (NTML), U.S. Army Tank Automotive Centre Land-Locomotive, the Vicksburg Waterway Experimental Station, and Caterpillar Tractor co. (Clark and Liljedahl, 1968).

In general, soil bins are divided into two classes, namely, outdoor (Lamande et al., 2007; Abdolmaleki et al., 2015) and indoor soil bins (Collins and Lalor, 1973; Onwualu and Watta, 1989; Mahadi, 2005; Ashrafi Zadeh, 2006; Gottland and Benoit, 2006; Yahya et al., 2007; Liu et al., 2007). In outdoor soil bins, experiments are affected by field and environmental conditions. Besides, the soil condition cannot be controlled. In contrast, indoor soil bins provide researchers with several benefits due to their capability of controlling the soil and environment conditions (Stafford, 1979).

In terms of design, indoor soil bins can be further divided into four groups. The first group consists of a fixed bin and a moving carriage (Godwin and Kilgour, 1980; Onwualu and Watta, 1989; Shikanai et al., 2000; Kawase et al., 2006; Rosa et al., 2008; Tiwari et al., 2009; Mardani et al., 2010). In this group, although the soil bin requires low space and power for the moving carriage, the design of the carriage is complex. The second group consists of a moving bin and a fixed carriage (Hermawan et al., 1998). In contrast with the first group, although the design of the carriage is not difficult, the bin requires higher power and more space. Furthermore, experiment conditions may vary during the investigations. The third group consists of a moving bin and a moving carriage (Stafford, 1979). This type of soil bin can provide relatively high-speed requirements for special studies. Finally, the fourth group is continuous soil bin (Batchelder et al., 1979) which has been used for soil erosion studies.

Several aspects of soil-tillage implement interactions can be studied using soil bins. As a pioneering research, Mamman and Qui (2005) studied the draft performance of a chisel plow model using a soil bin. The plow design parameters considered were: nose angle, slide angle, depth and travel speed.

The aim of this study was: (a) to design and develop an indoor soil bin facility with a fixed bin and a moving carriage, and (b) to evaluate the soil bin performance by investigating draft force and power requirements of a plane blade at different travel speeds.

Material and Methods

2.1. The Design Procedure of Soil Bin

The schematics of proposed indoor soil bin is depicted in **Figure 1**; as shown, the soil bin consisted of the following parts:

a) Soil tank. A rectangular bin was designed according to the Shoffer experimental method (Onwualu and Watta, 1989). Based on this method, and considering a maximum height of 20 cm and a width of 30 cm for soil-engaging tools moving in the bin, the effective inner dimensions of the soil bin were considered as 6 m (length), 1 m (width) and 0.5 m (height) where soil could be filled up to a height of 0.3 m. The tank frame was made from welded St-37 steel material. The longitudinal side walls of the tank were made of a transparent flat glass with 6 mm thickness to observe soil deformations during the experiments. Two 65 × 42 mm U profiles (DIN EN1026-1) were used on top of each longitudinal side of the bin for supporting the carriage and soil processing roller. Travertine stone material was placed at the bottom of the tank for proper drainage.

b) Carriage. The carriage body frame was made from welded St-37 steel material. The dimension of moving carriage was 0.9 m in width and 0.5 m in height, with total weight of 50 kgf. It was supported in the rails by four rigid wheels, which were installed at four corners of the carriage (**Figure 2**). The moving carriage was a double frame type, with inner and outer frames that could move vertically and laterally. The moving carriage had three degrees of freedom:

1) Longitudinal direction (X): the carriage was capable of moving forward and backward directions on the carriage rails using an electrical induction AC motor;
2) Lateral direction (Y): it was capable of moving by manual turning a steering wheel; and,
3) Vertical direction (Z): a vertical adjustment frame was designed to allow the adjustment of tool position along the vertical direction using a DC electrical motor. Adjustment in vertical position was achieved by turning the threaded rod clockwise or counterclockwise. The threaded rod was powered using an electrical motor which was fixed on the upper part of the outer frame (**Figure 3**).

c) Power transmission system. Two electrical motors were used for power transmission system. A 2 kW 380V-AC electromotor (100 L4A, MotoGEN, Iran) was used to move the carriage through the length of soil bin (X direction) by means of chain system. The carriage had the capability of traversing with a maximum speed of 10 cm/s. The output shaft of the electromotor was connected to the drive shaft of the chains which pulled the carriage forward or backward. An inverter was used to supply variable frequencies for the electromotor. A 1.5 kW 24V-DC electromotor (NSH-11D3, Bodine, USA) was used to move the inner frame of carriage at vertical direction by means of screw transmission (Tr 26 × 4). A manual handle was used to move the inner frame of carriage through the lateral direction by means of screw transmission (**Figure 2**).

d) Soil processing device. The initial state adjustment of the soil is a key for obtaining reliable data from soil bin-base experiments. To achieve this, a soil processing device was developed and installed in this study. The device consisted of a roller for controlled soil compaction. The roller was a 270 mm outer diameter steel pipe according to the ASME standard (ASME B36.12 Sch60). Two caps were connected at the two ends of the roller by welding process, on which some channels

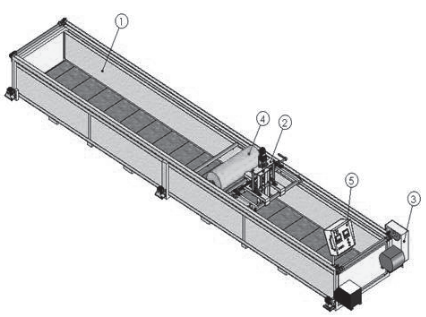


Fig. 1 Schematics of the soil bin unit

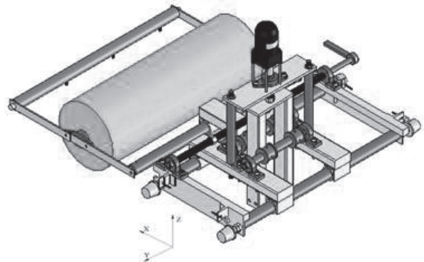


Fig. 2 Schematics of the moving carriage

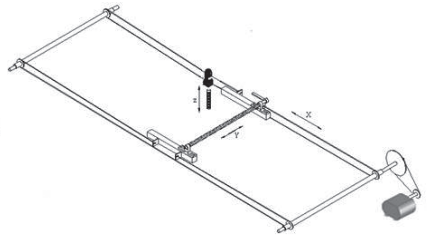


Fig. 3 Power transmission system used in the soil bin

were considered to charge the roller with sand to adjust its weight to obtain desirable soil compaction. The amount of soil compaction could be varied by increasing the vertical load applied to the roller by filling it with sand particles and adjusting its travel speed.

The soil characteristics in the soil tank were manually adjusted for each experiment. The soil surface was loosened using a hoe and then was leveled by a manual leveler before the experiments. Finally, the soil was compacted with the roller which was moved along with the carriage (**Figure 2**).

e) Control unit and instrumentation. A unit was considered for controlling the direction and travel speed of the carriage and the soil processing roller. A schematic view of the soil bin control unit is shown in **Figure 4**. The unit consisted of electrical components and an interface software. The electrical circuit elements consisted of two S-shaped load cells (DBBP, Bongshin, Korea) to measure soil horizontal (traction) and vertical deformations, two dataloggers (CAWL2RG, Camos, Iran) to transfer load cell data to a computer, an inverter (8300, Lenze, Germany) to supply variable frequencies for the electrical motor, two stop-start selector switches, and a contactor to activate the system. A graphical user interface (GUI) was developed as control software in Visual C environment for Microsoft Windows operating system. The software collected data from the dataloggers and produced a force time graph based on the data. The results were also recorded as a Notepad text file.

The constructed indoor soil bin in Laboratory of Soil-Machine Interactions in Department of Agrotechnology, College of Abouraihan, University of Tehran is depicted in **Figure 5**.

2.2. Experimental Conditions for System Performance Evaluation

To evaluate the system performance, several pre-experiments were carried out. The load cells were calibrated using dead weights before the experiments. To do this, linear regression analysis was used to find the relationship between dead weights and output data of the load cells. Excellent linearity with coefficients of determination (R^2) close to 1 was obtained during the calibration process. Calibration tests were conducted with three replications.

After calibrating the load cells, soil reaction forces on a plane blade with a length of 30 cm and a width of 10 cm in was studied (**Figure 6**). Soil properties in this study are presented in **Table 1**. Before the experiment, soil bed was processed using a hand hoe after water spraying, and then, was compacted by the roller. The mass of soil-compacting roller was considered equal to 100 kg. After that, the soil surface was covered with a plastic sheet for one day to allow uniform moisture throughout the soil. After the soil preparation, a hand operated soil cone penetrometer (ASAE EP542 FEB99) was used to measure the cone penetration resistance (ASAE, 2000). Measurements were carried out at five locations in the soil bin.

Table 1 Some physical characteristics of the experimental soil

Soil characteristics	Value
Soil texture	loam
Sand	34.6%
Silt	40.8%
Clay	24.6%
Particle density	1.3 g.cm^{-3}
Moisture content	16%
Cohesion	20 kPa
Adhesion	1.9 kPa
Frictional angle	35°

In this study, the soil-engaging tool was tested at the depth of 5 cm, rake angle of 90° and three travel speeds (1.8, 2.3, and 3.7 cm/s) to investigate the effects of travel speed on draft force. The experiment was conducted with three replications.

Experimental Results

The experiments were conducted using three different travel speeds for the determination of plane blade

Fig. 4 Schematics of the soil bin control system

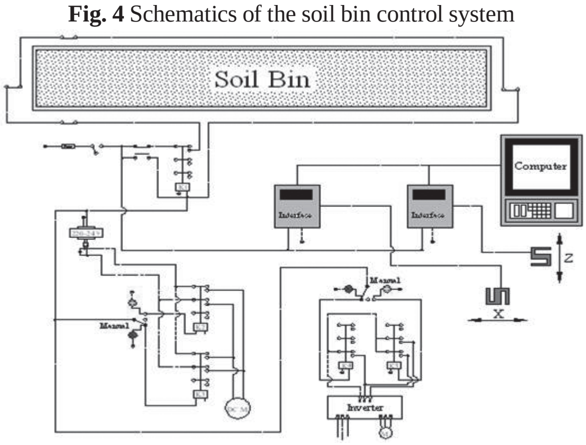
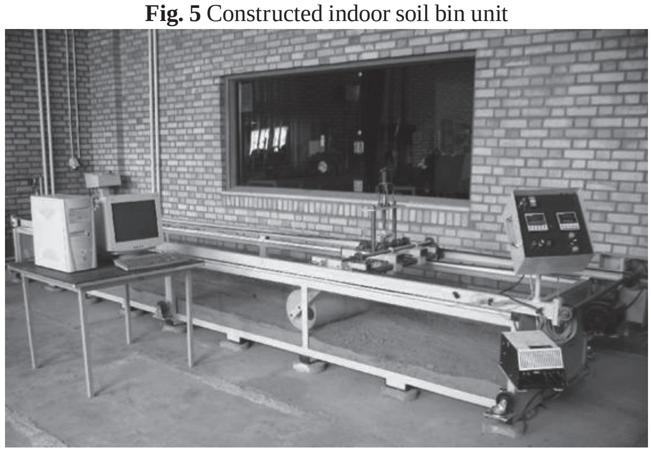


Fig. 5 Constructed indoor soil bin unit



draft force. This study was carried out to evaluate soil bin performance in soil-engaging tool investigations. The cone penetrometer resistance was obtained 30 ±2 N. The draft force versus time during the experiments are brought in **Figure 7**. According to the results obtained in this study, travel speed had major effects on draft force of blade so that draft force of blade increases by increasing the travel speed. Onwualu and Watts (1998) and Moeenifar et al. (2014) reported similar findings for draft force of plane tillage tools at several travel speeds. They found that blade speed had significant effects on draft force. According to the literature, three factors of weight, travel speed, and blade cut angle along with their interactions have significant effects on the draft force (Aykas et al., 2004).

Kheiralla et al. (2004) formulated a draft force model for plows based on travel speed and tillage depth; where the results were similar to the results obtained in this study. Furthermore, the effects of soil conditions, tillage depth and travel speed on soil translocation by chisel plow were studied by Van Muysen et al. (2000). Several models have been developed to predict draft for tillage tools based on soil condition, soil properties and implement width (Sahu and Raheman, 2006). Grisso et al. (1996) determined the draft force of a tandem disk, chisel plough and field cultivator in a silty clay loam soil in a wheat stubble field. Travel speed and tillage depth were used to study the draft of the tillage implements. They found the draft of the tillage implements is significantly affected by both travel speed and tillage depth.

The mean values of power consumption obtained at each travel speed are depicted in Figure 8. As shown, there is a linear relationship between travel speed and power consumption (R2 = 0.995). Draft force and power requirements of tillage implements are considerably affected by implement design and soil conditions (Moeenifar et al., 2014). Therefore, the results obtained by the developed soil bin is in along with the previous studies and it can be used for further investigations on soil-engaging implements.

Conclusion

A soil bin consisting of five main components, i.e., a fixed soil tank, a moving carriage, drive power transmission system, soil processing device, and control unit is designed and developed in this study. Results showed that the soil bin is a reliable device for investigations of depth and travel speed on behavior of soil-machine interactions. Although a plane blade is studied in this study, other soil-engaging tools can also be studied using the developed soil bin to obtain optimized and high-performance implements.

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Fig. 6 The plane blade traction experiment

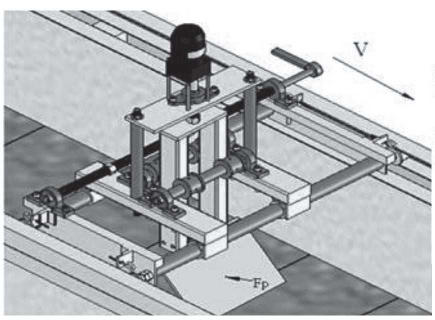


Fig. 7 The effect of travel speed on draft force of blade

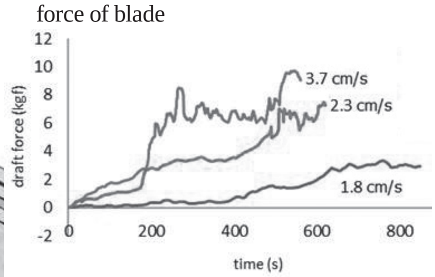
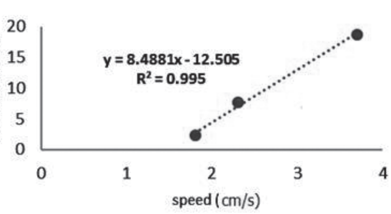


Fig. 8 Power consumptions versus travel speed



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■■

Application of a Parametric Method for Energy Use Pattern in Cassava Production in Nigeria

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Abstract

This study applied parametric equations to examine energy consumption in cassava production in three different farm sizes and technologies in Kwara State of Nigeria. Production data from 175 cassava farmers were collected through questionnaires during 2015-2017 cropping seasons. Selected cassava farms were divided into no-mechanization (small-scale; 1 to 5 ha), partial mechanization (medium scale; 6 to 15 ha) and fully mechanized (large-scale; 16 to 50 ha). There were 92 cassava farms in the no-mechanization category, partial mechanization category consisted of 54 farms and fully mechanized category consisted of 29 farms. Human labour, machinery, diesel fuel, chemicals, seed and fertilizers were considered as inputs that influenced cassava yield. Results of the study showed that cassava production used 4,904.87 MJ/ha in no-mechanization farms, 36,240.44 MJ/ha in partial mechanization farms and 96,257.93 MJ/ha in fully mechanized farms. The average energy output of cassava production in the study area was 107,632 MJ/ha, 604,800 MJ/ha and 2,016,000 MJ/ha in respective of the category of farm type. Energy input-output ratio was estimated as 16.13, 16.69 and 20.94 for the three groups of farm. Cobb-Douglas function was applied to determine effects of inputs on cassava outputs. Indirect energy and non-renewable energy contributed to yield more than direct energy and renewable energy in medium and large-scale farms. Empirical results revealed that human labour, fertilizers, chemicals and seed were statistically significant and contribute to yield.

Keywords: Agriculture, cassava, yield, energy use pattern, model

Introduction

Cassava (*Manihot esculenta*) is considered as the most popular tuber crop among all root and tuber crops grown in Nigeria. Globally, Nigeria is ranked the highest in cassava production with about 54 million metric tonnes therefore; cassava production has made significant contributions to the economy of Nigeria (Falola et al., 2016). Cassava also provides food security for families producing and consuming cassava and its products (Akinpelu et al., 2011). Harvested cassava tubers can be processed into many useful products for man, animals and industries (Adekanye et al., 2013).

Energy is defined as the capacity to do work, and it is required for all production of goods and services (Pishgar-Komleh et al., 2012). Energy in all its different forms is important for improvement of the society (Mohammadi et al., 2010). Crop production uses energy and supplies energy as bio-energy (Ebrahim, 2012). Agricultural energy analysis is increasing tremendously as human population increases hence, energy input and output relationship are necessary if adequate food and fiber must be provided to cater for the population. Energy use in agriculture depends on population involved, amount and size of cultivable lands, and stage of technology. Seeds, fertilizers, machinery, chemicals, human labour and diesel fuel used account for the energy inputs in agricultural production. Agricultural productivity is directly proportional to energy inputs (Mohammadi et al., 2010). Bayramoglu and Gundogmus (2009) opined that sustainability of agriculture largely depends on amount of energy input.

Many researchers have worked on

crop energy input-output. Demircan et al. (2006) studied analyzed energy inputs in sweet cherry production. Naeimeh et al. (2011) investigated energy use garlic production in Iran. Mohammadi and Omid (2010) examined energy inputs in cucumber production. Mousavi-avval et al. (2011) modeled energy flow in canola production. Rajabi-Hamedani et al. (2011) assessed energy use in potato production. Heidari and Omid (2011) used data envelopment method to determine efficiency of greenhouses. Pishgar-Komleh et al. (2012) examined energy use and CO_2 emission in potato production. Oladimeji et al. (2016) estimated energy use in 'egusi' melon production in Nigeria. Adekanye et al. (2020) reported energy efficiency and use of a parametric method for poultry production in Kwara State, Nigeria.

However, there is presently a dearth of research information on crop-energy input in Nigeria (Abubakar and Ahmed, 2010). Ibrahim and Ibrahim (2012) concluded that although there is no report on crop-energy use pattern in the country, yet such studies are necessary to combat hunger facing the populace. Therefore, there is a need for an evaluation of energy input-output in cassava farming systems in Nigeria. Energy use pattern in three different farm sizes and technologies were examined using Cobb-Douglas function. Furthermore, impacts of each of the inputs on yield were investigated and the correlation among various energy inputs and output were also examined.

This study involved energy expenditure in cassava production from tillage to harvesting, without considering other types of energy like rain, radiation, wind, etc. Age of equipment and machinery used in cassava production, energy used in processing cassava into different products and that used to transport farm materials to and from the farm was beyond the scope of this study. Generally, energy inputs in crop production are distinctly referred to as direct energy, indirect energy, renewable energy and non-renewable energy. Diesel fuel, electricity and human labour used in crop production processes represent direct energy (Farzad and Mohammed, 2012; Mobtaker et al., 2012). Indirect energy includes corporate energy in farmyard manure, machinery, fertilizers, seed, and chemicals. Fertilizers, chemicals, diesel fuel, and machinery represent non-renewable energy. Human labour, seeds and manure are grouped as renewable energy (Rajabi-Hamedani et al., 2011).

Material and Methods

This study was carried out in Kwara State of Nigeria. Kwara State is located in the North Central part of Nigeria. It lies between latitudes 7°45 N and 9°30 N and longitudes 2°30 E and 6°25 E (Oladimeji et al., 2016). Data used in this study were collated from 2015-2017 through questionnaires designed to obtain information on variables used in cassava production. Sample size was determined using the method described by Pishar-Komleh et al. (2012).

$$n = \frac{(\sum N_h S_h)}{N^2 D^2 + \sum N_h S_h^2} \quad (1)$$

where,

n = required sample size, N = number of farmers in the target population, N_h = number of farmers in the 'h' stratification, S_h^2 = variance of the 'h' stratification, $D^2 = d^2/z^2$ = permissible error in the sample population, defined to be 5% within 95% confidence interval, d = permitted error ratio deviated from average of population, z = reliability coefficient (1.96 which represent 95% confidence). A total of 175 cassava farmers were randomly selected for the study.

Cassava farms in this study were divided into no-mechanization (small-scale; 1 to 5 ha), partial mechanization (medium scale; 6 to 15 ha) and fully mechanized (large-scale; 16 to 50 ha). There were 92 cassava farms in the no-mechanization category, partial mechanization category consisted of 54 farms and fully mechanized category consisted of 29 farms. Human labour, machinery, diesel fuel, chemicals, seed and fertilizers were considered as inputs that influenced cassava yield.

Variables used for cassava production were specifically outlined to determine energy equivalent of each. Inputs used in the surveyed farms included chemicals, human

Table 1 Energy equivalents of inputs and output in agricultural production

Inputs	Unit	Energy equivalent (MJ)	Source
Human labour			
Man	Man-h	1.96	Canakci et al. (2005)
Woman	Woman-h	1.57	Canakci et al. (2005)
Machinery	kg	62.7	Canakci et al. (2005)
Diesel fuel	L	47.8	Canakci et al. (2005)
Total fertilizer			
Nitrogen	kg	66.14	Bamgboye and Babajide (2015)
Phosphate	kg	17.44	Bamgboye and Babajide (2015)
Potassium	kg	13.72	Bamgboye and Babajide (2015)
Chemicals			
Pesticides	kg	199	Rajabi–Hamedani et al. (2011)
Herbicides	kg	238	Rajabi–Hamedani et al. (2011)
Fungicides	kg	216	Rajabi–Hamedani et al. (2011)
Cassava sticks	kg	5.6	Demircan et al. (2006)

labour, machinery, diesel fuel, chemical fertilizers, seed and tubers (roots) as output. Energy equivalents of inputs and output in **Table 1** were used to calculate amount of inputs used. Equation 2 was used to calculate energy inputs by machines (e.g. tractors) per unit area.

$$ME = \frac{ELG}{TC_a} \quad (2)$$

(Pishgar-Komleh et al., 2012)

where,

ME = machine energy (MJ/ha), G = weight of machine (kg), E = production energy of machine (MJ/kg/year), L = useful life of machine (year), T = economic life of machinery (h) and C_a = effective field capacity (ha/h).

Energy use efficiency, energy productivity and specific energy for cassava production were calculated by using Equations (3) to (5), respectively to explore output-input energy and different forms (Mobtaker et al., 2012; Morteza et al., 2012; Hossein et al., 2013):

Energy use efficiency = Energy output (MJ ha^{-1}) / Energy input (MJ ha^{-1}) (3)

Energy productivity = Cassava output (kg ha^{-1}) / Energy input (MJ ha^{-1}) (4)

Specific energy = Energy input (MJ ha^{-1}) / Cassava output (MJ ha^{-1}) (5)

Cobb-Douglas function (Cobb and Douglas, 1928) was used to determine the correlation between energy inputs and yield. Cobb - Douglas production function is expressed in general form as:

$$Y = f(x)\exp(u) \quad (6)$$

(Mobtaker et al., 2012)

Eq. (6) can be transformed into Eq. (7):

$$\ln Y_i = a + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \; i = 1,2,3....n \quad (7)$$

where,

Y_i denotes the yield of the i^{th} farmer, X_{ij} the vector of inputs used in the production process, a, constant term, α_j represents coefficient of inputs which are estimated from the model and e_i is the error term.

On the assumption that energy input and cassava production are zero, Eq. (7) can be transformed into Eq. (8):

$$\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \; i = 1,2,3....n \quad (8)$$

Eq. (8) can be expressed as Eq. (9), with the assumption that a yield is a function of inputs energy:

$$\ln Y_i = \alpha_1 + \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + e_i \quad (9)$$

where,

X_1 = seed energy input, X_2 = human labour energy input, X_3 = machinery energy input, X_4 = diesel fuel energy input, X_5 = fertilizers energy input and X_6 = chemical energy inputs.

Cobb-Douglas function was also applied to assess the effects of direct, indirect, renewable and non-renewable energy as follows:

$$\ln Y_i = \beta_1 \ln DE + \beta_2 \ln IDE + e_i \quad (10)$$

$$\ln Y_i = \gamma_1 \ln RE + \gamma_2 \ln NRE + e_i \quad (11)$$

where,

Y_i = yield of the i^{th} farmer, DE = direct energy inputs, IDE = indirect energy inputs, RE = renewable energy inputs, NRE = non-renewable energy used for cassava production, β_1 and γ_1 = coefficients of variables and e_i is the error term.

Equations (9), (10) and (11) were determined by using ordinary least square method. Information obtained from farmers were recorded into Excel spreadsheet and analyzed with R software.

2.1 Management Practices in Cassava Farms in the Study Area

Management practices for cassava cultivation in the study area along with time periods of these practices are presented in **Table 2**. Group I belongs to the "no-mechanization farms" group where the cassava farmers employed manual labour mostly for tillage operations, planting, weeding, fertilizer application and harvesting. Group II belongs to the "partial mechanization farms" group where the cassava farmers employed machinery for tillage operations and manual labour mostly for planting, weeding, fertilizer application and harvesting. Group III belongs to the "fully mechanized farms" where the cassava farmers used manual labour and machinery for these operations; however, machinery was used for transportation of harvested tubers and farm workers during the growing season. All the farmers in this study area planted TMS 419 cassava variety.

2.2 Analysis of Energy Usage and Indices in Cassava Production

Table 3 shows average amount of

Table 2 Management practices of cassava in the study area

Operation	Group I	Group II	Group III
Land preparation period	February-March	February-March	February-March
Ploughing	Nil	Moldboard plough	Moldboard plough
Harrowing	Nil	Disc harrows	Disc harrows
Tractor used	Nil	MF 55hp	MF 55hp, MF 75hp
Planting time	April-August	April-August	Late March-Early September
Planting method	Manual	Manual	Manual, planter
Fertilizer and pesticide application	Manual (knapsack sprayers)	Manual (knapsack sprayers)	Manual and Boom sprayer
Weeding	Manual (cutlass and hoe)	Manual (cutlass and hoe)	Manual
Harvesting	Manual (cutlass)	Manual (cutlass)	Manual (cutlass), Harvester

inputs used for cassava production and outputs. Energy equivalents of inputs and output, per hectare basis in the farm groups are presented in **Table 4**. Total energy input for various processes in the no-mechanization farms group, partial mechanization farms group and fully mechanized farms group were calculated to be 4,904.87, 36,240.44 and 96,257.93 MJ/ha, respectively. In similar studies, Mohammadi et al. (2010) obtained 68,928 MJ/ha for corn production. Rajbi-Hamedani et al. (2011) obtained 39,232.79 MJ/ha for corn grain production in Iran. Bamgboye and Babajide (2015) obtained 7,388.6 MJ/ha from a study of ten small scale cassava farmers in Oyo State of Nigeria. Canakci et al. (2005) obtained 4, 950 MJ/ha for cassava production in Thailand. Pishgar-Komleh et al. (2011) calculated 47,000 and 79,300 MJ/ha as energy input and output for potato production in Iran. Table 4 also showed that energy input and output differs from one group to another. This is because farm sizes determine the amount of inputs required (Bamgboye and Babajide, 2015).

Table 4 also showed the distribution of the different energy used in the cassava farms. Energy equivalent in terms of human power used for cultivating one hectare of cassava in the No mechanization farms, Partially mechanized farms and fully mechanized farms gave a record of 120, 162 and 164 MJ/ha, respectively. Likewise 130 and 123 MJ/ha of machine power were used in partially mechanized farms and fully mechanized farms, respectively. Pishgar-Komleh et al. (2012) concluded that 911.2 MJ/ha of human power were consumed in potato production. Pishgar-Komleh et al. (2011), observed that human labour inputs varied between 90.56 and 421.5 MJ/ha. Bamgboye and Babajide (2015) opined that reduced energy inputs will results to yield reduction.

Results in **Table 4** also revealed that energy equivalent of 74,72.57 and 13,527.4 MJ/ha of diesel fuel were used in partially mechanized farms and fully mechanized farms, respectively. Diesel energy input increased in these two categories because many respondents in these groups used more machinery while farmers in the no-mechanization farms did not. Machines for ploughing, harrowing and ridging operations required diesel to operate. Tractors were used to transport farm workers and harvested crops.

Result also reveals that cassava production in the study area depends largely on manual labour as larger percentage of the farmers belonged to the no-mechanization farms. Human labour was mostly employed for field operations such as land preparation, planting, weeding, chemical application, fertilizer application and harvesting.

Table 5 presents energy indices and amount of different energy forms used for cassava production. Energy use efficiency for small, medium and large scale were estimated as 16.13, 16.69 and 20.94, respectively. Energy use efficiency increased with farm size. This implies that large size farms used energy efficiently. These agreed with

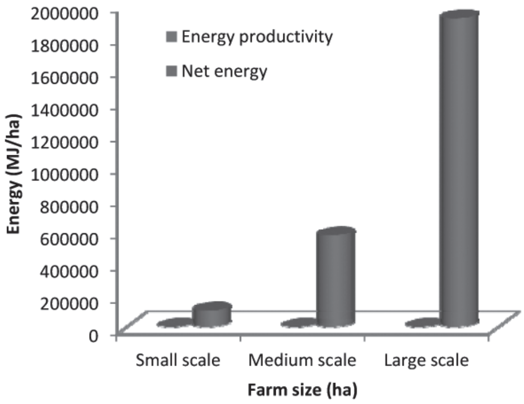
Table 3 Average amount of input and output in the cassava farms

Inputs	Farm size groups (ha)		
	Small (1-5)	Medium (6-15)	Large (>16)
A. Inputs			
1. Human labour	61.45	82.65	83.86
2. Machinery	-	2.07	1.96
3. Diesel fuel	-	156.3	283
4. Fertilizers			
a) Nitrogen (N)	3.72	17.45	76.43
b) Phosphate (P_2O_5)	10.51	23.74	111.76
c) Potassium (K_2O)	10.06	30.18	74.56
5. Chemicals			
a) Herbicides	1.49	1.73	1.73
b) Pesticides	1.52	1.67	1.67
c) Fungicides	0.77	1.65	1.65
6. Seed	606.01	13,022.41	9,481.35
Total inputs	695.53	13,339.88	10,117.97
B. Output			
Cassava output (kg)	19,220	108,000	360,000

Table 4 Average energy inputs and output in cassava production per hectare (MJ/ha)

Inputs	Farm size groups (ha)		
	Small (1-5)	Medium (6-15)	Large (>16)
1. Human labour	120.44	162.01	164.36
2. Machinery		129.80	122.90
3. Diesel fuel	-	7,472.57	13,527.4
4. Fertilizers			
Nitrogen (N)	246.04	1,154.14	5,055.74
Phosphate (P_2O_5)	183.29	414.02	1,949.09
Potassium (K_2O)	138.02	414.06	1,412.47
5. Chemicals			
Herbicides	354.62	411.74	411.74
Pesticides	302.48	332.33	332.33
Fungicides	166.32	356.4	356.4
6. Seed	3,393.66	25,393.37	72,925.5
Total energy input	4,904.87	36,240.44	96,257.93
Total energy output	107,632	604,800	2,016,000

Fig. 1 Energy productivity and net energy in the cassava farms



the submissions made by Pishgar-Komleh et al. (2011), Woods et al. (2010) and Canakci et al. (2005) who obtained 2.8 for wheat; Rajabi-Hamedani et al. (2011) who obtained 1.25 for potato; Pishgar-Komleh et al. (2012) who obtained 1.71 for wheat.

The average energy productivity values of 2.88, 2.98 and 3.74 kg/MJ were obtained for small, medium and large scale, respectively. This implies that 3.74 kg of cassava was produced per unit energy (MJ) in the fully mechanized farms. Hence, fully mechanized (large farms) can produce 0.52 kg and 0.76 kg output more than no-mechanization farms and partial mechanization farms, respectively.

Figure 1 shows that energy productivity and net energy increased significantly as the size of farms increased. This can be as a result of level of mechanization and management practices (Farzad and Mohammed, 2012). Hossein et al. (2013) estimated energy productivity of stake tomato and cotton to be 0.02 and 0.06, respectively. Yilmaz et al. (2005) obtained 0.06 for cotton and Erdal et al. (2007) obtained 1.53 for sugar beet.

2.3 Model Estimation of Cassava Production

Tables 6 to **8** present results of regression analysis for Equations (9) to (11) as Models I, II and III, respectively. Results revealed that each energy variable had different effects on cassava production. It was observed that certain energy inputs had positive effects on yield while chemicals had negative impacts on yield. Data collected in this study is cross-sectional. Durbin-Watson test was used to test for autocorrelation to establish that there was no correlation (Hossein et al., 2013). Durbin-Watson values obtained in the three models were less than 2, implying that there was no autocorrelation in the models at 5% significance level.

Results and Discussions

3.1 Results of Model I

In **Table 6**, human labour, chemical, fertilizer and cassava stem in one way or the other were found

Table 5 Energy input-output ratio in cassava production

	Unit	Small scale	Medium scale	Large scale
Energy ratio				
Energy use efficiency	-	16.13	16.69	20.94
Average energy productivity	MJ/ha	2.88	2.98	3.74
Net energy	MJ/ha	100,959	568,560	1,919,742
Energy forms				
Direct energy[a]	MJ/ha	120	7,634.56	13,691.76
Indirect energy[b]	MJ/ha	4,784.77	28,605.9	82,566.16
Renewable energy[c]	MJ/ha	3,514.1	25,555.4	73,089.86
Non-renewable energy[d]	MJ/ha	1,390.77	10,685.1	23,168.06
Total energy input	MJ/ha	6,673.21	36,240.4	96,257.93
Energy output	MJ/ha	107,632	604,800	2,016,000

a: includes human labour and fuel; b: includes seeds, machinery, chemicals and fertilizers; c: includes human labour and seeds; d: includes diesel fuel, chemicals, fertilizers and machinery

Table 6 The estimation results for Model I and their coefficients

Model I	$\ln Y_i = \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + e_i$								
Farm	No-mechanization			Partial mechanization			Fully mechanized		
Independent variables	α_i	t	P vaule	α_i	t	P vaule	α_i	t	P vaule
Human labour	0.18	7.523	0.001564**	0.017	1.879	0.06660	0.144	2.645	0.0148*
Chemical	0.02	3.264	0.000593***	-0.007	-0.784	0.437	0.045	5.45	1.83e-05***
Fertilizer	0.016	3.522	0.000682***	0.259	7.794	5.97e-10***	0.028	0.767	0.4513
Cassava stem	0.95	9.044	3.33e-14***	0.647	3.318	0.0018**	0.714	0.074	0.4826
Machinery				0.664	2.398	0.0218*	0.271	1.078	0.293
Fuel				0.173	1.082	0.285	0.011	0.038	0.970
R^2	0.892			0.926			0.952		
Durbin-Watson	1.82			1.73			1.83		
VIF_{max}	6.86			7.47			7.52		

*** significance at 0.1%, ** significance at 1%, * significance at 5%

significant and had positive effects on cassava yield. This implies that the dependent variables of the model in the case of no-mechanization farms had positive effects on the energy output. That is, an increase in any of the variables will result to an increase in the energy output. R-squared value obtained for model I was 0.89 showing that about 89% of the variability in the total yield was predicted by the model equation. The Durbin Watson Statistic value obtained indicates no autocorrelation at 5% significant level.

In the case of partial mechanization farms, all the coefficients had positive effects on cassava yield except for chemical energy input. This implies that increase in human labour, fertilizer, cassava sticks, machinery and fuel energies will increase the amount of output while an increase in chemical energy input will reduce output by 0.007%. Fertilizer, cassava sticks and machinery variables were significant at 0.1%, 1% and 5% significant level, respectively. The R-squared value obtained was 0.93 in this case and the Durbin Watson statistic value obtained indicates no autocorrelation at 5% significant level.

In the case of fully mechanized cassava farms, all the coefficients had positive effects on cassava production. Human labour and chemical energy inputs were significant at 5% and 0.1%, respectively. The variable with the highest impact was cassava sticks followed by machinery. It can therefore be inferred that an increase in any of the variables for this category will lead to an increase in the energy output. The R-squared value obtained was 0.95 and the Durbin Watson Statistic value obtained indicates no autocorrelation at 5% significant level. Maximum variance inflation factor for each group was less than 10; hence, independent variables in were not related. White test statistic showed that there is no heteroscedasticity.

3.2 Results of Model II

Table 7 presents analysis of direct energy (DE), indirect energy (IDE), renewable (RE) and non-renewable (NRE) energies. Impacts of direct and indirect energies were 0.114 and 0.029, respectively in no-mechanization farms. These results indicated that an increase in the different forms of energies led to 0.114% and 0.029% increase in cassava yield. The Durbin-Watson statistic value obtained was 1.81 at 5% significant level (no autocorrelation) while the R-squared value obtained was 0.81. **Table 7** also revealed that indirect energy (IDE) had more impact than direct energy (DE) in group II and III farms. This result was similar with (Heidari and Omid, 2011).

Direct energy and indirect energy were positive with the variable of highest impact being indirect energy in the partial mechanization farms. Thus, an increase in either variable implies an increase in the energy output. The coefficients of both variables were significant at 5% and 0.1% significant levels, respectively. Durbin-Watson and R-squared values obtained were 1.88 and 0.89, respectively at 5% significant level.

In the case of fully mechanized farms, both DE and IDE were positive with the variable of highest impact being IDE. The coefficients of both variables were significant at 0.1% and 1% significant levels, respectively. The Durbin-Watson statistic value obtained was 1.86 at 5% significant level showing no autocorrelation while the R-squared value obtained was 0.88. Maximum variance inflation factor (VIFmax) was observed to be less than 10 indicating that independent variables were not related. White test statistic showed that there is no heteroscedasticity.

3.3 Results of Model III

In the case of no-mechanization farms as shown in **Table 8**, renewable energy (RE) and non-renewable energy (NRE) had positive effects on cassava yield. With RE having the greatest impact and is statistically significant at 0.1% significant level. This means that an increase in either RE or NRE will result to an increase in the energy output. The Durbin-Watson statistic value obtained was 1.97 at 5% significant level (no autocorrelation) while the R-squared value obtained was 0.741.

In the case of partial mechanization farms, renewable energy and nonrenewable energy had positive effects on cassava yield. Thus, an increase in either variable implies an increase in the energy output. The coefficients of both variables were significant at 5% and 0.1%, respectively. The Durbin-Watson statistic

Table 7 Estimation for model II and their coefficients

Model II	$\ln Y_i = \beta_1 \ln DE + \beta_2 \ln IDE + e_i$								
Farm	No-mechanization			Partial mechanization			Fully mechanized		
Independent variables	β_i	t	P vaule	β_i	t	P vaule	β_i	t	P vaule
DE[a]	0.114	0.95	0.335	0.035	2.117	0.0393*	0.132	12.008	4.13e-12***
IDE[b]	0.029	11.54	<2e-16***	0.872	12.196	<2e-16***	0.45	2.781	0.00994**
R^2			0.811			0.885			0.875
Durbin-Watson			1.81			1.88			1.86

a - includes human labour and diesel fuel energies, b - includes machinery, fertilizer, seeds and chemical energies
*** significance at 0.1%, ** significance at 1%, * significance at 5%

value obtained was 1.83 at 5% significant level indicating absence of autocorrelation while the R-squared value was 0.89.

In the case of fully mechanized farms, renewable energy and non-renewable energy had positive effects on cassava yield. Thus, an increase in either energy results to an increase in the energy output. The renewable energy input was significant at 0.1%. The Durbin-Watson statistic value obtained was 1.544 implying no autocorrelation at 5% significant level while the R-squared value obtained was 0.838.

Conclusion

A parametric method was applied to examine energy use in cassava production in three different farm sizes and technologies in Nigeria. It was discovered that cassava production consumed a total energy of 4,904.87 MJ/ha in no-mechanization farms (small scale farms), 36,240.44 MJ/ha in partially mechanized farms (medium scale farms) and 96,257.93 MJ/ha in fully mechanized farms (large scale farms). The energy outputs were 107,632 MJ/ha, 604,800 MJ/ha and 2,016,000 MJ/ha respectively.

Energy ratio (energy use efficiency) obtained for groups I, II and III farms were 16.13, 16.69 and 20.94, respectively. Energy productivity obtained for groups I, II and III farms were 2.88 MJ/ha, 2.98 MJ/ha and 3.74 MJ/ha, respectively while net energy was estimated to be 100,959 MJ/ha for no-mechanization farms, 568,560 MJ/ha for partial mechanization farms and 1,919,742 MJ/ha for fully mechanized farms. Large-scale farms utilized energy efficiently than medium and small-scale farms. Indirect energy and non-renewable energy had higher impacts in mechanized categories than direct energy and renewable energies. The reverse was the case in no-mechanization farms.

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Table 8 Estimation for model III and their coefficients

Model III	$\ln Y_i = \gamma_1 \ln RE + \gamma_2 \ln NRE + e_i$								
Farm	No-mechanization			Partial mechanization			Fully mechanized		
Independent variables	γ_i	t	P vaule	γ_i	t	P vaule	γ_i	t	P vaule
RE	0.298	3.696	0.000376***	0.112	2.61	0.0119*	0.104	10.26	1.24e-10***
NRE	0.104	10.906	<2e-16***	0.345	12.9	<2e-16***	0.725	0.703	0.488**
R^2			0.741			0.893			0.838
Durbin-Watson			1.973			1.83			1.544

*** significance at 0.1%, ** significance at 1%, * significance at 5%

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Development and Evaluation of Tractor Drawn Farmyard Manure Applicator Cum Rice Planter

by

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Abstract

Tractor-drawn farmyard manure (FYM) applicator cum rice planter was designed and developed to apply an accurate quantity of FYM in the band form with simultaneously planting of rice seeds in the field. The developed FYM applicator cum planter had an FYM hopper capacity of 300 kg and was pulled by 50 hp tractor. The rectangular orifice of size 50 × 72 mm with an adjustable sliding plate was used for the band placement of FYM. An agitator type feeding mechanism for FYM was provided. The metering of FYM was maintained by the opening of orifice. An inclined metering plate was used to meter the rice seeds. The power transmission system, consisting of a chain and sprocket mechanism, the ground wheel was provided to get power from tractor forward speed. The FYM applicator cum planter had nine tine shovel type furrow opener to place the FYM in band form. Inverted 'T' type furrow opener was used to place the seeds with individual seed box for each furrow opener. A countershaft was fixed which takes drive from the ground wheel and to rotate agitator. The developed applicator was evaluated in the field for the Recommended Dose of Nitrogen (RDN) for rice.

The experiment was held to know about the effect of machine parameters on application rate and band placement of FYM on Kharif rice during the year 2018 and 2019. The treatments comprised two FYM application methods i.e. (manual broadcasting and FYM applicator cum planter) with control and three doses (100%, 75% and 50% RDN). Application rate suited for rice crop at different nitrogen doses through farmyard manure was observed with the combination of orifice opening and forward speed of operation at selected moisture content and applications in the field. The machine was tested in well-prepared land. The bulk density of soil was observed as 1,412 kg/m^3 at and moisture content of 19.1% wb. The average draft of the applicator for the FYM application was recorded 347 kgf. The average bandwidth of FYM was found to be 115 mm which clearly shows that shovel type furrow opener satisfactorily covered the opened furrow width by FYM band in the soil. Rice yield at 75 % RDN through FYM applicator cum planter was at par to the 100% RDN through manual broadcasting of FYM. Therefore 25% of farmyard manure was saved through uniform application of FYM in band form. The effective field capacity of tractor-drawn FYM applicator was found to be 0.81 ha/h with field efficiency 70.1% at the forward speed of 5.74 km/h. The cost of FYM application and seeding operation through FYM applicator cum planter was ₹ 1,080/ha and required 4 men-h/ha. The traditional method of FYM spreading and sowing with tractor-drawn inclined plate planter required additional ₹ 875/ha. The developed machine saved cost and energy were 52 and 41% respectively as compared to the traditional method of FYM application and seeding operation. The machine was found economical and energy-efficient. An increase in orifice opening and moisture content it increases the FYM application rate. The farmyard manure application rate was decreased with increasing forward speed and decreasing moisture content. FYM application rate per unit area was significantly affected by the forwarding speed of the machine and moisture content of FYM.

Introduction

Organic farming improves soil health by improving the physical properties; increasing soil aggregation, water holding capacity, hydraulic conductivity etc. (Singh and Thomas, 2010). The farmyard manure is the major alternatives for organic farming with higher plant nutrients. However, the application of this organic fertilizer is not easy due to lack of proper application machines. The application of farmyard manure is a basic input operation in crop production. The excessive use of chemical fertilizers adversely affects soil health. Manure improves biological activity, soil tilth, soil chemical properties and soil fertility. FYM application in fields needs uniform application in band form into the soil surface at a predetermined depth. The factor affecting the quality of the crop in mechanized crop production systems is the fertilizer application and planting operation. The more precise the FYM application with improved planter, the better the quality of crop harvested and there is also a reduction in the cost of sowing operation, thinning and gap-filling afterward. The availability of mechanical devices for spreading farmyard manure is not commercialized in India (Dhaiwal and Madan, 2004). Commercial types of equipment have not distributed the manure uniformly. They are having a large coefficient of variation (Hansen et al., 2004; Thirion et al., 1998). Exposure of manure in the air releases the ammonia and greenhouse gases. Immediately covering the manure within the soil should be necessary with harrowing or some other technique (Sapkale et al., 2010). Singh et al. (2013) conducted an experiment to determine the effect of band placement of farmyard manure (FYM) on autumn planted sugarcane. The obtained result showed that the 15 t/ha of band application of FYM can help to produce the statistically similar cane yield as the recommended rate of 20 t/ha. Reddy et al. (2013) suggested that agitator contains the agitator rods were assembled as the circular pattern in agitator shaft at the fixed interval with a sliding plate mechanism to control manure delivery rate to the spreading unit. To date, no metering mechanism is available for granular application of FYM in band form in the furrow. Keeping in view these problems, an FYM applicator cum planter was developed and evaluated at Indira Gandhi Agricultural University, Raipur. This machine was proposed to quantify the rate of application of FYM during the operation and apply uniformly, covering the surface of the field in band form and the sowing of seeds simultaneously.

Material and Methods

The developed machine is shown in **Fig. 1**. The tractor-drawn FYM applicator cum planter consisted of an FYM hopper, an agitator metering unit, seed box, inclined plate seed metering unit, a shovel assemble for FYM, an Inverted ‘T’ type assembly for seed, a box section mainframe, gauge wheel and box section iron planker.

Table 1 Physico-chemical properties of the experimental FYM

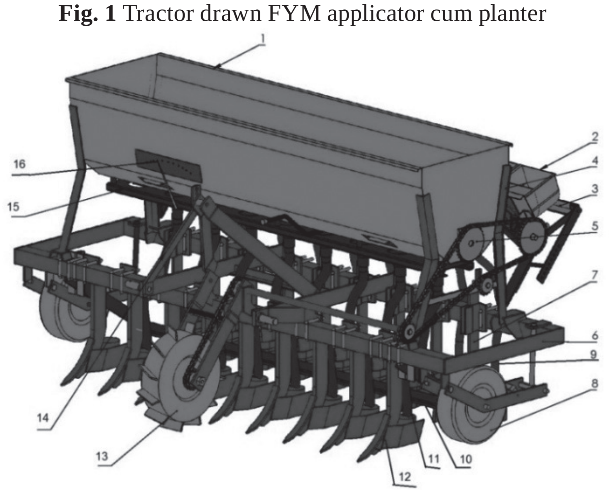
Contents, %	FYM
Nitrogen	0.65
Phosphorus	0.20
Potassium	0.50

The FYM hopper, with a capacity of 300 kg, was fabricated to store the FYM and with an agitating unit. A tractor of 50 hp was used to drive the FYM applicator cum planter. The hitching system was given to the implement which was a hitch to the tractor with a three-point hitch link. Tines of shovels were mounted on the mainframe their spacing was adjustable according to the row distance of crop. The depth of the FYM application can be varied with the help of the gauge wheel of the applicator. FYM was applied in band form and surface incorporation was done with box section iron bar behind of shovel assembly. The seed was sown on the band of FYM within the row. Seed spacing was adjusted with the help of an appropriate number of teeth of sprocket used in seed metering shaft.

Chemical Analysis

Chemical analysis was done in

Fig. 1 Tractor drawn FYM applicator cum planter



Part/Assembly name: 1. FYM hopper, 2. Seed box, 3. Seed box frame, 4. FYM hopper frame, 5. Power transmission system, 6. Mainframe, 7. Inverted 'T' type furrow opener (for seed), 8. Gauge wheel, 9. Seed delivery tube, 10. Planker (Box section iron), 11. FYM delivery tube, 12. Shovel type furrow opener (for FYM), 13. The drive wheel, 14. Three-point hitch link, 15. Funnel plate, 16. Orifice opening position indicator.

the dried form of FYM is presented in **Table 1**. The availability of nitrogen in experimental FYM was measured using the alkaline $KMnO_4$ method (Subbaiah and Asija, 1956). Phosphorus was also measured, using the Olsen's method, described in (Olsen et al., 1954). The availability of potassium in the FYM was determined by using the flame photometric method (Hanway and Heidle, 1952).

Laboratory Evaluation

The developed machine was tested for the FYM application rate in t/ha and bandwidth in mm. To test the application rate of FYM at different forward speeds, a polythene sheet having a size of 20 m (4 m was spread on the ground as shown in **Fig. 2**. Parameters of laboratory evaluation are presented in **Table 2**.

Experimental Details

FYM agitator crushes and delivers the FYM to the shovel type furrow opener to apply FYM in band form on a tilled field. Then the furrows were covered by soil with the help of a 50 mm box section iron bar (**Fig. 3**). Inverted 'T' type furrow opener was attached on the frame behind the shovel type furrow opener for the sowing of the rice seeds. For experimental purpose field size of (130 × 58 m) was used to investigate the performance of the developed FYM applicator cum planter for crop production. A total of five treatments and four replications were used in RBD design. The performance was studied based on a statistical analysis of different treatments. Rice crop was used in this study, the distance between tines was kept 22.5 cm. Spacing between two hills was 10 cm. To study the behavior of developing plants under different treatments, five plants were tagged at random in each plot for individual plant study. Data about the effect of different treatments on growth characters, yield attributes and yields were analyzed. Details of treatment and experimental details are presented in **Table 3**. The physic-chemical properties of soil of the experimental field are presented in **Table 4**.

In the experiment field during *Kharif* season, after the FYM application cum planting operation the flood irrigation was given. The plots were maintained at 5 ±2 cm during vegetative growth and development phases. To maintain the experimental area weed-free, weeder was employed twice in the entire experimental field at 25 and 35 DAS in

Fig. 2 Laboratory test of FYM applicator cum planter

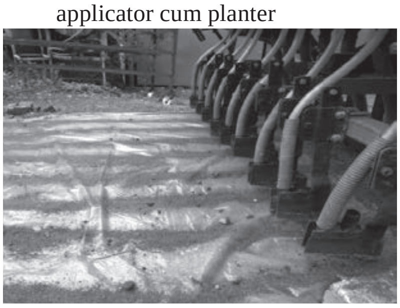


Fig. 3 FYM applicator cum planter in actual use

Table 2 Level and number of independent variables and dependent variables in the study

S. No.	Independent variables	Levels	Particular	Dependent variables
FYM parameters				
1	Orifice opening position	4	1/4th, 1/2nd, 3/4th and full	Application rate Bandwidth
2	MMD of FYM clod	4	37 mm	
3	Forward speeds, km/h	3	2, 4, 6	
4	Moisture content	3	31, 21 and 13 % db FYM	

Table 3 Details of treatments and other experimental details

Crop	Rice
Variety	IR 36
A. Treatments	Symbol
1. 100 % RDN through FYM by manual broadcasting then use planter	T_1
2. 100 % RDN through FYM by tractor-drawn FYM applicator cum planter	T_2
3. 75 % RDN through FYM by tractor-drawn FYM applicator cum planter	T_3
4. 50 % RDN through FYM by tractor-drawn FYM applicator cum planter	T_4
5. Control	T_5
B. Experimental details	
1. Experimental design	RBD
2. Field size	(130×58) m^2
3. Plot size	(28×12) m^2
4. Plant geometry	
a) Row to row spacing (cm)	22.5
b) Plant to plant spacing (cm)	10

Table 4 Physico-chemical properties of soil of the experimental site

Properties	Values
A. Physical properties	
1. Mechanical composition	
Sand (%)	22.10
Silt (%)	30.36
Clay (%)	47.54
Texture class	Vertisols
2. Bulk density (g/cc)	1.42
B. Chemical properties	
3. Organic carbon (g/kg)	0.62
4. Available N (kg/ha)	231
5. Available P (kg/ha)	21.60
6. Available K (kg/ha)	411
7. pH (1:2.5) Soil: water suspension	6.90
8. E.C. (ds/m)	0.14

rice. Pre-harvest data viz. plant population (No./m^2), plant height (cm), number of the tillers/hill and Leaf area index (LAI) were recorded. To avoid border effect the lengthwise two rows from both sides and widthwise two hills of the gross plot were removed to record post-harvest data viz. The number of effective tillers/hill, panicle length (cm), panicle weight (g), filled, unfilled and total grains/panicle, sterility percentage, test weight (g), grain and straw yield (q/ha) and harvest index (%).The remaining plant of the net plot was harvested manually by using a sickle and the crop was left in the field for sun drying for two days. After bundling, the produce was weighed plot-wise. Threshing was done manually with the help of wooden sticks. The material threshed from each plot was kept separately and grain was separated from the chaff and straw by winnowing after this the cleaned grains were weighed treatment wise on an electronic balance.

Results and Discussion

FYM Quantity Required

Different crops required different quantities of FYM, applying in terms of kg/ha. The FYM applicator cum planter was tested for rice. Rice crop requires 5 to 20 tonnes of FYM per hectare as it depends on soil quality. At present work, the FYM was applied based on the recommended dose of nitrogen for rice crops. Nitrogen (N) was applied as 100%, 75% and 50% of the recommended dose. The recommended dose of nitrogen was taken as 80 kg/ha, which indicate 100% N. Further, application of N was 60 kg/ha and 40 kg/ha which comes under 75% and 50% N. row to row spacing of the machine for rice crop should be considered as 225 mm. FYM was analyzed at zero percent moisture content to determine the NPK. From **Table 5** it is seen that FYM application rate decrease with a decrease in moisture content for all the recommended dose of nitrogen (RDN).

Experimental Design Observation

Application Rate

Tractor drawn prototype FYM applicator cum planter was calibrated in the laboratory. Desired FYM application rate was adjusted by the orifice opening position of applicator viz. 18, 36, 54 and 72 mm as 1/4th, 1/2th, 3/4th and full, respectively. A laboratory test was taken at 31% db, 21% db and 13% db of FYM for application rate and band-

Table 5 FYM quantity required as per recommended dose of nitrogen

RDN, %	N, kg/ha	FYM, kg/ha			
		00 % db	31 % db	21 % db	13 % db
(1)	(2)	(4)	(5) = (4) × 1.5	(6) = (4) × 1.3	(7) = (4) × 1.2
100	80	12,308	17,965	15,643	14,126
75	60	9,231	13,474	11,732	10,621
50	40	6,154	8,983	10,621	7,081

Table 6 Obtained mean application rate and results of ANOVA table for application rate of the selected parameters during the laboratory test

	A_1				A_2				A_3			
	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4
C_1	6.21	8.633	15.13	20.40	7.12	10.02	16.89	23.24	8.11	11.32	19.58	24.93
C_2	3.17	6.830	13.85	17.85	3.65	7.35	14.96	19.54	4.14	8.76	16.80	20.40
C_3	1.77	5.06	10.51	14.84	2.06	5.63	12.68	16.85	2.26	6.52	12.85	17.21

	CD (p < 0.01)	SE (m)
Factor (A)	0.100	0.036
Factor (B)	0.116	0.041
Interaction A × B	0.201	0.071
Factor (C)	0.100	0.036
Interaction A × C	0.174	0.062
Interaction B × C	0.201	0.071
Interaction A × B × C	0.348	0.123

A = Moisture content (% db), B = Orifice openings, C = Forward speed of tractor, A_1 = 13% db, A_2 = 21% db, A_3 = 31% db, B_1 = 1/4th opening, B_2 = 1/2nd opening, B_3 = 3/4th opening, B_4 = full opening, C_1 = 2 km/h, C_2 = 4 km/h, C_3 = 6 km/h

Table 7 Mean bandwidth and results of ANOVA for FYM bandwidth of the selected parameters during the laboratory test

	A_1				A_2				A_3			
	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4
C_1	35	57	91	115	34	55	90	110	33	53	87	110
C_2	33	54	80	102	32	53	81	100	31	51	77	97
C_3	32	52	76	100	30	49	71	90	29	46	71	90

	CD (p < 0.01)	SE (m)
Factor (A)	2.057	0.729
Factor (B)	2.375	0.842
Interaction A × B	N/A	1.459
Factor (C)	2.057	0.729
Interaction A × C	N/A	1.264
Interaction B × C	4.114	1.459
Interaction A × B × C	N/A	2.527

A = Moisture content (percent db), B = Orifice openings, C = Forward speed of tractor, A_1 = 13 percent db, A_2 = 21 percent db, A_3 = 31 percent db, B_1 = 1/4th opening, B_2 = 1/2nd opening, B_3 = 3/4th opening, B_4 = full opening, C_1 = 2 km/h, C_2 = 4 km/h, C_3 = 6 km/h width. Experiments were conducted for forwarding speeds 2, 4 and 6 km/h.

It is clear from **Table 6** that as the orifice opening level and moisture content levels were increased, the FYM application rate increased. Overall increasing the forward speed of tractor resulted in an increase in field capacity of the machine but a decrease in manure application rate per unit area. Therefore the effect of moisture content, orifice opening, and forward speed were individually and in combination, was significant ($p < 0.01$) on the FYM application rate.

Bandwidth

These data show that the FYM bandwidth increased with an increase in the orifice opening position. A similar trend was observed at all three moisture content followed by all three forward speeds. These results indicated that the bandwidth values were decreased at increasing forward speed. The same results were observed at all three moisture content and all four orifice openings. These values suggested that FYM bandwidth values decreased at increasing moisture content. This result was found due to dried particles were more shattered as compare to the moist particles. The effect of orifice opening, forward speed and moisture content were individually significant but their combination was non-significant on FYM bandwidth as shown in **Table 7**. Orifice openings, forward speed and moisture content have individually affected the bandwidth at ($p < 0.05$) significant.

Field Performance Parameters

The performance parameters were compared for rice sowing by the use of FYM applicator cum planter for the treatment T_2, T_3, T_4 and manual broadcasting of FYM then use of inclined plate planter for the sowing of rice. (**Table 8**).

Cost Economics and Energy Analysis

The traditional method of the FYM application requires a basket to spread in the field. Manually spreading FYM was added additional cost and labor in the sowing of rice. The cost of the developed machine was considered ₹ 162000. The developed machine required only one labour for operation and three labours for filling of FYM in the hopper. The data presented in **Table 9** shows that the cost of operation of FYM applicator cum planter was ₹ 1,080/ha. Manual spreading requires 4 labour per ha and therefore cost of FYM application was ₹ 1200/ha. The operational cost of the traditional method of FYM application with seeding was ₹ 1,740/ha. The data indicate that as compare to the conventional method of spreading of FYM and then seeding of rice by inclined plate to developed machine the cost and energy saved were 52% and 41% respectively.

The cost was minimum for FYM applicator cum planter as compare to conventional method T_1 because the developed machine can perform both the operation of FYM spreading in a band format and seeding of rice simultaneously. Additional field operations i.e. surface incorporation by disking needs extra cost in crop production. Environmental risk can be reduced through the FYM band application. Greenhouse gas and odor emission can be minimizing

Table 8 Field Performance Parameters

S. No.	Particulars	FYM applicator cum planter	Inclined plate planter
1	Plot area (ha)	0.034	0.034
2	Width of coverage (cm)	22.5 × 9	22.5 × 9
3	Speed of operation (m/s)	1.59	1.64
4	Time loss in turning and adjustment (s)	54.00	51.00
5	Fuel consumption (liter/h)	4.50	4.40
6	Draft (kg)	347.30	301.20
7	Power requirement (hp)	7.45	6.58
8	Effective field capacity (ha/h)	0.81	0.84
9	Field efficiency (%)	70.1	70.4

Table 9 Comparison of a different method of FYM application cum seeding

S. No.	Operational parameters	FYM applicator cum planter	Conventional method		
			Manual broadcasting of FYM	Inclined plate planter	Total
1	EFC, ha/h	0.81	-	0.84	0.84
2	Time req., h/ha	1.23	32.33	1.19	33.52
3	Man-days req./ha	3 +1	4.00	2.00	6.00
4	Fuel energy, MJ/ha	311.62		294.78	
5	Labour energy, MJ/ha	9.64	253.46	4.66	
6	Machine energy, MJ/ha	7.06		5.94	
7	Total energy, MJ/ha	328.32	253.46	305.38	558.84
8	Energy saved, percent	41.14	-		
9	Cost, ₹/ha	1,080.00	1,200.00	540.00	1,740.00
10	Cost-saving, %	51.62	-	-	

with surface incorporation of FYM.

Pre-harvest Observation

Plant population, Plant height, Number of tillers/hill and Leaf area index

Plant population, plant height, number of tillers/hill and leaf area index of rice at different treatments are presented in **Table 10**. The results revealed that the different recommended doses of nitrogen by FYM did not influence the plant population significantly at 30 DAS. Tallest plants were recorded under 100% N through tractor-drawn FYM applicator cum planter (T_2), followed by 75% N through FYM applicator cum planter (T_3). The variation in plant height due to different methods and rates of application of FYM was due to variation in the availability of nutrients to the rice crop. The number of tillers/hill was significantly affected at different method and rate of application of FYM. Out of four recommended doses of nitrogen treatment 100% N through FYM applicator (T_2) produced a significantly higher number of tillers/plants as compared to remaining treatments. However 75% N through FYM applicator (T_3) was at par to the treatment 100% N through FYM applicator (T_2). Further, the control plot (T_5) produced the lowest tillers. Significantly higher leaf area index was recorded under treatment 100% FYM through FYM applicator cum planter (T_2) as compared to others. However, treatment 75% N through FYM applicator cum planter (T_3) and 50% N through FYM applicator cum planter (T_4) also recorded comparable values as well as treatment control (T_5) was recorded lowest leaf area index (**Fig. 4**).

Post-harvest Observation

Number of Effective Tillers/plant

The data on the number of effective tillers/plant, panicle length (cm), panicle weight (g), test weight (g), total grains/panicle (No.) and filled grains per panicle (No.) as influenced by the different dose of nitrogen are presented in **Table 11**.

As regards to different dose of nitrogen, treatment with 100% N through applicator (T_2) showed a significantly higher number of effective tillers/plant, panicle length, panicle weight (g), test weight (g), total grains/panicle (No.) and filled grains per panicle (No.) as compared to others. However the treatment of 75% N through applicator at basal (T_3) was also recorded comparable values for these parameters. Significantly lowest number of effective tillers/plant, panicle length, panicle weight (g), test weight (g), total grains/panicle (No.) and filled grains per panicle (No.) were found under control treatment (T_5). The

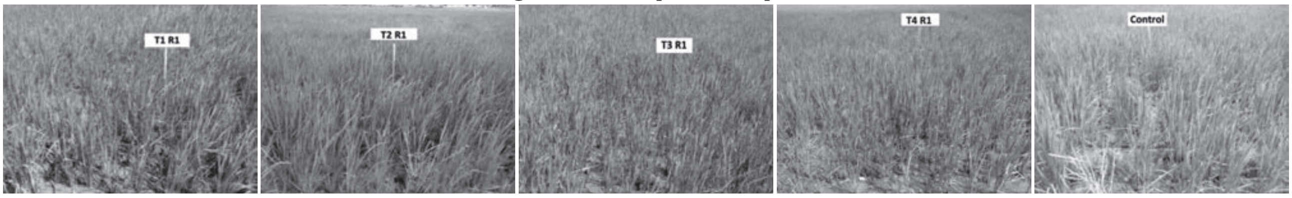
Table 10 Plant population (no./m^2), plant height, number of tillers/hill and leaf area index of rice at different treatments

Treatments	Plant population, no./m^2	Plant height, cm	No. of tillers/ plant	Leaf area index
T_1	107.4	39.6	5.2	1.34
T_2	107.6	46.4	6.8	1.56
T_3	106.4	43.1	6.1	1.48
T_4	106.4	40.4	5.5	1.28
T_5	107.0	32.6	4.0	0.90
SEm+	1.20	1.26	0.2	0.06
CD (P = 0.05)	NS	3.77	0.7	0.17

Table 11 Effective tillers/plant, panicle length, panicle weight and test weight of rice as influenced by different treatments and rate of application of FYM

Treatment	Effective tillers/plant	Panicle length (cm)	Panicle weight (g)	Test weight (g)	Total number of grains/ panicle, (No.)	Filled grains/ panicle, (No.)	Unfilled grains/ panicle, (No.)	Sterility (%)
T_1	8.2	23.80	2.91	23.25	162	127	35	21.60
T_2	9.3	26.64	3.24	24.66	188	146	41	21.80
T_3	8.9	25.74	3.04	24.06	176	138	37	21.02
T_4	7.5	23.131	2.74	22.16	147	111	36	24.48
T_5	5.4	18.90	2.38	20.91	122	97	25	20.49
SEm+	0.2	0.56	0.08	0.38	4	4	6	3.29
CD (P = 0.05)	0.6	1.68	0.25	1.16	13	12	NS	NS

Fig. 4 View of experimental plot



T_1 T_2 T_3 T_4 T_5

findings of different doses of nitrogen revealed that significantly the highest grain and straw yields were registered under 100% N through FYM applicator (T_2) as data presented in **Table 12**. The second highest grain yield was obtained under the treatment 75% N through FYM applicator (T_3) which was at par to treatment 100% N through FYM applicator (T_2). Band application of FYM has an advantage that the FYM was applicable only for those areas where seeds were applied. Therefore band application of FYM also reduces the excess amount of FYM application in the field.

Conclusions

The FYM applicator cum planter can be operated to achieve the desired application rate by increasing or decreasing the orifice openings. There was a linear relationship for the forward speed, opening position of orifice and moisture content with the FYM application rate and bandwidth. Based on grain yield there was 25% amount of FYM can be saved through developed applicator as compare to manure broadcasted FYM. This technology can reduce the cost and gave a better yield with soil improvement. Optimum moisture content was found 31% db to apply FYM satisfactorily through FYM applicator cum planter. The operational cost was saved with the FYM applicator cum planter was 52% as compared to the conventional practices. The developed machine saved 41% energy as compared to the traditional method of FYM application and seeding.

Table 12 Grain and straw yield and harvest index of rice as influenced by different treatment

Treatment	Grain yield (q/ha)	Straw yield (q/ha)	Harvest index (%)
T_1	33.51	56.81	37.10
T_2	40.51	70.90	36.36
T_3	38.49	66.99	36.49
T_4	28.55	47.52	37.53
T_5	18.41	35.35	34.24
SEm+	1.30	1.64	1.38
CD (P = 0.05)	3.0	4.93	NS

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Paddy Thresher Integrated with Infrared Rotary Dryer and Dehusker for On-farm Brown Rice Production

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Abstract

Though brown rice is rich in nutrition, one of the main reasons for non-adoption of brown rice is its higher cost. Looking into the importance of brown rice and foreseeing the increase in demand of brown rice, a need of a machinery fulfilling above purpose was felt, which can directly give output in the form of good quality brown rice at lower cost. Based on the review and physio-mechanical properties of four paddy varieties commonly grown in Haryana, the design concept of thresher for brown rice production was evolved, which consisted of co-axial split-rotor thresher that is especially suited for high moisture paddy; and two rotary dryers fitted with 18 nos. of ceramic infrared (IR) heaters (650 W) along the central axis of rotary dryer. Recently, IR radiation is being used for drying agricultural products for achieving fast and uniform heating of the grains for quick removal of moisture. A rubber sheller unit for brown rice production and conical abrasive polisher (as an optional feature) was added to produce white rice. Thus, a tractor operated paddy thresher-cum-dryer-cum-dehusker-cum-polisher was designed, developed and evaluated.

Keywords: infrared dryer; brown rice; threshing efficiency; cleaning efficiency; dehusking efficiency

Introduction

Rice is one of the main staple food of the world, establishing as the fundamental sustenance for huge number of the total populace. The paddy crop is usually harvested at 20 to 25% moisture content (wet basis) either manually or with the help of power operated equipment. Small farmers generally prefer to harvest manually and leave the crop in the field for drying. When the moisture content is about 15%, threshing of the paddy crop is done in farmers' field itself. Power operated threshers are generally used to detach the grains from the panicles of the paddy crop and the paddy grains are sold in the market at a very cheaper rate. The detached raw paddy grains are further processed at modern rice mills, which uses huller, sheller, dehusker to remove the husk and produce brown rice and polishers or whiteners to produce white rice of commercial quality, and thus major profit is earned by rice millers.

Though, brown rice is a rich source of the trace mineral manganese, and a good source of selenium (Se), phosphorus (P), copper (Cu), magnesium (Mg), and niacin (vitamin B_3), its consumption is very less may be due to lack of awareness about its health benefits, high cost, less shelf life etc. Thus, if a machine is available, which can thresh the paddy crop, dry and dehusk it at farm level, then the farmers will be able to get brown rice at cheaper cost and reap better benefits. Looking into the importance of brown rice and fore-seeing the increase in demand of brown rice, a new machinery was designed and developed which can directly give output in the form of brown rice.

An intensive review of literature indicates that no scientific study for the production of brown rice on the farm itself has been made. The real challenge involved in achieving this, is the drying of high moisture paddy to a level at which milling can be done efficiently. Previously convective dryers were used, where low temperature systems ensured moisture removal in such a way that the generation of moisture gradient is avoided. But it has been reported that IR radiation can be used effectively for reducing the moisture instantaneously at a very short period without sacrificing the milling quality.

Keeping in view the health benefits of brown rice and value addition by paddy processing at farmers field, present study is focused to study physio-mechanical properties of paddy grain that is grown in the northern part of India and to design and develop a system to integrate the tractor operated paddy thresher with an IR radiation dryer so that milling for brown rice production can be done at low cost in the farm itself.

Methodology

From the review and engineering properties of paddy, the design concept of thresher for brown rice production was evolved which consisted of co-axial split-rotor thresher for paddy threshing which is especially suited for high moisture paddy, infrared (IR) radiation dryer for drying the paddy and rubber sheller unit for brown rice production. Recently, IR radiation is being used for drying agricultural products for achieving fast and uniform heating of the grains for quick removal of moisture. High heating rate and energy efficiency are the added benefits of IR radiation over conventional drying methods. The machine was got fabricated from M/s. Viswakarma Engineering Works, Tohana, Dist. Fatehabad, Haryana.

The performance evaluation of the developed machine was done under two non-basmati paddy varieties i.e. Pusa-44 and PR-114 and two basmati paddy varieties i.e. Pusa-1121 and Pusa-1509 at Tohana, Dist. Fatehabad, Haryana. The performance of thresher was evaluated as per IS: 6284-1985 (Reaffirmed 1999); Test code for Power Threshers for cereals. The parameters like total grain output per unit time, broken grain, blown grain, un-threshed grain, spilled grain, threshing efficiency and cleaning efficiency were evaluated. The milling recovery and head rice recovery were also determined for dehusker. The following parameters were evaluated by using the relationship as given below:

$A = B + C + D$

Where

A = total grain input per unit time, B = quantity of grain (threshed, clean) collected from all grain outlet(s) per unit time, C = quantity of broken grain from all outlets per unit time, D = quantity of un-threshed grain from all outlets per unit time.

Percentage of broken grain = $(C/A) \times 100$

Percentage of blown grain = $(G/A) \times 100$

where

G = quantity of clean grain obtained at straw outlet per unit time, and

Percentage of un-threshed grain = $(D/A) \times 100$

Percentage of spilled grain = $(J/A) \times 100$

where

J = quantity of clean grain obtained at sieve overflow and underflow per unit time

Threshing efficiency = 100 − percentage of un-threshed grain

Cleaning efficiency = $(M/F) \times 100$

where

M = quantity of clean grain obtained from the sample taken at main grain outlet(s), F = total quantity of the sample taken at main grain outlet(s).

Coefficient of dehusking = $1 - (W_u/W_s)$

where

W_u = Weight of unhusked or unhulled paddy, W_s = Weight of sample used

Milling Recovery: This is the quantity of milled rice obtained from a given quantity of paddy. It is expressed as a percentage of milled rice including broken obtained from paddy as given below:

$M_r = (W_m/W_s) \times 100$

Where

M_r is milling recovery percentage, W_m is the weight of milled rice, W_s is the weight of sample used

Head Rice Recovery: This is the weight of head grains or whole kernels having more than seventy five percentage of the average length of the whole kernel in the rice lot. It is expressed in percentage as follows:

$M_h = (W_w/W_s) \times 100$

Where

M_h is the head rice recovery percentage, W_w is the weight of the whole grains

The cost of operation was estimated based on RNAM recommendations (UNESCAP, 1995). The cost of operation of any tractor operated equipment included both fixed cost and variable cost. The fixed cost remains independent of the machine usage, whereas variable cost depends on the machine usage.

Results and Discussion

3.1. Engineering Properties of Raw Paddy Relevant to the Design and Development of Paddy Thresher-cum-dryer-cum-dehusker

The purpose of this study was to

investigate the effect of moisture content and selected variety of raw paddy widely cultivated in Haryana on some engineering properties of paddy grain in relation to threshing and dehusking operation. Physio-mechanical properties of two non-basmati paddy varieties i.e. Pusa-44 and PR-114 and two basmati paddy varieties i.e. Pusa-1121 and Pusa-1509 were studied. The range of physio-mechanical properties of the above-said four varieties were found as: Moisture content (8.0 to 22.3% (w.b)), length (8.71 to 13.47 mm), width (2.10 to 2.58 mm), thickness (1.80 to 2.03 mm), geometric mean diameter (3.40 to 4.03 mm), aspect ratio (0.18 to 0.23), sphericity (0.29 to 0.39), surface area (33.1 to 42.2 mm^2), bulk density (523 to 649 kg/m^3), true density (1,338 to 1,742 kg/m^3), porosity (57.2 to 70.0%), one thousand grain weight (23.72 to 26.75 g), angle of repose (23.70 to 35.40), terminal velocity (5.70 to 6.10 m/s), single grain detachment force (1.70 to 3.25 N) and hardness (99.2 to 118.4 N).

Strong positive correlation between the moisture content and the static coefficient of friction (R = 0.970), terminal velocity (R = 0.840), equivalent diameter (R = 0.766) and geometric mean diameter (R = 0.763) has been observed. Other parameters like angle of repose (R = 0.627), 1000 grains weight (R = 0.683), thickness (R = 0.672), surface area (R = 0.614), width (R = 0.576), length (R = 0.301) and bulk density (0.273) has also positive correlation with moisture content. Strong negative correlation between the moisture content and the hardness (R = −0.806) and porosity (R = −0.708) has been observed. Other parameters like true density and sphericity were also negatively correlated with moisture content.

From the review and engineering properties of paddy, the design concept of thresher for brown rice production was evolved which consisted of co-axial split-rotor thresher for paddy threshing which is especially suited for high moisture paddy, rotary dryer fitted with ceramic infrared (IR) heaters for drying the paddy and rubber sheller unit for brown rice production. Recently, IR radiation is being used for drying agricultural products for achieving fast and uniform heating of the grains for quick removal of moisture. High heating rate and energy efficiency are the added benefits of IR radiation over conventional drying methods. Conical abrasive polisher was also added as an optional feature to produce white rice.

3.2. Design of Tractor Operated Paddy Thresher-cum-dryer-cum-dehusker

The tractor operated paddy thresher-cum-dryer-cum-dehusker has been designed with the following components:

a) Paddy thresher (for detachment of grains from the paddy crop)
b) Aspirator (for blowing the straw from the grains)
c) Infrared rotary dryer (for instant drying of paddy grains)
d) Rubber roll dehusker (for removal of husk from the paddy grains to produce brown rice)
e) Polisher (for removal of brown layer to produce white rice as an optional feature)

Physio-mechanical properties of the crop are the main characteristics which determine the selection of proper threshing mechanism for getting maximum desirable output. Based on the physio-mechanical properties, axial flow co-axial split type threshing drum of length 840 mm and diameter 400 mm having 21 spike teeth has been designed.

For drying of the paddy grains, rotary dryer (φ 430 mm) capable of running at different rpm (6, 7 and 8 rpm) at different inclination (4°, 5° and 6°) was fabricated. Wire mesh sieve was used as a surface to convey the paddy grains in the rotary dryer. Two separate rotary dryers each of length 3,600 mm were used. The selection of wire mesh sieve would ensure sufficient retention time inside the rotary dryer for proper drying of the paddy grains. Entire rotary dryer was covered with plain mild steel sheet (Ø 775 mm). For proper ventilation of the rotary dryers, two exhaust fans having 200 mm sweep capable of air delivery of 8.1 m^3/minute were used. Ceramic infrared heaters (18 Nos.) each of 650 W (Make: Elstein, Germany) were used. The heaters were placed along the axis of the rotary dryer directly above the grains. Provision was made to increase or decrease the height of the heaters above the grains. Arrangement was also made to rotate the heaters (1,800) to focus on the target area.

Paddy dehusker of 150 mm width and 254 mm outer diameter rubber rollers running at 1.28:1 friction ratio with the faster roller at 900 revolutions per minute has been designed. As an optional feature, a conical polisher with corborundum as abrasive material having the size of 380 mm (inlet side) × 450 mm (outlet side) × 600 mm length has

Fig. 1 LHS view of tractor operated paddy thresher-cum-dryer-cum-dehusker

Fig. 2 RHS view of tractor operated paddy thresher-cum-dryer-cum-dehusker

been designed to produce white rice.

3.3. Development and Evaluation of Paddy Thresher-cum-dryer-cum-dehusker for On-farm Brown Rice Production

Firstly, the machine was got fabricated as per the design details. LHS and RHS views of the tractor operated paddy thresher-cum-dryer-cum-dehusker are given in **Figure 1** and **Figure 2**, respectively. Secondly, the performance evaluation of the developed machine was done along with the optimization of operational parameters using response surface methodology (RSM) for maximum output and minimum loss.

3.3.1. Performance of Paddy Thresher

The evaluation of the paddy thresher was conducted in two non-basmati paddy varieties i.e., Pusa-44 and PR-114 and two basmati paddy varieties i.e. Pusa-1121 and Pusa-1509 at optimized operational parameters of paddy thresher viz., initial moisture content of crop at 20% (w.b.), threshing rotor rpm of 650, and separating rotor rpm of 750. The other parameters like feed rate (375 kg/h of crop) and concave clearance (17 mm) were kept constant.

The Performance evaluation of the paddy thresher under different paddy varieties is given in **Table 1**. The choice of opting co-axial split threshing cylinder had proved to be successful in achieving almost 100% threshing efficiency and more than 98% cleaning efficiency, even at higher moisture content of paddy crop. The percentage of broken and blown paddy grains was 0.32 and 0.15, respectively. The percentage of broken grains of basmati variety in comparison to non-basmati variety was on higher side, as the length of basmati varieties was more than the non-basmati variety, because of which, it was susceptible to more breakage. Lowest cleaning efficiency of 97.85% was found in Pusa-1509 being an awn variety.

Table 1 Performance evaluation of the paddy thresher under different paddy varieties

(Percent)

Paddy Variety	Broken grain	Blown grain	Un-threshed grain	Spilled grain	Threshing efficiency	Cleaning efficiency
Non-Basmati Variety						
Pusa-44	0.260	0.120	0.050	0.080	99.950	98.750
PR-114	0.280	0.180	0.020	0.100	99.980	98.250
Average	0.270	0.150	0.035	0.090	99.965	98.500
Basmati Variety						
Pusa-44	0.380	0.150	0.080	0.120	99.920	98.100
PR-114	0.360	0.140	0.030	0.050	99.970	97.850
Average	0.370	0.145	0.055	0.085	99.945	97.975

Table 2 Performance of paddy dehusker under different varieties

Paddy Variety	Coefficient of de-hulling	Brown Rice Recovery (kg per 100 kg of raw paddy)			
		Head Brown Rice*	Broken-I#	Broken-II$	Total Brown rice**
		1	2	3	1 + 2 + 3
Non-Basmati Variety					
Pusa-44	0.9880	56.30	11.15	7.40	74.85
PR-114	0.9910	56.50	11.20	7.50	75.20
Average	0.9893	56.40	11.18	7.45	75.03
Basmati Variety					
Pusa-1121	0.9865	36.45	18.30	18.05	72.80
Pusa-1509	0.9505	35.05	17.50	16.85	69.40
Average	0.9685	35.75	17.90	17.45	71.10

* Head brown rice: Head grains or whole kernels having more than seventy five percentage of the average length of the whole kernel in the rice lot
# Broken-I: Kernel having less than seventy five percentage but more than fifty percentage of the average length of the whole kernel
$ Broken-II: Kernel or piece of kernel having less than fifty percentage of the average length of the whole kernel
** Total brown rice recovery is also called as brown rice milling recovery

3.3.2. Performance of Infrared Rotary Dryer

The rotary dryer was also evaluated in all the four paddy varieties at optimized parameters of rotary dryers viz., initial moisture content of 20% (w.b), rotary dryer inclination of 50, and rotary dryer revolution of 7 rpm. The optimized output of paddy grains was 150 kg/h and the moisture reduction was 5.5%. The height of infrared heaters (10 cm) above the paddy grains and the number of heating lamps of 650 W were kept constant throughout the study. For all the varieties, the performance of the rotary dryers was similar (non-significant difference) to the performance obtained for non-basmati variety (Pusa-44).

3.3.3. Performance Evaluation of Paddy Dehusker

During the preliminary trial of the machine, it was found that the coefficient of dehusking or de-hulling of the dehusker was in the range of 0.65 to 0.75. Hence, the machine was modified in such a way that the paddy grains were passed through the dehusker for two times in order to ensure 100% de-hulling. After the modification, the machine performed satisfactorily. The developed machine was evaluated in two non-basmati paddy varieties i.e., Pusa-44 and PR-114 and two basmati paddy varieties i.e., Pusa-1121 and Pusa-1509 at optimum operational parameters of paddy thresher and rotary dryer for all the varieties.

Performance of paddy dehusker under different varieties is given in **Table 2**. Coefficient of de-hulling of all the varieties was more than 0.985 except for Pusa-1509 in which it was only 0.950, being an awn variety. The average brown rice recovery (brown rice milling recovery) was found to be 71 and 75% in basmati and non-basmati varieties, respectively. Average head brown rice recovery in the basmati and non-basmati varieties was approximately 35.75 and 56.40 kg per 100 kg of paddy, respectively. Percentage of head rice recovery was 50.28 and 75.20 in basmati and non-basmati varieties, respectively.

3.3.4. Techno-economic Analysis of Newly Developed Paddy Processing System for Brown Rice Production

The tractor operated paddy thresher-cum-dryer-cum-dehusker was operated with 50 hp tractor whose fuel consumption was found to be 7 litres per hour and the amount of paddy it handled was found to be 150 kg per hour. Considering a cost of Rs. 800,000 for tractor and Rs. 600,000 for the developed machine, the total cost (fixed cost, operating cost, and profit) was calculated to be Rs. 10 per kg paddy processed. The fixed cost included depreciation, interest on investment, tax, insurance and shelter. The operating cost included fuel, lubrication, repair and maintenance and operator wages.

For basmati paddy varieties, the minimum cost of brown rice produced by rice mill is Rs. 80 per kg. With the developed machine, the cost of brown rice was calculated to be Rs. 55 per kg, respectively. Thus, the reduction in the cost of basmati brown rice has been found to be 31%. For non-basmati paddy varieties, the minimum cost of brown rice produced by rice mill is Rs.45 per kg. With the developed machine, the cost of brown rice was calculated to be Rs.35 per kg. Thus, the reduction in the cost of non-basmati brown rice has been found to be 25%.

If the machine is operated for 450 hours in a year, then the machinery owner can earn a profit of Rs. 1,35,000 per annum. The Break Even Point (B.E.P.) was found to be lying at 284 hours. Payback period was calculated as 4.44 years whereas Return on Investment (ROI) was found to be 9.64%.

Conclusions

Overall, it is inferred that by using tractor operated paddy thresher-infrared rotary dryer-dehusker, the farmers will have an option to produce brown rice at his farm itself at a cheaper cost, consume it and remain healthy. Moreover, since the machine has an optional feature of having polisher, the machine can also be used for producing polished rice at cheaper price. In other words, the major profit which is being earned by middle men can be avoided and the farmers can get better price for the same.

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Comparative Performance of Seed-cum-Pressurized Aqua Fertilizer Drill, Zero Till Drill and Conventional Seed Drill on the Growth of Wheat Crop under Vertisols

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Abstract

The present study was done on the performance of seed-cum pressurized aqueous fertilizer drill with its comparison to zero till drill and conventional seed drill for wheat crop under vertisols. Field tests were conducted in the experimental farm of College of Agricultural Engineering. The field experiments were laid out following a randomized block design. Based on functional test evaluation, actual field capacity and field efficiency of the machine were 0.35 ha/h and 65.5% respectively. The field experiments reveled that aqueous fertilizer application advanced germination by at least two days. Rate of aqueous fertilizer gave enhanced growth performance parameters in addition to better germination, no of ear heads, plant height, dry root weight, grain yield and straw yield were 45%, 22.4%, 23% 37.5%, 25.3% and 19.6% respectively higher than to those plots with no aqueous fertilizer application. As per the working principle of the seed cum pressurized aqua fertilizer drill may be the better solution for the effect of agro-climatic changes in agricultural situations. This may take care of the situation such as dry spell maintained or improve the soil health as well as the environment.

Keywords: Aqueous Fertilizer, Vertisols, Germination, Field Capacity, Seed drill.

Introduction

For proper germination and growth of the plant, precise placement of seed with optimum required soil moisture content, nutrients and other climatic conditions is necessary. In this, agro-machinery plays a vital role in seedbed preparation as well as in seed placement along with aqua fertilizer (Which also supplement the water) for healthy initial growth. Placement of aqua fertilizer also has greater significance for enhancing 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.

Due to unavailability of sufficient soil moisture in the form of irrigation, main winter crop like wheat cannot be cultivated despite the suitability of the soil. The major problem is the deficit of soil moisture at sowing stage as at later stages of crop growth some amount of rainfall is received due to westerly disturbances in Northern and Western part of the country.

For proper germination and healthy initial growth, seed vigour and timeliness in sowing are the most important aspects. In fact, the seed is one of the seven vital inputs for agricultural production along with fertilizers, irrigation water, plant protection chemicals, agricultural machinery, an extension of scientific knowledge and credit. Research results have proved that the contribution of seed in attaining the potential crop yield is to the tune of 50 percent. It has been established that the delay in sowing after optimum time causes a loss in the yield to the extent of 35 to 40 kg/ha per day (Hobbs, 1985). Thus seedbed preparation and sowing/planting should be completed within a short period under available soil moisture condition by using efficient tillage and seeding machinery. It is needless to state that the application of efficient machinery helps in timely farm operations, better input use efficiency and increasing productivity by about 30%. Traditionally, in dryland areas seed-cum-fertilizer drill are not in use resulting in more input and less yield. A substantial advantage could be attained if farmers opt for a seed-cum-fertilizer drill for sowing operation. The major problem in these areas is that at sowing depth moisture deficit exists and thus, seed cannot utilize the applied fertilizer dose.

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 the 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 the seed. Agronomists have worked out quantify the aqueous fertilizer required for different winter crops in specific agro-climatic situations (Anonymous, 1996).

Material and Methods

The experiment was conducted at horticultural research farm, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, (M.P) during 2015-2017. Jabalpur has situated at 23°9’ North latitude and 79°58’ East longitudes with an altitude of 411.78 meters above the mean sea level.

Soil

The soil of the Jabalpur region is broadly classified as vertisols as per norms of U.S. classification. It has medium to a deep depth and black in colour. It has the ability to swell after wetting and to shrink after drying. Thus, it develops deep and wide cracks on the surface during the summer season. It has poor workability under excessive dry as well as wet conditions. The physical composition of the soil in the experimental field was clay (50.75%), silt (20.15%), and other (29.10%).

Design of Field Experiments

The performance evaluation of seed-cum pressurized aqua fertilizer drill was undertaken in the experimental farm of the College of Agricultural Engineering, JNKVV, Jabalpur as stated above. To determine the influence of aqueous fertilizer application rate on crop, six different treatments were taken. The test field was subdivided into six plots of size 38 × 6 m^2. Randomize block design was used for conducting experiments of field study with three replications of each treatment. Different sowing systems are shown in **Fig. 1**.

Details of Treatments

Following combinations of sowing system and rate of aqua fertilizer were used to determine the influence of pressurized aqua fertilizer seed drill:

- T1S1D1 = Conventional tillage + Seed-cum pressurized aqua fertilizer drill (SCPAFD) + 6,500 l/ha (aqueous fertilizer)
- T1S1D2 = Conventional tillage + Seed-cum pressurized aqua fertilizer drill + 5,500 l/ha (aqueous fertilizer)
- T1S1D3 = Conventional tillage + Seed-cum pressurized aqua fertilizer drill + 4,500 l/ha (aqueous fertilizer)
- T1S2 = Conventional tillage + Conventional seed cum fertilizer drill (CSCFD)
- T2S3 = Conventional tillage + Zero till seed cum fertilizer drill (ZTSCFD)

Fig. 1 Different sowing machines used in the field

a) Seed cum pressurized aqua ferti drill b) Zero till seed cum fertilizer drill c) Conventional seed cum fertilizer drill

T1S4 = Conventional tillage + Seed-cum pressurized aqua fertilizer drill with granular fertilizer

Experimental Details

Design	RBD
Replications	3
Net plot size	12 × 6 m
Plot area	72 m^2
Distance between replications	1.0 m
Distance between plots	3.0 m
Total number of plots	18
Variety	GW 273
Seed rate	80 kg/ha
Recommended dose of fertilizers application:	120 kg N, 60 kg P_2O_5 & 40 kg K20 /ha

Measurement of Machine Parameters

Theoretical Field Capacity

The theoretical field capacity was calculated by using the relationship given below:

Theoretical field capacity (ha/h) = (Width of equipment (m) × Speed of operation (km/h)) / 10 (1)

Actual Field Capacity

Actual field capacity (ha/h) = (Width of field coverage (m) × length of field coverage (m)) / (Time for covering the total area (h) × 10,000) (2)

Field Efficiency

The field efficiency is the ratio of actual field capacity (ha/h) to the theoretical field capacity (ha/h).

Field efficiency (%) = Effective field capacity / (Theoritical field capacity × 100) (3)

Fuel Consumption

For the measurement of fuel consumption (l/h) the intake and overflow fuel line was connected to a cylindrical container from bottom and top. The cylindrical container has a capacity of 3.0 liter and having the marking in 50 ml apart. In each treatment, the time of operation, area covered and fuel consumed (ml) was observed and fuel consumption was estimated as given below:

Fuel consumption (1/ha) (Fuel consumption (ml/s) / Area covered (m^2/s)) × 100 (4)

Draft

To determine the draft of implement load cell was used. The dynamometer was placed in between two tractors and implement was hitched by the rear tractor. The gear of the rear tractor was kept in a neutral position and implement hitched behind the tractor and desirable depth was given with hydraulic control lever. Front tractor pulled the rear tractor with an implement. The reading of load indicator was recorded from the dial gauge. The difference of calculated draft and rolling resistance was taken as the draft of implement for further calculations. (RNAM, 1983)

Measurement of Soil Parameters

Moisture Content of Soil

Soil moisture content on dry weight basis was determined randomly before tillage and after sowing and 30, 60, 90 DAS in different treatments. The soil samples were taken from the experimental plots, at a depth 0-150 mm. with the help of an auger. The moisture per cent (dry basis) was calculated using the relationship given below.

Mc (db) = [(Ww − Wd) / Wd] × 100

Measurement Biometrics of Plants Parameters

To evaluate field performance of pressurized aqua fertilizer seed drill, different crop parameters particularly those which are related to crop growth like germination start, germination count, no of plant/m, number of shoot/plant, number of ear head/m length, plant height, length of ear head, root length, root weight, grain yield and straw yield. The parameters were measured for the different rate of aqueous fertilizer application in the soil at the time of sowing.

Determination of Germination Start

The germination start was observed after sowing in plots with an application of aqua fertilizer and control plots. For this, germination start was observed every day after sowing and whenever sprouting of seed emerged out from the soil the data was noted down in terms of days after sowing (DAS).

Determination of Germination Count

The germination count was done after 11 and 18 days of sowing (DAS) from one-meter row length of sowing. For this, in every replication of the treatment at three places, one-meter length of the crop was randomly selected and germination count was made. Arithmetic mean of these three counts gave average germination of that plot. These test locations were marked for further study.

Result and Discussions

The machines, soil and crop parameters were taken in account to compare the performance of three different systems of sowing of the soybean crop in vertisols.

Field Capacity and Field Efficiency of the Machines

Average field capacity of 0.35 ha/h was obtained for continuous operation of aqueous fertilizer drill at an average speed of 3 km/h. A field efficiency of 65.5, 66.6 and 70.3% for seed cum pressurized aqueous fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill respectively was observed which was in the prescribed range of 60 to 80% for seed drill. The major loss in field efficiency was due to refilling of aqueous fertilizer tanks. No repairs, breakdown and adjustment of components during the operation were observed.

The ANOVA reveals that the calculated value of F statistic (29.73) at the time of test is greater than the corresponding F table value F1 %

= 10.92, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant (**Table 1**).

Table 1 ANOVA table of field capacity for different sowing machines

Source	DF	SS	MSS	F cal.	F tab5%	F tab1%
Replication	3	0.00	0.00	12.73^{**}	4.76	9.78
Treatment	2	0.00	0.00	29.73^{**}	5.14	10.92
Error	6	0.00	0.00			
Total	11	0.00				

SEd = 0.004, SEm = 0.003, CD 5% = 0.010

Fuel Consumption of Sowing Systems

In case of seed cum pressurized aqueous fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill, the fuel consumption was found to be 10.85, 9.97 and 8.42 l/ha respectively. Fuel consumption of zero till and conventional seed drill was less than seed cum pressurized aqueous fertilizer drill by 8.1 and 22.3% because the field capacity of ZTSCFD and CSCFD is more than SCPAFD.

Draft Requirement of Different Tillage Implement

The draft requirement for seed cum pressurized aqua fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill was 3.6, 3.0 and 2.31 KN respectively. In case of SCPAFD draft was 16.6 and 35.8% more than ZTSCFD and CSCFD respectively. This is due to the extra weight of two aqueous fertilizer tanks on the SCPAFD.

Influence of Seed Cum Pressurized Aqua Fertilizer Drill on Soil Moisture Content

The percentage increase in soil moisture due to aqua fertilizer application at the rate of 6,500, 5,500 and 4,500 l/ha were 162, 136 and 124% just after sowing. The rate of 6,500 l/ha maintained soil moisture levels of 28.7 and 24.6% at 3 DAS and 6 DAS, which was above the germination limit (**Fig. 2**). The application rate of 5,500 l/ha was also able to maintain soil moisture above germination moisture content for three days. It could be concluded that for initial field moisture of above 12%, aqueous fertilizer rate of 6,500 l/ha is sufficient to maintain germination moisture during the period of germination. The moisture content of 10 cm depth was in the range of germination moisture, however, the application of aqueous fertilizer at the rate of 6,500, 5,500 and 4,500 l/ha could increase soil moisture by 113, 107 and 92.1% after sowing, **Fig. 2**. At higher depth moisture loss was expected to be slow. The results showed the expected trend. The moisture loss at 5 cm depth of 6,500 l/ha aqueous fertilizer application rate was 12.5% after 3 days and 14.28% after 6 days while at 10 cm depth, the same were 10.1% and 11.37%. Similar trend was observed for other application rates of aqueous fertilizer. This pattern gives choice to the farmer to select a depth of sowing as per the moisture availability.

Crop Response to Aqueous Fertilizer Application

Germination Start

Germination start was observed after sowing in aqueous fertilizer fields and control plots. It was found that the emergence of seed from soil took place at 4 days after sowing in aqueous fertilizer field and 7 days after sowing in other treatments (control field). In control plot germination start was not normal. The early emergence of seed in aqueous fertilizer treatment was due to an adequate amount of moisture provided at the time of sowing. It means we can save a minimum of 3 days for the next cultivation season.

Germination Count Per Meter Row

The data on germination count was taken at 11 days after sowing and 18 days after sowing. Data shows that in all the aqua fertilizer plots, the germination was better as compared to control plots. This may be due to the fact that proper placement of aqueous fertilizer, which increased the soil moisture at sowing depth led to better germination than in the case of without aqueous fertilizer. Amongst different plots with aqueous fertilizer, the initial plant population was almost the same. Number of plant per meter row at 11 days after sowing were 74, 71, 66, 44, 42 and 51 in the plots with aqueous fertilizer rate of 6,500, 5,500, 4,500 l/ha, ZTSCFD, CSCFD and SCPAFD (with water only) respectively (**Fig. 3**). In general, higher the application rate of aqueous fertilizer, higher was the germination count. Thus, a maximum of 40% and 33% increase in germination count was observed due to the application of aqueous fertilizer at the

Fig. 2 Pattern of moisture content after application of aqueous fertilizer

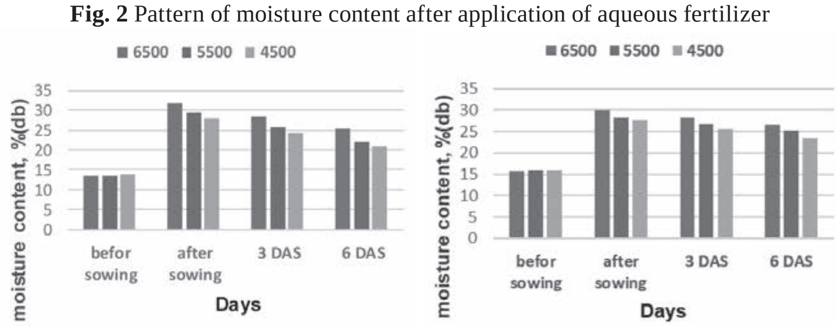


Table 2 ANOVA for number of plant per meter length

Source	DF	SS	MSS	F cal.	F tab5%	F tab1%
Replication	2	289.69	144.85	206.42**	4.10	7.56
Treatment	5	6,578.50	1,315.70	1,875.00**	3.33	5.64
Error	10	7.02	0.70			
Total	17	6,875.21				

SEd = 0.684, SEm = 0.484, CD 5% = 1.524

rate of 6,500 and 4,500 l/ha, respectively. The reference for comparison was controlled plots i.e. ZTSCFD, CSCFD and SCPAFD (water only) with no aqueous fertilizer application. The difference in germination count for the cases of 6,500, 5,500 and 4,500 l/ha application rate of aqueous fertilizer was statistically significant at 1% level in comparison to germination count in no aqueous fertilizer plots.

Number of Plant Per Meter Row

The number of the plant was counted at 90 days after sowing. The number of plants per meter was 150, 146, 124, 105, 102 and 110 with the discharge of rate of 6,500, 5,500, 4,500 l/ha and control treatments i.e. CSCFD, ZTSCFD and SCPAFD (with water only) respectively, **Table 2**. A maximum of 32% and a minimum of 17.7% increase in the number of plant per meter was observed due to the application of aqueous fertilizer at the rate of 6,500, 4,500 l/ha, respectively. The plant population was 102 per meter in case of ZTSCFD which was appreciably low in comparison to aqueous fertilizer application at 6,500 l/ha. The plant population (number of tillers) after 90 DAS for the wheat crop in the same soil under normal irrigation condition has been reported as 450/m^2, (Anonymous, 2006). Statistical analysis shows that there were significant differences among the aqueous fertilizer field in comparison to control plots (**Table 2**). This is because all the seeds got germinated and there was good growth of the crop in the plots with aqueous fertilizer by 90 days after sowing.

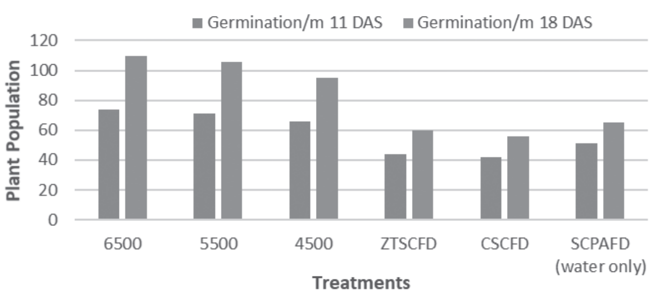
Number of Tiller Per Plant

The total number of tillers per plant was measured at 90 days after sowing. Data shows that the number of tiller per plant were 4, 4, 3, and 2.5, 2.5, 2.5 in the plots with aqueous fertilizer application 6500, 5500, 4500 l/ha and controlled plots i.e. CSCFD, ZTSCFD, SCPAFD (with water), respectively.

Number of Ear Head Per Meter Row

Number of ear head per meter row length was more in 110 in a plot with an aqueous fertilizer application rate of 6,500 l/ha followed by 107 in case of the plot with 5,500 l/ha, 102 for 4,500 l/ha. In controlled plots, the number of ear head per meter row was 84 for CSCFD, 80 for ZTSCFD and 82 for SCPAFD (with water only). This was due to aqueous fertilizer which enhanced the early germination of seed after sowing. This increase ultimately led to higher crop yield. Same trend found by Dey (2004).

Fig. 3 Influence of aqueous fertilizer rate on germination count



Plant Height

Plant height was recorded after 30, 60 and 90 days of sowing. The analysis of data revealed that the height of plant was significantly varied in various treatments up to 90 DAS but after these periods no significant variation was observed in plant height in various treatments. A maximum of 19.5% and a minimum of 14.2% increase in plant height was observed due to the application of aqueous fertilizer at the rate of 6,500 and 4,500 l/ha, respectively. The same trend was found by Dey (2004).

Root Length

Root length at 30 days for different aqueous fertilizer rates was found to be significant. Root length for 30 DAS was 90.6, 87 and 80.2 mm for aqueous fertilizer rate 6,500, 5,500 and 4,500 l/ha respectively. Whereas, non aqueous fertilizer treatments had root length after 30 days was found to be 76.14, 70.91 and 75.20 for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Root length was observed maximum 21.7% and minimum 11.5% with aqueous fertilizer rate 6,500 and 4,500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD.

Dry Root Weight

Effect of different aqueous fertilizer treatments on dry root weight was significant at 1% level of significance. Maximum and minimum dry root weight was found 0.79 and 0.68 g for aqueous fertilizer rate 6,500 l/ha and 4,500 l/ha for 30 DAS. Whereas for non-aqueous fertilizer treatments dry root weight was found to be 0.63, 0.55 and 0.65 g for CSCFD, ZTSCFD and SCPAFD (water only) respectively after 30 days sowing.

Table 3 Influence of aqueous fertilizer application on crop yield

Sl. No.	Treatments	Grain yield, kg/ha	Straw grain ratio	1,000 grain weight
1	6,500 l/ha	5,230.00	1.58	47.00
2	5,500 l/ha	5,180.00	1.50	43.60
3	4,500 l/ha	5,010.00	1.49	41.80
4	CSCFD	4,200.00	1.35	36.00
5	ZTSCFD	4,070.00	1.32	33.70
6	SCPAFD (6,500 l/ha water only)	3,907.00	1.29	30.90

Length of Ear Head

Length of ear head was measured after 60 and 90 days after sowing. Data showed that the length of the ear head was almost same 6.6 mm and 14 mm for 60 and 90 DAS respectively, for all the three aqueous fertilize treatments and slightly higher than the plots without aqueous fertilizer fields i.e. 5.2, 5 and 5.4 mm (60 DAS) and 11.4, 10.6 and 10.4 mm (90 DAS) for CSCFD, ZTSCFD and SCPAFD (with water only) respectively

Grain Yield

The grain yield data was recorded after harvesting the crop by taking samples from per meter square area. The grain yield was maximum 5,230 kg/ha with 6,500 l/ha followed by 5,180 and 5,010 kg/ha with 5,500 l/ha and 4,500 l/ha. With non-aqueous fertilizer treatments, the yield was 4,200, 4,070 and 3,907 kg/ha for CSCFD, ZTSCFD and SCPAFD (with water only) respectively, **Table 3**. Thus, a maximum of 25.29% and a minimum of 22% increase in grain yield was observed due to the application of aqueous fertilizer at the rate of 6,500 and 4,500 l/ha, respectively. The yield of the same wheat crop in irrigated fields in the experimental area at JNKVV has been reported 4,200 kg/ha. (Chouhan, 2015), which is comparable to the yield from plots with aqueous fertilizer application of 6,500 l/ha.

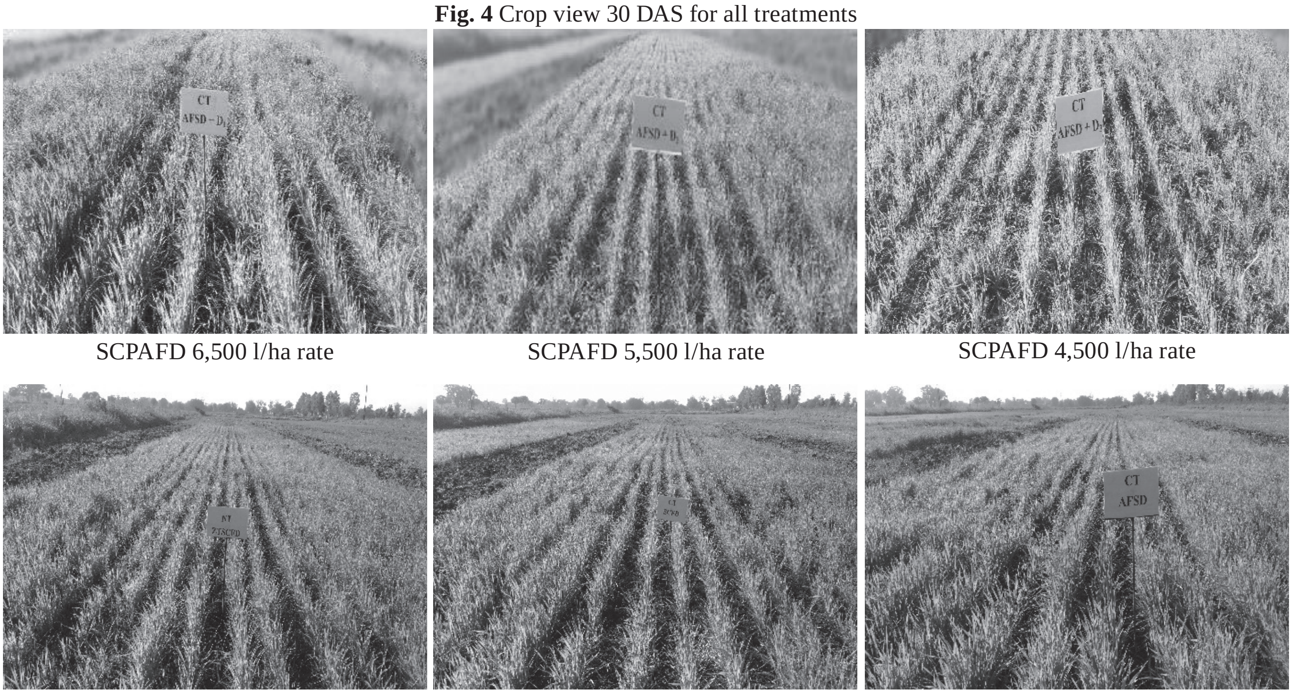
Straw Grain Ratio

Straw grain ration was recorded after harvesting the crop by taking samples from per meter square area. Data showed that the straw grain ratio recorded a similar trend as grain yield due to the supplication of aqueous fertilizer at different rates. The maximum straw yield was found in aqueous fertilizer rate of 6,500 l/ha (1.58) followed by 5,500 l/ha (1.50) and without aqueous fertilizer straw grain ratio was 1.35, 1.32 and 1.29 for CSCFD, ZTSCFD and SCPAFD (with water only) respectively, **Table 3**. Thus, a maximum of 15.1% and minimum 12.8% increase in straw grain ratio was observed due to application aqueous fertilizer at the rate of 6,500 and 4,500 l/ha. All the comparisons were with non-aqueous fertilizer treatments. Analysis of variance shows that the straw grain ratio of all aqueous fertilizer fields is significantly higher than that from non-aqueous fertilizer plots.

Conclusion

Based on findings of the studies it is concluded that the developed

Fig. 4 Crop view 30 DAS for all treatments



SCPAFD 6,500 l/ha rate | SCPAFD 5,500 l/ha rate | SCPAFD 4,500 l/ha rate

ZTSCFD | CSCFD | SCPAFD with water

seed cum pressurized aqua fertilizer drill is the best solution for deficit soil moisture content areas (in M.P. the fellow land is available approximately 25% of the total cultivated area in rabi season, apart from the deficit soil moisture content cultivated area. This fellow land may also be utilized by this machine) and had significant effects over the existing sowing systems. Application of aqueous fertilizer increased the germination rate as well as the fertilizer use efficiency in terms of all the crop parameters especially grain yield which directly influences the economic condition of the farmers.

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Development and Performance Evaluation of a Wet Red Chilli Seed Extractor

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Abstract

A wet red chilli seed extractor was developed and fabricated at All India Co-ordinated Research Project on Post Harvest Engineering and Technology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra. The major components of the machine include main frame, feed hopper, seed extraction unit and power transmission system. The performance of the machine was evaluated by varying the operational parameters viz., feed rate and shaft speeds. The results of the machine showed that a maximum extraction efficiency of 97.51%, minimum seed loss of 0.24% and maximum germination of 94.78% were found at 300 kg/h feed rate and 850 rpm shaft speed.

Introduction

Chilli (*Capsicum annuum* L.) is an important vegetable-cum-spice crop, grown extensively in different parts of India. Seed is a key component among all inputs for sustainable crop production. Indian vegetable seed industry is growing extensively. It is estimated that the quality of seed accounts for 20-25% of productivity. The traditional method of seed separation/extraction from dry red chilli fruits involves various operations like harvesting, sun drying, beating and winnowing. These operations are carried out manually, which are time consuming and seed obtained by this method is of poor quality. Farmer's traditional practice of using locally made mechanisms for wet chilli seed extraction leads to the damage to the seed as well as the reduction in quality of seed in terms of germination and viability. Presently, no appropriate machine is available with the farmers for extraction of seed from wet chillies. For the chilli seed growing farmers, it is needed to develop the seed extractor for wet chillies having appropriate crushing and seed extraction mechanism.

AICRP on PHET, Akola Centre has developed chilli seed extractor for dried red chillies (capacity 100 kg/h). In this machine, the continuous sneezing and body irritation of labour is reduced. Dried chillies are to be handled manually by labour, which is a difficult, tedious and cumbersome job and not liked by them. Further, in dry red chilli seed extraction, the chillies are dried first. Generally, sun drying of red chilli fruit is carried out for a duration of 10-15 days. During drying, inner husk particles are stuck to the seed that reduces the purity of chilli seed after extraction. Also, the collection of dry red chilli seed and dry husk are difficult to handle as it causes body irritation and sneezing. This can be further minimized if the wet red chilli seed extractor machine is developed. The other advantage of such extractor development is that drying time is reduced as compared to chilli fruit drying. Further, husk particles are not able to stick with the seed and thus the good quality seed obtained through wet red chilli seed extractor.

Nicholos (1971) developed a mechanical vegetable seed extracting machine consisting of a shaft with

Table 1 General machine specifications

Particulars	Specification
Overall length	1,280 mm
Overall width	738 mm
Overall height	1,603 mm
Power transmission	v-belt and pulley

beaters rotating inside a horizontal drum. Two outlets were provided, one at bottom of the drum, to collect the extracted seeds and juice, coming out of the screen. The second outlet was provided at the rear end to remove the pulp. Dry feeding of brinjal resulted in 75% of seed extraction efficiency. The capacity was 10 kg of seeds per hour and 93% germination.

Kachru and Sheriff (1992) evaluated the performance of an axial flow vegetable seed extractor. Five wet vegetables and fruits (tomato, brinjal, watermelon, muskmelon and pumpkin) were tested. The seed loss and mechanical damage ranged between 0.82 and 15.02% and 0.97 and 5.79%, respectively were recorded. The seed germination for tomato was 93%.

Gabani and Siripurapu (1993) fabricated a chilli seed extractor. In this unit, the dried chilli fruits were crushed and a screen separated the seed from the crushed material. The mixture of seed and skin was separated in a cleaner and seed were collected separately.

Mohanty et al. (1997) designed, developed and tested a low-cost vegetable seed extraction machine. The seed extraction machine consists of fixed cylinder casing with sieve and rotating shaft that had cutting, crushing and conveying blades. The capacity of the machine was 210 kg/h for tomatoes at 370 rpm with an average seed extraction efficiency of 84.7%. Germination percentage of seed was 82.8% without any visible damaged seeds.

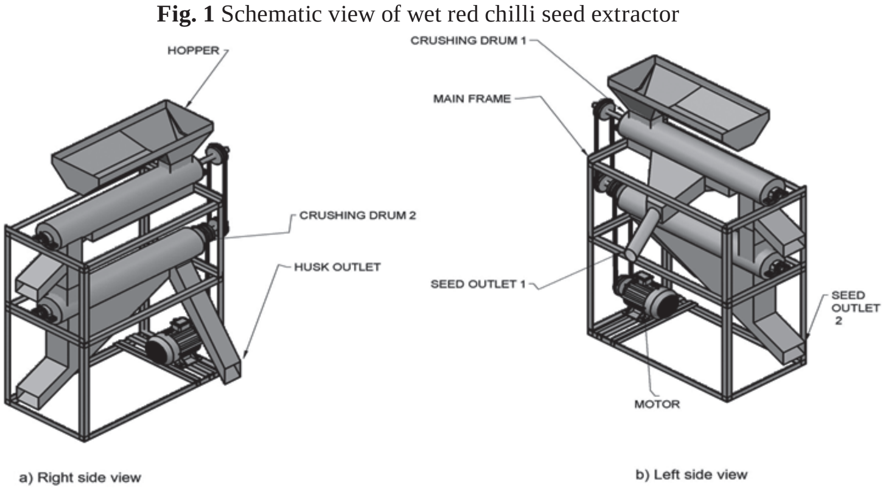
Kingsly (1998) fabricated a brinjal seed extractor. It consisted of a fruit-crushing chamber and seed separation unit. In the crushing chamber the brinjal fruit were crushed into pulp by crushing rods. The pulp was fed into the seed separation unit and continuously agitated by a shaft rotating at 35 rpm. Due to the difference in specific weight, the pulp floated and the seed sank in the water, passed through a sieve kept at the bottom, and were collected through a seed outlet. The seed efficiency of the unit was 98.8%.

Kailappan et al. (2005) fabricated and evaluated a tomato seed extractor having a capacity of 180 kg of fruits per hour. The unit had a seed extraction efficiency of 98.8%. As compared to manual method of seed extraction, the unit recorded 96.6% saving in time and 89.6% saving in cost.

Balakrishnan et al. (2006) developed a seed extraction machine for chillies to over-come human drudgery by manual seed extraction process. The unit consisted of a beater for extraction of seeds and a perforated concave sieve for separation of seeds. It was operated by a one hp single-phase electric motor. Trials were conducted at various peripheral speeds and extraction efficiency and germination were determined. The test results of the machine showed that a maximum seed extraction efficiency of 94% and the germination of 92% were attained at 480 m/min peripheral speeds.

Borkar et al. (2015) studied the performance of PKV chilli seed extractor coupled with chilli seed grader. The seed extractability was observed to be 98.71%. Grading efficiency and cleaning efficiency was observed to be 86.20 and 84.40%. The germination per cent of chilli seed in all the cases was observed to be above 70%.

Fig. 1 Schematic view of wet red chilli seed extractor



Material and Methodology

Machine Description and Specifications

The extraction machine consists of main frame, feed hopper, seed extraction unit, power transmission system and 3 hp electric motor. The feeding of the wet red chillies to the machine was carried out from the feed hopper located at the top of the machine. The chillies from feed hopper reach to the upper seed extraction drum located below the feed hopper. The seed extraction drum with shaft and shearing and crushing action of flat pegs crushes the chillies and convey it forward. In this process, the seed and husk get separated and seed is collected through seed outlet first. The chillies left with some seed are conveyed to lower seed extraction drum for extraction of remaining seed. The extracted seed passes through the semicircular perforated round hole sieve and collected through seed outlet second and husk is collected through husk outlet. The schematic view of wet red chilli seed extractor and general specifications of the machine are shown in **Figure 1** and **Table 1**.

Performance Evaluation of the Machine

The machine performance was evaluated with regard to extraction efficiency, seed loss and germination per cent and following variables.

Feed rate (100, 159, 300, 441 and 500 kg/h) and

Shaft speed (600, 688, 900, 1112 and 1200 rpm)

Extraction Efficiency

The per cent extraction efficiency was estimated by using Eqn (1) and Eqn (2):

$$\text{Extraction efficiency, (\%)} = 100 - \text{Un-extracted seed (\%)} \quad (1)$$

$$\text{Un-extracted seed, (\%)} = C/D \times 100 \quad (2)$$

where,

C = Weight of un-extracted seed, g, and

D = Weight of total seed input, g

Seed Loss

The per cent of seed loss during seed extraction was estimated by using the Eqn (3)

$$\text{Seed loss, (\%)} = E/F \times 100 \quad (3)$$

where,

E = Free clean seed collected from husk outlet, g, and

F = Total seed input, g

Seed Germination

Fifty seed were randomly taken from each replication and placed on moist towel paper, laid over a polyethylene cover, the paper towel was rolled and placed in the seed germinator maintaining 20 ±1 °C temperature and 90% relative humidity. The germination of the seed was counted on the twelfth day and expressed in per cent.

Results and Discussion

Seed Extraction Efficiency (%)

The results of the extraction efficiency indicate that the extraction efficiency of developed seed extractor was increased up to certain level and beyond certain level extraction efficiency was decreased. The data presented in **Table 2** reveal that different feed rates and shaft speeds had significant effect over the extraction efficiency of the extractor. The effect of feed rate and shaft speed on seed extraction efficiency is shown in **Fig. 2**. The feed rate of 300 kg/h and shaft speed of 900 rpm showed higher extraction efficiency of 99% compared to other combinations. If the feed rate increased beyond 300 kg/h the extraction efficiency was decreased. This might be due to excess raw material above certain limit creates barrier for crushing action between shaft and chillies. Also, at higher shaft speed shearing between the shaft and chillies was much higher than required due to which seeds remain

Table 2 Performance of wet red chilli seed extractor

Feed rate, (kg/h)	Shaft speed, (rpm)	Extraction efficiency, (%)	Seed loss, (%)	Germination, (%)
300	1,200	88.00	0.38	84
300	900	98.50	0.26	95
159	1,112	91.10	0.36	85
300	900	97.50	0.27	95
100	900	96.09	0.36	88
300	600	94.28	0.35	92
300	900	99.00	0.26	97
500	900	91.88	0.32	93
159	688	95.40	0.37	91
300	900	98.96	0.26	96
300	900	98.90	0.27	97
441	688	91.00	0.34	92
441	1,112	92.66	0.37	93

Fig. 2 Effect of feed Rate and shaft speed on extraction efficiency

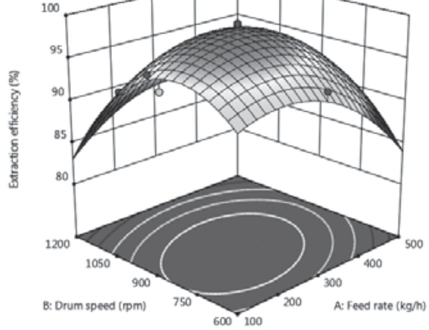


Fig. 3 Effect of feed rate and shaft speed on seed loss

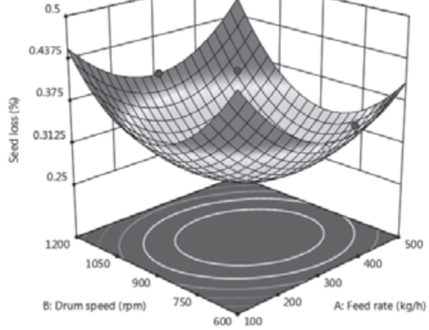
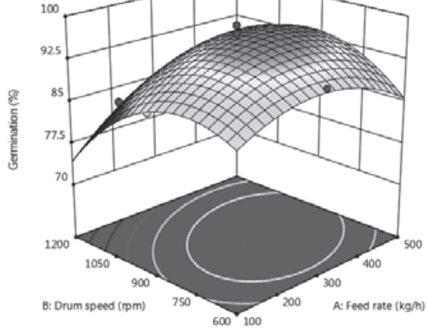


Fig. 4 Effect of Feed Rate and Shaft Speed on Germination percent



attached to husk thus resulted in increased un-extracted seed and less efficiency and low shaft speed has less impact on seed and there was less shearing between the shaft and chillies, which being not sufficient resulted in un-extracted seed and less efficiency.

Percentage Seed Loss

The results of the percentage seed loss showed that, the seed loss of developed seed extractor was decreased with increased in feed rate 300 kg/h. If the feed rate was further increased the seed loss found to be increased. Seed loss was also decreased with increase in shaft speed up to 900 rpm. As the shaft speed was further increased above 900 rpm, the seed loss was increased. The minimum seed loss (0.26%) was observed at feed rate of 300 kg/h and shaft speed of 900 rpm. The seed loss was found to be dependent on feed rate and shaft speed. The effect of feed rate and shaft speed on percentage seed loss is shown in **Fig. 3**. If the feed rate and shaft speed increased beyond this level, seed loss was increased because at higher feed rate the extracted seeds was moving fast rate, which resulted in conveying seeds along with husk and at higher shaft speed seed was not properly detached from chillies thus resulted in increased seed loss.

Germination Percentage

The results of the germination study revealed that the germination percentage of the chilli seeds extracted from the developed seed extractor was decreased with increase in feed rate and shaft speed above 300 kg/h and 900 rpm. The data presented in **Table 2** observed that different feed rates and shaft speeds had significant effect over the germination percentage of chilli seeds extracted from developed seed extractor. The combination 300 kg/h feed rate and 900 rpm shaft speed gave maximum germination of 97%. The least germination percentage was observed at treatment having the combination 300 kg/h feed rate and 1,200 rpm shaft speed. The effect of feed rate and shaft speed on germination percentage is shown in **Fig. 4**.

Optimization of Variables

Software Design Expert version 11 and Central Composite Rotatable Design was used for the optimization of responses. The main criteria for optimization was maximum extraction efficiency, minimum seed loss, maximum germination per cent and the input parameters in range. The optimized variables and their predicted responses are shown in **Table 3**.

Verification of the Model

The performance of this model was also verified by conducting an experiment for the validation. In order to validate the optimum conditions, three experiments were conducted at optimum input parameters. The average values of three experiments are given in **Table 4**. It reveals that the experimental values were very close to the predicted values which confirmed the optimum conditions (**Table 4**).

Table 3 Optimized variables and their predicted responses

Variable	Optimized values	Responses	Predicted values
Feed rate, kg/h	300	Extraction efficiency, %	98.569
Shaft speed, rpm	850	Seed loss, %	0.263
		Germination, %	96.182

Table 4 Predicted and experimental values of response at optimum operational parameters for wet red chilli seed extractor

Sr. No.	Responses	Predicted values	Experimental values (±SD)
1	Extraction efficiency (%)	98.57	97.51 (±0.56)
2	Seed loss (%)	0.26	0.24 (±0.01)
3	Germination (%)	96.18	94.78 (±0.31)

Conclusions

The wet red chilli seed extractor was developed operating on three horse-power, three phase electric motor which was found suitable for extraction of seed from wet red chillies.

The operational parameters of wet red chilli seed extractor namely, feed rate 300 kg/h and shaft speed 850 rpm were found optimum for maximum extraction efficiency (97.51%), minimum seed loss (0.24%) and maximum germination (94.78%).

Acknowledgement

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(Continued from page70)

Analysis of Sorting Fresh Jew's Mallow (*Corchorus Olitorius*) Leaves Using Imagery Characteristics

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Design, Development and Testing of a Tractor Mounted Date Palm Pollination Machine for Sudanese Farms

by

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Abstract

Date palms' pollination is an important stage for date's production. In Sudan, as in many other date's producing countries, its pollination is practiced manually, which is not only time consuming but also poses several challenges. The main objective of this research was to design, develop and field test a date pollination machine to facilitate the pollination operation. The pollination machine was fabricated using local materials, in the workshop of the Department of Agricultural Engineering - Faculty of Agriculture, University of Khartoum. The machine consisted of a gearbox and air compressor mounted on a metal frame. It is equipped with pollen tank and metallic pipes to convey the pollen mixture to the date palm tree bloom area. It was mounted on a tractor through its three-point linkage and operated by the tractor PTO shaft. The results of laboratory tests showed that air velocity, flow rate of air inside the pollination tube were, 4 m/s and 0.0003 m^3/s respectively, while pressure loss was 559 Pa. The field tests indicated that the pollination machine capacity was 18 tree/h, with pollen application rate of 0.5-1 g/tree. The pollination machine cost was 9.1 SDG /tree and it required one operator to pollinate 720 trees per year. The pollination machine reached up to 10 m in height during pollination operation. It can be concluded that the developed pollination machine is effective and efficient in date palms pollination. It is cost effective and can significantly help in saving time and labor.

Keywords: Date palms, pollination machine, Fabrication, Sudan

Introduction

Farm machinery management and introduction of new machines to perform and improve specific farm operations are of great importance. To justify their use these machines must have positive impact on production of specific crop by increasing production, improving quality of product or reducing labor requirement and production cost (Kepner et al., 1982). Date palms are important fruit tree crop grown in many areas worldwide. Dates production is a well-recognized agricultural industry worldwide, producing about 5.4 million metric tonnes (Mt) of date fruits. The dates are produced largely in the hot arid regions of South West Asia and North Africa and all over the world as a high-value confectionery Abdellouahhab (1999). The date fruit crop remains an extremely important subsistence crop in most of the desert regions in the Middle East and North Africa. Most of crop producing cultural practices are manual. There are two methods of harvesting the date fruits, traditional method and mechanical method. In the former method, a person climbs the tree and then picks fruit into the buckets, he cuts bunches and then lowers to the ground. In mechanized harvesting, there are several systems for elevating the worker to the fruit area, who removes the fruit from the bunch and packs them subsequently. The other one is the date tower that is operated straight down the row between two rows of palms; it helps the worker to remove all the mature bunches from two opposite palms. Date palms pollination occur either naturally through air or artificially (Brown and Perkins, 1972; Perkins and Burkner, 1973). Dowson (1982) explained that the artificial technique of pollination is to cut the strands of male flowers from a freshly opened male spathe and place two to three of these strands lengthwise in an inverted position, between the strands of the female inflorescence. Abdellouahhab (2002) showed that mechanical pollination requires approximately 2-3 times more pollen than the manual pollination. To overcome this problem date grower are mixing the pollen with fillers and the ratio of pollen/filler is 1:9. There are different types of pollination machines available, for example, Hand Pollinator, Ground-Level Duster, Omer Pollination Machine (Ibrahim, 1988). According to Fatihi (2005), tractor drawn machines are used in farms where distance between palms are wide and uniform, which allow tractors' free moving. There is another pollination machine called Japanese hand pollinator. It is small and light, which can easily be held to palm beak. There are also other bigger machines used for pollinating palms up to 10 m and found effective in fruit set of date palms (Hamood and Mawlood 1989). Many countries in the world developed their own pollination machines to suit their local conditions (Ibrahim et al., 1989; Abdul-Soud, 2011; Cini, 1990; Hajian, 2005; Haffar, 2013, Al-Wusaibai et al., 2012). Sudan ranks number eight in the list of top date producing countries of the world with an annual production of about 330,000 tonnes and a date palm population of about 8 million trees,. However, Sudan has availability of irrigation water and a suitable climate for date production. Sudan has been relying on growing indigenous varieties of dry and some semi-dry dates. An improvement in harvest, postharvest handling and preparation of dates for marketing in Sudan are required. History shows the date palm is a traditional crop in northern Sudan so it is providing all varieties of dates to the local markets, and it is economic crop to its native people also. The overall trend has been to move traditional date cultivation from mixed and random oasis date palm cultivation to organize it as a plantation crop for a more efficient execution of cultural practices. It is difficult to prescribe definite plant spacing but there are specific factors influencing the spacing such as the planting density depends on ecological factors (mainly humidity) and on varieties. In general, commercial plantations use 10 × 10 m, 9 × 9 m or 10 × 8 m. AbdelGabbar (1972) explained that in Sudan date palm trees are usually pollinated manually, in which a man to cut the strands of male flowers from a freshly opened male spathes and to tie three to four strands together, or cut the strands to small pieces with length 10-12 cm and tied 3-4 strands or pieces togeth-

Fig. 1 Manual pollination

Fig. 3 The metal pulleys and belt

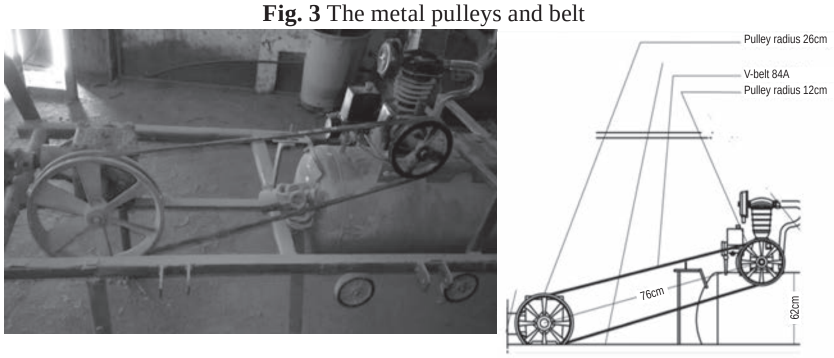
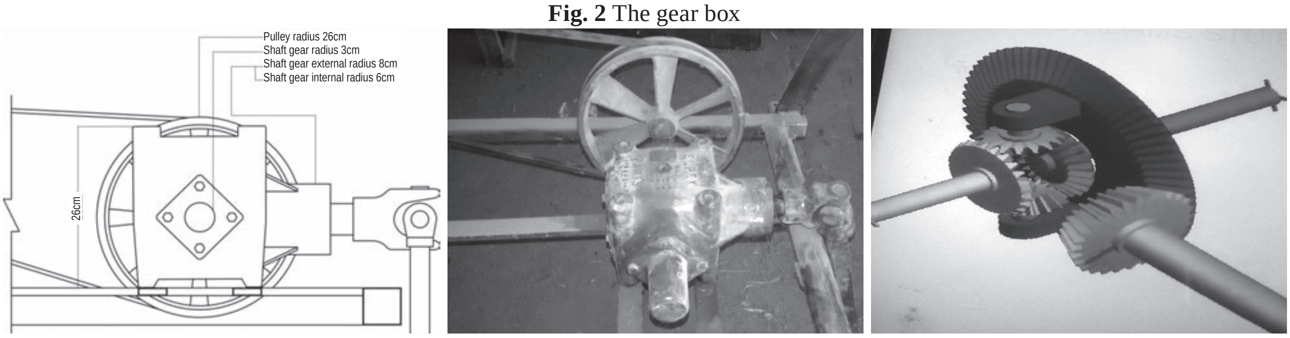


Fig. 2 The gear box



er into bag and to climb the female palm trees (8-10 m length) to put the strands in the mid of each freshly opened female spathe for fertilization (**Fig. 1**). This practice is important for high and proper dates production. This manual pollination may lead to risk of accidents or death.

The overall objectives of this research were to: design, fabricate and test the date palm pollination machine for trees up to 10 m height, to save manpower, time and to make this operation easier, safer and to be done from the ground. The specific objectives were: a) to design, fabricate a pollination machine, and b) to evaluate the performance of the machine under laboratory and field conditions.

Material and Methods

The pollinator was designed and fabricated at the workshop of the Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum, while its application was carried out at the Experimental Orchard farm, during 2017 and 2018 seasons. Local materials and equipment were used for designing and manufacturing of the proposed pollinator having the components described in the below sub-sections.

2.1 Power Transfer System

The power source was a 2-wheel tractor of 50 hp and the power was transferred as follows:

a) **The gearbox**: A tractor PTO shaft rotates the conical gear with 100 teeth, this gear rotates the small conical gears set that is connected with the pulley shaft. When the big gear rotates one cycle the small gears rotate five cycles (**Fig. 2**).

b) **Metal pulleys and belt**: The gearbox and air pump were connected by means of metal pulleys with one convention v- belt (specified as 84 A). The diameters of pulleys for gearbox and

2.2 Preparation of Air Compressor and Tank:

a) **Air pump and filter**: It consisted of shaft, piston, small cylinder and pressure regulator. The air pump was connected to the PTO shaft by means of gearbox and iron pulleys with two conventional V -belts. Piston is the dynamic part in the pump cylinder; when the piston moves down, it allows air inter through the siphon then into the piston cylinder and then the piston moves upward to push the air into the compressor tank, as shown in **Fig. 4**.

Air pump are 0.26, 0.12 m respectively as shown in **Fig. 3**.

b) **Safety and control valves**: Safety relief valve was fitted at the compressor air-tank to regulate the air pressure and relieve excessive air, while the control valve was used for controlling the air direction as shown in **Fig. 5**.

c) **Pressure regulator and gauge**: these devices were used to regulate and identify the suitable pressure and measurement as shown in **Fig. 6**.

d) **Air tank**: Medium cylinder size, with a volume of 50 liters, 0.58 m length and diameter of 0.35 m was used to store the air during operation, as shown in **Fig. 7**.

Fig. 4 Air pump and filter

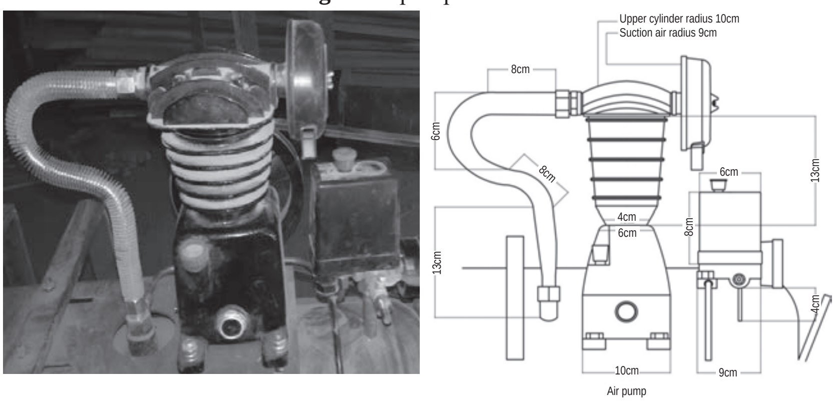


Fig. 5 Safety and control valves

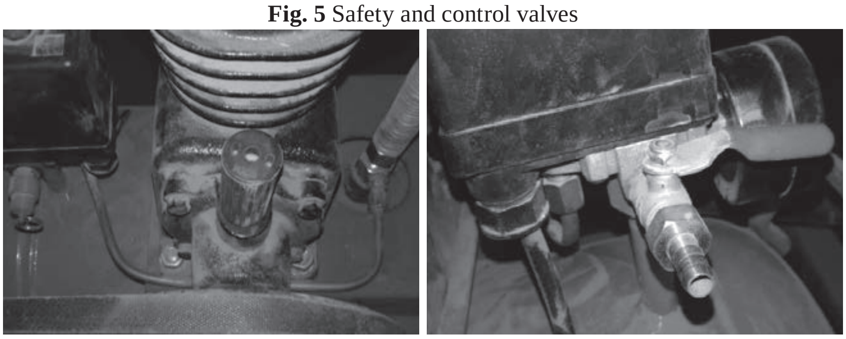
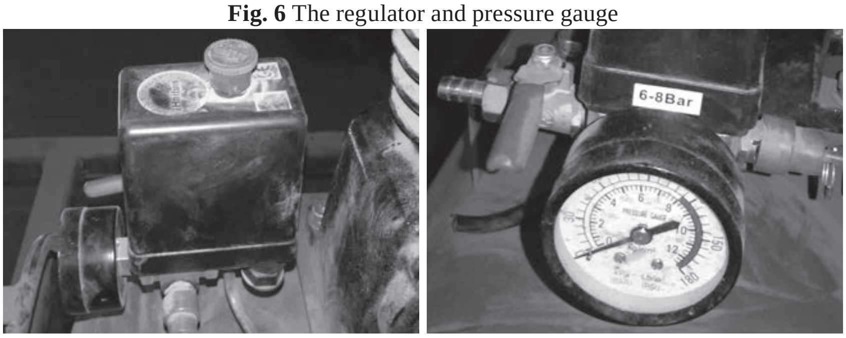


Fig. 6 The regulator and pressure gauge



2.3 Preparation of Iron Frame and Hitch:

a) The frame: It was hollow rectangle cross-section frame with three trivets welded together, having a length of 1.74 m and width of 0.62 m, the ribs consisted of iron slates. The trivets are telescopic; every trivet had two overlapped tubes to control the mechanical pollinator height from the ground by rivets. Trivets were made from iron tubes with lengths of 0.52 m (**Fig. 8**).

b) Hitches: The three point hitches consist of three ribs made from solid iron slates on triangle shape welded together, the length of ribs are 80 cm and the length of the base is 83 cm, it's the basement of the weigh load of the mechanical pollinator, as shown in **Fig. 9**.

2.4 The Pollen Application Control System

The system consisted of the following components:

a) Pollen tank: made from aluminum in pyramidal shape with two cylinders, an upper cylinder that was prepared with aluminum of 7.5 cm in length and 4 cm in diameter and holding capacity of 250 g for pollen mixture, as shown in **Fig. 10**.

b) The air vacuum device (Adapter): The adapter length is 30 cm, it creates a pressure drop into small tube (length is 4 cm), that forces the pollen mixture up through a small metal tube (length is 10 cm) and into the air stream (length is 10 cm), consisting of three short tubes welded with external helix scabs and had three sides with internal helix, as shown in **Fig. 11**.

c) Air supply control valve (Outlet valve): this valve presses the air flow through a ventury orifice (radius is 1 cm) in the adapter and controls the flow as shown in **Fig. 12**.

d) Metallic pipes and air hose: The metal pipes (length 4 m) and air hose (length 4 m) with a total length of 8 m linked together by an adapter were used to convey the pollen mixture to the bloom area (**Fig. 13**).

e) The operation of pollen control system: When the air supply control valve is operated, the air flows from the pollen tank through a ventury orifice in the adapter, thus creating a pressure drop that forces the pollen mixture up through a small solid and light aluminum metal tube with the air stream. When the air supply valve is closed, the air flow stops causing immediate termination of pollen application. Two metal pipes and an air hose with a total length of 8 m fitted together, where the the tube ends must close the bloom area through the spray

Fig. 7 The air tank

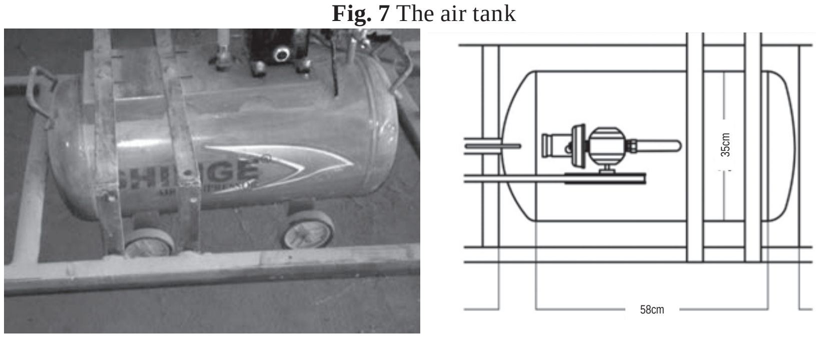


Fig. 8 Top view of pollinator on the frame

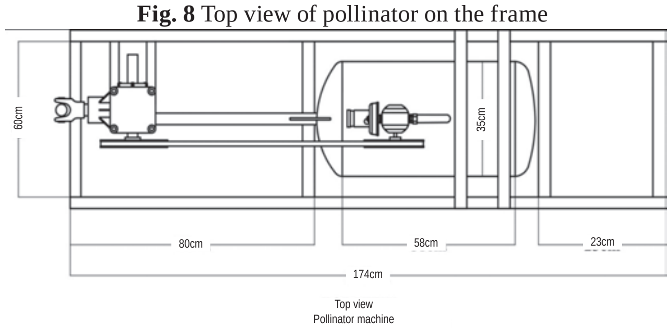


Fig. 9 The three point hitch

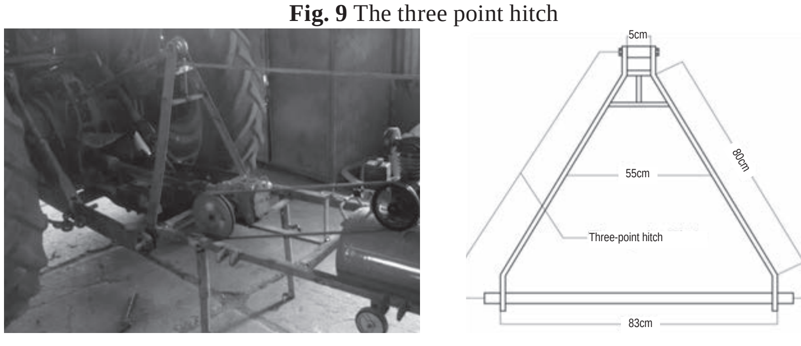


Fig. 10 The pollen tank

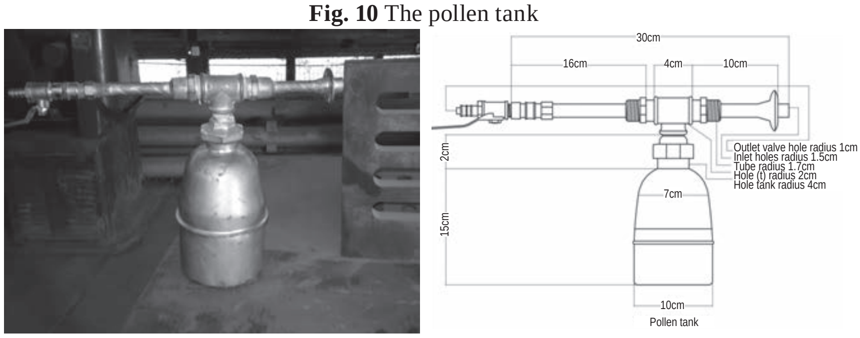


Table 1 Density and viscosity of air at different Temperature

Temperature C°	Density kg/m^3	Viscosity Pa.s (μ)
-10	1.341	16.768×10^{-6}
0	1.292	17.238×10^{-6}
10	1.247	17.708×10^{-6}
20	1.204	18.178×10^{-6}
30	1.164	18.648×10^{-6}
40	1.127	19.118×10^{-6}
50	1.092	19.588×10^{-6}

nozzle to ensure that the pollen mixture reaches the spathes. One operator is required for the pollinator (**Fig. 14**).

2.5 Mechanical Pollinator Components:

The main components of the mechanical pollinator are, an air compressor (SHIMGE (R)) capable of producing a maximum air pressure of 180 psi or 12 bar (1,034 Pa), a gearbox and compressor - connected by means of two iron pulleys and v-belt. The power was derived from PTO of a 50 hp tractor. A safety relief valve was fitted at the compressor air-tank, to regulate the air pressure and relieve excessive air. The gearbox and compressor were mounted on iron frame with three telescopic trivets made from iron. The important part of the machine is the pollen tank with capacity of 250 g for pollen mixture. Pollen tank consists of two cylinders, upper and bottom cylinder, in pyramidal shape. It consists of air vacuum device (adapter) which created a pressure drop into small tube (length 4 cm), that forces the pollen mixture up through a small metal pipe and into the air stream (**Fig. 15**).

2.6 Workshop and Laboratory Testing:

The calculation of air flow rate in the tube:

a) The flow rate in the tube:

The flow rate in the tube = Q = π × (r2 / 4) × V (1)

Where: V = velocity, r = tube diameter, Q = flow rate.

b) The roughness of the inner surface to the diameter coefficient (f) depending on the tube material (**Table 1**) = 0.015: ϵ/r accordingly (2)

Where: ϵ (mm) = Surface roughness coefficient.

c) The loss in pressure inside the tube (Assuming that the coiled tube), at (30°C). ΔP = ρ(fL) / d × (V2) / 2 (3)

Where: ρ = density, f = friction, v = velocity, p = pressure.

Fig. 11 The air vacuum device

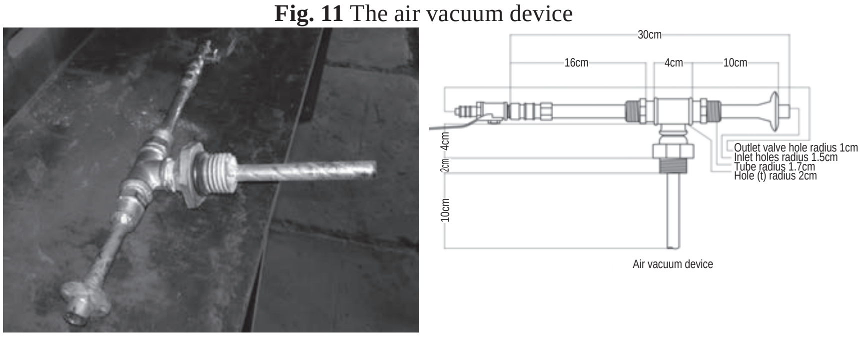


Fig. 13 The metal pipes

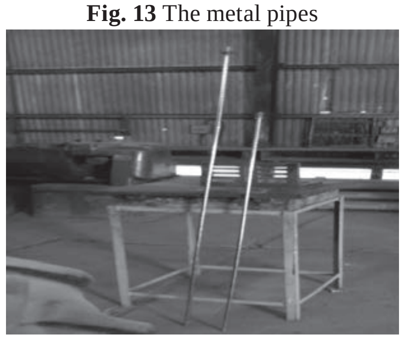


Fig. 12 The air supply control valve

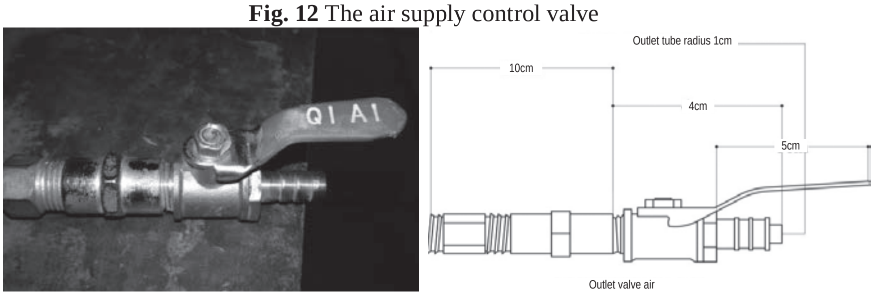


Fig. 14 The pollen application control system

Fig. 15 The air supply control valve

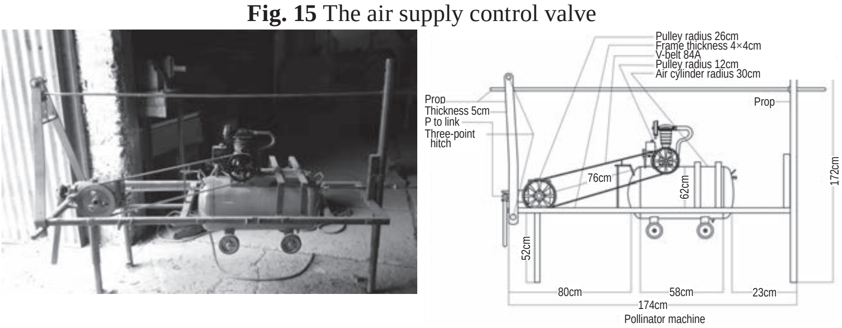


Table 2 Surface roughness coefficient for some material used to manufacture air tubes

Material	Roughness, mm
Steels	0.9-9.0
Plumbing ferric	0.26
Coiled tube	0.015
Plastic, and vitreous, soft	0.0

Table 3 The cost of manufacturing the pollinator (2017)

No	Items	Cost in SDG
1	Compressor 100-150 psi	4,000
2	Pollen tank	1,000
4	Metal tube + Plastic tube	200
5	Iron pulley + conventional V-belt	1,000
6	Gearbox	1,000
7	Hitches + Frame	2,000
8	Others	800
9	Total	10,000

$ = 24 SDG

d) Re = Reynolds number calculation (**Table 2**) = Pvd / μ (4)

e) The Bernoulli equation: Pt = Ps + Pv (5)

Where: Pt = total pressure, Ps = static pressure, Pv = dynamic pressure.

After calculation of the Re value, the Moody chart (**Fig. 16**) was used to find the coefficient of friction at the tube per unit length (f) as 0.075 (30°).

2.7 The Mechanical Pollinator Field Capacity Evaluation:

The field efficiency and actual field capacity of the machine as number of trees pollinated per hour could be calculated by using the following equations:

FE = T1 / (T1 + T2 + T3 + T4) (6)

AC = N / (T1 + T2 + T3 + T4) (7)

Where: FE = field efficiency of the machine (%), AC = actual Field capacity (no. of pollinated trees/h), N= Number of pollinated trees, T1 = Actual pollination time (h), T2 = Time for adjustment and filling the pollen tank (h), T3= Time for travel between trees and turning at row ends (h), T4 = Functional time losses (h).

Maximum number of pollinated trees/seasons = Effective time for pollination (h)/year × machine field capacity (No of tree/h) / number of pollen applications (8)

Results and Discussion

3.1 Pollinator Specifications and Operation:

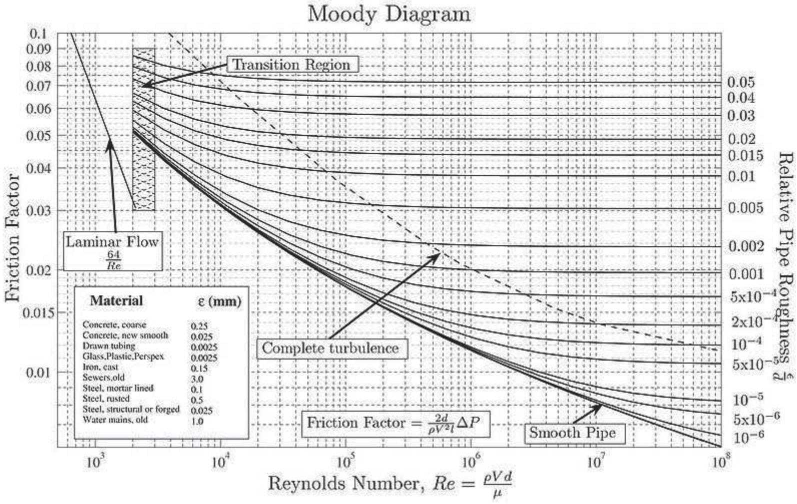
The mechanical pollinator is operated through the PTO shaft that rotates the conical gears set inside the gearbox which rotates the air pump to fill the compressor air-tank. A safety relief valve is fitted on the tank to regulate the air pressure and relieve excessive air. The pollen application control system works when the valve is opened and presses the air flows through a ventury orifice in the adapter, thus creating a pressure drop that forces the pollen mixture up through a small iron tube and into the air stream at flow velocity and rate of 4 m/s and 0.0003 m^3/s respectively. When the air supply valve is released, the air flow stops, causing immediate termination of pollen flow. The mechanical pollinator is mounted behind the tractor by the three-point hitches and equipped with aluminum pipes to carry the pollen mixture to the bloom area (**Fig. 17**). The mechanical pollinator is manufactured from local materials with low cost as indicated in **Table 3**.

3.2 Workshop and Field Performance Evaluation of the Machine

Engineering analysis with mathematical equations were carried out for the system components and flow pressure and velocity of the air and pollen mixture as given in **Table 4**. The results showed that the engineering parameters measured were efficient and effective in system

Fig. 17 Machine pollination from the ground

Fig. 16 The Moody charts



development and performance. The evaluation of the system indicated that the mechanical pollinator characterized by high reliability and efficient control over pollen flow and application rate. The field performance of the pollinator at two pressures is shown in **Table 5**. It can be observed that the pollinator field efficiency was 28% at the two seasons and for the two pressures, which is in line with the other ground level pollinators (22-27%), but considered low as compared to Alnahreen pollinator (Ibrahim, 1989), that had field efficiency of 39%. The time loss for repair requirement and filling pollen tank of the mechanical pollinator at the two seasons was 33%, which was average as compared to other ground level pollinators (22-42%), but the Alnahreen pollinator was recorded lower value as (11%). The functional time loss was (17%) which was higher than manual pollination (8%) and also the other mechanical pollinators like Babil pollinator (Ibrahim, 1988). The present pollinator has a considerably low pollen application rate (1.0-0.5 g/tree/application) as compared to Babil and Hamorabi pollinator (3 and 1 g/tree/application respectively). This shows the efficiency of its pollen application system.

The present pollinator has application height of 10 m but Hamorabi and Hawala have a limited application height of 6 m (Ibrahim et al., 1989). The pollinator produced a maximum air pressure of 180 psi, but Alnahreen pollinator produced a maximum air pressure of 150 psi.

Table 4 The results of machine lab tests

Item tested	Results
The velocity inside the tube	4 m/s
The flow rate inside the tube	0.0003 m^3/s
The roughness of the inner surface of the tube	0.015 mm
The coefficient of friction at the tube per unit length	0.075 m
The loss in pressure inside the tube at 30 °C	559 Pa
The decline in pressure inside the tube whenever the height increasing 1 m	70 Pa
Total Operating Cost	41.1
Pollination Cost per tree	9.1

Table 5 Field performance test of the mechanical pollinator (Average of two seasons)

Items	low pressure (1-4 bar)		high pressure (5-8 bar)	
No. of trees	15 trees		15 trees	
Total Field time (min)	18	100%	18	100%
T1 (min)	5	28%	5	28%
T2 (min)	6	33%	6	33%
T3 (min)	4	22%	4	22%
T4 (min)	3	17%	3	17%

*Each number is the mean of 5 readings. T1: Time for actual pollination (min) T2: Time for adjustment and filling the pollen tank (min). T3: Time for travel between trees and turning at row ends (min). T4: Functional time losses (min) (manufacture defect).

3.3 Maximum Number of Pollinated Trees/seasons and Labor Requirement:

Data analysis in **Table 6** indicated that the field capacity of the mechanical pollinator as calculated by using equation (8) was found to be 18 tree/h. This was considerably lower than other ground pollinators which was (43-89 tree/h). The maximum number of trees that can be pollinated per season could be estimated by assuming a 8-hours effective work per day and five days work per week over a pollination season extending for four weeks, the effective working hours for pollination was 160 h/season. Accordingly, it was found to be 720 trees. This was considerably lower also than that of Babil and Hamorabi pollinators (Ibrahim et al., 1989) which were 1,800 and 2,650 trees/season, respectively. This could be attributed to the difference in size and numbers of labor used. Labor requirements of the mechanical pollinator can be indicated by comparing the labor requirements to pollinate the same number of trees by hand and mechanical pollination. Since

Table 6 Effect of using mechanical pollination techniques on efficiency yielding and number of date palms during 2017 and 2018 seasons

	Low pressure		High pressure		P-value	$Lsd_{0.05}$
	2017	2018	2017	2018		
Cost of labor (SDG/day)	$100.00^b \pm 0.31$	$100.00^b \pm 0.31$	$100.00^b \pm 0.31$	$100.00^b \pm 0.31$	0.002**	29.571
Palm tree height (m)	8-10	8-10	8-10	8-10	-	-
Pollen grain weight (g/palm)	$1.00^b \pm 0.07$	$1.00^b \pm 0.07$	$0.50^c \pm 0.02$	$0.50^c \pm 0.02$	0.0301*	0.042
Pollination time (min/tree)	$5.00^b \pm 0.11$	$5.00^b \pm 0.11$	$5.00^b \pm 0.11$	$5.00^b \pm 0.11$	0.0*	6.531
Number of laborers	$1.00^b \pm 0.07$	$1.00^b \pm 0.07$	$1.00^b \pm 0.07$	$1.00^b \pm 0.07$	0.049*	0.876
Number of pollinated date palms per hour	$18.00^a \pm 0.25$	$18.00^a \pm 0.25$	$18.00^a \pm 0.25$	$18.00^a \pm 0.25$	0.0*	10.599
Fuel consumption (gallon/h)	1.0	1.0	1.0	1.0		

Values are mean ±SD. Mean value(s) bearing different superscript letters within a row are significantly different ($P < 0.05$) according to DMRT.

160 man-h is required to pollinate 200 trees, the labor requirements to pollinate 200 trees by the pollinator should be estimated. By dividing the number of trees (200) by field capacity (18 trees/h), the time required for one application is found to be 11.1 h. For 4 applications/season and one operator per system the labor requirement is calculated as 44.4 man-h. This represents 78% reduction in labor requirements.

3.4 Cost of Pollination

Results of machine operating cost calculation for different components is given in **Table 7**. The relative importance of each cost item could be indicated by its percentage to total operating cost. The highest cost percent was for labor and depreciation which amounts 30.4% of total operating cost. The fuel and oil cost were 17.7%, where the other cost components form appreciable values. This was attributed mainly to the fact that these cost factors were related to machine initial value. The pollination cost of the pollinator per tree was calculated by dividing the total operating cost by machine field capacity (FC) and multiplying by 4 (number of pollen application/season) and average of the two seasons was 9.1 SDG/tree.

Conclusions

The design requirements for a standard mechanical pollinator have been successfully met with the development of the present pollination machine and the mechanical pollinator is able to convey the pollen mixture to heights more than 10 m with efficient control over pollen application rate.

The field tests showed that the pollinator has high field efficiency, field capacity and lower labor requirement and cost of pollination. Application of the machine provided an increase of 360% in the number of pollinated trees per season and 78% reduction in labor requirements. Therefore, the feasibility of adopting the mechanical pollinator as a replacement for hand pollination is based on its impact on increasing the maximum number of pollinated trees/season, reduction of labor requirements and pollination cost, in addition to its suitability to palm plantations.

Table 7 Results of pollination cost calculation in SDG/h

Item	Cost
Depreciation Cost	12.5
Interest Cost	1.9
Housing Cost	0.6
Repair and Maintenance Cost	6.3
Fuel and Oil Cost	7.3
Labor Cost	12.5
Total Operating Cost	41.1
Pollination Cost per tree	9.1

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Analysis of Sorting Fresh Jew's Mallow (*Corchorus Olitorius*) Leaves Using Imagery Characteristics

by

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Abstract

Development in the computer world has led to the solution of many problems in the agricultural field. Classification and sorting of vegetables are the complex fields that require great human experience. Emergence of new technologies can contribute for problem solving, such as machine vision. As Jew's mallow is a leafy vegetable that is very sensitive to environmental conditions and rapidly deteriorate after harvesting, so it is necessary to configure out a suitable proof of concept for that visual sorting in processing plants. In the present study, several Jew's mallow's leaves were selected, varying widely in terms of severity of greenness, which varied due to different circumstances. An optical meter was used to measure the Chlorophyll Content Index, CCI, for each leaf. Experiments were carried out in November 2019 at the Laboratory of Department of Horticulture, Faculty of Agriculture, Kafrelsheikh University. The experimental procedures were performed in three stages. In the first stage, a CCI-based primary classi?cation is made that is further converted to wilting percent. In the second stage, a digital Red, Green, and Blue (RGB) camera is used for image capturing for each leaf sample class. Then a scale for leaves images from freshness to wilting was established according to General Appearance (GA) rules and wilting percent. After which the classified leaves images of Corchorus olitorius are processed to extract characteristic features among the predetermined classes. Morphological analysis shows a significant difference among classes and RGB pixel intensity distribution on grey scale from 0 (pure white) to 255 (pure black) can potentially differentiate among classes according to RGB intensities on the scale. Based on the statistical analysis of pixel intensity distribution of each image, the developed non-linear multiple regression equation (R2=0.99) could predict precisely the wilting percent of the leaf. Eventually the color gradient model can be used effectively to discriminate the leaf color of green, yellow and dark.

Keywords: Image features extraction, and categorization, Jew's mallow quality classification.

Nomenclature

P%: Percent
E: Entropy
CCI: Chlorophyll Content Index, ratio
M: Mean
GA: General Appearance
D: Standard Deviation
RGB: Red, Green and Blue (primary colors)
MC: Moisture Content
B-H: B-H value established by Horsfall and Barratt (1945)

Introduction

Corchorus olitorius, also known as “Jew’s mallow”, “Tossa jute”, “Bush okra”, “Molokhia, “Krinkrin” or “West African sorrel”, and other local names (Nyadanu et al., 2017). It is an important green leafy vegetable in Egypt. Its cultivated area is about 7,306 ha in Egypt and production is about 2,173 tons with a productivity of 2.45 ton/ha (FAO, 2016). *Corchorus olitorius* is a type of vegetables that eaten in both dry and humid areas of Africa. The nutritional components of *Corchorus olitorius* comprise proteins, carbohydrates, oils and calcium; iron phosphorus and magnesium (Ghaemi et al., 2014). Image segmentation is an important process that extracts expressive information from grey scale or color (RGB) spectrum (Agrawal et al., 2013). During the segmentation procedure, a digital image is disjointed into multiple areas, or items, due to extract and interprets the related information. In recent years, such technique has been extensively used in many key fields, such as medical imaging (Taher et al., 2013) remote sensing (Ghamisi et al., 2014), and pattern recognition (Pal N. R. et al., 1993). Image preprocessing refers to low level processes on digital images to fix degradations and to enhance critical attributes for high level processes. These processes are usually classified as blur correction, illumination correction, filtering, morphological operations, noise removal, thresholding, segmentation, point processing, edge detection, etc., each of which can be further characterized (Raja et al., 2014). In vegetable and fruit image processing, the raw images are transformed with a subset of those operations, based on the character of applications. Generally, attribute extraction, background equalization and contrast enhancement are essential in image processing of vegetable and fruit (Kondo, 2010). Defining the threshold level to discrete an image into required items (foreground) from background is an important stage in imaging science. Many researchers have shown the efficacy of computer-vision-based attitudes in precise grading of vegetable and fruit in food industry in the recent years (George, 2015). Multispectral images were utilized in the quality estimation of pomegranate based on the Total Soluble Solids (TSS) quantification, firmness attributes and pH (Khodabakhshian, 2017). Jhawar, (2016) used recognition-based method for orange maturity defining with a single color image of a fruit. Therefore the main aim of the current study is to extract appropriate imagery classifying features for Jew’s mallow (*Corchorus olitorius*) freshness-based sorting, for further implementation in machine visions

Table 1 Standard B-H mean and its corresponding value of wilting percent

2-2.9 B-H Mean*	Wilting Percent, %	3-5.9 B- H Mean*	Wilting Percent, %	6-8.9 B- H Mean*	Wilting Percent, %	9-11 B- H Mean*	Wilting Percent, %
0-0	0.0	3.0	9.2	6.0	63.1	9.0	97.4
0.1	0.2	3.1	9.9	6.1	64.4	9.1	97.7
0.2	0.4	3.2	10.5	6.2	67.2	9.2	97.9
0.3	0.7	3.3	11.1	6.3	68.4	9.3	98.3
0.4	1.0	3.4	11.9	6.4	71.2	9.4	98.4
0.5	1.3	3.5	12.6	6.5	72.8	9.5	98.5
0.6	1.6	3.6	13.4	6.6	74.3	9.6	98.7
0.7	1.9	3.7	14.8	6.7	75.1	9.7	98.9
0.8	2.1	3.8	15.6	6.8	76.2	9.8	99.0
0.9	2.4	3.9	16.8	6.9	78.5	9.9	99.1
1.0	2.6	4.0	17.3	7.0	80.5	10.0	99.2
1.1	2.8	4.1	18.9	7.1	82.4	10.1	99.3
1.2	3.1	4.2	20.6	7.2	83.6	10.2	99.3
1.3	3.3	4.3	23.3	7.3	85.4	10.3	99.4
1.4	3.5	4.4	26.2	7.4	86.3	10.4	99.5
1.5	3.7	4.5	28.1	7.5	89.1	10.5	99.5
1.6	3.9	4.6	29.4	7.6	90.2	10.6	99.6
1.7	4.2	4.7	31.9	7.7	91.4	10.7	99.7
1.8	4.5	4.8	33.4	7.8	92.7	10.8	99.8
1.9	4.7	4.9	36.1	7.9	93.3	10.9	99.9
2.0	4.9	5.0	38.3	8.0	94.5	11.0	100
2.1	5.1	5.1	42.5	8.1	94.9		
2.2	5.4	5.2	45.3	8.2	95.3		
2.3	5.8	5.3	46.9	8.3	95.8		
2.4	6.0	5.4	49.2	8.4	96.1		
2.5	6.4	5.5	51.8	8.5	8.5		
2.6	6.8	5.6	54.2	8.6	8.6		
2.7	7.4	5.7	56.1	8.7	8.7		
2.8	8.2	5.8	58.3	8.8	8.8		
2.9	8.6	5.9	59.6	8.9	8.9		

* Dimensionless

Fig. 1 Opti-Sciences CCM-200

in Jew's mallow (*Corchorus olitorius*) processing plants in Egypt.

Material and Methods

Experimental Procedures and Instrumentation

Leaves were visually chosen based on an extensive range of greenness intensity, which diverse due to nutrient deficiencies, position on the plant, and leaf age. Chlorophyll Content Index determined by a CCM-200 meter was measured at identical position on each leaf three times and averaged. A leaf was removed from same place as the measurement for imagery characteristics analysis. Ripened Jew's mallow was used in the study and collected from a private farm in Kafr Elsheikh Governorate. The fresh leaves were cleaned to remove all foreign materials such as dust, dirt, immature and damaged parts. Otsu's based image thresholding technique provides the optimal threshold of a given image by maximizing variance function between classes. This process has showen its efficacy on grey scale and color images. Otsu's methodology with the assistance of the RGB histogram is considered for color image segmentation. In RGB space, each color pixel of the image is a combination of Red, Green, and Blue and for that similar image, the data space size is $[0, L\text{-}1]^3$, (R = [0, L-1], G = [0, L-1], and B = [0, L-1]). The empirical built segmentation technique can be considered as follows:

For a certain RGB image, let there be L intensity degrees in the field [0,1,2,..., L-1].

Formerly, the probability distribution h_i^c can be shaped as:

$$h_i^c = h_i^c/N \quad \sum_{i=0}^{L-1} h_i^c = 1 \qquad (1)$$

Where i is a specific intensity degree in the scope $\{0 \le i \le L{-}1\}$ for the color constituent(C), $C = \{R,G,B\}$, N is the whole pixel numbers in the image, and h_i^c is the pixels number for the matching intensity level i in constituent C. Obtained results can be predicted by using the equation 2. CCM-200 instrument output is the radiation transmission ratio of a Light Emitting Diode (LED) centered at 931 nm to the radiation transmission of LED run at 653 nm according to the user manual of the CCM-200, Equation 2.

$$\text{Chlorophyll Content Index (CCI)} = (\%\ \text{transmission 931 nm}) / (\%\ \text{transmission 653 nm}) \qquad (2)$$

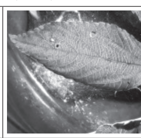
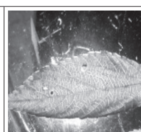
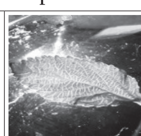
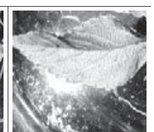
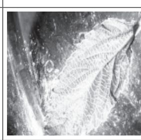
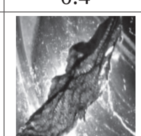
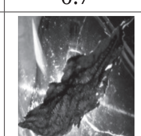
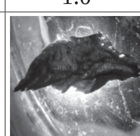
CCI values determined by the CCM-200 are only relative gauges of chlorophyll concentration, as CCI has no direct correlation to chlorophyll concentration. Several investigations have settled chlorophyll prediction equations by CCI values (Richardson et al., 2002; Jifon et al., 2005; Oncalves et al., 2008 and Cerovic et al., 2012).

Standard B-H table established by Horsfall and Barratt (1945), **Table 1** was used to convert the output of CCM-200 (CCI) and its corresponding value of B-H mean index to wilting percent.

Visualization of Leaves' Color Gradient (Chlorophyll Content)

Recognizing color distribution in Jew's mallow leaves is important to evaluate the chlorophyll content and eventually wilting percent in leaves. The models were utilized to visualize and map each pixel of the RGB images in the form of chemical image to predict CCI in the different leaves. The resulting chemical image or prediction map is shown with a linear color scale, where the CCI or wilting percent linearly matched to the color scale. Then, by testing the color variations in the established map we can evaluate the anticipated distribution of CCI. All steps involved in visualization purposes were implemented with a program developed using Matlab (Version 2009a, the Mathworks Inc., Mass, USA).

Table 2 General Appearance (GA) measurement of some samples of Jew's mallow leaves

Whole leaf image								
CCI*	25.2	25.4	25.9	27.3	27.8	28.1	28.4	28.7
B-H**	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Percent***	0	0.2	0.4	0.7	1.0	1.3	1.6	1.9
Whole leaf image								
CCI*	29.0	29.3	29.5	30.5	32.4	32.9	33.8	
B-H**	0.8	0.9	1.0	1.1	1.2	1.3	1.4	
Percent***	2.1	2.4	2.4	2.8	3.1	3.3	3.5	

* CCI measured by CCM-200, ** The values of B-H mean are used to calculate the wilting percent from **Table 1**, *** Wilting percent is obtained from **Table 1**

Results and Discussion

Wilting results of different samples of Jew's mallow leaves were obtained by CCM-200 and converted to wilting percent according to the standard Table of Horsfall and Barratt (1945) as listed in **Table 2**.

Chlorophyll Content Index Measurements

CCI determined by CCM-200 meter is built on the proportion of NIR to red wavelengths transmission. Transmission of radiation is non-linearly related to the absorbing compound quantity in leaf tissue and linearly correlated to the compound absorbance (Atkins, 1990). Transmission of Near Infra-Red (NIR) radiation is not influenced by chlorophyll and is hence principally measured by the quantity of non-chlorophyll compounds, by presumption an even spreading of chlorophyll in leaves.

Measurements of General Appearance (GA)

Evaluation was done by considering the leaves' freshness and wilting, according to the following scale: 1 = very weak, 2 = weak, 3 = average, 4 = good and 5 = excellent (Troncoso et al., 2005). General Appearance, GA measurements were illustrated by **Figure 2**. It can be noticed that the appearance changes during the storage period under laboratory conditions of Jew's mallow leaves. On the other hand, **Table 3** indicates the corresponding changes of CCI values for the same leaves.

The experiment of image segmentation is implemented by Matlab R2010a. Procedures of implemented segmentation are followed up form Matlab central webpage. Segmented image and RGB histogram, are represented at **Figures 4-7** the RGB image segmentation is a complex problem due to the three unlike color rhythms of Red, Green and Blue components. The histogram of an RGB image is more difficult than the grey scale histogram of the image. Searching for optimal threshold on such composite histogram is a complex task. Each color distribution should be distinctly analyzed seeing the RGB histogram, which may upsurge the computational period. The conforming optimal thresholds (R, G, B) are shown in the **Figures 4-7**.

Table 3 Six time's daily measurements of CCI for five days' storing under laboratory environment conditions

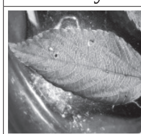
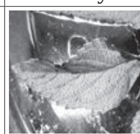
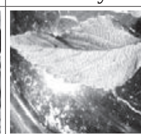
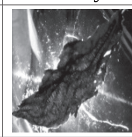
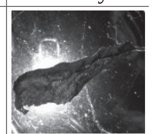
Daytime, h	CCI, ratio				
	1st day	2nd day	3rd day	4th day	5th day
					
8	26.3	28	41.7	54.2	54.5
10	31.2	26.5	29.5	52.6	56.8
12	24.3	24.7	32.2	45.7	57.2
14	25.0	19.6	35.6	48.3	63.1
16	25.2	42.4	34.3	51.9	52.8
18	26.2	43.4	33.7	53.2	64.3

Fig. 2 General Appearance from the first to the fifth experimental day

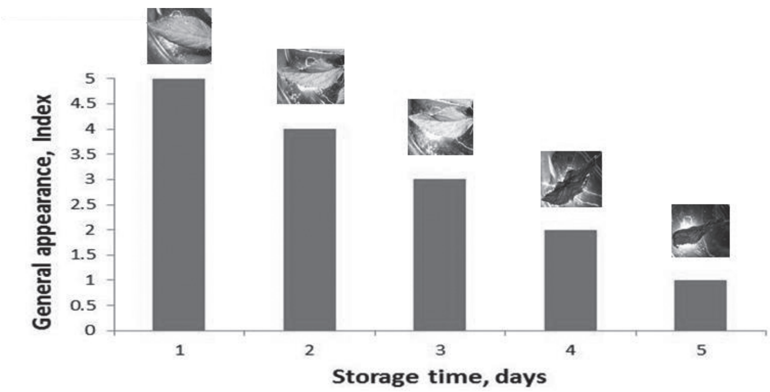
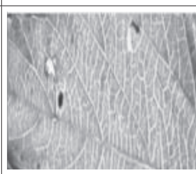
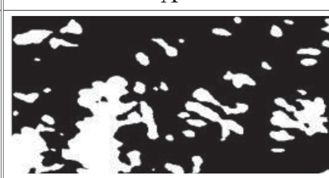
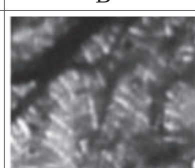
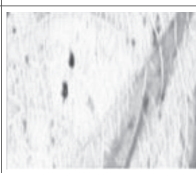
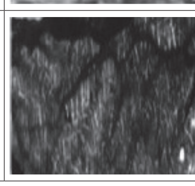


Fig. 3 Morphological analysis (A), original images (B), and wilting percent (C) of Corchorus olitorius leaves images

A	B	C	A	B	C
		0%			2.8%
		2.1%			3.5%

Morphological System for Image Processing

Morphological Image Processing is a procedure for adjusting pixels in an image. In the example of Gray scale image, the pixels are defined by the binary numbers 0 and 1, and the procedure is carried out using complex image processing algorithms, or less complex calculations. It includes contracting and stretching as well as opening and closing. The goal of formalizing images is to remove unwanted defects or improve image quality. **Figure 3** shows an open process: The opening process of Morphological analysis (A), original images (B), and wilting percent (C) is a process that erodes first and expands later. It is used to get rid of small objects in the image, separate objects at thin points, and smooth the outlines of larger objects without significantly changing the size of the objects. The process ability of images decreases to eliminate the small black spots just when the moisture content of the leaves decreases, which means that as wilting percent increases, the black area tends to be the predominant in the image.

RGB Histogram for Pixel Intensity Distribution

An image histogram is a type of histogram that expresses the distribution of the color value in a digital image. The graph consists of plotting the pixels number of each color degree. By looking at the graphic representation of a particular image, the viewer can, at a glance, judge the overall distribution of tonal values. Image histograms are found on many modern digital cameras. Photographers can use this feature in order to show the distribution of captured tonal values, and if a certain detail in the image has been lost due to too brightness or due to obscuring shadows. The x-axis (horizontal) of the graphic representation represents the various color values on the scale from zero (dark areas) to 255 (light areas), while the y-axis (vertical) represents the number of pixels in a specific color value. The left side of the x-axis shows the black parts, the middle side represents the medium Gray areas and the right side represents the light and pure white areas. While the y-axis represents the size of the captured region in each of these areas. Therefore, the histograms of a very dark image will most of its points on the left and middle side of the graph. On the contrary, a histogram of a very light image with few dark zones and / or shadows will most of which are located in the right and middle part of the graph. **Figures 4-7**, show RGB histogram that illustrates the color channels of the leaves sheets with different degrees of freshness. It is noticed that the green channel on the right side of the horizontal axis represents that the light color, which decreases with a decrease in the degree of freshness.

$$P, \% = 18281.77E^2 + 0.018M^2 + 1.75D^2 - 281789E + 382.28M - 664.39D - 52.01EM + 68.39ED - 0.53MD + 1091100$$

$$R^2 = 0.99 \qquad (3)$$

Where P, % is welting percent, E, is the image pixel entropy, M, is mean pixel intensity value over the region of interest, and D is the standard deviation of pixel intensity. According to the data acquired from pixel intensity analysis for each freshness grade of Jew's mallow, an expressive nonlinear multiple regression equation was developed, Equation 3. The equation can be used to predict the wilting percent according to image pixel intensity statistical analysis, for further leave image classification processes. Comparing obtained data with those

Fig. 4 RGB pixel intensity histogram of leave sample of 0.0% wilting percentexperimental day

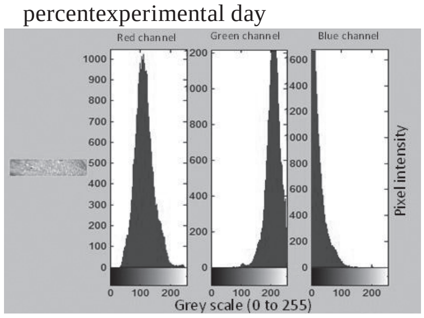


Fig. 5 RGB pixel intensity histogram of leave sample of 1.3% wilting percent

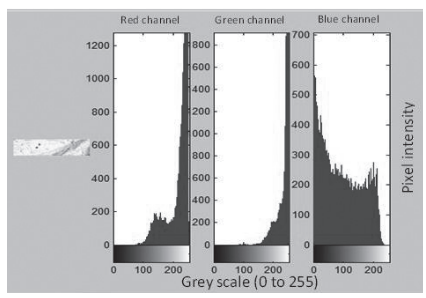


Fig. 6 RGB pixel intensity histogram of leave sample of 3.1% wilting percent

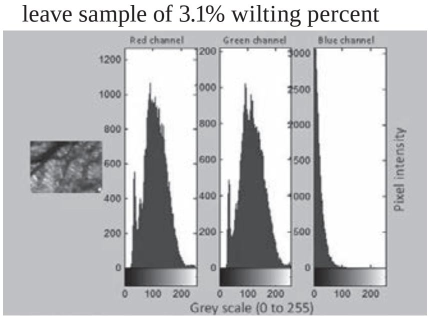


Fig. 7 RGB pixel intensity histogram of leave sample of 3.5% wilting percent

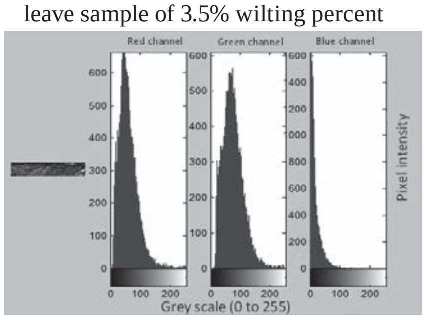
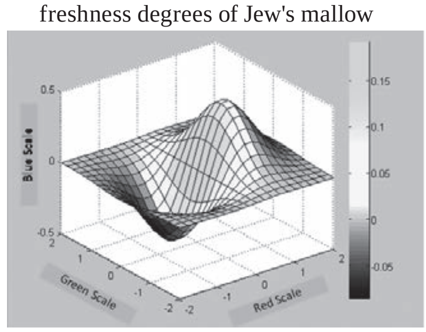


Fig. 8 RGB color-map based on freshness degrees of Jew's mallow



predicted by Equation 3, the prediction showed imagery characteristics values banded along the straight line, which showed that the suitability of the developed equations in describing the obtained results, (R^2 = 0.99).

Visualization of Jew's Mallow Freshness by RGB Color Space Model

A jet type color-map was used to determinate the degree of freshness of Jew's mallow. The final pattern generated was transferred with optimal wavelengths for each pixel of the image, to predict the brightness degrees of all leaf samples. An expectation image that called a distribution map was generated after multiplying the regression coefficients of the model by the spectrum of each pixel in the image to visualize the degree of freshness within the sheets. In the resulting distribution map, pixels with the same spectral attitudes gave the same expected value for luminosity gradients, which were then visualized with a similar color in the image. Diverse gradients of brightness were demonstrated from high to low in diverse colors from green to black (color bar on the right in **Figure 8**). This technique is beneficial to the Jew's mallow industry by conducting a quality assessment and inspection, as it means monitoring the process in the primary stage of production. Such technology offers a new objective and quantitative technique for evaluating the quality of Jew's mallow products.

Conclusions

Jew's Mallow "Molokhia" is a very important leafy vegetable for Egyptians due to its delicious taste and nutritional value. Within Jew's mallow processing plants, there are three main processes which conducting on leaves after receiving from suppliers; mincing, packaging and freezing. The received product has some quality defects need to be treated by sorting and grading. Leaves color is a vital characteristic ensures product quality. So the suitable technology for leaves sorting is vision technology which depends on image processing and pattern recognition. The sorting process is reliant on the integration of vision, appropriate software and mechatronics engineering. Image processing is an essential part for pattern recognition of logic design. Feature extractions and characteristic definition for each quality category of captured leaves images are necessary for machine and computer vision designs. RGB color segmentation can give a good categorization of leaves color by color map and wilting percent by the developed non-linear multiple regression equation. The morphological analysis technique can rapidly discriminate among four classes of Jew's mallow leaves.

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(continued on page56)

Development of a Tractor-operated Check Row Planter for Small Farm Mechanization

by

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Abstract

Check row planting is an essential part of precision agriculture, which allows weeding in both direction and sunlight up to the bottom of the crop. A tractor-operated check row planter was designed and developed for planting two rows of maize at a spacing of 4,040 cm. An electronic seed metering system was developed to maintain equal seed-to-seed distance. The planter was assisted with hydraulically controlled row guiding system to maintain straight path while moving forward. The effective field capacity, field efficiency and field machine index were found to be 0.12 ha.h^{-1}, 75.20 and 72.72 respectively. The mean multiple index, quality of feed index, miss index and precision were observed to be 13.31, 75.74, 10.94, and 18.42, respectively in field conditions. Mean seed spacing was 40.32 cm, while mean row spacing was found to be 41.25 cm for the planter. The total cost of operation per hour in case of check row planter and manual check row planting were 3,000 and 18,750 Rs.ha^{-1}. So total saving was 84% in case of check row planter as compared to manual planting. The breakeven point for the check row planter was 68 hours per year.

Introduction

In India, small and marginal holding farmers cultivate around 46.94% of the area, and they produce around 60% of the total food grain production and over half of the country's fruits and vegetables production (Agricultural census, 2015-16). These farmers cannot invest in costly farm machinery and depend on hiring of implements to carry-out agricultural operations in their fields. One of the cardinal causes for low agricultural productivity in developing countries is the lack of appropriate machineries those suit to the needs of the small farm. So, there is need to mechanize the small farm. Small farm mechanization is a major challenge for developing country. Maize is the third most important crop after rice and wheat in India. It accounts for approximately 9% of total food grain production in theecountry. Maize production in India has grown over the last ten years from 15.10 million tonnes in 2006-07 to 27.23 million tonnes in 2018-19 and the area under maize cultivation in the period has increased from 7.89 million hectares in 2006-07 to 9.18 million hectares in 2018-19 (Directorate of Economics & Statistics, DAC & FW, 2019). Now people are interested to replace different coarse cereals with maize crop. Crop diversification is the main aspect helping farmers to cultivate different crops other than paddy as it consumes large amount of water and fertilizer. In order to increase the maize production, the planting of maize has to be done precisely because planting is the most vital farm operation, which decides overall production of the crop and judicious use of costly farm inputs. Check row planting is an essential part of precision agriculture. It is a method of planting in which row-to-row distance and plant-to-plant distance is maintained constant, which allows adequate space for weeding operation in both direction and permitting sunlight up to bottom of the crop. Check row planter helps in saving seeds. The check row planter saves 66.75% of money over manually transplanting and 72.38% of money over manually dry seeding methods (Pandey et al., 2018). Proper plant spacing in case of check row planting reduces the nutrient intake competition among the plants, allows efficient disease management and makes harvesting easier from all sides without sabotaging its neighbour. Planting the crop with a plant geometry of 15 × 15 cm spacing gave significantly higher yield (59.18 q/ha) than other geometry of 20 × 15 cm, 25 × 15 cm and 30 × 15 cm (Yadav and Tripathi, 2008). Weight of cob (18,507 kg.ha^{-1}) and net income (Rs. 17,253) was recorded significantly higher at 50 × 50 cm and 30 × 30 cm in maize respectively over the plant geometry of 50 × 30 cm and 30 × 60 cm (Thakur et al., 2015).

Pandey et al. (2018) evaluated manually operated check row planter for dry seeding of rice. They reported that the planting cost was Rs. 767/ha with check row planter which was less as compared to manually transplanting in SRI and dry seeding manual method requiring additional cost of Rs. 2,307/ha and Rs. 2,777/ha respectively. Therefore, the machine saves 66.75% and 72.38% of money over manually transplanting and manual dry seeding methods respectively. The planter required 5.44-man days per hectare, which was much less as compared to both manual transplanting in SRI and dry seeding method.

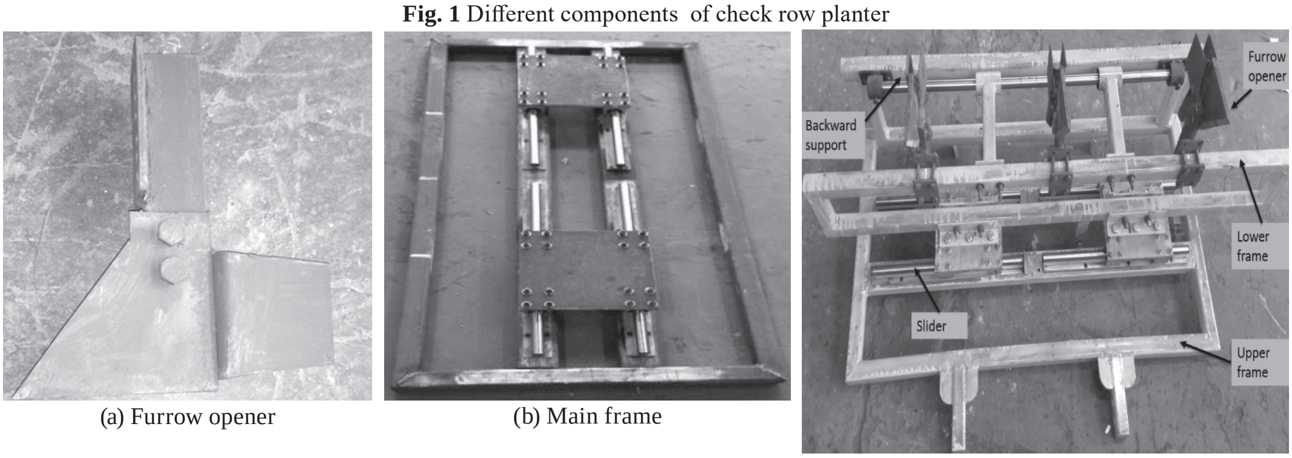
Verma (2020) developed a manually operated check row planter, which was capable of planting two rows of rice at a spacing of 25 × 25 cm. The effective field capacity, field efficiency and seed rate of the planter were found to be 0.023 ha.h^{-1}, 47.38% and 10.1 kg.ha^{-1} respectively. He compared performance of the developed check row planter with manual transplanting and dibbling of seeds in System of Rice Intensification (SRI). The planter required Rs. 853/ha, which was less as compared to manually transplanting in SRI and dibbling. The machine saves 66.7% and 72.4% of money over manual transplanting and dibbling methods.

Check row planting by manual method is time consuming and require more labours. So, check row planter will be helpful for the precision planting in small farm by saving time, increasing productivity and requiring less farm inputs. In spite of the advantages of check row planter, few works have been done for designing the check row planter in Indian perspective. Considering the above facts, a tractor operated check row planter was designed and developed. The planter was assisted with a row guiding system to maintain proper alignment while operating in field. Performance of the developed check row planter was evaluated in field and results obtained are discussed in this paper.

Material and Methods

Check row planter was designed and developed for maize crop. An electrohydraulic row guiding system was developed and incorporated in the planter to guide it along row in straight path. The planter was evaluated in the field by attaching with a

Fig. 1 Different components of check row planter



(a) Furrow opener

(b) Main frame

(c) Lower and upper frame assembly

15 hp tractor.

Design of Furrow Opener

Design of furrow opener was decided according to type of crop and required depth for particular seed. Two furrow openers were used in planter. Shoe type furrow opener of 290 mm shank length were provided with seed outlets. The furrow opener was attached to the main frame with rigid clamps and holes were provided to adjust the depth of operation in the vertical direction. No separate covering device was provided as seeds were covered by the rushing of adjacent soil during operation by the curved sheets provided on the side of boot pipe behind the furrow opener. The furrow opener (**Fig. 1a**) was designed on the basis of soil resistance acting on the furrow opener.

$$D_e = A \times S_r \times FOS \quad (1)$$

A = 1/2 × width of furrow depth of furrow

Width of the furrow = $2 \times a_{max} \times B_o$

Where, A = Cross sectional area of furrow, cm^2; FOS = Factor of safety; S_r = Soil resistance, $N.cm^{-2}$; D_e = Theoretical draft on one furrow × factor of safety = D × FOS, N; B_o = Width of furrow opener = 1 cm, and a_{max} = Maximum depth of operation 6 cm.

Assuming specific draft of sandy loam soil as 3 $N.cm^{-2}$, the width of the furrow and draft on one furrow opener were obtained as 12 cm and 216 N respectively.

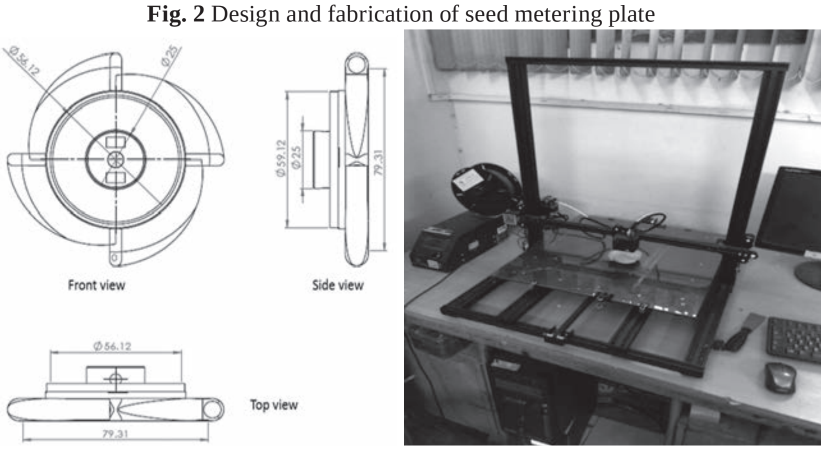
Design of Main Frame

The main frame of 1,200 × 600 mm was fabricated using mild steel square pipe section of size 40 × 40 × 4 mm (**Fig. 1b**). Seed box, hydraulic oil tank and double acting hydraulic cylinder were mounted on the main frame. Three-point hitch was attached to the main frame. Two rectangular pipes of size 65 × 30 × 5 mm were provided in the middle of the upper frame to support the lower frame. The main frame was subjected to both bending force and torsional force due to the weight of the equipment and soil force acting on the working element during the operation, respectively. So, total force acting on the main frame due to furrow opener is calculated as:

D_T = draft on one furrow opener number of furrow opener (2)

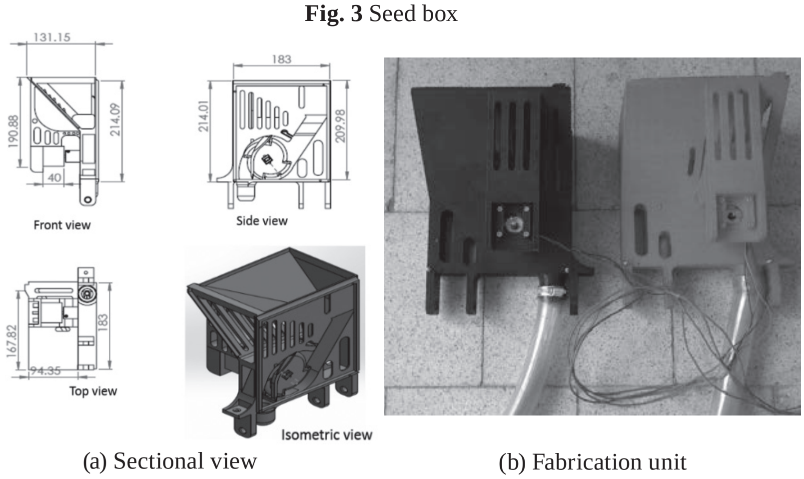
So, total load acting on the mild steel square cross section was 16,480.8 N for allowable stress of 1,050 $kg.cm^{-2}$. The designed main frame was able to take the draft acting on the furrow as well as the load of the different components of the planter those were mounted on the main frame.

Fig. 2 Design and fabrication of seed metering plate



(a) Sectional view (b) Fabrication using 3D printing

Fig. 3 Seed box



(a) Sectional view (b) Fabrication unit

Design of Lower Frame

A lower frame was attached to the main frame and two furrow openers were mounted on the lower frame (**Fig. 1c**). The lower frame of size 1,500 × 200 mm was fabricated by using mild steel of size 40 × 40 × 4 mm. The lower frame was supported by two pairs of sliders to allow side-wise movement of the lower frame. The sliders were bolted to the upper frame. The double acting cylinder that was mounted on the upper frame, controlled the side wise movement of the lower frame along with the furrow opener. A backward support was provided to prevent the bending of the lower frame assembly due to soil resistance and any obstacles encountered.

Design of Seed Metering Mechanism

(a) Determination of Physical and Engineering Properties of Maize

Various physical and engineering properties of the seed affect the performance of seed metering mechanism. Relevant seed properties for maize seed i.e. size & shape, bulk density, angle of repose and 100 grain weight, were selected for design. Seed picking, singulation and dropping is influenced by above parameters. Various seed properties were measured and used for designing of metering mechanism, seed box and seed hopper of planter.

(b) Design of Seed Metering Plate

Vertical circular plate with cell was used as metering unit. The seed plate was designed on the basis of different properties of the maize seeds. Diameter of the cell was taken as the largest dimension of the seeds and the depth of the cell was taken as thickness of the seeds. given on the periphery and dropped gently into the seed tube. The outer edges of the cells were machined to provide equal cell size for desired accurate seed spacing. The cell plate of electronic metering mechanism was designed by determining the speed of the cell plate and number of cells to achieve the desired spacing. Based on the seed physical properties, five different cell size (8.80 mm, 9.73 mm, 10.82 mm, 11.90 mm, 12.83 mm) seed metering unit was fabricated and the best size was optimised for maize crop. The Front, Side and Top view of designed seed metering plate are shown in **Fig. 2a**. The seed-metering unit was fabricated with the help of 3D printer (**Fig. 2b**). The vertical plate was allowed to pass through the seed hopper. Seeds were picked in the cell.

(c) Design of Seed Box

The seed box was fabricated using 3D printer in the laboratory (**Fig. 3**). The provision to hold the stepper motor was provided in the seed box assembly. The seed hopper was designed according to angle of repose of the maize crop (45 degree). The slope of the hopper was kept slightly higher than that of the angle of repose of the seeds to allow continuous flow of the seeds without obstruction in the hopper.

The sensor-controlled metering mechanism was developed using stepper motor, stepper motor drive, LIDAR sensor, microcontroller, power supply and the required wiring. Two Nema 17 stepper motors were used in metering unit of the planter. A 12 V battery powered the metering circuit while motor driver was to provide abstraction by acting as a translator between a hardware device and the software. Different components electronic seed metering mechanism were connected as per circuit diagram in **Fig. 4**.

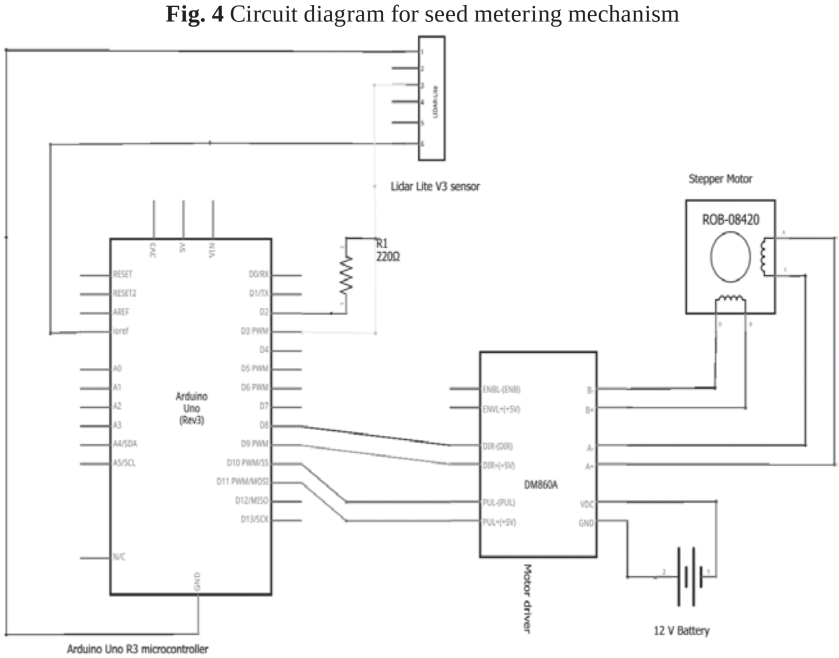
Design and Development of Hydraulic-operated Row-guiding System

The hydraulic row guiding system was designed on the basis of the force requirement to move the furrow opener across the furrow. The force acting on the shoe type furrow opener was 75 N (Damora and Pandey, 1994). Based on this force, the components of hydraulic power pack i.e. oil tank, pump, double acting hydraulic cylinder, direction control valve, hose pipe, pressure gauge were designed and pressure control valve and oil level indicator were selected. The designed values were given in **Table 1**. These components were connected as shown in **Fig. 5**. Power from the P.T.O of tractor was taken to pump of hydraulic power pack by step pulley and belt arrangement (**Fig. 5**). The direction control valve was electronically

Table 1 Design values for hydraulic power pack

Component	Design parameters	Values
Double acting hydraulic cylinder	Bore (D), mm	40.00
	Piston rod diameter (d), mm	22.00
	Pressure required for cylinder extension, kg.cm^{-2}	13.68
	Pressure required for cylinder retraction stroke, kg.cm^{-2}	19.61
Pump	Stroke (L), mm	150.00
	Pump discharge (Q_p), lpm	6.30
Tank	Capacity (C), pm	25.20
	Length (l), mm	450.00
	Width (b), mm	300.00
	Height (h), mm	250.00

Fig. 4 Circuit diagram for seed metering mechanism



controlled by the microcontroller unit. The direction control valve controlled the movement of oil to the double acting hydraulic cylinder on the basis of signal received from the microcontroller. Upper frame was fixed to three-point hitch of tractor while, lower frame was connected to double acting hydraulic cylinder. The frame was allowed to move across the direction of movement of planter and controlled by double acting hydraulic cylinder.

Evaluation of Check Row Planter

Field preparation was done as per the agronomic requirement of maize crop. Maximum depth of placement of the maize crop is 6 cm. A plot of size 15 × 10 m was taken for the planting of the maize crop. The planter was operated by a 15 hp Mahindra Yuvraj tractor at a forward speed of 2 km.h^{-1} (**Fig. 6**) to evaluate its performance in terms of actual depth of placement of seed, average spacing between the plants along the rows, field capacity, field machine index and field efficiency.

Performance Parameters Considered for Field Evaluation

The effective field capacity is the actual coverage of the field including the time lost related to the field area and time lost related to the machine. But it excludes the time lost for fuel filling before the operation and any permanent damage to the machine.

(a) Theoretical field capacity

$$TFC = (W \times S) / 10 \quad (3)$$

Where, W = Width of coverage, m; TFC = Theoretical field capacity, ha.h^{-1}, and S = Speed of operation of the machine, km.h^{-1}.

(b) Effective field capacity

$$AFC = (A \times 0.36) / T \quad (4)$$

Where, AFC = Actual field capacity, ha.h^{-1}; A = Area of coverage, m^2, and T = Time taken to cover the area, s.

Field efficiency is the ratio of AFC to the TFC and could be expressed as:

$$E_f = (AFC \times 100) / TFC \quad (5)$$

Where, E_f = Field efficiency, %; AFC = Actual field capacity, ha.h^{-1}, and TFC = Theoretical field capacity, ha.h^{-1}.

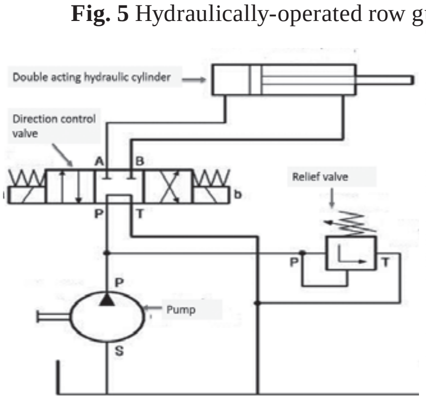
The field machine index indicates how a particular field geometry affects the working capacity of the machine. The field machine index could be calculated as:

$$FMI = (T_p - T_o - T_t) / (T_p - T_o) \quad (6)$$

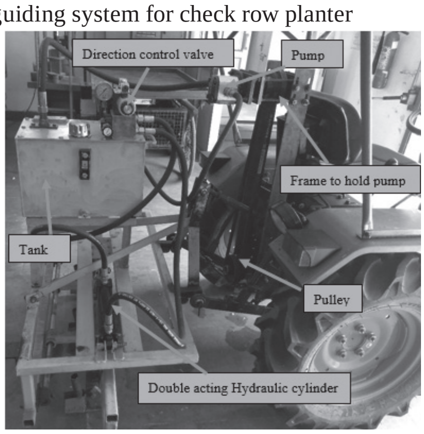
Where, FMI = Field machine index, %; T_o = Total time for support functions (not including turning), min/plot; T_p = Total time to cover the field, min/plot, and T_t = Total turning time, min/plot.

The total cost of check row planting was determined by adding the fixed cost and variable cost. The different cost components were calculated in fixed cost and variable separately and then the cost of the check row planter was compared to manual check row planting to find its cost effectiveness.

Fig. 5 Hydraulically-operated row guiding system for check row planter



(a) Hydraulic circuit



(b) Row guiding system

Results and Discussion

Physical and Engineering Properties of Maize Seeds

The physical and engineering properties of maize seeds were measured in the laboratory for designing the different components of the planter. The observed values for

Table 2 Physical properties of maize seeds

Sl. No.	Property	Range	Mean	Standard deviation	Coefficient of variation (CV), %
1	Length (mm)	8.88-12.83	10.93	0.91	8.38
2	Breadth (mm)	7.45-10.37	8.69	0.76	8.80
3	Thickness (mm)	3.46-4.93	4.213	0.53	12.71
4	Geometric mean diameter (mm)	6.53-8.31	7.348	0.45	6.14
5	Sphericity	0.58-0.76	0.67	0.04	6.57
6	Aspect ratio	0.62-0.98	0.79	0.08	10.29
7	Angle of repose (degree)	29.8-38.6	35.6	2.830	7.94
8	Bulk density (kg.m^{-3})	732.81-795.32	758.4	17.60	2.32
9	Particle density (kg.m^{-3})	1,286.16-1,352.88	1,325	21.68	1.63
10	Test weight (100 seeds), (g)	27.28-29.90	28.86	0.67	2.35

the length, breadth, thickness and geometric mean diameter of maize variety were in the range of 8.88-12.83 mm, 7.45-10.37 mm, 3.46-4.93 mm and 6.53-8.31 mm, respectively. The maximum and minimum length of the seeds were taken for designing the cell size of the metering unit. The sphericity of the maize seeds was in the range of 0.58-0.76 while aspect ratio of in the range of 0.62-092. Similar result was observed by Brar et al. (2017) for maize the seed. The angle of repose was found to be in the range of 29.8 degree to 38.6 degree for the maize variety. The mean value for bulk density and particle density were 758.4 kg.m^{-3} and 1,325 kg.m^{-3} (**Table 2**). The bulk density of the seeds was used to design the volume of the hopper.

Field Performance of Check Row Planter

The check row planter was operated at forward speed of 2 km.h^{-1} and the spacing between the furrow was kept at 400 mm. Different performance parameters were measured during field testing. The average depth of placement of seed was found to be 52 ±13.10 mm (**Table 3**). The theoretical field capacity and field efficiency of the check row planter were found to be 0.16 ha.h^{-1} and 75.2%, respectively. The mean seed spacing along the row and across the rows were found to be 403.2 mm and 412.5 mm respectively. The multiple index, miss index, quality of feed index and precision were 13.51%, 10.81%, 75.67% and 18.025%, respectively, for the check row planter under field condition (**Table 4**). The quality of feed index was lower than the maximum value of it in laboratory condition. The miss index can be reduced by increasing the cell size of the metering unit. Check row planting was obtained with mean seed spacing 40.32 cm along the row and average seed spacing 41.25 cm across the rows in the field condition.

Cost of Operation

The total cost of the check row planter was calculated by adding the fixed cost and variable cost. The savings in cost of operation by check row planter was calculated by comparing to manual check row planting. The fixed cost and variable cost of the check row planter were 91 and 269 Rs.h^{-1}, respectively (**Table 5**). The total cost of operation per hour in case of check row planter and manual check row planting were 3,000 and 18,750 Rs.ha^{-1}. So total saving was 84% in case of check row planter as compared to manual planting. Verma. (2020) also reported that manual check row planter saves 68.7% and 73.9% of money over transplanting manually and dibbling of seeds. The breakeven point for the check row planter was 68 hours per year. Therefore, the cost of the planter can be recovered in six months of its use.

Conclusions

Firstly, the physical and mechanical properties of the maize seeds were determined in the laboratory. Using different properties of the seeds, the metering unit was designed and fabricated. Different components of the hydraulic row guiding system was designed and

Fig. 6 Field evaluation of check row planter

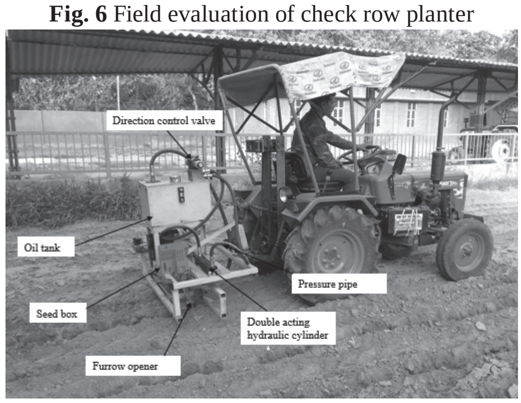


Table 3 Field performance of check row planter

Sl. No.	Performance parameters	Result
1	Average depth of seed placement, mm	52 ±13.10
2	Speed of operation, km.h^{-1}	2 ±0.05
3	Actual field capacity, ha.h^{-1}	0.12
4	Field efficiency, %	75.20
5	Field machine index, %	72.72

Table 4 Performance indices in field operation

Sl. No.	Performance indices	Mean	Standard of deviation	Coefficient of variation, %
1	Multiple index, %	13.31	0.32	2.39
2	Quality of feed index, %	75.74	1.47	1.94
3	Miss index, %	10.94	1.43	13.12
4	Precision, %	18.42	1.90	10.31
5	Seed to seed spacing, mm	403.2	5.46	13.54
6	Row to row spacing, mm	412.5	1.11	2.69

Table 5 Cost involved in check row planting

Sl. No.	Cost	Values
1	Cost of manual planting, Rs.ha^{-1}	18,750
2	Fixed cost of check row planter, Rs.h^{-1}	91
3	Variable cost of check row planter, Rs.h^{-1}	269
4	Total cost of planter, Rs.h^{-1}	360
5	Breakeven point, h.yr^{-1}	69

all the components were selected on the basis of design values to develop the electro-hydraulic row guiding system. The check row planter was designed and fabricated in the workshop. The check row planter was tested in the field condition and performance parameters were measured. Based on the analysis of results, the following conclusions were drawn:

(a) A row guiding system was developed based on different design parameters. It was integrated with the developed check row planter.

(b) The dimension of the seeds i.e. length, breadth and thickness, helped in designing the cell size of the metering unit.

(c) The sphericity and aspect ratio of the maize crop was in the range of 0.58-0.76 and 0.62-0.98, respectively. The sphericity of the crop was used to determine the shape of the cell. As the sphericity value was greater than 0.5, it was assumed to be spherical in shape for designing purpose.

(d) The angle of repose of 40 degree and bulk density of 760 $kg.m^{-3}$ were used in designing the hopper and seed box, respectively.

(e) The mean seed spacing along the row and row to row distance were found to be 403.2 mm and 412.5 mm, respectively in field condition.

(f) The saving in cost was 84% with use of the check row planter as compared to manual check row planting. The breakeven point of the check row planter was 68 hours per year. Therefore, the cost of the planter can be recovered in six months of its use.

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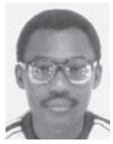
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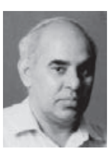
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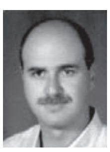
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● Seamless and durable rubber crawler assures high performance movement with low ground pressure.
● Simple and compact design allows easy operation for everybody.
● Ship structure underbody and rotary bogie system absorb the impact and allow the stable movement.
● Rubber crawler is used as base body of wide range of industrial machines.
● Rubber crawler and HST (hydrostatic transmission) system enables easy control for smooth & stable movement and huge driving power.
For forestry
For agriculture and multipurpose
ROTARY SCREEN
FORWARDER
MOBILE WOOD CRUSHER
FORKLIFT
SHOVEL LOADER
CARRIER
MOROOKA
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