*International specialized medium for agricultural mechanization in developing countries*

ISSN 0084-5841

# AMA

## AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.47, No.3, SUMMER 2016

FARM MACHINERY INDUSTRIAL RESEARCH CORP.

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*Edited by*

YOSHISUKE KISHIDA

*Published quarterly by*

Farm Machinery Industrial Research Corp.

*in cooperation with*

The Shin-Norinsha Co., Ltd.

and

The International Farm Mechanization Research Service

TOKYO

**CIRCULATION**

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1-12-3, Kanda Nishikicho, Chiyoda-ku, Tokyo 101-0054, Japan
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This is the 168th issue since its maiden issue in the Spring of 1971

# EDITORIAL

In this spring, we published a special issue focusing on agricultural machinery industry/research in Asia. Thanks to the cooperation of many people as it became a good issue on current mechanization. We have received words of compliments from many people. Now, we are preparing to publish second special issue focusing on the other Asian countries on January 2017.

It has passed more than 40 years since I first published AMA. The circumstance which promotes agricultural mechanization has drastically changed. The world population has already exceeded 7.4 billion and keeps increasing towards 9 billion. As I have been telling many a time, we have to increase land productivity. For that, timely and precise operation in agriculture is essential.

And aging of farmers who support agriculture is advancing around the globe. In Japan, 80 % of farmers are over 60 years old. It means 80 % of them will become over 80 years old after 20 years and then only the rest 20 % must engage in agriculture. In order to compensate Japanese agriculture by the remaining 20%, we have to increase labor productivity by 5 times. In China, which has a huge population, the average age of farmers is also over 60 years as well. The reduction of agricultural labor force has been continuing in many countries. Thus, agricultural labor productivity must be increased by new agricultural mechanization systems.

To solve food problem around the globe, development of agricultural mechanization is really necessary. For promoting agricultural mechanization in developing countries, we have to research, develop, produce and spread various machines, from simple to complicated that should fit the specific area in local place. Latest technology must be adopted.

At present, smart phones are spreading in each country. And each computer in the world is becoming to be connected by internet and used by everybody. Furthermore, the period of IoT (Internet of Things), that more things are being connected, is coming. In this situation, we have to think about new type of agricultural mechanization which uses new technology. CAD (computer-aided design) is being used widely now. If it becomes evolved and simplified more, every farmer will be able to design their own necessary machine by themselves.

We, all together, have to think about the use of new information technology and AI in considering the future of agricultural mechanization.

**Yoshisuke Kishida**
**Chief Editor**

July, 2016

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## AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

**Vol.47, No.3, Summer 2016**

# Grain Recovery Efficiency of a Developed Rice Stripper Harvester for Rural Use in Nigeria

by

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## Abstract

High performance machines with broad range of adaptability and resistance to environmental factors are required for harvesting and threshing biological materials that constantly changes with time. At harvest, crop, field and climatic conditions influence test to be carried out, procedures and data obtained. Any farmer will readily go for any simple harvesting machine that will maximally recover the crops during harvesting. Proper machine testing procedures must be simple and must reveal the facts necessary to determine a machine's technical and economic performance in light of the local conditions and economy that it will serve in terms of the performance, life and general suitability and appeal to the end-user. The result of technical capability, capacity and economic potential determination of machine under given conditions of use can help to estimate the adaptability of the machine. The grain recovery estimation of rice harvesting with a self-propelled grain stripper developed in Nigeria was carried out. At the best machine settings of critical operating parameters of the machine, total minimum unrecovered grains harvest estimation was 13.5 % of the total yield, while the unrecovered grains during manual harvesting was 20.3 % under the same condition. The machine setting at this combination was 270.0 mm rotor height, 670 rpm peripheral rotor speed and 3.0 km/h forward speed which gave unrecovered grains due to shattering as 5.5 %, due to stubble was 4.9 % and due to lodging was 3.1 % of the total yield. Planting pure seed variety will increase grain recovery rate of the stripper header at harvest because it was found that it will result in uniform crop height at maturity. With this stripping harvester, 84.1 % of total crop yield was recovered at harvest.

***Key words:*** Grain, Recovery, Efficiency stripper, Rice

## Introduction

More than half of human population in the World takes rice as staple food, Stout and Cheze (1999) and only 31 % of the rice is harvested by combine harvester while the rest is by hand tools (Quick, 1997). The rice farmers are always anxious to reap the rewards of their season's effort, but the harvest is a bottleneck most especially in developing World. Mature paddy is highly susceptible to losses and serious downgrading if the harvest is drawn out too long. Hence the aim is to recover as much whole grain because rice has its highest value as whole grain which is possible if harvested under wetter condition than the conventional condition. Due to lack of proper harvest and post-harvest technologies for handling, processing and storage, it is estimated that some times as much as 25 % of the produce is lost which call for great assistance of proper appropriate technologies to reduce these losses for farmers (Salokhe and Oida, 2003).

High performance machines with broad range of adaptability and resistance to environmental factors are required for harvesting and threshing biological materials that constantly changes with time. At harvest, crop, field and climatic conditions influence test to be carried out, procedures and data obtained, Nicholas (1975). Any farmer will readily go for any simple harvesting machine that will maximally recover the crops during harvesting. Proper machine testing procedures must be simple. It must reveal the facts necessary to determine a machine's technical and economic performance in light of the local conditions and economy that it will serve in terms of the performance, life and general suitability and appeal to the end-user, Nicholas (1975). The result of technical capability, capacity and economic potential determination of machine under given conditions of use can help to estimate the adaptability of the machine (Wanders, 1975).

Grain loss at harvest reduces the profitability of crops which happens in a number of places during harvest and must be assessed for a newly developed machine for corrective action to be taken (Riethmuller, 2001). Combine harvesters are designed to harvest small grains like, rice, wheat, soybean and corn with other cereal crops. The machines are also used for wide variety of small-area or special seed crops. There are direct combining (harvesting) which require cutting and harvesting in one operation which is currently most common, (Kepner *et al.*, 2005).

Stripping harvester is a new technology which is being developed and so far is becoming effective for rice and wheat harvesting, Tado and Quick (2003). This is a device developed and found very effective for removing the seed and grain from a range of crops' head which has also proved to be effective for defoliating crops (Bruce, 2001).

Every attempt to reduce post-harvest losses must inevitably start with minimizing losses during harvesting. Introduction of modern high-yielding varieties which are more susceptible to shattering loss than traditional varieties has increased the problem of harvesting because of the greater amount of crop that has to be handled with increase in crop density (Tado and Quick, 2003).

Whenever serious grain losses occur at harvest, it reduces the profitability of crops. The grain can be lost at a number of places during harvest like pre-harvest loss due to natural shedding, at the front due to front header type or set up, and also from the threshing system of the machine due to concave drum and sieve settings, (Riethmuller, 2001). Seed losses occur in the four basic operations performed by conventional combine harvester in recovering the seed which are cutting, threshing, seed and chaff separating and cleaning units (Kepner *et al.*, 2005). Grain losses in stripper harvesting occur at the gathering/stripping operation which are shatter-

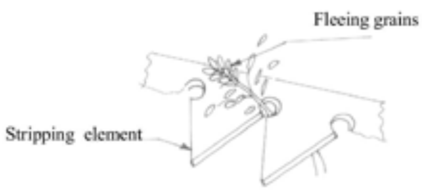


**Fig. 1a** Stripping operation

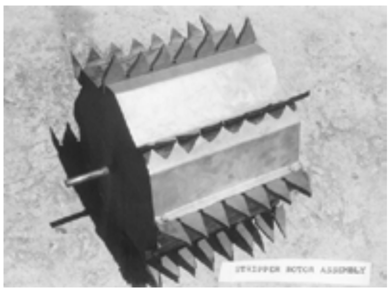

**Fig. 1b** Stripper rotor assembly

**Fig.3** Rice harvester

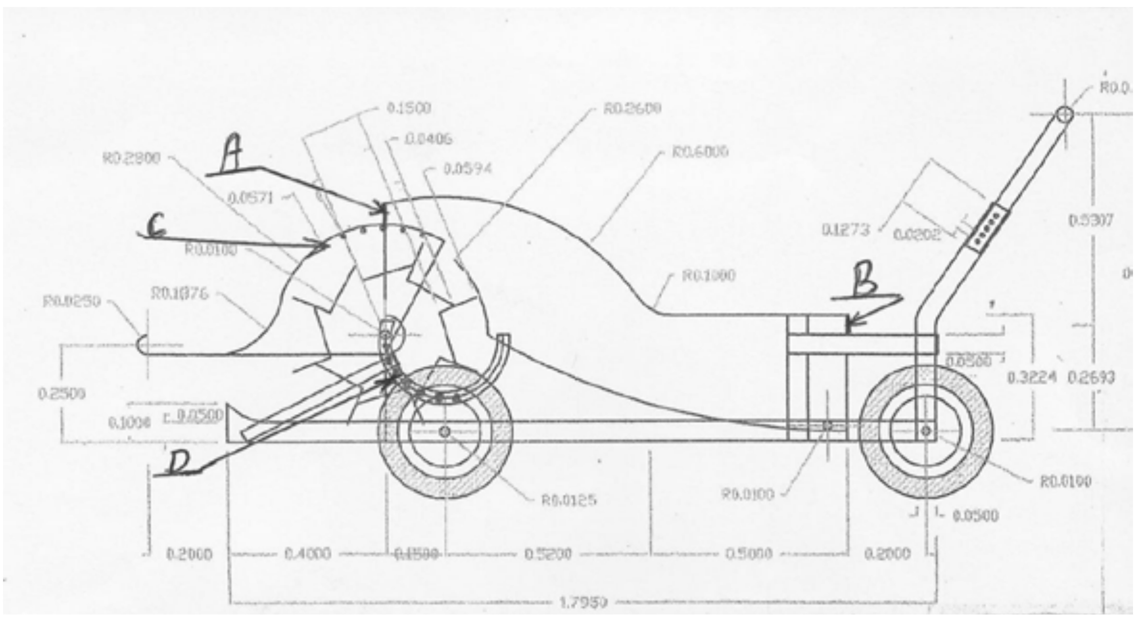


**Fig. 2** Side view of stripper header.

ing (grains spilled on the ground), stubble (grains left on the standing stalks) and lodging (grain left on the lodged stalks) losses. These losses can be reduced by resetting the machine and changing the harvesting technique. The magnitudes of the unrecovered grains vary widely among different crops, conditions and machine types. Grain and non-grain recovery of this machine can be determined at different operation and conditions of shattering, subtle and lodging of the machine. Although the assessment of machine losses have been done, grain recovery determination is also needed for corrective measure on the machine critical operating setting to minimize the losses which is the main purpose of this study for a newly developed self-propelled pedestrian controlled prototype stripping harvester developed in Nigeria for rural use powered by 3.71 kw (5 hp) petrol engine (Adisa, 2009).

## Methodology

**Field Experiment**

Preliminary field experiment was carried out to study the performance of the machine at various settings of the functional component machine parts to identify which of the part require modification. All the necessary adjustments and modifications were done before the commencement of the field data collection. The preliminary field experiment on the rice field could not be carried out elaborately until there was ripe rice field before the real field data was taken. Field experiments were carried out on an upland rice field (Faro 44 variety) along Basawa road, Samaru, Zaria, Nigeria by the middle of September, 2008. Seed variety identification was done by taking sample of the harvested rice seed grains to nearby National Seed Service Centre at Samaru.

The adopted method analyses was randomized Complete Block Design (RCB) to carry out the study of grain recovery at various stripper rotor heights, rotor speeds and forward speeds and MOG (matters other than grain)/grain ratios. This was adopted as 2 × 5 × 5 factorial treatment combination of two levels of rotor height which were 270 mm and 220 mm five levels of forward speed which were 3 km/h, 4 km/h, 5 km/h, 6 km/h and 7km/h and five levels of rotor stripping speeds which were 400 rpm, 500 rpm, 600 rpm, 700 rpm and 800 rpm.

The stripper rotor elements performed grain stripping and acted as blower which provided aerodynamic mechanism for grain cleaning/separation for grain recovery. The inner wall of the stripping rotor housing was lined by rubber sheet to reduce the bouncing speed of fleeing grains and to better control the air steam as part of grain recovery aid. See **Fig. 1a** for the stripping operation and **Fig. 1b** for the Stripper rotor assembly. A large amount of air was blown from the stripper rotor that cleaned and separated the mixture of paddy rice (brown rice), stones and other objects that were stripped by aerodynamic mechanism. The blower air flow rate controlled both by speed and air intake adjustment as shown in baffle A and C in **Fig. 2** was measured by digital air flow meter while terminal velocity of paddy grains was calculated by Equation (1):

$V_T = \sqrt[7]{z\rho d}$ ......(1) (Glorial and 'O' Callaghan,1990)

Where;

$V_T$: Dehusked rice terminal velocity

$Z$: Volume shape factor ρ - Rice density, kg/m$^3$

$d$: geometric mean diameter of rice, mm

The volume of air blew the materials lighter than the paddy grains through horizontal outlet of grain box B as shown in **Fig. 2**, while materials like stones that are heavier than paddy grains dropped vertically into grain box bottom using terminal velocity speed principle. The header unit height adjustment was accomplished as shown in D, **Fig. 2**. This mixture was subjected to separation-cum aspiration to separate light weight paddy husk which were discharged through horizontal opening and other impurities from the heavier paddy and rice received at hopper. Cleaning of paddy- related to dockage involved the separation of undesirable foreign matter or materials other than grain stripped and leaving fairly cleaned paddy by the aerodynamic mechanism. The average terminal velocity of paddy rice grain was 7.5 m/s while the set stripper rotor blower air velocity was 9.8 m/s. The variables that were measured throughout each run for header losses are unrecovered grain due to shattering, stubble and lodging. Shatter header loss was measured by weighing the grain that was collected in the quadrant placed on the ground of known area (0.1m$^2$), made of square iron rod. This was placed in the crop ahead of the harvester, and the value was extrapolated to give the loss in kilograms per hectare. Pre-harvest loss was eliminated in this way. Also the amount of grain left on the standing stalks unstripped by the rotor header was collected weighed (stubble loss). While those left behind on the lodged stalks was collected and weighed (lodged loss) for each plot of 0.3 m width by 10m length size. Rice field size of 20 m by 50 m was divided into three blocks which was subdivided further into these plots size where the experiment was carried out in three replications. Along the side with the stripper harvesting, manual harvesting with sickle was carried out, threshed, cleaned manually and weighed while all the operations were timed. **Fig. 3** is the picture of the prototype harvester.

**Laboratory Field Experiment Measurement**

Field experiments were carried out by four field men. It included harvester operator that guides harvester through each run, the time keeper took note and recorded the time taken for each run and measured amount of fuel consumed per run from a calibrated cylinder.

Another man picked the unrecovered grains left on the stubble (standing crop), grain left on lodged crop, and grains that spilled or shattered on the ground within the 0.1 $m^2$ quadrant. A technician assisted the team to change the pulleys and belts to obtain right machine and rotor speeds and rotor height variations. The speed combinations were checked to confirm the accuracy of the forward speed, rotor speed, auger' speed and rotor height before each set of run commences. The instruments made used for the laboratory and field experiment data measurements were lutron digital photo/contact tachometer of 0.5 to 100,000 rpm range and accuracy ±0.05 % used to measure speeds. The weighing was done in the laboratory with the Mettler Model 2010 electronic scale of up to 0.1 g accuracy. An analogue stop watch which gave time readings of 0.01 seconds was used to measure time. Measuring tape of 50 m length calibrated in mm was used to measure length and distance. **Fig. 5a** is the rice field before harvesting while **Fig. 5b** shows

**Table 1** Field performance indices (measured)

| Measured indices | Mean values |
|---|---|
| Mean crop yield | 1,300kg/ha |
| Pre harvest loss | 40kg/ha |
| Crop moisture content at harvest | 21%-15.6% |
| Height of the crops | 55cm-90cm |
| Weight of grains left unrecovered on the stubble | 18.8g/plot |
| Weight of grains left unrecovered on lodged crops | 11.4g/plot |
| Weight of materials other than grains (MOG) stripped | 16.8g/plot |
| Weight of total grains and MOG stripped | 288.1g/plot |
| Weight of grains found in quadrat (unrecovered) (shattered loss) | 22.9g/plot |
| Maximum wind velocity at time of harvest | 2.34m/s |
| Time taken to reap a plot | 14.3s/plot |
| Weight of grains threshed during harvest | 255.2g/plot |

**Table 2** Field performance indices (computed)

| Computed indices | Mean values |
|---|---|
| Unrecovered due to Shattering | 6.90% |
| Cracked grain loss | 0.00% |
| Unrecovered due to Lodging | 3.40% |
| Unrecovered due to Stubble | 5.70% |
| Crp purity | 89.70% |
| Total grain unrecovered | 15.90% |
| Total grain recovered from machine harvest | 84.10% |
| Fuel consumption rate | 8.4ml/plot |
| Effective harvester field capacity | 0.044ha/h |
| Harvester field efficiency | 56.68% |
| Harvester efficiency | 78% |

**Fig. 5a** Rice field before harvesting

**Fig.5b** Harvester in field operation

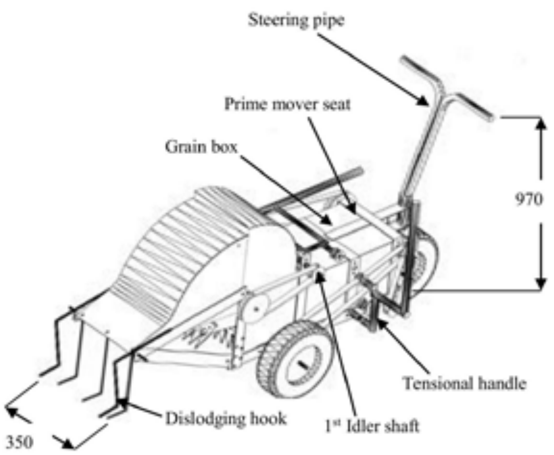


**Fig.4a** Isometric left side view of stripper harvester

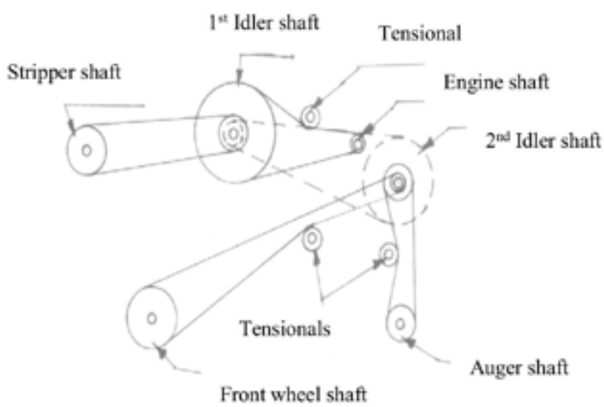


**Fig. 4b** Machine power transmission layout

harvester in field operation. **Fig. 4a** is the isometric view and **Fig. 4b** is power transmission layout of the prototype machine.

## Results

**Table 1** is the field performance indices measured while **Table 2** is the field performance indices computed. **Fig. 6** is effect of stripper rotor speed on total loss at two levels of rotor height, **Fig. 7** is effect of harvester's forward speed on total loss at two levels of rotor height, **Fig. 8** is contribution of the various sources of loss to the total loss in a 2 × 5 × 5 factorial experiment and **Fig. 9** is contribution of the various sources of loss in a 2 × 5 × 5 factorial experiment.

## Discussions

**Results of the field experiment**

The field performance indices measured from **Table 1** shows the mean

Crop's yield was 1,300 kg/ha, the pre-harvest loss was found to be 40 kg/ha. The unrecovered grains due to shattering was 22.9 g/plot, unrecovered grains from the stubble was 18.8 g/plot while unrecovered grains due to lodging was 11.4 g/plot which was the least because there was no serious lodging of the rice crop. Stripping operation was effective where mean total grains stripped with MOG was 288.1 g/plot out of which 255.2 g/plot of grains was threshed leaving very small unthreshed.

Field performance indices computed from **Table 2** shows the mean values of the unrecovered grains due to shattering was found to be 6.9 % which was the highest, followed by unrecovered grains due to stubble which was 5.7 % and that due to lodging was 3.4 % and cracked grain loss was 0.0 % out of the total unrecovered grains of 15.9 %. Cracked grain was absent because the inner hood of the stripper with which the fleeing stripped grains collided was lined with rubber carpet to reduce grain rebounding (ricocheting). The crop moisture content during the seven day experimental test varied from 21.0 % to 15.6 % on wet basis. Soil moisture content was 11.0 % on the average while the crop height varied from 55.0 cm to 90.0 cm because it was discovered that the seed grains planted were not pure when taken to the National Seed Service Centre at Samaru. The manual harvesting total unrecovered grains was 20.3 % of the total yield which was done in 120.0 seconds while the same plot size was harvested within 14.3 seconds and the total unrecovered grains was 13.5 % of the total yield.

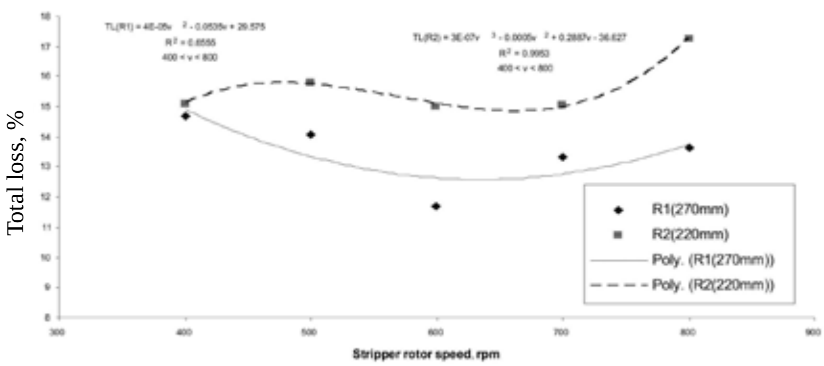


**Fig. 6** Effect of stripper rotor speed on unrecovered grains at two levels of rotor height

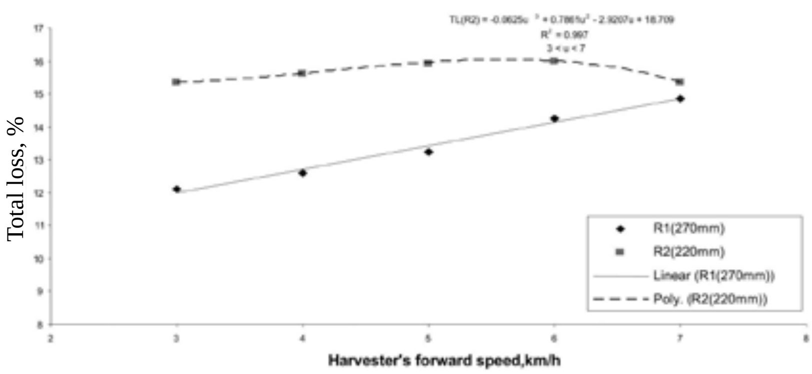


**Fig. 7** Effect of harverter's forward speed on unrecovered grains at two levels of rotor height

**Effect of harvesters settings on total loss**

**Fig. 6** shows the trend with which the total unrecovered grains increased with the rotor speed. The minimum total unrecovered grains occurred at 270 mm of rotor height setting which were 556 rpm and 669 rpm before it both increased again. **Fig. 7** shows how the total unrecovered grains increase both linearly and polynomially as the harvester's forward speed increased. This was as a result of combined effects of machine's behaviour under varied material feeding rate of stripping unit and rotor height in relation to crop height. The minimum total unrecovered grains mean occurred at stripper rotor speed 700 rpm which was 13.5 % of total yield at 220.0 mm rotor height settings. It occurred at harvester's forward speed 7.0 km/h and lowest total unrecovered grains mean been 14.3 % of the total yield at rotor height setting 270.0 mm.

The histograms or bar chart in **Figs. 8** and **9** shows the contributions of the various sources of loss to unrecovered grains. **Fig. 8** shows that the shattering contributed the highest of 40.2 % to the total unrecovered grains at a rotor height 270.0 mm while the shattered loss also had the highest contribution of 46.6 % of the total unrecovered grains for rotor height 220.0 mm. **Fig. 9** shows the histogram of the contributions of the various sources of unrecovered grains computed as a percentage of total yields. The shattered unrecovered grains was more pronounced, contributing about 5.5 % of the total yield at rotor height 270.0 mm and 7.3 % at rotor height 220.0 mm. This was closely followed by unrecovered grains due to stubble, contributing 5.0 % and 6.0 % of total yield at rotor height 270.0 mm and 220.0 mm respectively. The unrecovered grains due to lodging were 3.1 % and 3.6 % of total yield at rotor heights 270.0 mm and 220.0 mm respectively.

**Harvester settings for minimum loss**

The minimum total unrecovered grains was obtained at rotor height of 270.0 mm and estimated values of stripper rotor speed was 669 rpm and 3.0 km/h harvester forward speed. At rotor height 220.0 mm the estimated values of stripper rotor speed 556.0 rpm and 4.2 km/h harvester forward speed. Hence operating the harvester at these settings 270.0 mm, 670 rpm and 3 km/h combination brought the unrecovered grains due to shattering to the barest minimum of 5.5 %, unrecovered grains due to stubble was 4.9 % and lodging was 3.1 % of the total yield. Operating the harvester at 220.0 mm, 560 rpm and 4.2 km/h gave unrecovered grains due to shattering as 7.3 %, unrecovered grains due to stubble was 6.0 % and unrecovered grains due to lodging was 3.6 % of the total yield. Kalsirislip and Singh (2001) tested a similar rice stripping machine developed in Thailand and got the shattering loss to be 5.3 %, stubble loss was 4.0 % and lodging loss was 5.6 % of the total yield. Klinner *et al.* (1987) got over all losses which ranged between minimum of 4.3 % and as high as 10.7 % of the total yield on his stripping machine that was tested in England on some cereal crops.

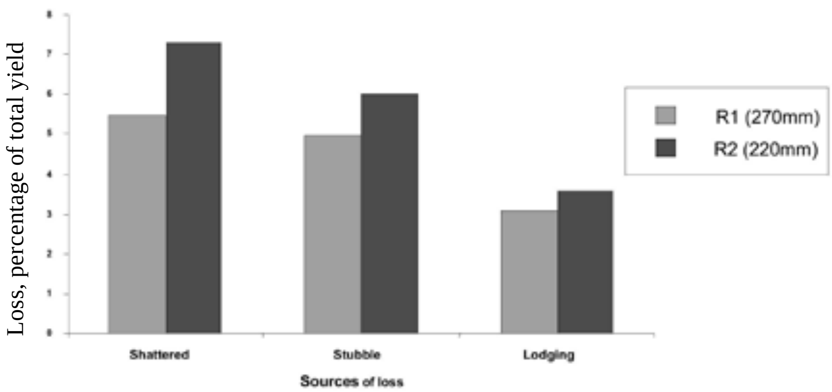


**Fig. 8** Contribution of the various sources of loss to unrecovery of grains in a 2 × 5 × 5 factorial experiment

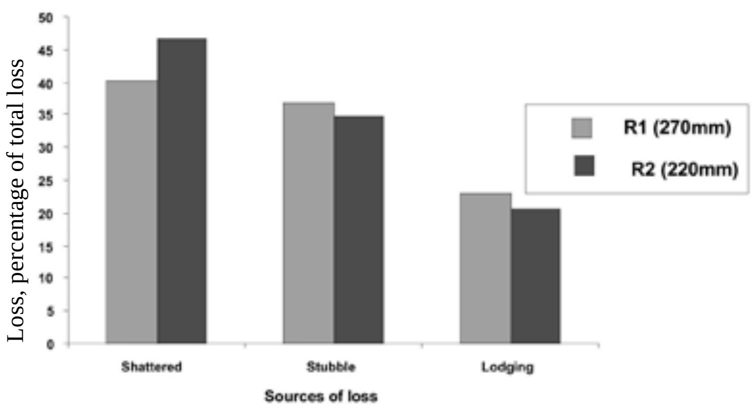


**Fig. 9** Contribution of the various sources of loss to the total unrecovered grains in a 2 × 5 × 5 factorial experiment.

## Conclusion

Grain recovery estimation of rice harvesting with a grain stripping harvester developed in Nigeria gave overall of 13.5 % unrecovered grains of the total yield at best settings. At 270.0 mm rotor height, 670 rpm rotor speed and 3.0 km/h forward speed combination setting, minimum unrecovered grains due to shattering was 5.5 %, stubble was 4.9 % and lodging was 3.1 % of the total yield. At 220.0 mm rotor height, 560 rpm rotor speed, and 4.2 km/h forward speed combination settings, minimum unrecovered grains due to shattering was 7.3 %, stubble loss was 6.0 % and lodging loss was 3.6 % of the total yield. These unrecovered grains values were found to be too high and will require further improvement work to be done on the machine to increase recovered grains to the acceptable level. Also planting pure seed will reduce losses at harvest because it will result in more uniform crop height at maturity. At best machine setting of critical operating parts, 84.1 % of the total crop yield was recovered at harvest at machine field efficiency 56.7 % and harvester efficiency 78.0 %.

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■■

# Development of Low Cost Plastic Evaporative Cooling Storage Structure


by

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## Abstract

A 200 kg storage capacity evaporative cooling storage structure was developed with plastic material and cooling media as coconut husk chips ensuring water flows with the influence of gravity with dripper arrangement. The structure operates on the principle of evaporative cooling. In the evaporative cooling structure temperature drop was measured 11 °C at noon time without loading product and 12 °C at noon time after keeping tomato in structure. The average relative humidity inside the evaporative cooling storage structure was 91.90 % during tomato storage and the inside temperature was found about 24 to 27 °C. The average cooling efficiency was found to be 95.83 %. In evaporative cooling storage, the 50 % firmness was retained for 18 days of tomato storage. The TSS content was found about an average of 5.47 °Brix. The total cost of the Evaporative cooling storage structure was estimated to be about Rs. 5800. Ratio of cost for ambient storage to Evaporative cooling storage structure 5.71: 1


## Introduction

Fruits and vegetables are important sources of minerals and vitamins especially A and C. They also provide carbohydrates and protein that are needed for normal healthy growth. When vegetables are harvested, the moisture in them reduces partly due to respiration since there is no replenishment to this loss to the atmosphere. If equilibrium moisture content is not achieved vegetables begin to die gradually. The most common method followed by the vegetable traders in local famers is to add moisture to the air around the commodity as mists, sprays, or at last resort, by wetting the store room floor.

In India quality deterioration of horticultural produce takes place immediately after harvest due to lack of on-farm storage. The essence of storage is of great importance because not all the harvested vegetables or crops in general will be used immediately after harvest. Therefore, measures for preserving the vegetables before it exceeds its shelf life are of great importance. Most of the peasant farmers are not able to afford the cost of purchasing high tech storage equipment for their harvested crops. The spoilage of fruits and vegetables can be controlled by reducing the storage temperature. Maintenance of low temperature is a great problem in a tropical country. Refrigeration is energy intensive, expensive, not so easy to install and operate in remote areas and not always environment friendly. Evaporation not only lowers the air temperature surrounding the produce, it also increases the moisture content of the air. This helps prevent the drying out of the produce, and therefore, extends its shelf life. Evaporative cooling is best for rural area and also for farmer as an on-farm storage chamber, for fresh fruits, vegetables and flowers to extend their marketability. Considering acute energy crisis and lack of cool storage facility effort was made to develop a low cost/low energy cooling chambers.

## Materials & Methods

### Design Principles

The design of the evaporative cooler is based on the principle of evaporation which causes a cooling effect to its surrounding. Water drips into the coconut husk chips pad at a constant rate through a water distribution system. As the water drips into the pad, the warm air which has the sensible heat passes through the wetted pad and is changed to latent heat due to the evaporation. According to Rusten (1985), the conditions at which evaporative cooling would take place are high temperatures, low humidity, spraying of water and air movement.

### Design Considerations for Evaporative Cooling Storage Structure

Following design considerations were kept for development of evaporative cooling storage structure.

1. The storage capacity of the structure should be 200 kg tomato.
2. There should be arrangement for continuous flow of water in cooling media.
3. Cooling media should have more water holding capacity, long lasting and locally available ensuring uniform wetting for evaporation of water.
4. The structure should be low cost, light in weight, movable and easily made with locally available material.
5. The material of construction should be non-corrosive and durable.
6. The shape of the cooler is cuboids to provide large surface area for air movement.

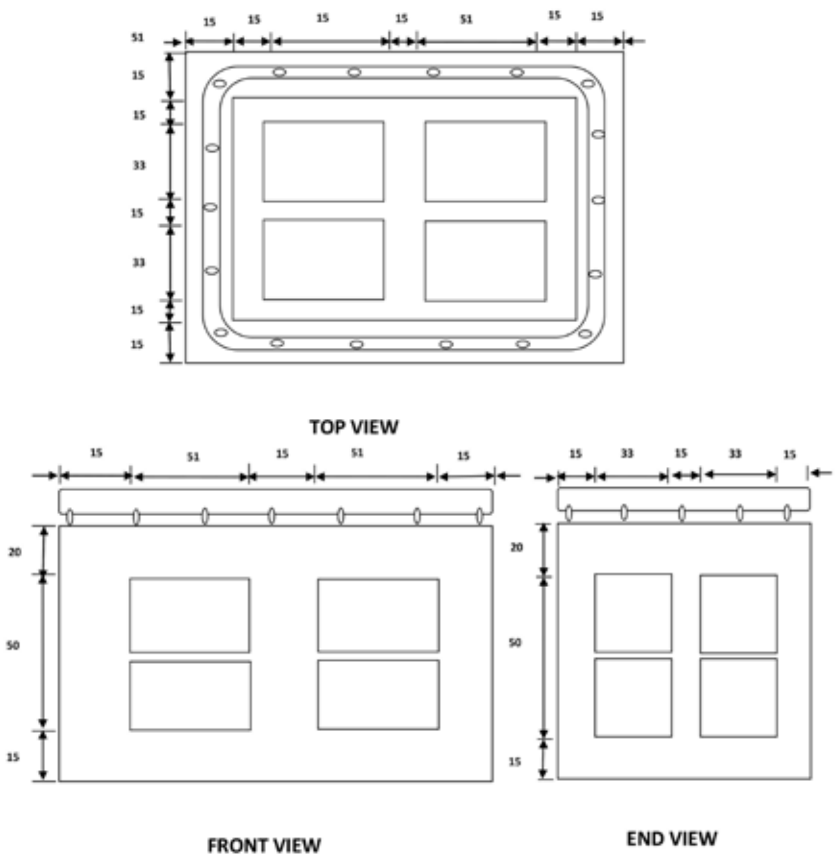


**Fig 1** Dimensions of evaporative cooling sotrage
All Dimensions are in cm

### Description of the Evaporative Cooling Systems

The evaporative cooling structure consisted of water dripping system, cooling media, frame, cover, trolley with handle and drain pipe. The calculated length, width and height of evaporative cooling structure were 1770, 1410 and 850 mm respectively (**Fig 1**).The evaporative cooler is made up of PVC pipe and PVC net having square hole (25 mm) mounted on trolley made of block board with sun mica to avoid moisture absorbance. The cooling media is used as coconut husk chips as it locally available and more water holding capacity. Coconut husk chips were placed in annular space with PVC string at 220 mm spacing to prevent sagging. A 100 mm pipe as closed loop is used for water storage to circulate water to the cooling pad through dripper fitted lower side of reservoir pipe.

### Cooling Media

The selection on the type of pad used in the designed was based on the porosity, water absorption/evaporation rate of the material, availability, cost and ease of construction. Coconut husk chips were used as cooling media as it has more water holding capacity and locally available material (**Fig 2a**).

### Water Supply System

A 100 mm PVC pipe was used for water storage of about 48 liters, surrounding the annular space of the evaporative cooling storage structure. Drippers was spaced on 100 mm diameter PVC pipe at 300 mm apart to carry out uniform discharge through the coconut husk chips cooling media. A half round pipe of

100 mm diameter pipe was cut and fixed at the bottom to allow excess water drip out of the pad and it is channeled to a reservoir (**Fig 2c**).

### Experimental Procedure and Performance Evaluation

The experiment was mainly consisting of fabrication of the evaporative cooling storage structure, performance evaluation in terms of temperature drop, relative humidity, storage life of tomato and quality of tomato etc. The experimental evaporative storage structure was located under a shadow. The cooling pad was wetted with continuous discharge from dripper. The reservoir pipe was filled once in a day. Experimental tests were undertaken with evaporative storage structure loaded with produce and without produce in place. The no load test was done to establish its transient response to variations in prevailing weather conditions in terms of temperature reduction between the ambient and the evaporative storage structure chamber and change in relative humidity before storage of tomatoes began.

Load tests were conducted to determine the length of storage of the tomato in the cooler before spoilage. A control test in which the same product inside the evaporative cooler was exposed to open air conditions under a shade was used to evaluate the evaporative storage structure effectiveness in preservation of the tomato. Control test samples were weighed every day to determine the weight loss and the colour while tomato in evaporative storage structure was examined every 3 day to determine, weight loss, firmness, TSS content and the colour changes.

Fresh mature tomatoes not completely ripe, obtained from the market of popular variety GT-3. A measurement of temperature and relative humidity was taken at intervals of two hours for all the tests conducted starting from 9.00 to 17.00 hrs local time. The wet and dry bulb temperatures inside the evaporative storage structure and ambient conditions were recorded with two glass thermometers. The relative humidity was also monitored with a hygrometer. The test was conducted during the April to May 2012. The evaporative storage structure was evaluated on the temperature drop, change in relative humidity and cooling efficiency.

The cooling efficiency is calculated as follows (Lertsatitthanakorn *et al.*, 2006):

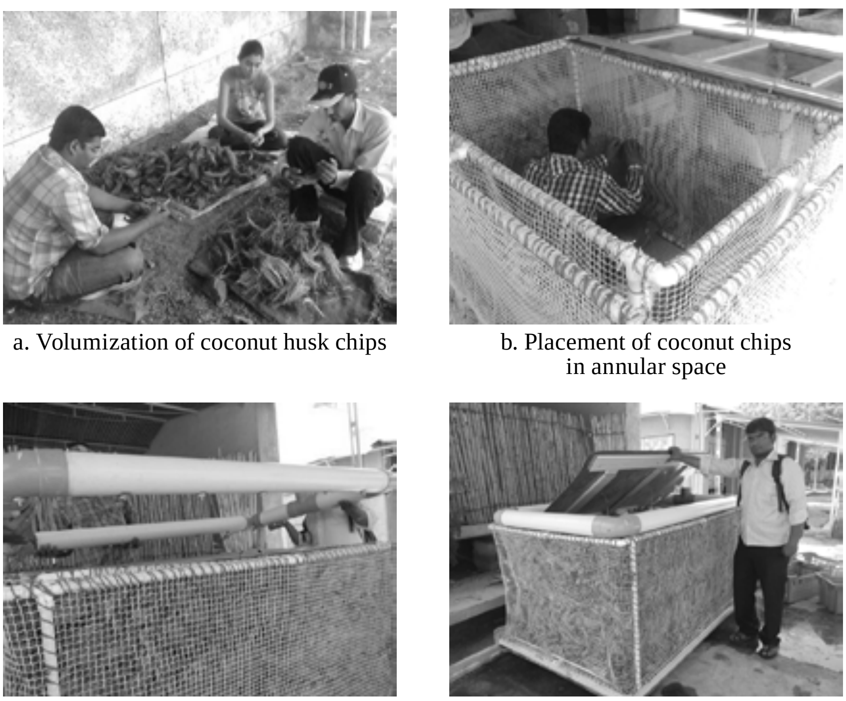
$$\eta = (T_{db} - T_s) / T_{db} - T_w) \times 100 \quad \text{.......................................................(2)}$$

Where;

$T_{db}$ = Ambient dry bulb temperature

$T_w$ = Wet bulb temperature

$T_s$ = Storage chamber temperature



a. Volumization of coconut husk chips

b. Placement of coconut chips in annular space

c. Dripper discharge over coconut cooling pad

d. View of the evaporative storage structure

**Fig. 2** Construction of plastic evaporative cooling storage structure

## Results and Discussion

### Physical Properties of the Cooling Pad Material

Some basic physical properties of the coconut husk chips as cooling pad were measured and their respective values were found as density of 24.52 kg/m$^3$, water holding capacity of 4.83 g/g and amount of water absorbed was 1.222 kg.

### Performance Evaluation of Evaporative Cooling Storage Structure

The performance evaluation of the developed evaporative cooling storage structure was carried in terms of temperature drop and cooling efficiency The testing was done without keeping tomato as no load condition to check whether system is effective or not. For evaluation of quality parameters in terms of weight loss, firmness and total soluble solid was carried out after loading tomato in the structure.

### No Load Test of the Evaporative Cooling Storage Structure

Temperature and relative humidity regime in evaporative cooling storage structure

The evaporative cooler was tested without been loaded with the vegetables. The dry bulb and the wet

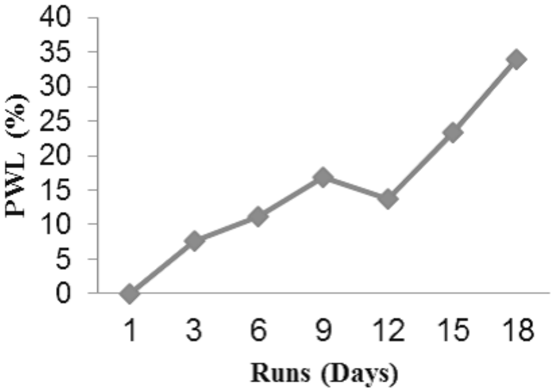



**Fig. 3** Physiological weight loss of tomato during evaporative cooling storage

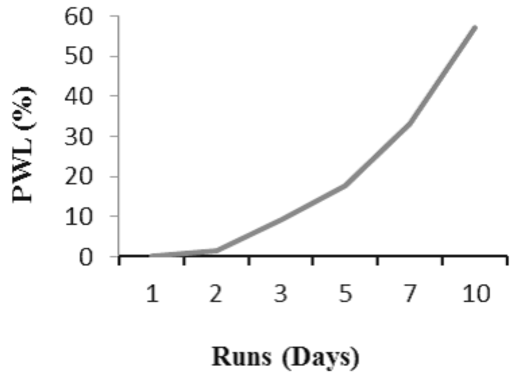



**Fig. 4** Physiological weight loss of tomato during ambient conditions storage

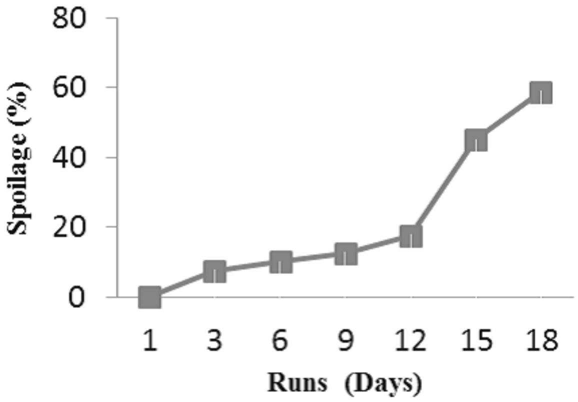



**Fig. 5** Spoilage of tomato during Evaporative cooling storage

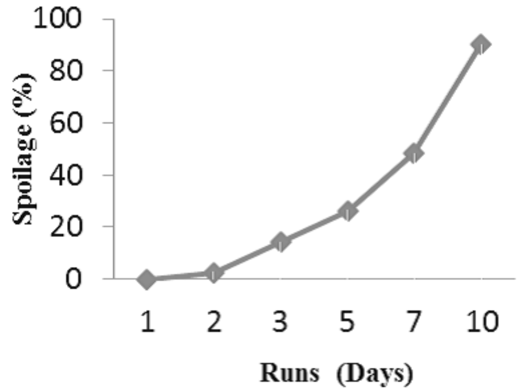



**Fig. 6** Spoilage of tomato during ambient conditions storage

bulb thermometers were used to measure the temperature and the relative humidity was determined using the psychometric chart. From the **Appendix A**, it was clear that the highest temperature drop was found at noon time and lowest at morning and afternoon for no load condition. The highest temperature drop was found to be 11 °C at noontime. It was observed that as the outside temperature increased, then the temperature drop also increased. The inside temperature was found about 24 to 27 which is favourable for storage of vegetables. The results clearly indicated that the evaporative cooler may be conveniently used for preservation of vegetables and fruits since the temperature depression for cooling application are in the range of 2-12 °C reported in literature (Anyanwu, 2004).

The relative humidity was calculated from the psychometric chart after getting the readings of both the dry and wet bulb thermometer and data was presented in **Appendix A**.The results showed that the evaporative cooler can reduce the daily maximum ambient temperature from 28-38 °C to 24-27 °C i.e. a temperature reduction of up to 11 °C and increase the relative humidity of the air from 38-78 % of the ambient to 92-100 % of the storage chamber.

**Cooling Efficiency**

The cooling efficiency is the measure of effectiveness of cooling storage structure. It indicates whether the cooling structure is viable for storage or not.

The cooling efficiency was also calculated when not on load based on formula by (Harris, 1987);

$SE = [T_1(db) - T_2(db)] / [T_1(db) - T_1(wb)]$..............................................(4.1)

Where,

$T_1(db)$ = dry-bulb outdoor temperature, °C

$T_2(db)$ = dry-bulb cooler temperature, °C

$T_1(wb)$ = wet-bulb outdoor temperature, °C

The overall average cooling efficiency is of the evaporative cooling storage structure was found to be 86.00 % (**Appendix A**).The results also showed that the higher cooling efficiency and cooling capacity was achieved at a higher temperature and low relative humidity, this agreed with the work of Jain (2007).

**Testing of Evaporative Cooling**

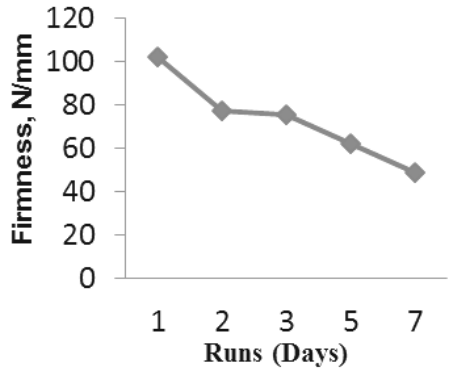



**Fig. 7** Firmness of tomato during ambient conditions storage

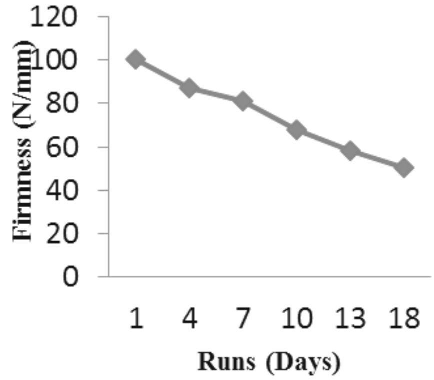



**Fig. 8** Firmness of tomato during evaporative cooling storage

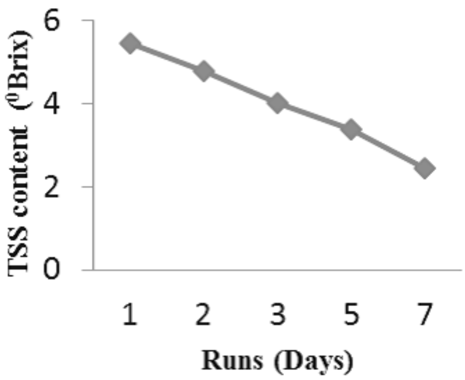



**Fig. 9** Total Soluble Solid of tomato during ambient conditions

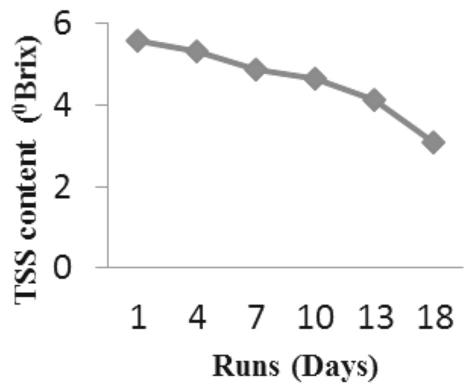



**Fig. 10** Total soluble solid of tomato during evaporative cooling storage

**Storage Structure During Storage of Tomato**

***Temperature and relative humidity regime of evaporative cooling storage structure during storage of tomato***

From the **Appendix B**, it was clear that there was highest temperature drop was found at noon time and lowest at morning and afternoon for during the storage of tomato in evaporative cooling storage structure. The inside temperature of evaporative cooling storage structure was in the range of 24 to 29 °C. The highest temperature drop was found to be 12 °C at noontime. The overall temperature drop was found 8.34 °C in case of evaporative cooling storage structure. As presented in **Appendix B**, the relative humidity inside the evaporative cooling storage structure was in the range of 79 to 100 % while it was 32 to 75 % for ambient condition. The overall average relative humidity inside the evaporative cooling storage structure was 91.90 %. This shows favourable condition for vegetable crop storage, as it requires high humidity.

***Cooling efficiency of evaporative cooling storage structure during storage of tomato***

The cooling efficiency is the measure of effectiveness of cooling storage structure. The cooling efficiency was in the range of 63.6 to 100 %. The overall average cooling efficiency is of the evaporative cooling storage structure was found to be 95.83 % (**Appendix B**).

***Physiological weight loss in tomato storage in evaporative cooling storage structure***

The change in the weight of the samples both stored in the ambient and the evaporative cooling storage structure was estimated as moisture migration from the product to the surrounding for a total of eighteen days storage. The physiological loss is presented graphically in **Fig. 3** for evaporative cooling storage and **Fig. 4** for ambient condition storage. It is clear that the physiological loss increases with the increase in storage period. It is observed that physiological loss in ambient condition was much higher than tomato stored in evaporative cooling storage structure. After 18 days of storage in evaporative cooling storage structure, the loss was 33.92 %, while it was 57.14 % after 10 days storage in ambient condition.

***Spoilage in tomato storage in evaporative cooling storage structure***

The spoilage of the tomato is presented graphically in **Fig. 5** for evaporative cooling storage and **Fig. 6** for ambient condition storage. The increasing trend was observed with storage period for tomato kept in evaporative cooling storage structure. It was noticed that after 10 days of storage in ambient condition, all the tomatoes were spoiled. During the cooling storage tomatoes were preserved for 18 days with 58.33 % spoilage.

## Assessment of the Quality of Stored Products

***Colour changes***

The colour changes noticed with the product stored in the ambient condition were most evident. The tomatoes colour changed from the reddish colour and some parts turned to yellow and later to black .The tomato stored in the ambient started changing its colour on the 3rd day of the experiment run until there was a total change on the 7th day. But the samples stored in the evaporative cooling structure still retained their colour with little significant change within the test period.

***Firmness***

Firmness is the measure of freshness of the product. The loss of moisture from product causes retardation in quality in terms of market value and nutritive value. The results of firmness of tomato during ambient conditions storage and in evaporative cooling storage structure are shown in **Figs. 7** and **8**. It was observed that the firmness was decreased in both storage conditions. In evaporative storage the 50 % firmness was retained for 18 days of storage. During ambient conditions storage of 7 days the firmness reduced to 50 %. This may be due to the microbial activity started at high temperature and causing softness of tomato.

***Chemical property of tomato***

The moisture content of the tomato was measured by hot oven drying method. The average moisture content for tomato was found to be 9.12 %, The chemical properties in terms of total soluble solids were determined and graphically shown in **Figs. 9** and **10**. From the graph, it was cleared that the total soluble solid was decreased as the time elapsed in an ambient conditions storage as well as evaporative cooling storage structure. The TSS content was found about an average of 5.47 °Brix initially and decreased to 2.43 in ambient storage conditions of 10 days. For evaporative cooling storage structure, the TSS content was found about an average of 5.57 °Brix initially and decreased to 3.07 after 18 days.

## Cost Analysis of Developed Evaporative Cooling Storage Structure

The cost of the developed storage structure was estimated by adding the costs of different materials used in the fabrication of the Evaporative cooling storage structure. The total cost of the Evaporative cooling storage structure developed was estimated to be about Rs. 5,800.

Considering 1tonneof tomato storage and market value of tomatoes as 20 Rs/kg, for 12 days storage in ECSS (Evaporative cooling storage structure) and 10 days in ambient conditions,

*The loss in ECSS is* = 176 kg

*Market value loss (Rs)* = 176 × 10 = 1760

*The loss under ambient storage* = 900 kg

*Market value loss (Rs)* = 900 × 10 = 9,000

The comparative cost analysis is presented in the **Table 1** for ambient condition and evaporative cooling storage structure It has been found that the cost for 1 tons tomato storage using the developed evaporative cooling storage structure comes

**Table 1** Comparative cost for storage of tomato in ambient condition and evaporative cooling storage structure

| Sr. No. | Particulars | | Total Cost (Rs.) |
|---|---|---|---|
| I | Ambient storage | | |
| | Total storage loss for 10 day | | 9,000 |
| | Loss per day | | 900 |
| | Total cost of storage Rs./tone | | - |
| | Net cost of storage Rs./day/tone | | 900 |
| II | Evaporative cooling storage structure | | |
| | Initial cost of evaporative cooling storage structure | | 5,800 |
| A | Fixed cost | | |
| | Depreciation of the evaporative cooling storage structure | 10 years useful life, 20 % salvage value | 522 |
| | Interest on investment | @12 % on initial cost of grader | 696 |
| | Total fixed cost Rs./year | | 1,218 |
| | Fixed charges Rs./day | 120 working days/year | 10.2 |
| B | Variable cost | | |
| | Loss for 12 day | | 1,760 |
| | Total storage loss Rs./ day | | 147 |
| | Total variable cost Rs./ tone | | 147 |
| Total cost of storage in Evaporative cooling storage structure / day | | (A + B) | 157.2 |
| Total cost of storage in Evaporative cooling storage structure Rs./tone | | | |
| Ratio of cost for ambient storage to Evaporative cooling storage structure | | | 5.71: 1 |

to be Rs. 157.6. This facilitated a saving of about Rs. 742.4 per tons per day for tomato storage using the developed ECSS over the ambient storage. The ratio of cost for ambient storage to ECSS comes to around 5.71: 1.

## Conclusions

Based on this study, which was to provide an alternative source of storage for vegetables using a coconut husk chips as cooling media evaporative cooling storage structure made of plastic material can be used as a temporary means of storage of fruits, vegetables and flowers requiring humid environment.

## REFERENCES

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**Appendix A** Temperature drop and cooling efficiency of evaporative cooling storage structure (Without Products)

| Runs | | Ambient Condition | | | Storage chamber Conditions | | | Temperature drop (°C) | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|
| Days | Time | Tdb (°C) | Twb (°C) | RH % | Tdb (°C) | Twb (°C) | RH % | | |
| 1 | 09.00 | 28 | 25 | 78 | 26 | 25 | 92 | 2 | 66.67 |
| | 11.00 | 34 | 26 | 53 | 27 | 26 | 92 | 7 | 87.50 |
| | 13.00 | 38 | 26 | 38 | 27 | 26 | 92 | 11 | 91.67 |
| | 15.00 | 36 | 26 | 45 | 27 | 26 | 92 | 9 | 90.00 |
| | 17.00 | 34 | 25 | 48 | 27 | 26 | 92 | 7 | 77.78 |
| 2 | 09.00 | 29 | 25 | 72 | 25 | 25 | 100 | 2 | 100.00 |
| | 11.00 | 31 | 25 | 61 | 26 | 25 | 92 | 5 | 83.33 |
| | 13.00 | 37 | 25 | 38 | 26 | 25 | 92 | 11 | 91.67 |
| | 15.00 | 35 | 26 | 49 | 27 | 26 | 92 | 8 | 88.89 |
| | 17.00 | 30 | 25 | 67 | 26 | 25 | 92 | 4 | 80.00 |
| 3 | 09.00 | 28 | 25 | 78 | 25 | 25 | 100 | 3 | 100.00 |
| | 11.00 | 29 | 25 | 72 | 26 | 25 | 92 | 3 | 75.00 |
| | 13.00 | 36 | 26 | 45 | 26 | 26 | 100 | 10 | 100.00 |
| | 15.00 | 33 | 25 | 52 | 26 | 25 | 92 | 7 | 87.50 |
| | 17.00 | 30 | 25 | 67 | 26 | 25 | 92 | 4 | 80.00 |
| 4 | 09.00 | 29 | 24 | 66 | 24 | 24 | 100 | 5 | 100.00 |
| | 11.00 | 30 | 24 | 61 | 26 | 24 | 85 | 4 | 66.67 |
| | 13.00 | 37 | 26 | 42 | 27 | 26 | 92 | 10 | 90.91 |
| | 15.00 | 34 | 26 | 53 | 27 | 26 | 92 | 7 | 87.50 |
| | 17.00 | 29 | 25 | 72 | 26 | 25 | 92 | 4 | 75.00 |
| | | Overall average cooling efficiency | | | | | | | 86.00 |

Note: $T_{db}$ = Dry bulb temperature $T_{wb}$ = Wet bulb temperature
$T_{dp}$ = Dew point temperature RH = Relative humidity

**Appendix B-1** Daily temperature and relative humidity data evaporative cooling storage structure during storage of tomato

| Run | | Ambient Condition | | | Storage chamber Conditions | | | Temperature drop | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|
| Date | Time | Tdb (°C) | Twb (°C) | RH% | Tdb (°C) | Twb (°C) | RH% | | |
| 25.04.2012 | 12:00 | 35 | 27 | 54 | 28 | 27 | 79 | 7 | 87.5 |
| | 13:00 | 38 | 26 | 38 | 29 | 26 | 79 | 9 | 75.0 |
| | 14:00 | 39 | 26 | 35 | 29 | 26 | 79 | 10 | 76.9 |
| | 15:00 | 39 | 27 | 39 | 28 | 27 | 93 | 11 | 91.7 |
| | 15:45 | 38 | 27 | 43 | 28 | 27 | 93 | 10 | 90.9 |
| | 16:00 | 35 | 28 | 59 | 28 | 28 | 100 | 7 | 100.0 |
| 26.04.2012 | 9:00 | 29 | 24 | 66 | 24 | 24 | 100 | 5 | 100.0 |
| | 10:00 | 30 | 25 | 67 | 25 | 25 | 100 | 5 | 100.0 |
| | 11:00 | 30 | 25 | 67 | 25 | 25 | 100 | 5 | 100.0 |
| | 12:00 | 35 | 25 | 44 | 25 | 25 | 100 | 10 | 100.0 |
| | 13:00 | 39 | 25 | 32 | 28 | 25 | 78 | 11 | 78.6 |
| | 14:00 | 39 | 26 | 35 | 29 | 26 | 79 | 10 | 76.9 |
| | 15:00 | 38 | 26 | 38 | 29 | 26 | 79 | 9 | 75.0 |
| | 16:00 | 37 | 26 | 42 | 30 | 26 | 73 | 7 | 63.6 |
| | 17:00 | 36 | 27 | 50 | 28 | 27 | 93 | 8 | 88.9 |
| 27.04.2012 | 9:00 | 30 | 25 | 67 | 25 | 25 | 100 | 5 | 100.0 |
| | 11:20 | 35 | 26 | 49 | 26 | 26 | 100 | 9 | 100.0 |
| | 13:00 | 39 | 27 | 39 | 28 | 27 | 79 | 11 | 91.7 |
| | 14:30 | 40 | 29 | 44 | 29 | 27 | 69 | 11 | 100.0 |
| | 15:30 | 39 | 29 | 47 | 28 | 27 | 93 | 11 | 110.0 |
| | 16:30 | 39 | 29 | 47 | 28 | 26 | 85 | 11 | 110.0 |
| | 17:00 | 38 | 29 | 51 | 27 | 26 | 92 | 11 | 122.2 |
| 28.04.2012 | 10:00 | 29 | 25 | 72 | 25 | 25 | 100 | 4 | 100.0 |
| | 11:30 | 35 | 26 | 49 | 28 | 26 | 85 | 7 | 77.8 |
| | 13:30 | 37 | 26 | 42 | 28 | 26 | 85 | 9 | 81.8 |
| | 15:00 | 39 | 25 | 32 | 27 | 25 | 85 | 12 | 85.7 |
| | 16:00 | 37 | 26 | 42 | 28 | 26 | 85 | 9 | 81.8 |
| 29.04.2012 | 9:00 | 28 | 24 | 72 | 24 | 24 | 100 | 4 | 100 |
| | 9:30 | 30 | 24 | 61 | 24 | 24 | 100 | 6 | 100 |
| | 11:00 | 34 | 25 | 48 | 25 | 25 | 100 | 9 | 100 |
| | 13:30 | 36 | 30 | 64 | 28 | 25 | 78 | 8 | 133.3 |
| | 14:30 | 40 | 30 | 48 | 29 | 25 | 75 | 11 | 110 |
| | 16:00 | 39 | 29 | 47 | 28 | 25 | 78 | 11 | 110 |
| | 16:30 | 39 | 28 | 43 | 28 | 26 | 85 | 11 | 100 |
| 30.04.2012 | 11:00 | 36 | 26 | 45 | 26 | 26 | 100 | 10 | 100 |
| | 13:30 | 38 | 27 | 43 | 29 | 27 | 86 | 9 | 81.8 |
| | 15:00 | 39 | 29 | 47 | 29 | 27 | 86 | 10 | 100 |
| | 17:00 | 37 | 30 | 60 | 28 | 26 | 85 | 9 | 128.6 |
| 01.05.2012 | 9:00 | 29 | 24 | 66 | 24 | 24 | 100 | 5 | 100 |
| | 11:30 | 37 | 25 | 38 | 25 | 25 | 100 | 12 | 100 |
| | 13:15 | 40 | 27 | 36 | 28 | 27 | 93 | 12 | 92.3 |
| | 15:30 | 39 | 28 | 43 | 29 | 28 | 93 | 10 | 90.9 |
| | 16:00 | 39 | 28 | 43 | 29 | 27 | 93 | 10 | 90.9 |
| | 17:00 | 31 | 26 | 67 | 27 | 26 | 92 | 4 | 40 |
| 02.05.2012 | 9:00 | 29 | 24 | 66 | 24 | 24 | 100 | 5 | 100 |
| | 11:45 | 36 | 26 | 45 | 26 | 26 | 100 | 10 | 100 |
| | 13:00 | 37 | 26 | 42 | 26 | 26 | 100 | 11 | 100 |

**Appendix B-2** Daily temperature and relative humidity data evaporative cooling storage structure during storage of tomato

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15:00 | 39 | 27 | 39 | 29 | 27 | 86 | 10 | 83.3 |
| | 17:00 | 38 | 28 | 47 | 28 | 27 | 93 | 10 | 100 |
| 03.05.2012 | 10:00 | 31 | 25 | 61 | 25 | 25 | 100 | 6 | 100 |
| | 11:00 | 34 | 26 | 53 | 26 | 26 | 100 | 8 | 100 |
| | 13:10 | 38 | 27 | 43 | 28 | 27 | 93 | 10 | 90.9 |
| | 15:30 | 37 | 29 | 55 | 29 | 27 | 86 | 8 | 100 |
| | 17:00 | 35 | 27 | 54 | 28 | 27 | 93 | 7 | 87.5 |
| 04.05.2012 | 8:45 | 29 | 25 | 72 | 25 | 25 | 100 | 4 | 100 |
| | 10:00 | 32 | 25 | 57 | 25 | 25 | 100 | 7 | 100 |
| | 11:00 | 35 | 26 | 49 | 26 | 26 | 100 | 9 | 100 |
| | 13:30 | 37 | 27 | 46 | 28 | 27 | 93 | 9 | 90 |
| | 15:00 | 36 | 27 | 50 | 28 | 27 | 93 | 8 | 88.9 |
| | 16:30 | 35 | 26 | 49 | 27 | 26 | 92 | 8 | 88.9 |
| 05.05.2012 | 8:45 | 29 | 25 | 72 | 25 | 25 | 100 | 4 | 100 |
| | 10:00 | 33 | 25 | 52 | 25 | 25 | 100 | 8 | 100 |
| | 11:30 | 34 | 27 | 58 | 27 | 27 | 100 | 7 | 100 |
| | 13:00 | 37 | 26 | 42 | 26 | 26 | 100 | 11 | 100 |
| | 15:15 | 36 | 27 | 50 | 27 | 27 | 100 | 9 | 100 |
| 06.05.2012 | 11:30 | 34 | 25 | 48 | 26 | 25 | 92 | 8 | 88.9 |
| | 14:00 | 38 | 27 | 43 | 29 | 27 | 86 | 9 | 81.8 |
| | 16:30 | 37 | 26 | 42 | 27 | 26 | 92 | 10 | 90.9 |
| 07.05.2012 | 11:00 | 33 | 26 | 57 | 26 | 26 | 100 | 7 | 100 |
| | 11:30 | 34 | 27 | 58 | 28 | 27 | 93 | 6 | 85.7 |
| | 14:00 | 36 | 27 | 50 | 28 | 27 | 93 | 8 | 88.9 |
| | 16:30 | 34 | 28 | 63 | 29 | 27 | 86 | 5 | 83.3 |
| 08.05.2012 | 11:00 | 33 | 27 | 63 | 27 | 27 | 100 | 6 | 100 |
| | 13:00 | 37 | 30 | 60 | 29 | 27 | 86 | 8 | 114.3 |
| | 16:30 | 34 | 30 | 75 | 28 | 27 | 100 | 6 | 150 |
| 09.05.2012 | 10:30 | 33 | 27 | 63 | 28 | 27 | 93 | 5 | 83.3 |
| | 13:00 | 39 | 29 | 47 | 29 | 29 | 100 | 10 | 100 |
| | 15:00 | 38 | 28 | 47 | 29 | 28 | 93 | 9 | 90 |
| | 16:30 | 37 | 26 | 42 | 28 | 26 | 85 | 9 | 81.8 |
| 10.05.2012 | 9:00 | 30 | 26 | 73 | 26 | 26 | 100 | 4 | 100 |
| | 11:30 | 34 | 27 | 58 | 27 | 27 | 100 | 7 | 100 |
| | 13:00 | 37 | 30 | 60 | 29 | 27 | 86 | 8 | 114.3 |
| | 15:30 | 39 | 31 | 56 | 28 | 27 | 93 | 11 | 137.5 |
| | 16:30 | 36 | 26 | 45 | 26 | 26 | 100 | 10 | 100 |
| 11.05.2012 | 11:30 | 35 | 26 | 49 | 29 | 26 | 79 | 6 | 66.7 |
| | 13:30 | 37 | 27 | 46 | 28 | 27 | 93 | 9 | 90 |
| | 15:30 | 37 | 27 | 46 | 29 | 27 | 86 | 8 | 80 |
| 12.05.2012 | 9:00 | 30 | 24 | 61 | 24 | 24 | 100 | 6 | 100 |
| | 11:00 | 35 | 25 | 44 | 26 | 25 | 92 | 9 | 90 |
| | 13:30 | 39 | 27 | 39 | 27 | 27 | 100 | 12 | 100 |
| | 15:30 | 37 | 27 | 46 | 28 | 27 | 92 | 9 | 90 |
| Overall average | | 35.55 | 26.69 | 51.03 | 27.21 | 26.14 | 92.04 | 8.34 | 95.83 |

Note:

$T_{db}$ = Dry bulb temperature; $T_{wb}$ = Wet bulb temperature

$T_{dp}$ = Dew point temperature; RH = Relative humidity

# Effect of Mechanical Planting on Grain and Straw Yields, Water Use Efficiency and Profitability of Rice Cultivation





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## Abstract

Experiments were conducted in rainfed condition to study the effect of mechanical planting methods on straw and grain yields, water use efficiency and net returns from rice cultivation. Field efficiency of planting machines was compared with the traditional method of manual transplanting with root washed seedlings. Variations in yields of straw and grain and water use efficiency due to use of machines were not significant compared to the manual transplanting. Compared to manual transplanting, saving in cost of planting with the use of machines was substantial (average: Rs. 1,048/ha` against Rs. 9,250/ha) which reduced the total cost of production by 24 % and enhanced the net profit by 42 % (to Rs. 31,465/ha).


## Introduction

In recent years in India, scarcity of labour and high labour wage has hit rice cultivation hard. In this scenario returns from rice farming are marginal since increase in market price of the produce is not in same proportion to the increase in cost of production. Transplanting, weeding - especially in uplands and aerobic conditions and harvesting are the major labour intensive operations in rice cultivation. Time available for transplanting in all the production seasons, namely Kharif, Rabi and Boro is limited. Delay in transplanting reduces yield and profitability. Compared to traditional (manual) transplanting, mechanized planting of rice reduces labour requirement, speeds up planting process and reduces cost of operation substantially.

Pandey (2002) reported performance of 8 row self propelled mat type transplanter using 21 days old rice seedlings with 4 plants/hill and 46 hills/m². Labour requirement of the transplanter was 42 man-hours/ha with cost of operation of Rs. 1,130/ha against the cost of manual transplanting of Rs. 2,240/ha. Singh and Vasta (2007) reported field capacity of a manual rice transplanter as 0.03 ha/h. Use of the transplanter reduced labour requirement to one-third and cost of paddy cultivation over traditional method of manual transplanting by 54-73 %. Manjunath *et al.* (2009) reported working efficiency of 8 row paddy transplanter and suggested that the transplanter should work in an area of 28 ha per year to achieve breakeven point for cost reimbursement. Jha *et al.* (2011) adopted four planting practices, namely, direct sowing in dry fields, direct sowing of sprouted seeds in puddled field using drum seeder, mechanical and manual transplanting. They reported that the direct seeding of sprouted seeds gave significantly higher grain yield of rice (5.70 t/ha), followed by direct seeding under dry field (5.32 t/ha) and mechanical transplanting (5.21 t/ha), whereas the lowest yield was recorded in manual transplanted rice (5.11 t/ha). Mohapatra *et al.* (2012) found that planting by seed drill with sprouted seeds does not affect yield and water use efficiency. They also found that planting more plants in a unit area by sprouted seed drill or transplanters, compared to a single plant, as advocated in the system of rice intensification (SRI), increased grain yield and water use efficiency. Avasthe *et al.* (2012) reported optimum hill spacing of

**Fig.1** Four row manual drum seeder

**Fig.2** Six row manual drum seeder

**Fig.3** Four row manual rice transplanter

**Fig.4** Self propelled 8 row transplanter

**Fig.5** Self propelled hill seeder

**Fig.6** Tractor drawn seed drill

20 cm × 20 cm in hilly acidic soil where wider and narrower spacing than this resulted in reduced grain yield.

From field water balance studies, Mohapatra (2006) determined grain water use efficiency (GWUE) of several rice cultivars for upland, shallow lowland and deep water situations under rainfed ecosystem. He reported that evapotranspiration (ET) of a cultivar mainly depends on its duration.

## Materials and Methods

The experiment was conducted at Central Rice Research Institute, Cuttack, Odisha, India in rainfed environment of shallow lowland condition in Kharif season of years 2010-12 with rice CV 'Gayatri'. The soil was aeric endoaquept with available N: 190 kg, Bray's P: 20 kg and K: 203 kg per hectare before start of the experiment. Same nutrient level was maintained in all the treatments by addition of 5.0t farm yard manure (FYM) and 60:30:30 kg NPK per hectare. All FYM, P and K and 20 kg N were applied as basal dose. Twenty kg N was applied each time after 3 weeks of plant establishment and at panicle initiation stage. Nurseries raising and direct seeding were done at same time. In wet land condition, CRRI four and six-row manual drum seeders (**Figs. 1** and **2,** respectively) with sprouted seeds, CRRI 4 row manual rice transplanter (**Fig. 3**) and self propelled 8 row transplanter (**Fig. 4**) with mat type seedlings were used. Twenty two days old seedlings were used in case of transplanters and manual transplanting. Sprouted seeds were sown by drum seeder. CRRI self propelled hill seeder (**Fig. 5**), CRRI bullock drawn seed drill and CRRI tractor drawn seed drill (**Fig. 6**) were used with dry seeds in dry land condition. There was one weeding by use of conoweeder in direct seeded plots. The crop was free from diseases and insect attacks. The crop was harvested after 155 days of germination.

The experimental plots were arranged with randomized complete block design (RCBD) with 3 replications.

Grain water use efficiency (GWUE) was determined as the ratio of grain yield and evapotranspiration (ET) of the crop. As per the procedure adopted by Mohapatra (2006), ET was computed from the field water balance (FW) of rainfall:

$FW = R - R_o - S_p \pm S_r + W_s$............(1)

Where,

$R$ = rainfall,

$R_o$ = runoff,

$S_p$ = seepage and percolation,

$S_r$ = soil profile contribution (or retention), and

$W_s$ = water applied from sources other than rainfall (irrigation).

Average rainfall during growth period of 'Gayatri' (15th June to 18th Nov. of the years 2011 and 2012) was 1,292 mm. Runoff was measured during these years from a 100m$^2$ plot to which inflow was blocked from all sides. A 5-slot device with a buried drum was used to measure runoff. In few cases runoff could not be measured. Their values were obtained from the graph between rainfall of individual showers and corresponding runoffs. Total value of runoff was found to be 443 mm which was 34.3 % of rainfall.

**Table 1** Planting machines with specifications

| Planting method/ machine | Planting material | Seed rate (kg/ha) | Source of draft | Hill spacing | Plants/ hill | No. of rows in one swath |
|---|---|---|---|---|---|---|
| CRRI 4-row manual drum seeder | Sprouted seeds | 50 | Manual | 15 cm × 20 cm | 4-5 | 4 |
| CRRI 6-row manual drum seeder | Sprouted seeds | 53 | Manual | 15 cm × 20 cm | 5-6 | 6 |
| CRRI 4 row manual rice transplanter | Mat type seedlings | 60 | Manual | 14 cm × 24 cm | 4-5 | 4 |
| Self propelled transplanter | Mat type seedlings | 60 | 4hp engine | 14 cm × 24 cm | 4-5 | 8 |
| CRRI self propelled hill seeder (walking type) | Dry seeds | 50 | 3hp engine | 15 cm × 20 m | 4-5 | 3 |
| CRRI tractor drawn seed drill | Dry seeds | 55 | 35hp tractor | 15 cm × 20 cm | 5-6 | 10 |
| CRRI bullock drawn seed drill | Dry seeds | 58 | Animal | 15 cm × 20 cm | 6-7 | 3 |
| Manual transplanting (traditional) | Root washed seedlings | 63 | Manual | 15 cm × 20 cm | 2-3 | NA |

Seepage and percolation were measured by drum culture, i.e. by use of buried bottom-closed and bottom-open drums. These were found to be within 2 % of rainfall during crop growth period ($S_p$ = 26 mm). The low value could be attributed to the saturated aquifer condition and rice fields, all around the experimental plots, limiting the scope of horizontal and vertical outflow inside the soil. Soil profile contribution was measured by taking soil samples from field before planting and after harvest of the crop. This was found to be negligible due to saturated condition of soil at the time of planting and harvest of the crop ($S_r$ = 0.0). Irrigation water was not applied ($W_s$ = 0.0). Using Eq.1, value of ET of 'Gayatri' was determined as 823 mm.

Plant height from 10 hills and number of unproductive tillers and ear bearing tillers from a square meter area were recorded before harvest. Dry grain and straw yields were recorded from the whole plot (50 $m^2$ each).

Cost inputs including seed, FYM, fertilizer, nursery raising, tillage, puddling, planting (direct sowing by seeders, mechanical and manual transplanting), harvesting, threshing and labour required for these operations were recorded for different treatments, separately, to arrive at the total cost of production. Returns from rice cultivation were determined from local market rates of straw (Rs. 100/q) and paddy (Rs. 1,000/q). Profitability (net returns) from rice cultivation was determined as the difference of returns and total cost of cultivation.

Planting machines with specifications adopted in the experiment is given in **Table 1**.

## Results and Discussion

**Planting Efficiency**

Results presented in **Table 2** show that there was a significant variation in planting capacity of different implements. Average capacity of sprouted seeders was 0.047 ha/h compared to 0.075 ha/h of manual dry seeders and 0.38 ha/h of tractor drawn seed drill. Planting capacity of 6-row seeder was higher than 4-row seeder but the operator faced difficulty to turn the 6-row seeder at corner of the plots. Planting capacity of self propelled transplanter (0.205 ha/h) was 9 times faster than manual transplanter (0.022 ha/hr) and 82 times faster than manual transplanting (0.0025 ha/h). Missing hills due to manual and self-propelled transplanters were within 8 % and 5 % respectively. Sprouted seeders required leveled puddled-field with maximum standing water depth of 10 mm. Plant mortality was noticed where standing water was higher due to rotting of young shoots.

**Grain yield**

There was no significant difference in number of unproductive tillers (Average: 56.7 Vs. 57.3/$m^2$: 1.1 %), ear bearing tillers (Average: 303.2 Vs. 307.8/$m^2$: 1.5 %), plant height (Average: 106.1 vs. 108.6 cm: 2.3 %), grain yield (Average: 5.73 vs. 5.85 t/ha: 2.1 %) and water use efficiency (Average: 0.697 vs. 0.711 kg/$m^3$: 2 %) between mechanical planting (including all seeders and transplanters) vs. manual transplanting. This finding is slightly different to the finding by Jha *et al.* (2011) who reported that 10.4 % and 3.4 % higher grain yields were obtained from direct seeding of sprouted and dry seeds respectively than manual transplanted rice. But the present study is in agreement with the findings of Avasthe *et al.* (2012) where they found that hill spacing, wider than 20 cm × 20 cm, generated higher number of tillers per hill but failed to produce corresponding increase in panicles/m$^2$ and narrower spacing increased panicles/m$^2$ but shortened panicle length with reduced number of grains which reduced the grain yield.

**Straw Yield**

Unproductive tillers were 15.7 % of total number of tillers (Average: 303.8/m$^2$). Straw yield was slightly higher in case of manual transplanting (9.5 t/ha) compared to mechanical transplanting (9.13 t/ha) and direct seeding (8.23 t/ha). Contribution of straw yield towards net returns was significant with an average of Rs. 8,985/ha at local market rate of Rs. 100/q.

**Cost and Net Returns**

There was a significant saving of cost in direct seeding and transplanting due to use of machines, compared to manual (traditional) transplanting (average cost of Rs. 1,048 against Rs. 9,250/ha). Cost of manual transplanting was higher by 13 times than sprouted seed drills (cost: Rs. 672/ha), 7 times than self propelled transplanter (cost: Rs. 1,157/ha), 5.8 times than self propelled hill seeder (cost: Rs. 1,364/ha) and 4.2 times than manual transplanter (cost: Rs. 1,772/ha). Initial investment of tractor drawn and self propelled implements is high but it is compensated with the speed and efficiency of planting operation. Although yield from different planting methods did not vary significantly, the cost of planting made a significant difference in total cost of cultivation and net returns. Highest net return of Rs. 34,138/ha was obtained from self propelled transplanter followed by manual transplanter (Rs. 32,580/ha) compared to Rs. 22,222/ha of manual transplanting. Average net return from dry seeded plots was Rs. 30,863/ha against Rs. 30,476/ha of sprouted seeded plots, Rs. 33,359/ha of mechanically transplanted plots and Rs. 22,222/ha of manually transplanted plots.

## Conclusions

Manual transplanting is the most expensive input in traditional rice cultivation but the planting cost of Rs. 9,250/ha can be reduced to Rs. 851/ha by use of dry seeders, to Rs. 1,364/ha by self propelled hill seeder, to Rs. 672/ha by sprouted seeders and to Rs. 1,157/ha by self propelled transplanter. Compared to manual transplanting, mechanized direct seeding and transplanting decrease total cost of cultivation by an average of 24 % (from Rs. 45,778/ha to Rs. 34,789/ha) and increases net returns by 42 % (from Rs. 22,222/ha to average of Rs. 31,465/ha). Maximum area is transplanted in an hour by the self propelled transplanter in puddled soils by using mat type seedlings. In well drained, puddled condition, where standing water remains within 10 mm, plant-

**Table 2** Effect of planting implements on productivity, GWUE and net returns (CV ‘Gayatri’, Kharif, 2010-12)

| Planting implement | Planting capacity (ha/h) | Cost of * planting (Rs./ha) | Total cost of cultivation (Rs./ha) | Plant ht. (cm) | Unproductive tillers/m$^2$ | Ear bearing tillers/m$^2$ | Straw yield (t/ha) | Grain yield (t/ha) | GWUE (kg/m$^3$) | Net # return (Rs./ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| Four row manual drum seeder | 0.04 | 772 | 34,788 $ | 105.6 | 53.3 | 295.3 | 8.75 | 5.59 | 0.679 | 29,862 |
| Six row manual drum seeder | 0.053 | 572 | 34,290 $ | 107.4 | 58.0 | 301.6 | 8.38 | 5.70 | 0.693 | 31,090 |
| Bullock drawn seed drill | 0.07 | 936 | 35,040 $ | 105.7 | 58.3 | 297.8 | 8.75 | 5.63 | 0.684 | 30,010 |
| Tractor drawn seed drill | 0.38 | 766 | 34,764 $ | 105.9 | 60.0 | 302.2 | 9.0 | 5.76 | 0.700 | 31,836 |
| Self propelled hill seeder | 0.08 | 1,364 | 35,508 $ | 106.1 | 55.7 | 302.4 | 9.25 | 5.70 | 0.693 | 30,742 |
| Four row manual rice transplanter | 0.022 | 1,772 | 34,920 | 105.7 | 59.3 | 308.9 | 9.0 | 5.85 | 0.711 | 32,580 |
| Self propelled 8 row transplanter | 0.205 | 1,157 | 34,212 | 106.2 | 52.0 | 314.2 | 9.25 | 5.91 | 0.718 | 34,138 |
| Manual transplanting | 0.0025 | 9,250 | 45,778 | 108.6 | 57.3 | 307.8 | 9.5 | 5.85 | 0.711 | 22,222 |
| SEm ± | - | 33.27 | 255.43 | 0.182 | 2.31 | 5.425 | 0.156 | 0.109 | 0.013 | 1,470.3 |
| CD (P = 0.05) | - | 68.84 | 528.48 | 0.377 | 4.78 | 11.224 | 0.323 | 0.226 | 0.028 | 3,042 |

* Excluding cost of seed/nursery operations $ Includes cost of 1 weeding by cono-weeder
# Rate of paddy = Rs. 1000/q, Rate of straw = Rs. 100/q

ing by sprouted seed drills is most economical. Compared to manual transplanting, it reduces cost of planting to 1/14th and increases net profit from rice cultivation by 37 %. In dry land situation tractor drawn seed drills work efficiently and give a high net return of Rs. 31,836/ha. Although grain and straw yields and water use efficiency do not vary significantly, wide variation in cost of planting due to use of different implements results in significant difference in net returns.

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# New Co-operating Editors

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# Design of Nitrogen (Liquid Urea) Metering Mechanism for Point Injection in Straw Mulched Fields

by


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## Abstract

Metering system is an important component of a fertilizer applicator to ensure proper and uniform fertilizer application. Different types of granular fertilizer metering systems have been developed and are in use on seed drills and planters. But, metering mechanism for nitrogen (liquid urea) is currently not available for accurate and uniform application of nitrogen in straw-mulched crops. Hence, this study was undertaken to design a nitrogen (liquid urea) application metering mechanism. It comprised of radial injectors attached to a distribution hub with in-line mounted flow control valve and cut-off system. Constant supply of liquid urea to the distribution hub by means of a piston pump produced pressure adequate to expel urea solution through the flow control valve as it opened. The opening and closing of flow control valve was regulated through a specially designed lever and stationery cam. The time duration of opening of flow control valve regulated the liquid urea flow rate. The flow, metering and cut-off system were developed by analyzing the flow characteristic of liquid urea at optimum pressure and optimizing structural parameters in the metering mechanism. The newly designed metering system will pave the way for development of point injected nitrogen (liquid urea) applicator for straw mulched crops. This paper contains design approach and details of the liquid urea metering mechanism evaluated under actual field conditions at the Experimental Farm of Punjab Agricultural University, Ludhiana (India). The point injected nitrogen increased the nitrogen uptake and yield by about 20 % over conventional practice (broadcasting) of nitrogen application. The nitrogen use efficiency (NUE) in case of urea solution injected with nitrogen applicator was 47.1 % more than that of broadcasting of urea (Singh *et al*., 2014).

## Introduction

Nitrogen (N) fertilizer is a vital input for sustaining and enhancing grain yields of high intensity cereal crops. However, excessive quantity and inappropriate application methods lead to low N efficiency and high N losses through immobilization, leaching, runoff, de-nitrification and ammonia volatilization (Kirda *et al*., 2001 and Zhu *et al*., 2000) resulting in a series of environmental problems and soil degradation. Proper and efficient nitrogen utilization is indeed the need of the hour.

In high residue no-till farming systems, proper and efficient application of nitrogen fertilizer (urea) has emerged as a challenge in recent years. In wheat production, about 125-150 kg N/ha is applied, with more than 75 % it applied as top dressing through broadcasting. The fertilizer granules are retained on mulch resulting in ammonia volatilization losses, leading to low N efficiency (Barreto *et al*., 1989). Only about 40 % of the N fertilizer applied to irrigated wheat is utilized by the plants due to inefficiency in application (wrong method or timing of application) and/or the inherent properties of current fertilizer products (Singh *et al*., 2008). Where urea or urea-based fertilizers are surface applied, particularly in the presence of organic residues, crop yields are often reduced (Singh *et al*., 2008). A review by researchers (Scharf and Alley, 1988) found that on an average 25 % of the nitrogen applied as urea is lost via ammonia volatilization. Researchers have shown that reducing fertilizer nitrogen contact with straw by placing fertilizer below soil surface can reduce nitrogen immobilization and ammonia volatilization which, if saved can contribute to higher grain yield, plant N uptake and N utilization efficiency (Blackshaw *et al*., 2002 and Rochette *et al*., 2009).

The rapid adoption of no-tillage system has led to increased demand of urea. There is, thus need to enhance profitability, and ensure environmental protection. All these are reasons for developing a liquid urea applicator for efficient use in directly sown mulched-fields. Fertilizer metering mechanisms for granular fertilizers are commercially available. But the metering mechanism for liquid urea application is not available. This led to this study to design an efficient liquid urea applicator for straw- mulched crops.

## Materials and Methods

Three basic methods of fertilizer application are broadcasting, drilling and point- injection. Urea is a highly mobile in nature. If it could be injected with a device in the soil beneath straw mulch at some uniform spacing, the fertilizer use efficiency could be enhanced. The design of nitrogen (liquid urea) metering mechanism is based on the characteristics of urea fertilizer. It was planned to inject the urea in the liquid form with the help of injectors mounted on the periphery of a rotary wheel. The conceptual sketch of nitrogen (liquid urea) applicator is shown in **Fig. 1** Its main components include metering mechanism consisting of an injector, distribution hub and cut-off mechanism.

### Design of Injector

The injection spacing is an important parameter for efficient utilization of nitrogen by the plants. In order to decide the longitudinal and lateral (across row) injection spacing, the spread diameter of wetted soil was studied under laboratory and field conditions. Different volumes of water were injected into two different types of soils (light texture and heavy texture soils) using a syringe and spread diameter of wetted soil was recorded after 20 minutes of injection (**Table 1**).

The Spread Index with volume of 20 ml per injection was highest. Hence, volume of 20 ml per injection was selected for developing the metering mechanism.

*Average Spread diameter of wetted soil with 20 ml volume/injection* = 18.91-19 cm

In the present study, liquid urea was to be applied in the irrigated wheat crop (15-18 % soil moisture content). Hence, there would be some more movement of nitrogen in the soil due to high mobility of nitrogen.

*Assuming movement of nitrogen from each side* = 3 cm

*Wet spread area between successive point of injection* = 9.5 + 9.5 + 3.0 + 3.0 = 25 cm

Hence, *injection spacing within a row* = 25 cm

For lateral injection spacing, *Inter row spacing in wheat crop* = 20 cm

Adoption of lateral injection intervals of two-row spacing (40 cm) would ensure that every wheat row had access to injection sites on at least one side.

The researchers (Janzen and Lindwal, 1989) had recommended maximum longitudinal and lateral (across row) fertilizer nitrogen in-

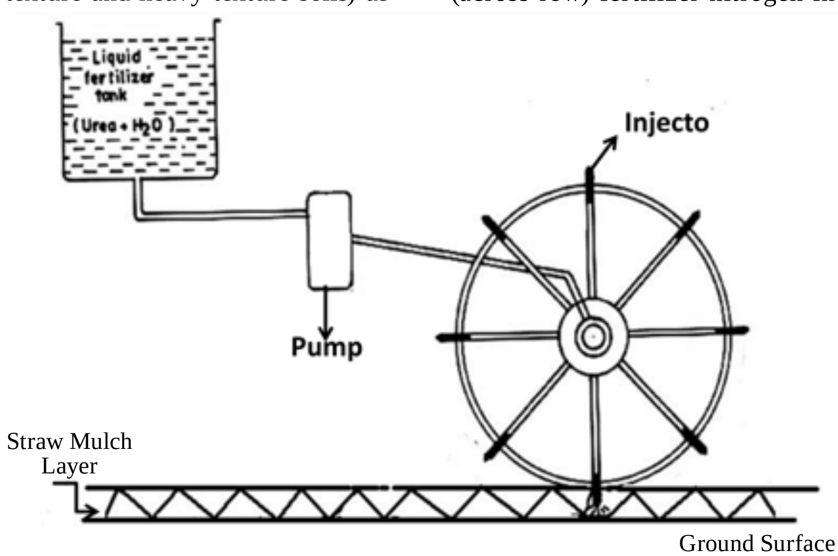


**Fig. 1** Conceptual sketch of nitrogen (liquid urea) application mechanism

jection interval for wheat as 40 cm and equivalent of two row spacing (40 cm), respectively. It was also reported that higher intervals resulted in unacceptable variability in N availability.

Based on the wet spread diameter and review, the longitudinal injection interval within the row was taken as 25 cm. Keeping row spacing in mind, the lateral distance (across row) of injector was taken in alternate crop row i.e. 40 cm.

Hence, *Area covered/injection* = 25 × 40= 1000 cm$^2$ = 0.1 m$^2$

*Injection rate* = 20 ml / 0.1 m$^2$ = 0.2 L/m$^2$

*Number of injections / ha* = (10000 × 100 × 100) / 1000=100000

*Volume of liquid urea solution / ha* = volume injected / injection × number of injection per ha

Or (20 × 100000) / 1000 = 2000 L/ha

***Size of spoke wheel***

Assuming, injector opening = 30° (Based on the design of cam/cut off system)

*Interval between consecutive injectors = 45°*

∴ *Number of injectors per spoke wheel = 360° / 45° = 8*

*Circumference of spoke wheel = injection spacing × number of injectors per spoke wheel*

*Circumference of spoke wheel = 25 × 8= 200 cm*

∴ *Diameter of spoke wheel (D) = 200 / π = 63.7 cm*

*Average thickness of straw mulch mat in 'Happy Seeder' sown field = 5.0 - 5.5 cm* (measured in the field)

∴ *Length of injector ($L_i$) = 6 cm* (so that it can penetrate inside the straw mulch mat of 5.5 cm thick easily)

∴ *Total diameter of spoke wheel = 63.7 + 6.0 = 69.7 cm*

***Injection timing***

The liquid urea injection time for a point injected nitrogen (liquid urea) application is calculated as given below.

Injection spacing = 25 cm

*Speed of operation = 2.5 km/h = (2.5 × 1000) / 60 = 41.7 m/min*

*Diameter of rotary wheel, D = 69.7 cm = 0.697 m*

∴ *π D N= 41.7* Or *N = 41.7 / (π×0.697 ) = 19.04 ~19 rpm*

*Injector opening = 30°* (Based on the design of cam/cut off system)

*Time required by rotary wheel to rotate 30° = 1 / 360 × 60 / 19 × 30 = 0.263 sec*

Hence, injector has to deliver 20 ml volume of liquid urea in 0.263 sec.

***Orifice size***

*Injection volume* = 20 ml/injection

*Injection time* = 0.263 sec

∴ *Flow rate of the injector* = 20 ml/0.263 sec or 76.04 ml/sec or 4.56 L/min

*Pressure delivered by pump* = 3.0 kg/cm$^2$

The pressure difference in the injector is proportional to the square of liquid urea flow rate through the injector orifice as given by following equation.

$$p_i - p_s = \frac{Q_i^{\,2} \times \rho_d}{2(C_d \times a)^2}, kg/cm^2 \quad ...........(1)$$

( Sharma and Mukesh, 2010)

Where,

$p_i$ = Pressure at injector orifice, kg/cm$^2$

$P_s$ = Penetration resistance of soil, kg/cm$^2$

$Q_i$ = Rate of liquid urea flow through injector per second

$\rho_d$ = density of liquid urea, kg/L

$C_d$ = coefficient of discharge

$a$ = Cross sectional area of injector orifice, cm$^2$

The nitrogen (liquid urea) is to be applied after irrigation (15-17 % moisture content) in top layer of soil (20-30 mm). The average penetration resistance of soil is 1.3 kg/cm$^2$ (measured experimentally).

$P_s$ = 1.3 kg/cm$^2$

$p_i$ = 3.0 kg/cm$^2$

$Q_i$ = 4.56 L/min= 0.076 L/sec

$\rho_d$ = 1.04 kg/L *(measured)*

The discharge coefficient cd is a function of the orifice opening. It varies considerably with changes in area ratio and the Reynolds number. A discharge coefficient cd = 0.60 may be taken as standard.

*Take* $C_d$ = 0.6

Putting the value in equation 1

$$3.0 - 1.3 = \frac{(0.076)^2 \times 1.04}{2\,(0.6 \times a)^2}$$

or $a^2$ = 4.908 ×10$^{-3}$

∴ $a$ = 0.0701 cm$^2$ = 7.01 mm$^2$

Also X-sectional area of injector orifice *(a)* = $\pi d_i^2 / 4$ = 6.17 mm$^2$

Where, $d_i$ = diameter of injector orifice, mm

∴ $d_i$ = 2.99 mm ≈ 3.0 mm

Diameter of injector orifice *($d_i$)* = 3.0 mm

**Table 1** Spread diameter of wetted soil at different volumes of water injected

| Moisture content of the soil (%) | Volume of water injected, ml | Spread diameter of wetted soil (cm) | | | | | Spread Index |
|---|---|---|---|---|---|---|---|
| | | Light textured soil | | Heavy textured soil | | Mean | |
| | | Lab condition | Actual field condition | lab condition | Actual field condition | | |
| 15.1 - 17.3 | 10 | 6.42 | 7.54 | 7.74 | 7.82 | 7.38 | 0.738 |
| | 15 | 9.94 | 11.72 | 12.97 | 13.68 | 12.08 | 0.805 |
| | 20 | 17.84 | 18.06 | 19.02 | 20.12 | 18.91 | 0.945 |
| | 25 | 18.8 | 19.9 | 22.72 | 24.6 | 21.5 | 0.86 |
| | 30 | 21.64 | 22.7 | 23.6 | 25.72 | 23.41 | 0.78 |

**Distribution Hub**

The distribution hub (**Fig. 2**) acts as a reservoir in which liquid urea is supplied longitudinally from one side and exits tangentially out of spokes mounted on the periphery of the distribution hub. The distribution hub mounted on an axle with two ball bearings at both ends and acts as a rotary valve for metering and supplying liquid urea from the main supply to the spokes fitted on the periphery of the distribution hub. Two holes on the periphery of axle facilitate the exit of liquid urea into the cylindrical hub.

***Size of distribution hub***

The diameter of distribution hub was selected as per the standard outside diameter of radial ball bearing. The radial ball bearings are available in standard size of bore of 10 to 80 mm. A radial ball bearing of 30 mm bore (bearing no. 6006) was selected.

*Bore of ball bearing* = 30 mm

*Diameter of axle* ($d_a$) = bore of ball bearing+ axle seat limit = 30 + 5= 35 mm = 0.035 m

*Standard outside diameter of 30 mm bore ball bearing* = 55 mm

*Internal diameter of hub* ($d_i$) = 40 mm = 0.04 m

*We know, volume of liquid urea delivered per injection* = 20 ml

To avoid fluctuation in discharge rate, we need to store adequate quantity of liquid urea in the distribution hub. Let, volume stored into distribution hub be 10 times of discharge per injection.

∴ *Volume of liquid urea stored in the distribution hub= 20 × 10 = 200 ml = 0.2 l = 2 × 10-4 m³*

Also, *Effective volume of distribution hub* = $\pi / 4\ (d_i^2 - d_a^2)\ l$

Where $l$ = Effective width of distribution hub (m)

$d_i$ = Internal diameter of distribution hub (m)

$d_a$ = diameter of axle (m)

∴ $\pi / 4 \times l \times (0.04^2 - 0.035^2) = 2 \times 10 - 4$

or $l$ = 0.679m = 67.9 cm

∴ Effective width of distribution hub ($d_h$) = 67.9 ~ 68 cm

*Standard width of 2-ball bearings* = 13 × 2= 26 mm

*Standard width of 4 seal* = 7.75 × 4 = 31 mm

*Total width of distribution hub = 68 + 26 + 31 = 125 mm*

Total width of distribution hub ($l_h$) = 125 mm

***Friction loss in the distribution hub***

Friction loss from liquid urea flow in the distribution hub is estimated by the pipe flow equations. If 'lh' is the length of distribution hub of diameter 'dh' the head loss due to friction in hub is calculated using Darcy-Weisbach equation for head loss in circular pipes

$$h_f = \frac{4 f l_h v^2}{2 g d_h}$$ ............(2)*(Bansal, 2005)*

Where,

$$f = friction\ factor = \frac{0.079}{(R_e)^{1/4}}$$

.............................(for turbulent flow)

$R_e$ = Reynolds number = Vd / v

$v$ = Kinetic viscosity = Dynamic viscosity / density= μ / ρ

For liquids $\mu = \mu_0 \{1 / (1 + \alpha t - \beta t^2)\}$ ..................................*(Bansal, 2005)*

Where

$\mu$ = viscosity at t °C in poise

$\mu_0$ = viscosity at 0°C in poise

$\alpha, \beta$ = constants for the liquid

For water

$\mu_0 = 1.787 \times 10^{-3}$ poise (N-s/m²)

$\alpha = 0.03368$

$\beta = 0.000221$

∴ $\mu = 1.787 \times 10^{-3}$

$$\left\{\frac{1}{1 + 0.03368 \times 20 - 0.000221 \times 20^2}\right\}$$

= 0.001127 poise

Or $\mu$ = 0.0001127 kg/s-m

Density of liquid nitrogen ($\rho$) = 1,040 kg/m³

Kinetic viscosity, v = 0.0001127 / 1040 = $1.084 \times 10^{-7}$ m²/s

Velocity of liquid ($V$)

= Rate of flow / Area

$$= \frac{0.076 \times 10^{-3}\ m^3/sec}{\frac{\pi}{4}\ (0.04^2 - 0.035^2)\ m^2}$$

= 0.258 m/s

Reynolds number ($R_e$)

$$= \frac{0.258 \times 0.005}{1.084 \times 10^{-7}}$$

= 11,904.17 ($R_e$ > 2000, flow is turbulent)

Friction factor ($f$)

$$= \frac{0.079}{(11904.17)^{1/4}} = 0.825$$

= 0.825

Head loss due to friction in distributor hub, $h_f$

$$= \frac{4 \times 0.825 \times 0.63 \times (0.258)^2}{2 \times 9.81 \times 0.005}$$

= 1.41 m

Pressure loss in the distributor hub

= ρghf = 1.04 × 9.81 × 1.41 = 14.39 Pa = 14.4 N/m²

= $1.44 \times 10^{-4}$ kg/cm²

So, pressure loss in the distribution hub is negligible.

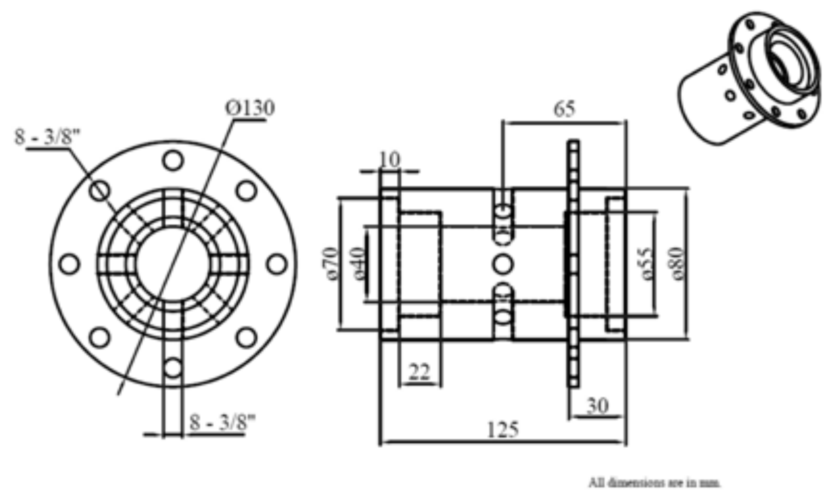


**Fig. 2** Views of distribution hub

**Cut-Off Mechanism**

The nitrogen (liquid urea) cut-off mechanism consists of an inline mounted flow control valve to regulate the liquid urea flow between distributor and injector. Each flow control valve fitted in spoke assembly (**Fig. 3**) is provided with independent cutoff lever. A specially designed crank lever regulates the opening and closing of flow control valve. The load arm of the lever is attached with a helical tension spring; which kept the flow control valve in closed position. The effort arm of the crank lever is actuated by a stationery cylindrical cam fitted tangentially on a plate with the spoke wheel. The cam is so designed that it will operate the cutoff lever for 30° of rotation of spoke wheel as an injector touches the soil surface. With the rotation of spoke wheel, the effort arm of the lever strikes with the cam and is pushed back; which results into the opening of the flow control valve. As the lever arm passes the cam, the flow control valve comes to its closed position by the tension of the spring.

***Spring***

The liquid urea pressure acting on the ball of flow control valve will try to open the flow control valve. So, a helical tension spring was provided at one arm of lever so that the tension of spring keeps the flow control valve in closed position.

Liquid urea pressure on the flow control valve = 3 kg/cm$^2$

Bore of valve = 0.75" = 1.875 cm

Cross sectional area of the ball of flow control valve = $\pi d^2$ / 4 = ($\pi \times 1.875^2$) / 4 = 2.76 cm$^2$

∴ Total load acting on ball of flow control valve = 3 × 2.76 = 8.28 kg = 81.22 N

This load is transferred to lever and helical tension spring as spring force.

This force produces a deflection ($\delta$) of 50 mm in spring.

∴ Axial load on helical tension spring ($W$) = 81.22 N

The ultimate tensile strength ($S_{ut}$) of selected material ranges from 1014-1951 N/mm$^2$

Let $S_{ut}$ = 1620 N/ mm$^2$

Permissible stress ($\tau$)= 40 % of $S_{ut}$.......*(Khurmi and Gupta, 2009)*

∴ $\tau$ = 0.4 × 1620= 648 N/mm$^2$

Spring index (C) = 4-12 (for general springs)

Assume C = 6

Also spring index (C) =( D)/d = 6

Or $D$ = 6d

Where $D$ = mean coil diameter (mm)

d = spring wire diameter (mm)

Wahl's correction factor ($k$) = (4C - 1) / (4C - 4) + 0.615 / C

∴ k =( 4 × 6 - 1) / (4 × 6 - 4) + 0.615 / 6 = 1.2525

Shear stress in spring wire,

$$\tau = \frac{8\,PD}{\pi d^3}\ \mathrm{k}$$

∴ 648

$$= \frac{8 \times 81.22 \times 6d \times 1.2525}{\pi d^3}$$

∴ $d$ = 1.55 mm (select standard diameter of wire i.e. 1.6 mm)

$D$ = 6 × 1.6= 9.6 mm ≈ 10 mm

Also deflection of the spring ($\delta$) for the maximum force,

$$\delta = \frac{8\,W.D^3.n}{Gd^4}$$

Where $\delta$ = deflection in spring coil

$G$ = Modulus of rigidity (80 × 103 N/mm$^2$)

$W$ = axial load on spring (N)

$n$ = the number of coils

Putting the values in above eqn

$$50 = \frac{8\times81.22\times10^3\times n}{80\times10^3\times1.6^4}$$

Or n = 40.3 ~ 40

For helical tension spring, all coils are active. Therefore,

Number of turns in the coil (nt) = 40

Solid length of spring (l) = $N_t$.d

Or $l$ = 40 × 1.6 = 64 mm

***Cut-off lever***

Considering the cutoff mechanism as a lever with forces acting in the same plane as shown in **Fig. 4**, the point A and B through which the load and effort is applied are known as load and effort points, respectively. F (spindle of flow control valve) is the fulcrum about which the lever is capable of oscillating.

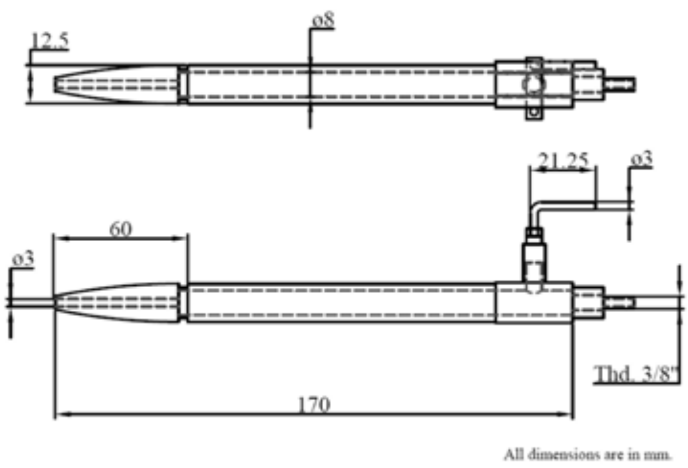


**Fig.3** View of spoke with injector

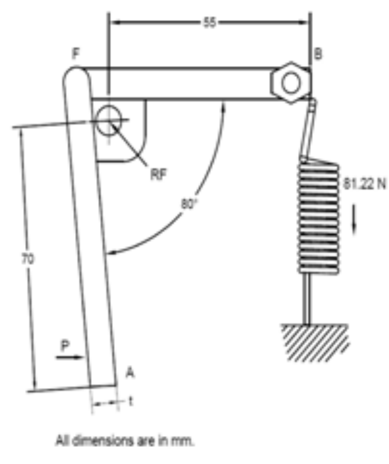


**Fig. 4** Crank Lever for cut-off mechanism

The perpendicular distance between the load point and the fulcrum ($l_1$) is known as load arm and the perpendicular distance between the effort point and the fulcrum ($l_2$) is known as effort arm. According to the principal of moments,

$P \times l_2 = W \times l_1$

Spring load ($W$) = 81.22 N

Load arm ($l_1$) = 55 mm

Effort arm ($l_2$) = 70 mm

P × 70 = 81.22 × 55

or $P$ = 63.81 N

∴ Effort (P) required to open flow control valve ($P$) = 63.81 N

Reaction of fulcrum pin at F,

$$R_F = \sqrt{(W^2 + P^2 - 2W \times P \times Cos\theta)}$$
$$= \sqrt{(81.22^2 + 63.81^2 - 2 \times 81.22 \times 63.81 \times Cos\ 80^\circ)}$$

∴ $R_F$ = 94.17 N

**Fulcrum Pin/ Spindle of Flow Control Valve**

Let

$d_s$ = diameter of fulcrum pin / spindle

$l$ = length of fulcrum pin

$p_b$ = Safe bearing pressure on pin (10-15 N/mm$^2$)......*(Khurmi and Gupta, 2009)*

Considering, the fulcrum pin in bearing. The load on the fulcrum pin ($R_F$) is

$R_F = d \times l \times pb$

$l$ varies from 1 to 2d,

assume $l$ = 1.5d

∴ 94.17 = $d \times 1.5d \times 13$

or $d$ = 4.82 mm

So, minimum diameter of fulcrum pin = 4.82 mm

As per the standard size of flow control valve (3/4 inch), diameter of spindle is 5 mm. So we select diameter of spindle = 5mm

Length of fulcrum pin = 1.5 × 5 = 7.5 mm

***Check for shear stress:***

Since the pin is in double shear, therefore load on the fulcrum pin

$R_F = 2 \times (\pi / 4) \times d^2 \times \tau$

or 94.17 = $2 \times (\pi / 4) \times d^2 \times \tau = 2 \times (\pi / 4) \times 5^2 \times \tau$

∴ $\tau$ = 2.4 N/mm$^2$ = 2.4 MPa

Since the shear stress induced in the fulcrum pin/spindle is less than the safe shear stress of 60 MPa, therefore design for fulcrum pin/ spindle of flow control valve is safe.

A brass bush of 2 mm thickness is pressed into the boss of fulcrum as a bearing to reduce wear and easy renewal.

∴ Diameter of hole in the lever = d + 2 × 2 = 5 + 4 = 9 mm

Diameter of boss at fulcrum = 2d = 2 × 5 = 10 mm

***Check for bending stress induced in the lever arm at the fulcrum:***

The section of the fulcrum is shown in **Fig. 5**.

Bending moment at the fulcrum (M) = W × load arm (FB)

= 81.22 ×55 = 4467.1 N-mm

Section modulus, Z

$$= \frac{\frac{1}{12} \times 7[(10)^3 - (9)^3]}{10/2}$$

= 56.93 mm$^3$

∴ Bending stress, $\sigma_b$ = M / Z = 4467.1 / 56.93 = 78.46 N/mm$^2$ = 78.46 MPa

Which is more than the safe bending stress of mild steel (75 MPa), therefore it is not safe. To make it safe against bending, increase diameter of boss at fulcrum to 11 mm.

Section modulus, Z

$$\frac{\frac{1}{12} \times 7[(11)^3 - (9)^3]}{10/2}$$

= 70.23 mm$^3$

Bending stress, $\sigma_b$ = M / Z = 4467.1 / 70.23 = 63.60 N/mm$^2$ = 63.60 MPa

Now, this value is less than safe bending stress of mild steel (75MPa), hence it is safe.

***Crank lever***

It is assumed that the lever extends up to the centre of the fulcrum from the point of application of the load and is made of mild steel. Lever is subjected to bending moment.

Let

$d$ = diameter of lever rod

Bending moment = 63.81 (70) =

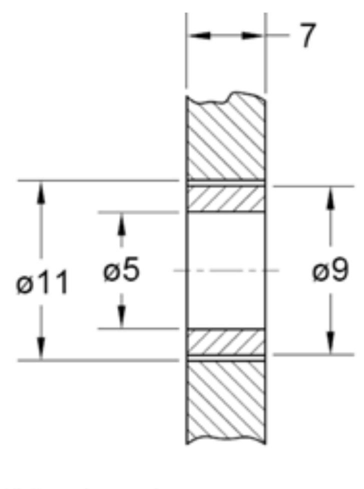


**Fig. 5** Section of the fulcrum

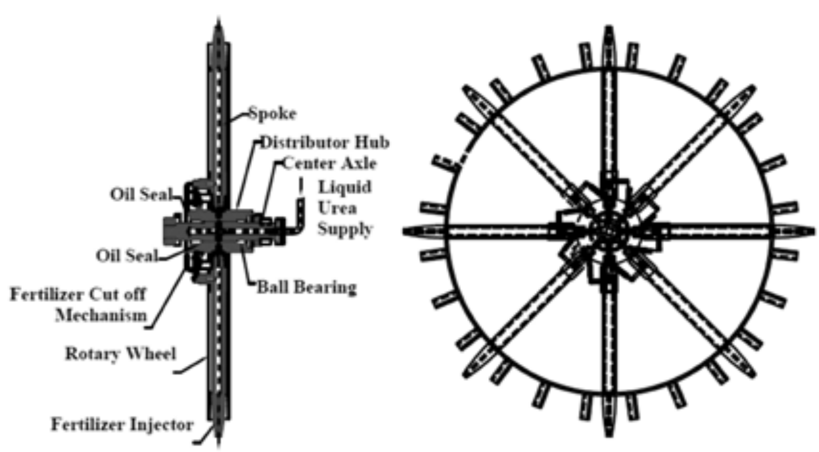


**Fig. 6** Views of Nitrogen (liquid urea) metering and cut-off mechanism

4466.7 N-mm

Section modulus, $Z = (1/6) \times d^3$

We know that the bending stress ($\sigma_b$) = M / Z

Safe stress in bending ($\sigma_b$) = 75 N/mm$^2$

$$\therefore 75 = \frac{4466.7}{\frac{1}{6} \times d^3}$$

or $d$ = 7.09 mm ≈ 7.0 mm

Hence, size of lever rod ($d$) = 7

The specifications of the designed components along with material of construction are given in **Table 2**. A self-propelled point injection nitrogen (liquid urea) applicator using the designed metering mechanism was also developed and evaluated.

**Laboratory Evaluation**

The metering mechanism was evaluated in the laboratory conditions for discharge rate, application rate, spread diameter of wetted soil, depth of injection, discharge variation within injectors and discharge variation with simultaneously injectors opening. The standard test rig with variable drive was used to test the nitrogen (liquid urea) metering mechanism (**Fig. 7**). The operating pressure of liquid urea was monitored by an engine operated piston type pump. The metering mechanism was evaluated for three levels of operating pressures (2.5, 3.0 and 3.5 kg/cm$^2$) and three levels of peripheral speed (0.56, 0.70 and 0.83 m/s). Rectangular trays were used to collect the liquid urea discharged from each injector for one minute duration. Application rate of liquid urea (L/ha) was calculated from discharge rate and assuming row to row spacing of 40 cm and perimeter of injectors. Parameters like depth of injection and spread diameter of wetted soil were measured by operating the nitrogen applicator in field cum lab condition.

The average application rate of 1,969.67 L/ha was obtained at peripheral speed of 0.84 m/s and operating pressure of 3.5 kg/cm$^2$; while the application rate of 2095.40 L/ha was obtained at peripheral speed of 0.70 m/s and operating pressure of 3.0 kg/cm$^2$, which were close to liquid urea application rate (2000 L/ha) used in the design of current metering mechanism. The spread diameter of wetted soil was significantly higher (151.20 mm) at peripheral speed of 0.70 m/s and operating pressure of 3.0 kg/cm$^2$ than that of 150.40 mm at peripheral speed of 0.83 m/s and operating pressure of 3.5 kg/cm$^2$. Therefore, a peripheral speed of 0.70 m/s (forward speed of 2.50 km/h), operating pressure of 3.0 kg/cm$^2$ and application rate of 2,095.00 L/ha were selected as optimum speed, operating pressure and liquid urea solution application rate for the field operation of self-propelled walk behind nitrogen (liquid urea) applicator (Dixit *et al.*, 2015).

**Field Evaluation of Nitrogen Applicator**

A field study was also conducted to determine the impact of point injected nitrogen (liquid Urea) application on nitrogen uptake and crop productivity under straw mulched no-till wheat (**Fig. 8**). The lower ni-

**Table 2** Specifications of the designed components along with material of construction

| Sr. No. | Components | Specifications | Material of construction |
|---|---|---|---|
| 1 | Injector | | High Carbon Steel |
| i) | Type | Cone shaped | |
| ii) | Length of injector | 60 mm | |
| iii) | Orifice diameter of injector | 3 mm | |
| 2 | Spoke | 9.5 mm | Mild steel |
| 3 | Distribution hub | | Mild Steel |
| i) | Shape and size | Cylindrical, 50 x 125 mm | |
| ii) | No. of spoke on hub | 8 | |
| iii) | Diameter of axle | 35 mm | |
| 4 | Cut-off mechanism | | |
| i) | Type | Cam actuated flow control valve | Brass |
| ii) | Size of valve | ¾ inch | |
| iii) | Crank lever | size: 55 × 70 mm , ϕ= 7 mm | Mild steel rod |
| iv) | Helical tension spring | | Carbon steel |
| | Solid length | 64 mm | |
| | dia. Of spring wire | 1.6 mm | |
| | Number of turns in the coil | 40 | |
| v) | cam | stationery, cylindrical in shape | Mild steel |

**Fig. 7** View of the laboratory evaluation of nitrogen (liquid urea) metering mechanism (Source: Dixit *et al.*,. 2015)

**Fig. 8** View of developed nitrogen (liquid Urea) Applicator operation under actual field conditions

trogen accumulation in straw mulch in case of point injected nitrogen application indicated the reduced nitrogen loss under this system of fertilizer urea application particularly under straw mulched conditions. The point injected nitrogen increased the nitrogen uptake and yield about 20 % over conventional practice (broadcasting) of nitrogen application. The nitrogen use efficiency (NUE) in case of urea solution injected with nitrogen applicator was 47.1 % more than that of broadcasting of urea (Singh *et al*., 2014).

## Conclusions

A nitrogen (liquid urea) application metering mechanism was designed for point injection of liquid urea solution into straw- mulched fields. The designed metering mechanism shall pave the way for development of point injected nitrogen (liquid urea) applicator for straw mulched crops in order to reduce ammonia losses and to enhance nitrogen use efficiency.

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# Evaluation of Tractor Drawn Potato Planter in West Bengal State of India


by

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## Abstract

Performance evaluation of tractor drawn semi-automatic potato planter was carried out at farmers' fields of three villages in Hooghly, the major potato grawing district of West Bengal in India. Field capacity and field efficiency of potato planter was found to be 0.088 ha $h^{-1}$ and 67 %, respectively. There was an average 30 % increase in potato yield and a reduction of 30 % seed rate during the mechanised cultivation. Due to mechanization, labour requirement was reduced by 90 % that resulted in 32 % reduction in cost incurred in planting operation.


## Introduction

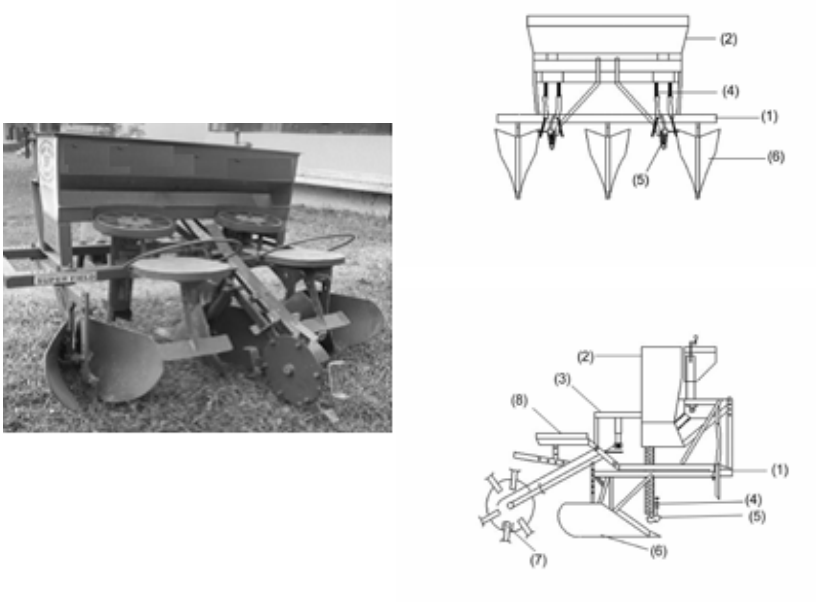
One of the very important tools of the Indian government towards achieving a target of about 6 % annual growth in foodgrain yields during the 12th Five Year Plan (2012-2017) is farm mechanization. With a view to enhance the pace of agricultural mechanization, the government has stressed on providing financial assistance to farmers and other target groups for purchase of different kinds of farm equipment, demonstration of equipment for spread of new technology and human resource development in operation (Dev, 2011). Due to the implementation of various anti-poverty programmes by the Government of India during the last few years, availability of farm labour has become a crisis and their output has also declined drastically. This is making the implementation of farm mechanization inevitable even in states like West Bengal with landholdings mostly dominated by marginal fields.

West Bengal accounts for around one-third of the country's total potato (*Solanum tuberosum* L.) production while Hooghly district stands tall in potato cultivation with world's second highest productivity. With a production of 10.27 million tonnes, West Bengal is the second largest producer of potato in the country. West Bengal accounted for a 22.86 % of all-India potato production in 2012-13. Hooghly is a district where there is a long tradition of potato cultivation with built in infrastructure. Hooghly district contributes more than 28 % of potato production of the state.

In West Bengal, potato cultivation is done conventionally in most of the areas. Conventional method is very labour-intensive and requires about 145 man-days per hectare. This method is quite disadvantageous because of its high labour and time requirement, that leads to high cost of operation. Adoption of potato planter and potato digger has become necessary in potato cultivation for cost reduction and timeliness.

Planters of different types and capacities are now being extensively used in India and around the world for sowing of potato seed tubers. Placement of seeds at correct depth is important for proper seed germination especially under dryland farming where soil moisture is at greater depth. So precision placement of seeds are necessary for achieving higher production.

The study on the effect of different planting methods on the yield of potato in Uttar Pradesh, India reported lowest man-hours requirement of 544 m-h/ha with potato ridger, while the highest man-hours (2142 m-h/ha) requirement were



1- Main frame; 2- Seed Box; 3-Seed plate; 4- Seed tube; 5-Furrow opener; 6- Ridger; 7- Ground wheel; 8- Seat for potato dropper
**Fig. 1** Schematics of two-row potato planter

observed with manual planting and earthing up by kudali (Singh and Singh, 2000). Tractor mounted two-row semi-automatic belt type potato planter ridger was extensively tested at farmer's fields in Uttar Pradesh. Due to demonstration of the equipment, the potato planter ridger has been replacing manual planting by spade in the region (Singh *et al*., 2006).

Field trials on a power tiller operated potato planter showed that the effective field capacity of the machine was about 0.03 ha/h (Gupta and Verma, 1990). The field efficiency on an average was about 67 %. There was a net saving of 32 % in the cost of planting potatoes and 88 % reduction in the labour requirement compared to traditional methods.

Considering the above stated facts, a study was undertaken to evaluate the performance of a two-row semi automatic potato planter with respect to field capacity, field efficiency and fuel consumption (Roy and Mandal, 2012; Majumder and Bhowmick, 2013). Field evaluation of the planter was carried out with k. Jyoti variety of seed potato over two years and comparative study of the planter was carried out with respect to traditional method.

## Materials and Methods

The experiments related to performance evaluation of the potato planter were carried out at six different farms of three villages- digsui, khanyan and pandua of Hooghly district in cooperation with Digsui U.L.S., Primary Co-operative Agricultural Credit Society Limited, Hooghly (West Bengal).

**Salient Features of The Potato Planter**

The planter (**Fig. 1**) was procured by the Faculty of Agricultural Engineering, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia (West Bengal) from Ludhiana (Punjab), India. The tractor mounted planter consists of three ridgers, seed box, fertilizer box, and metering mechanism mounted on mild steel frame. There are nine (9) cups in the seed plate of the metering device. The power transmission from ground wheel to metering mechanism is done by chain and sprocket. Important specifications of the potato planter are presented in **Table 1.**

**Field Evaluation**

All the field experiments for performance evaluation of the planter were carried out following standard test code for potato planter (BIS Standard- IS: 9856-1981). Certified seeds, fertiliser and other inputs were taken from the Digsui U.L.S., Primary Cooperative Agricultural Credit Society Limited, a Primary Agricultural Cooperative Society. Field evaluation and demonstrations at all the sites were carried out with a 50 hp John Deere tractor (**Fig. 2**).

**Field Condition**

For uniform sprout emergence and young plant vigour, a uniformly firm, porous, moist seedbed is one of the aspects necessary for potato cultivation (Cortbaoui, 1988). Uniformity of plant emergence is related to a uniform planting depth. Without a well-prepared and moist (70-80 % of available soil water) seedbed at 13-16 °C, a uniform emergence will not be achieved (Van Loon *et al*., 1985).

In the present study, the soil was of Gangetic alluvium type. Soil

**Fig. 2** Performance evaluation of the 2-row semi-autimatic potato planter

charecteristics revealed a soil pH of 5.8 to 6.1. A level seed bed with a good soil tilth and optimum moisture availability was ensured for testing the potato planter. After the harvest of previous kharif paddy, fields were tilled by two-phases of rotavator. Soil compaction was favourable with an average cone index of 750 kPa. Planting was done in well prepared seed bed, i.e. at least 150 mm depth, firm, fine structure, smooth and level, a good moisture content.

**Quality of Seeds**

Pregerminated seed tubers of *k. Jyoti* variety with 3-6 mm germ length was used for experiment. Tubers of 50 g or more sizes were cut longitudinally through the crown eye, depending on its size, ensuring that each piece has at least one or two eyes. During cutting, precaution was taken that the cutting knife was disinfected with rectified spirit just to prevent the spread of mechanically transmitted viruses. The cut seed tubers were treated with Dithane M-45 for protecting them from various fungal diseases. The period for dipping in solution may be from 20 to 30 minutes.

**Table 1** Specifications of potato planter as per IS 9856-1981

| Sl. No | Parameters | Specifications |
|---|---|---|
| 1 | Power source | 72 hp tractor |
| 2 | Overall dimensions | |
| 2.1 | Length, mm | 1,400 |
| 2.2 | Width, mm | 1,300 |
| 2.3 | Height, mm | 1,250 |
| 3 | Furrow opener | Shovel type |
| 4 | Ridge maker Type | Ridger |
| 5 | Metering mechanism | |
| 5.1 | Type | cup type. |
| 5.2 | No. of cups | 9 |
| 5.3 | Internal diameter of seed tube, mm | 105 |
| 5.4 | Speed ratio- seed metering device to ground wheel | 2:3 |
| 5.5 | Provision of shovel in front of seed tube | yes |
| 5.6 | Size of shovel, mm × mm | 130 × 75 |
| 5.7 | Height of lower end of seed tube | |
| | From ground, mm | 190 |
| | From lower end of shovel, mm | 75 |
| 6 | Hopper | |
| 6.1 | Potato box | |
| | (i) Top (mm × mm) | 400 × 1,220 |
| | (ii) Bottom (mm × mm) | 150 × 1,220 |
| | (iii) Height (mm) | 270 |
| 6.2 | Fertilizer box | |
| | (i) Top (mm × mm) | 200 × 1,190 |
| | (ii) Bottom (mm × mm) | 80 × 1,190 |
| | (iii) Height (mm) | 230 |
| 7 | Ground wheel details | |
| 7.1 | No of wheels | 1 |
| 7.2 | Size, mm | 300 |
| 7.3 | Method of transmitting power to shaft | Chain and sprocket |
| 7.4 | Type of ground wheel | Wheel with lugs |
| 8 | Type of hitch | Three-point linkage |
| 9 | Row to row Spacing, mm | 610 |
| 10 | Number of rows | 2 |
| 11 | Operator's seat | |
| 11.1 | Number of seat | 2 |
| 11.2 | Length of seat, mm | 355 |
| 11.3 | Width of seat, mm | 335 |
| 11.4 | Provision of foot support | Yes |

**Measurement of Fuel Consumption**

A device consisting of a plastic graduated measuring cylinder, two plastic pipes, and iron hanger with clamp was set up for measuring fuel consumption during field evaluation. The set up was temporarily attached to the tractor frame with the help of a clamp. Initially, the cylinder is filled with fuel up to its full capacity (1,000 ml). During field operation, the difference in the level of fuel in the measuring cylinder was observed.

## Results and Discussion

In conventional method, about 145 man-days per hectare were required in four phases to finish sowing operation per hectare that included 45 man-days for placing seeds, 55 for earthing up, 30 for furrow formation and 15 for creating irrigation channels.

**Table 2** shows the germination data related to manual and mechanical planting. Rate of germination in manual planting was higher than mechanical planting. Plant count per square metre area in manual planting was higher due to lower plant-to-plant and row spacing.

In manual operation, farmers prefer a spacing of about 150 mm between the seeds, while the spacing between the seed tubes in the planter is generally set at 200 to 250 mm. This led to higher plant population in manual planting. Specific operational information related to performance parameters is presented in **Table 3.**

**Table 2** Comparative germination data of three experimental plots

| Parameter | Pandua, Hooghly | Khannan, Hooghly | Digsui, Hooghly | Average of Mechanized | Manual planting |
|---|---|---|---|---|---|
| Germination percentage (%) | 89.6 | 96.5 | 94.2 | 94.4 | 98.4 |
| Plant population (plant/m²) | 18 | 18 | 22 | 19 | 35 |
| Average number of plant in every germination point | 2.3 | 2.3 | 3.3 | 2.6 | 1.5 |
| Germination count (No of plants/m-row) | 9 | 11 | 12 | 11 | 16 |

**Table 3** Performance parameters observed at different experimental sites

| Parameters | Pandua, Hooghly | Khannan, Hooghly | Digsui, Hooghly | Average Value |
|---|---|---|---|---|
| Effective working width (mm) | 1,220 | 1,220 | 1,220 | 1,220 |
| Traveling speed (km $h^{-1}$) | 1.65 | 1.24 | 0.98 | 1.29 |
| Theoretical field capacity (ha/h) | 0.207 | 0.136 | 0.149 | 0.164 |
| Effective field capacity (ha/h) | 0.145 | 0.090 | 0.095 | 0.088 |
| Field efficiency (%) | 70.00 | 66.18 | 63.76 | 66.65 |
| Row to row distance (mm) | 600 | 612 | 588 | 600 |
| Plant to plant distance (mm) | 205 | 215 | 195 | 205 |
| Depth of sowing (mm) | 150 | 153 | 163 | 155 |
| Height of ridge (mm) | 309 | 304 | 302 | 305 |
| Fuel cnsumption (g/bhp-h) | 66.8 | 62.3 | 58.6 | 62.6 |

**Table 4** Input requirement and expenditure for manual and mechanical planting

| Parameters | Mechanized cultivation | | | | Mannual operation |
|---|---|---|---|---|---|
| | Pandua | Khannan | Digsui | Average Value | |
| Field size (ha) | 0.244 | 0.349 | 0.286 | - | 0.340 |
| Seed requirement (kg $ha^{-1}$) | 1,313 | 1,125 | 1,500 | 1,313 | 1,875 |
| Potato yield (q $ha^{-1}$) | 300.50 | 356.25 | 318.75 | 325 | 281.25 |
| Labour requirement for planting (No) per ha | 15 | 15 | 15 | 15 | 150 |
| Cost due to tractor & planter hiring (Rs $ha^{-1}$) * | 15,200 | 14,500 | 15,600 | 15,100 | - |
| Cost of labour (Rs $ha^{-1}$) | 6,300 | 6,100 | 6,200 | 6,200 | 31,500 |

* Custom hiring rate: Tractor (Rs/h) = 800; Planter/ Digger (Rs/day) = 100; Plough (Rs/ha) = 4500

Average effective field capacity and field efficiency of potato planter were found to be 0.088 ha $h^{-1}$ and 67 %, respectively. These values could be increased for a field with larger sizes. Since, the experimental plots were of small sizes, much time was lost for turning of the prime mover with the planter. Information on inputs and yield of potato has been presented in **Table. 4**.

Average seed requirement for manual planting was 1,875 kg $ha^{-1}$, while that for mechanized planting was 1,313 kg $ha^{-1}$. This was due to the lower planting spacing in a row for conventionl operation. Thus seed requirement in manual planting was lowered by about 30 %.

Average cost of planting operation in manual planting was Rs. 31,500/- per hectare, while that for mechanized operation was only Rs. 21,300/- per hectare leading to a reduction of 32.4 %. Eventhough the seed requirement was lowered, the yield of potato in mechanized cultivation increased by 15.6 %. This was due to the fact that, with proper ridging and higher seed spacing, there were ample space for the tubers to grow.

## Conclusions

Field performance of the semi-mounted potato planter was highly encouraging. Average effective field capacity and field efficiency of potato planter was found to be 0.088 ha $h^{-1}$ and 67 %, respectively. Seed requirement was lowered by about 30 %. Time requirement in mechanical method was found to be 45 man days $ha^{-1}$ less than that of conventional method. Germination count, plant population and plant density was higher in manual planting than those in mechanized cultivation. Due to mechanized planting, labourer requirement was reduced by 90 %. Cost of planting in mechanized operation was reduced by 32 %. Fuel consumption of potato planter was found to be about 63 g/bhp/h. The yield of potato in mechanized cultivation was increased by about 16 %.

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# Design and Development of a Power Operated Tamarind Huller Cum Deseeder

by

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## Abstract

India is the largest producer of Tamarind in the world and hulling and deseeding of it are mostly done manually. The separation of seeds and hulls of the pods is a crucial task and is time consuming, labour intensive and tedious work. Therefore, a power-operated tamarind huller cum deseeder was designed and developed and consisted of 0.75 kW motor with power transmission system, feed hopper, hulling cum deseeding chamber with pegs, hull/seed outlet, and pulp outlet. The pods were fed from the top at desired rate and then the pulp, hull, and seeds were separated without collapsing fruit shape. The capacity of the developed unit was 85 kg/h as compared to 3 kg/h with manual method. The hulling and deseeding efficiencies of 89.09 and 89.91 % were obtained at optimized hulling-drum speed of 300 rpm at 8 mm clearance with 19 % moisture (d.b.) fruits. The approximate cost of the machine was Rs. 13,000 (US$ 260). The machine resulted in saving of 87.0 % in cost of operation and 95.0 % in time. The break-even point for utility of this machine was 1.8 t/annum and pay-back period was 1.3 years. This developed machine was compact, portable, gender friendly and cost effective.

## Introduction

Tamarind (Tamarindus indica), an evergreen legume native to East Africa belong to the family Leguminosae, is now distributed all over the world. India is the world largest producer of tamarind with a production of 206,340 t annually (Anon, 2011). The pulp may constitute 30 to 55 %, the shells and fiber 11 to 30 %, and the seeds 33 to 40 %. India is the foremost exporter of this 'Indian-date' and its products since ancient time to western countries (Anon, 2010).

The tamarind tree produces its fruit in pods which consist of a brittle outer shell which encapsulates the pulp and enclosed seeds. The fruit is used for consumption when it becomes mature. The fruit pulp is sour as well as sweet to taste (Morton, 1987). In India, the fruit pulp is used to enrich the flavor of vegetarian as well as non-vegetarian dishes. It is also a raw material for the preparation of wine like beverages. In medicine, it is used as appetizer, laxative, healing and antihermitic. The fruit is also valued in cooked dishes, where the addition of tamarind juice adds acidity and sharpness that is similar to, but not identical to, the acidity of citrus juices (Julia *et al*., 1986). There are 3-12 seeds present in each pod, having oblong shape, shining with dark brown color. The outer cover of the pod is fragile and easily separable (Krishnamurthy *et al*., 2008).

Tamarind is generally dried under sun and collected in heaps and it is manually hulled by beating the tamarind bulk with sticks. The hulled tamarind is collected and with the help of a rubber ring, deseeding of tamarind is done manually in crude and unhygienic way. Although there are some mechanisms exist for tamarind hulling and deseeding, they are not popular among the farming community due to various factors. The tamarind dehuller developed at University of Agricultural Sciences, Bangalore, India with a capacity of 500 kg/h has the hulling effi-

**Table 1** Assumptions and conditions for the design of the unit

| Consideration | Assumption / conditions |
|---|---|
| Diameter of deseeding unit (D) | 400 mm |
| Length of peg (Lp) | 85 mm |
| Diameter of peg | 11 mm |
| Number of pegs | 30 |
| Diameter of shaft | 25 mm |
| Torque (T) | 13.4 Nm |
| Actual power requirement | 0.55 kW |

ciency of 80 and 58 % for the large size curved fruits and small fruits, respectively (Ramakumar *et al*., 1997). The GKVK model developed in Bangalore was not perfect due to intermittent stopping for every half an hour during the operation for removing the paste of tamarind over the deseeding mechanism due to stickiness of pulp. The wet method of deseeding developed by M/s Best Engineering Technologies Private Ltd, Hyderabad, India is applicable only for making tamarind concentrate. However, tamarind is stored in mud pots conventionally after deseeding and hence, this wet method of tamarind pulp extraction is not familiar. Another model (Prabha *et al*.,. 2008) required moisture content of hull to be 8-10 % and that of pulp to be 12-14 % which is quite risky to achieve by which it was not commercialized. As the seed removal efficiency was less than 50 % with another pulp extractor (Shalini *et al*., 2007), it was also not adopted in farms. The tamarind seed remover as well as continuous tamarind deseeder developed at Tamil Nadu Agricultural University, Coimbatore, India (Karpoora, 2010 and Karthickumar, 2011), have their own limitations like shapeless outcome of pulp with high moisture and less output.

Based on the existing mechanical constraints and the drudgeries involved in dehulling and deseeding of tamarind fruits into consideration, a tamarind huller-cum-deseeder was developed at Tamil Nadu Agricultural University, Coimbatore, India. This paper explains about design, development and evaluation of the tamarind huller cum deseeder unit besides optimization of machine parameters like clearance and speed of the unit.

## Materials and Methods

### Design and Development of Functional Components of the Unit

Based on the set of design assumptions and conditions (**Table 1**), values of design parameters for the tamarind huller-cum-deseeder were obtained. A prototype tamarind huller-cum-deseeder was fabricated to overcome the existing manual methods of tamarind processing. The tamarind huller-cum-deseeder consisted of feed hopper, hulling cum deseeding unit, outlet, power transmission system, motor, and frame.

***Feed Hopper***

A wedge shaped feed hopper was mounted on the hulling cum deseeding unit at an inclination that facilitates the fruit to flow uniformly into the extraction chamber. It was held in place by the top cover of the hulling cum deseeding unit which was hinged on to the tool frame. The hopper gradually tapers down towards the hulling cum deseeding unit from a width of 340 mm to 160 mm through a length of 440 mm. It was made of 18 gauge mild steel sheet. The feeding of tamarind was perpendicular to the length of the hulling shaft.

***Hulling Cum Deseeding Drum***

Hulling and deseeding are the important functions of the machine. The shaft was made up of mild steel with a hulling cum deseeding drum over it and fixed with pegs of 85 × 11 mm size in a zigzag manner for conveying impact load on the fruit. A mild steel pipe was modified into a hulling cum deseeding drum of 150 mm length and 165 mm diameter. The hulling shaft was made to rotate in an anti-clockwise direction. Both ends of the central shaft on which the hulling cum deseeding drum was supported suitably on the pillow block bearing over the frame. One end of the shaft was coupled to the power transmission system.

***Hulling cum deseeding unit***

It was fixed for separating hull, fiber and seeds from fruit. In this section, the fruits were subjected to impact load by the pegs to create failure of the hull, break open the fruits and shearing action by the same pegs over the fruits to push the seeds out of the rectangular sieve of size 150 × 80 mm. The main components of the hulling and deseeding unit were pegs and concave. Pegs were made by half threaded screw of 75 × 100 mm. Initially the screw was with screw head which was then removed to achieve a peg size of 5 × 85 mm and it was fixed at the threaded end. It was inserted to the hulling cum deseeding drum in a zigzag manner. The peg was designed by removing the head and 85 mm was projected out in the hulling cum deseeding drum. The linear space between two pegs fixed on the hulling cum deseeding drum was 75 mm. The radial angle between the pegs in two rows was $30^{o}$. The diameter of the each peg was 10 mm. Concave was made in semi-circular shape with rectangular flats of 160 × 12.7 × 6.35 mm surrounded below the hulling drum. It was made up of 40 flats of 6.35 mm thickness, fitted between two circular frames of thickness 6 mm and diameter 350 mm. The space between each flat was 8 mm leaving rectangular openings of size 150 × 8 mm, so as to allow the broken hull, fiber and seeds to pass through the openings. It allowed the removed hull, fiber and the extracted seeds through the rectangular openings after being separated from the broken fruit epicarps. A spacing of 8 mm was fixed so as to allow only the seeds, hull and fibers and not to allow the opened fruit epicarps to pass through the hull and the seed outlet.

***Outlet***

After the fruits got impacted in the hulling cum deseeding unit, fruits were opened and are void of hull, fiber and the seeds. Two separate outlets were made for collecting pulp and hull, fiber and seeds separately. The extracted pulp came out through the pulp outlet. The delivery outlet which was a rectangular closed channel fabricated from mild steel was welded at the top open end of the concave sieve. It formed a passage through which the extracted pulp came out from pulp outlet of the hulling cum deseeding unit. The dimension of the pulp outlet was 200 × 160 × 100 mm. The shelled hull and the extracted seeds dropped into a transition channel under the deseeding unit. The transition channel fabricated from mild steel was attached below the concave sieve at an angle of 45° to the horizontal. It formed the passage through which the extracted seeds, hull and fiber flew out through the seed outlet.

***Power Transmission System***

Optimization of mild steel shaft speed was essential for efficient hulling and separation of seed from the failed fruits. Preliminary tests conducted with the developed unit by coupling the unit to a variable speed motor showed that the mild steel shaft speed of 300 rpm yielded good results. Hence, sub-frame and pulley and V-belt were used in the unit in order to transfer required speed. The sub frame was made to fix the motor. Two mild steel flat rods of 5 × 50 mm were welded on the bottom of the main frame. The space between them was 180 mm and the length of the motor mounted frame was 320 mm. For the tamarind deseeding experiment, the speed of hulling cum deseeding drum was also considered as one of the variables. Pulley of 400 mm diameter was attached at the one end of the hulling cum deseeding drum to reduce the speed of 1,440 rpm to 310 rpm. V-belt of length 850 mm was used to transmit the power from the motor to the m.s. shaft. A step down pulley was fitted to the motor shaft so as to vary the speeds for evaluating with different speeds.

***Motor***

An impact load was required to create failure in the dried tamarind fruit and to operate the hulling cum deseeding unit at low speed, a 0.75 kW three phase electric motor of 1,440 rpm was selected.

***Frame***

The size of the frame at the top was 530 × 260 mm and at the bottom was 590 × 330 mm. The height of the frame was 1,000 mm. The frame was well-braced to provide rigidity to mount and support other parts of the machine and to withstand vibrations during operation.

**Description of Tamarind Huller-Cum-Deseeder**

The hulling cum deseeding unit consisted of hulling drum fitted with pegs, connected to a rotating shaft and a concave sieve. The entire unit was made up of mild steel considering the cost as well as frictional properties. The concave sieve was made up of 40 numbers of flats, 150 mm in length fitted to a circular frame in a concave pattern, with a clearance of 8 mm between each flats (12.7 × 6.35 × 160 mm). There were two outlets present one for pulp and the other for hull, seed and fiber to pass out through. At the hulling cum deseeding unit, there was a concave and pegs threaded to the hulling and deseeding drum. Concave was made up of 40 numbers of mild steel flats with 8 mm gap in between them. The radius of the concave sieve was 370 mm. When the hulling and deseeding drum was subjected to rotary motion in an anti-clockwise direction, the pegs exert impact load over the tamarind fruit which was fed from the hopper. Thus, an impact load which was sufficient enough to break the hull and to create failure to remove the seed out of pulp was exerted over the fruit. In this mechanism, impact load alone was enough to break both the hull as well as to create failure of the fruit, so as to separate the hull, fiber and seeds out of pulp. Thus, a machine with simple working principle was fabricated for hulling and deseeding the tamarind efficiently. When the machine is exerting impact load over the fruit, the fruit shape is not collapsed. The machine is compact in size and prototype of the unit is shown in **Figs. 1** and **2**.

**Performance Evaluation of Tamarind Deseeder**

Performance of the tamarind huller-cum-deseeder was evaluated based on the hull removal capacity from the fruit and its seed extraction capacity out of pulp. There should be proper interaction of tamarind with the unit to achieve maximum hulling as well as deseeding efficiency. Since the hulling and deseeding efficiencies depend mainly on machine parameters of the hulling and deseeding unit as well as properties of tamarind. Performance of the machine was tested by three main parameters viz. preparation of raw material, experimental design, and testing procedure.

***Preparation of Raw Material***

Inside the brittle shell, the fruit was filled with firm soft pulp surrounding the seeds forming cavities and held firmly by the fibers. So as to remove the hull and seed mechanically from the fruit, the fresh tamarind fruit with high initial moisture content of 37 ±1 % (d.b.) had to be dried for 4 or 5 days depending upon the weather conditions to a safe moisture level of 20 % (d.b.) or below. As tamarind was hygroscopic in nature, it would re-

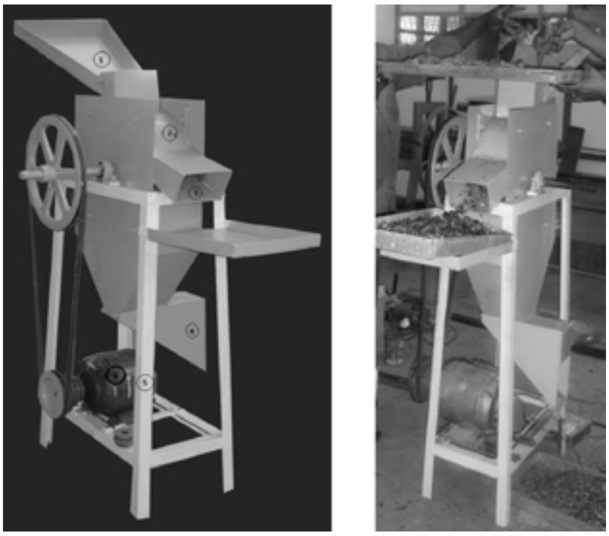
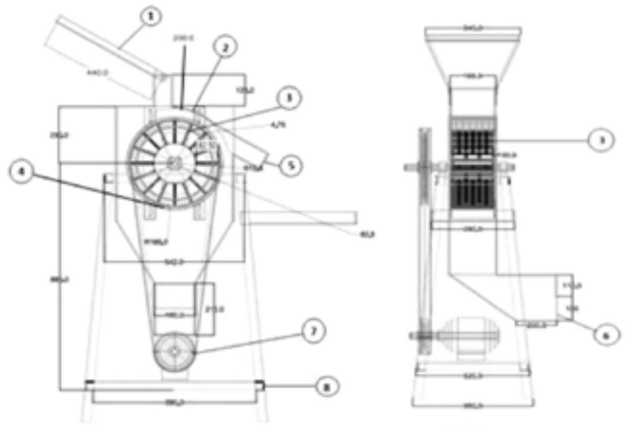


**Fig. 1** The Prototype



Side view Front View
1. Feed hopper, 2. Hulling cum deseeding unit, 3. Pegs, 4. Concave sieve, 5. Pulp outlet, 6. Hull outlet, 7. Motor, 8. Frame
**Fig. 2** Tamarind Huller cum Deseeder

gain the moisture up to 5-10 % (d.b.) whenever it was exposed to atmosphere. Traditionally, tamarind was stored at a moisture level of 20 % (d.b.). Before hulling or deseeding, the tamarind fruits had to be dried under the sun or in the mechanical dryer.

***Experimental design***

A three factorial completely randomized block design was adopted to conduct performance tests. The unit was tested for its performance under three variable conditions. Three different rotational speeds of shaft viz., 200 rpm ($S^1$), 250 rpm ($S^2$), 300 rpm ($S^3$) were selected. Three moisture contents of the tamarind 19 % ($M^1$), 22 % ($M^2$) and 25 % ($M^3$) and three clearances between the hulling and deseeding shaft and the concave viz., 6 mm ($C^1$), 8 mm ($C^2$) and 10 mm ($C^3$) were considered for optimizing the selected parameters influencing the hulling and deseeding efficiencies. Three replications were made to statistically evaluate the hulling and deseeding efficiency of the tamarind huller-cum-deseeder.

***Testing Procedure***

Stickiness of the pulp with the hulling cum deseeding mechanisms was the major problem and in view of its direct proportionality to the moisture content of tamarind fruits, it was decided to test the machine under different moisture contents of the tamarind. As it was experienced based on preliminary studies that the stickiness was negligible at 25 % moisture content of the tamarind on dry basis, three different moisture contents such as 19, 22, and 25 % (d.b.) were achieved by cabinet drying and tested for finding out the influence of moisture content on deseeding efficiency. A 0.75 kW three phase variable speed motor was coupled to vary the rotational speed of the shaft. Based on the trials conducted, it was decided to test the machine at 200, 250 and 300 rpm speed levels. By adjusting the mild steel pegs towards the mild steel concave with flats, various clearances such as 6, 8 and 10 mm were achieved, respectively. Based on these three variables, the hulling and deseeding efficiency was calculated and was summarized in **Table 2**. The procedure for calculating the hulling efficiency (percent) of the newly developed machine was similar to that of the efficiency given by (Jagadishwar, 1971). Hulling efficiency was calculated using the following equation.

$\eta_H = (W / T) \times 100$

where, $\eta_H$ = hulling efficiency (percent), $W$ =actual hull weight (kg), and $T$ =theoretical hull weight (kg).

The procedure for determining the deseeding efficiency (percent) of the prototype was the same as that of finding the percent seed extraction efficiency (Al-Gaadi *et al.*, 2011). Deseeding efficiency was calculated from the following equation.

$\eta_{DS} = (S^1 + S^2)\ 100 / (S^1 + S^2 + S^3 + S^4)$

where, $\eta_{DS}$ = deseeding efficiency, $S^1$ = weight of seeds collected in seed outlet (g), $S^2$ = weight of seeds collected in pulp outlet (g), $S^3$ = weight of seeds separated manually from opened fruits (g), and $S^4$ = weight of seeds separated manually from unopened fruits (g).

## Results and Discussion

**Optimization of Machine and Performance Parameters**

The speed of 300 rpm gave a maximum hulling and deseeding efficiency of 89.09 % and 90.76 % respectively which was comparable with the results reported by Abouegela *et al.* (2007). The driving pulley speed of 200-400 rpm was a major controlling factor that affected the unstripped capsules losses of flax seed.

While considering the individual parameters, all the parameters along with their interactions were found to be significant at 1 % level. Hence, it was observed that all the three parameters were influencing the hulling efficiency of the tamarind huller-cum-deseeder. While considering the individual parameters, all the parameters except the moisture content was significant and the interactions were found to be not significant except for the speed and clearance interaction at 1 % level. Hence, from **Table 2**, it was observed that speed and clearance are influencing deseeding efficiency of the unit.

### Economics

Economics of the unit was analyzed as per the RNAM test code and procedure for deseeders (Anon, 1995). Cost of the tamarind huller-cum-deseeder was Rs. 13,000 (US$ 260). Capacity of the prototype was found to be 85 kg/h and the cost of operation of the prototype worked out Rs. 0.54/kg (US$ 0.0108/kg), whereas the capacity of manual hulling and deseeding was 3 kg/h and the cost of operation was Rs. 4.20/kg (US$ 0.084/kg) of tamarind fruit. The conventional method was nearly seven times costlier than mechanical hulling and deseeding. Hence it was observed that the mechanical hulling-cum-deseeding registered cost-saving of 87.0 % and time-saving of 95.0 %. The break-even point and pay-back period for

**Table 2** Performance evaluation of tamarind huller-cum-deseeder

| Speed of hulling shaft (rpm) | Clearance (mm) | Time taken to deseed/hull (s) | Moisture content (%) (d.b.) | Pulp weight (kg) | Unseeded Tamarind at pulp outlet (kg) | Hull weight (kg) | Weight of seed at seed outlet, S1 (kg) | Weight of seed at pulp outlet, S2 (kg) | Weight of seed manually taken from opened fruits, S3 (kg) | Weight of seed manually taken from unopened fruits, S4 (kg) | Hulling efficiency (%) | Deseeding efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 6 | 43.2 | 19 | 0.967 | 0.358 | 0.079 | 0.257 | 0.155 | 0.074 | 0.045 | 35.45 | 77.85 |
| | | 97.2 | 22 | 1.244 | 0.392 | 0.084 | 0.185 | 0.121 | 0.057 | 0.020 | 37.98 | 79.87 |
| | | 201.6 | 25 | 0.825 | 0.456 | 0.070 | 0.403 | 0.109 | 0.095 | 0.089 | 31.53 | 73.41 |
| | 8 | 118.8 | 19 | 0.748 | 0.215 | 0.076 | 0.300 | 0.122 | 0.037 | 0.021 | 34.08 | 84.83 |
| | | 154.8 | 22 | 0.929 | 0.124 | 0.071 | 0.317 | 0.115 | 0.040 | 0.038 | 31.83 | 84.76 |
| | | 309.6 | 25 | 1.708 | 0.426 | 0.053 | 0.235 | 0.155 | 0.056 | 0.024 | 23.87 | 83.43 |
| | 10 | 151.2 | 19 | 1.264 | 0.192 | 0.132 | 0.185 | 0.121 | 0.057 | 0.020 | 59.65 | 79.73 |
| | | 183.6 | 22 | 0.954 | 0.277 | 0.051 | 0.114 | 0.012 | 0.018 | 0.010 | 23.12 | 81.68 |
| | | 345.6 | 25 | 1.529 | 0.105 | 0.038 | 0.117 | 0.103 | 0.021 | 0.018 | 17.24 | 84.74 |
| 250 | 6 | 82.8 | 19 | 1.573 | 0.279 | 0.191 | 0.132 | 0.123 | 0.056 | 0.045 | 85.88 | 71.25 |
| | | 104.4 | 22 | 0.674 | 0.215 | 0.159 | 0.129 | 0.109 | 0.079 | 0.039 | 71.44 | 65.87 |
| | | 122.4 | 25 | 1.285 | 0.307 | 0.143 | 0.123 | 0.118 | 0.096 | 0.027 | 64.29 | 66.22 |
| | 8 | 118.8 | 19 | 1.116 | 0.162 | 0.195 | 0.139 | 0.135 | 0.035 | 0.032 | 87.98 | 80.23 |
| | | 129.6 | 22 | 0.529 | 0.178 | 0.160 | 0.112 | 0.012 | 0.016 | 0.012 | 72.04 | 81.37 |
| | | 176.4 | 25 | 1.065 | 0.153 | 0.140 | 0.140 | 0.123 | 0.065 | 0.023 | 63.24 | 74.21 |
| | 10 | 111.6 | 19 | 0.968 | 0.103 | 0.161 | 0.120 | 0.116 | 0.052 | 0.035 | 72.35 | 73.62 |
| | | 126.0 | 22 | 0.583 | 0.237 | 0.173 | 0.236 | 0.121 | 0.085 | 0.026 | 78.04 | 76.53 |
| | | 169.2 | 25 | 0.845 | 0.128 | 0.110 | 0.149 | 0.137 | 0.034 | 0.023 | 49.59 | 82.65 |
| 300 | 6 | 72.0 | 19 | 0.974 | 0.107 | 0.145 | 0.104 | 0.018 | 0.020 | 0.016 | 65.31 | 77.23 |
| | | 100.8 | 22 | 0.871 | 0.093 | 0.166 | 0.116 | 0.110 | 0.054 | 0.032 | 74.59 | 73.56 |
| | | 115.2 | 25 | 1.121 | 0.095 | 0.159 | 0.269 | 0.172 | 0.096 | 0.018 | 71.59 | 79.41 |
| | 8 | 108.0 | 19 | 1.129 | 0.040 | 0.167 | 0.259 | 0.153 | 0.075 | 0.046 | 75.04 | 77.82 |
| | | 118.8 | 22 | 0.620 | 0.071 | 0.189 | 0.230 | 0.126 | 0.069 | 0.027 | 85.32 | 78.76 |
| | | 122.4 | 25 | 1.312 | 0.027 | 0.197 | 0.142 | 0.121 | 0.035 | 0.032 | 88.88 | 79.93 |
| | 10 | 75.6 | 19 | 1.272 | 0.035 | 0.170 | 0.165 | 0.095 | 0.018 | 0.013 | 76.72 | 89.91 |
| | | 118.8 | 22 | 1.163 | 0.052 | 0.175 | 0.143 | 0.077 | 0.020 | 0.012 | 78.97 | 87.32 |
| | | 165.6 | 25 | 0.534 | 0.075 | 0.181 | 0.126 | 0.112 | 0.021 | 0.018 | 81.53 | 85.92 |

(Input weight = 3 kg)

the tamarind huller-cum-deseeder were 520 kg/annum and 1.7 years, respectively.

## Conclusions

The developed tamarind huller-cum-deseeder was suitable to break both the hull as well as to create failure of the tamarind fruit by exerting an impact load over the fruit, so as to separate, seeds out of pulp and fiber. The working capacity of the unit was 85 kg/h as compared to 3 kg/h with manual method and resulted in improved quality of operation. The hulling and deseeding efficiencies of 89.09 and 89.91 % were obtained at optimized hulling-drum speed of 300 rpm at 8 mm clearance with 19 % moisture (d.b.) fruits. Hulling and deseeding of a kg of tamarind through machine resulted in 87.0 % cost-saving and 95.0 % in time-saving. This machine was gender friendly, portable and suitable for on-farm task with unskilled women workers besides reducing drudgery in traditional method.

**Fig 3** Tamarind fruit

**Fig. 4** Hull and Seeds (Hull/SeedOutlet)

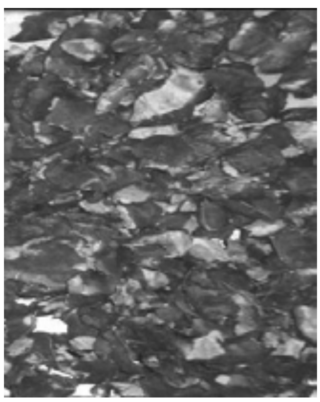


**Fig. 5** Pulp (Pulp Outlet)

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# Energy Use for Wheat Cultivation in Southeast Anatolia Region of Turkey



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## Abstract

The objective of this study was to examine energy inputs and outputs for wheat production in the Southeast Anatolia region (GAP) of Turkey. The data used in this study were collected through a questionnaire by face to face interviews. The amount of energy that consumed in tillage, planting, fertilizing, agricultural spraying, harvesting and transport stages were calculated for wheat cultivation. The energy inputs such as human labor, tractors, tools/machineries, fuel/oil, fertilizers, pesticides, irrigation and seed obtaining processes were taken into consideration to determine the amount of energy that used in wheat cultivation. The total energy used in various farm inputs for wheat cultivation was 17,159.5 MJ/ha. The energy output/input ratio, specific energy, energy productivity and net energy efficiency were found to be 2.21, 7.18 MJ/kg, 0.14 kg/MJ and 20,746.5 MJ/ha, respectively.



***Keywords:*** Wheat, Southeast Anatolia, Turkey, Energy use.


## 1. Introduction

Energy consumption per unit area in agriculture is directly related with the development of technological level and cultivation. The inputs such as fuel, electricity, machinery, seed, fertilizer and chemical account for a significant share of the energy supplies to the cultivation system in modern agriculture. The use of intensive inputs in agriculture and access to plentiful fossil energy has provided an increase for standards of living and food production. However, some problems in agricultural production have been faced due to mainly high level dependency on fossil energy. The problems with the use of fossil energy have become into focus by oil embargo in 1973 and increase in energy prices. Nowadays, environmental issues such as global warming are the major concerns related to the use of fossil energy. Furthermore, considering the fossil energy as a limited resource, it has to be conserved for future generations by using efficiently in a sustainable manner. Energy is considered to be a key player in the generation of wealth and also a significant component in economic development. This makes energy resources extremely significant for every country in the world. Energy use has been a matter of policy concern since the 1970s. After the oil crises in 1973 and 1979, governments intensively promoted energy conservation measures. Then in 1980s, the primary focus shifted to air pollution caused by combustion of fossil fuels. In the recent years, energy use and associated greenhouse gas emissions and their potential impacts on the global climate change have been the worldwide concern. Improving the end-use energy efficiency is one of the most effective ways to reduce energy consumption in the industrial, commercial, transportation, utility, residential and agricultural sectors and their associated pollutant emissions (Dinçer *et. al*., 2004).

Efficient use of the energy resources is vital in terms of increasing production, productivity, competitiveness of agriculture as well as sustainability to rural living. Energy auditing is one of the most common approaches to examine energy efficiency and environmental impact of the cultivation system. It enables researchers to calculate input-output ratio, other relevant indicators and energy use pattern in an agricultural activity. Moreover, the energy audit provides sufficient data to establish functional forms to investigate the relationship between energy inputs and outputs. Estimating these functional forms is very useful in terms of determining flexibilities of inputs on yield and production. Energy use pattern and contribution of energy inputs vary depending on farming systems, crop season and farming

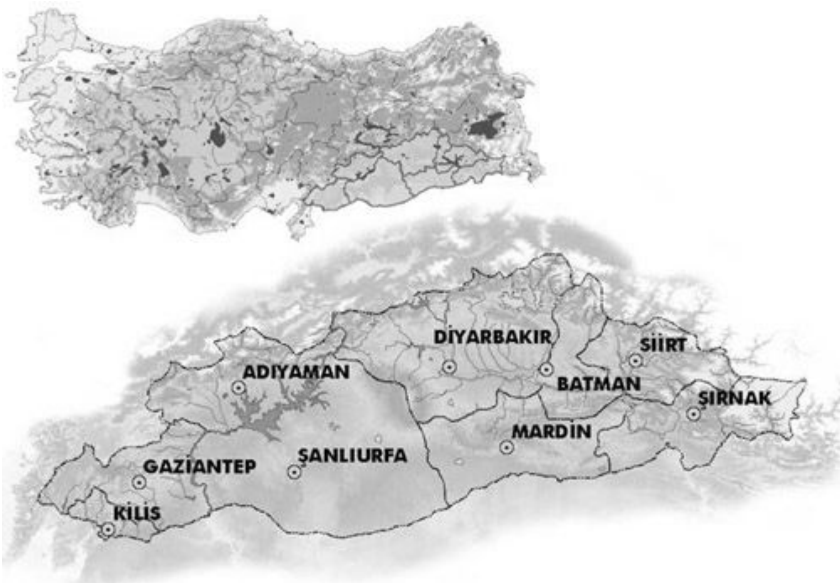


**Fig. 1** The Southeast Anatolia region (GAP) of Turkey

conditions. Considerable work has been conducted on the use of energy in agriculture with respect to efficient and economic use of energy for sustainable production. Energy input-output analysis is usually used to evaluate the efficiency and environmental impacts of production systems. This analysis is important to perform necessary improvements that will lead to a more efficient and environment-friendly production system (Özkan *et. al.*, 2003; 2004). Comprehensive studies have been performed on energy use in different agricultural products (Ahmad *et. al.*, 1991; Bobobee, 1992; Dash and Das, 2000; Elbatawi and Mohri, 1999; Hetz, 1992; 1998; Joshi *et. al.*, 1992; Mahapatra *et. al.*, 2003; Palaniappan and Subramaniantz, 1998; Singh and Singh, 1992; Singh *et. al.*, 1997; Özkan *et. al.*, 2003; 2004; Shahan *et.al.*, 2008, Singh *et. al.*, 2004a; 2004b; Ülger *et. al.*, 1993; Singh, 2010). Optimization of energy use in agriculture is reflected in two ways, i.e. an increase in productivity at the existing level of energy inputs or conserving the energy without affecting the productivity (Singh *et. al.*, 2004a).

The GAP region extends over an area of 75,358 km² and a wide range of crops each requiring different climatic conditions are raised in this area. The region has 3.2 million hectares of land fit for crop culture. Forested areas make up 1.3 million hectares while 2.3 million hectares of land consists of pastures and ranges. The GAP's share in the total population of Turkey is almost 10 %. Covering the provinces of Adıyaman, Batman, Diyarbakir, Gaziantep, Kilis, Mardin, Siirt, Sanlıurfa and Şırnak. The GAP region has a surface area of 75,358 km², which corresponds to 9.7 % of the total surface area of Turkey (**Fig. 1**).

In the period 2000-2010, the rate of population growth in the region was 2.5 % as annual average while it was 1.8 % for the country. Field crop cultivation contributes significant income, employment and export opportunities in the research region. The GAP focuses on efficient utilization of these natural resources. For the first time in Turkey, the management, operation and maintenance of new irrigation systems have been directly transferred to Irrigation Districts, which are the organizations formed by local farmers. Favorable climatic conditions in the region make it possible to reap two crops a year. The region is also relatively fit for animal husbandry. In this context, research projects led by the GAP Administration focus on genetic improvement and development of advanced breeding techniques. Crop yields of cotton, wheat, barley, lentil and other grains have reportedly tripled in the Harran plain as a result of irrigation from the Ataturk Dam. Land values have risen rapidly. Family income, number of personal vehicles and number of tractors in the region have nearly tripled in the past eight years.

The region of GAP has a significant share in the total agricultural production in Turkey. The main crops grown in the GAP region are wheat, cotton, barley and lentil. These crops are grown in 75 % of the total cultivated field area in this region. For that reason, energy use in wheat cultivation was examined in the present study. The main objective of this study was to evaluate the energy input and output for wheat cultivation in the GAP region of Turkey. Data for the cultivation of wheat were collected from 132 farms by using a face to face questionnaire method. This study seeks to analyze the effect of indirect and direct energy on yield using functional form. The energy ratio, specific energy, energy productivity and net energy efficiency as indicators for the determination of energy efficiency were calculated in the wheat cultivation.

## 2. Materials and Methods

### 2.1. The Basic Characteristics of Surveyed Farms

In this study, the field crop farmers were surveyed in Diyarbakır, Mardin and Şanlıurfa provinces of the GAP region. The data included energy inputs from different sources, data input to various farm operations and yield. The basic characteristics of the surveyed farms

**Table 1** Energy consumption values for the production of pure substance in chemical fertilizers (Ramirez et Worrel, 2006).

| Chemical fertilizers | Energy consumed (MJ/kg) |
|---|---|
| Nitrogen (N) | 45 |
| Phosphorus ($P_2O_5$) | 8 |
| Potassium ($K_2O$) | 5 |

are given in **Table 1**. Taking actual farm size as the variable, the total 132 farms was randomly selected by using stratified random sampling. The permissible error was defined to be 5 % for 95 % reliability (Yamane, 1967).

$n = (\Sigma N_h S_h) / (N^2 D^2 + \Sigma N_h S_h^2)$ ......(1)

where; n is the required sample size, N is the number of holdings in target population, Nh is the number of population in h the stratified, Sh is the variance of h the stratified, and D is the precision where (x-X).

The total agricultural land of the investigated 132 farms is 2413.7 hectares. Almost 30 % of the farm size was less than 5 hectares, and 50 % less than 10 hectares. In spite of large number of small farms, less than 5 hectares, cultivated area accounts for only 5 % of total land, and 14 % cultivated area by the farms less than 10 hectares, cumulatively. Although, farms over 50 hectares which are only 6 % of the total number of investigated farms, cultivate 28 % of total land. The average size of farms is 18.3 hectares, while 37.2 % of farm land is under irrigation. This proportion is relatively high at small farm groups.

In general, farm lands have been divided into many parcels. The average number of parcel is three. A 80.3 % of average operated land by farms is owned, 13.5 % of it rented and rest (6.2 %) is share cropped. Tenancy is more common at small farm groups. The share of rented land at small farm group (less than 5 hectares) increases up to 25 %. Share cropping is not common in the region. Its share is only around 6 %. This proportion is lower at small farm groups.

### 2.2. Analysis of Energy Use in Wheat Cultivation

A questionnaire format was prepared in order to collect the required information related to the land possessed by the farmers and the utilization pattern, crop yield, operation time, fuel consumptions, fertilizer, chemical and seed inputs. The energy inputs as direct and indirect inputs were studied in two groups for the wheat cultivation in the Southeast Anatolia region of Turkey.

#### *2.2.1. Direct energy inputs*

Direct energy inputs, which were calculated according to inputs that used directly and have high energy values in the cultivation of wheat. In this case, during the cultivation process, fuel and oil energies that were consumed by agricultural tools/machineries were evaluated as direct energy inputs. Thus,

$EI_{direct} = E_{fuel} + E_{oil}$ ...........................(2)

where;

$EI_{direct}$ = Direct energy input (MJ/ha),

$E_{fuel}$ = Fuel energy consumption per area (MJ/ha) and

$E_{oil}$ = Oil energy consumption per area (MJ/ha).

##### *2.2.1.1. Energy input of fuel and oil consumption*

The amount of consumed fuel energy for unit cultivation area in the wheat cultivation (ha) is calculated depending on the amount of fuel that consumed by the tractor and the calorific value of diesel fuel, using following relation:

$E_{fuel} = M_{fuel} \times FHV_{fuel}$ ......................(3)

where;

$E_{fuel}$ = Fuel energy consumption per area (MJ/ha),

$M_{fuel}$ = The fuel consumption of the tractor per area (L/ha) and

$FHV_{fuel}$ = The lower calorific value of fuel (MJ/L).

The oil energy input which occurs due to engine oil consumption in wheat cultivation was determined by considering of the oil consumption of the farm tractor per hour, during the process of cultivation. The oil consumption of the farm tractor per hour was determined by depending on the highest PTO (power take off) shaft power of the tractor, that can be calculated as follows (Öztürk, 2011):

$OCT = 0{,}00059 \times HSP_{max} + 0{,}02169$ ........................................................(4)

where;

$OCT$ = The oil consumption of the farm tractor per hour (L/h) and

$HSP_{max}$ = The maximum PTO shaft power of the tractor (kW).

The maximum PTO shaft power (HSPmax) of the agricultural tractor that was used for the cultivation process of wheat was considered as 88 % of its rated power (RPT, kW) and determined as follows (Öztürk, 2011):

$HSP_{max} = 0{,}88 \times RPT$ .....................(5)

The oil energy amount that consumed per unit area in wheat cultivation process was calculated depending on the amount of oil that consumed by the tractor per hour during the manufacturing process, the lower calorific value of consumed oil and work efficiency of the tractor per area, which is defined as:

$E_{oil} = OCT \times OHV_{oil} \times WCT$ ........(6)

where,

$E_{oil}$ = Oil energy consumption per area (MJ/ha),

$OCT$ = Oil consumption of the farm tractor per hour (L/h),

$OHV_{oil}$ = The lower calorific value of oil (MJ/L) and

$WCT$ = Working capacity of the tractor per area (h/ha).

During cultivation operations in the field, the specific mass value of engine oil (SAE 40) that consumed by the tractor and agricultural tools/machineries was taken into account as 0.91 kg/L and also its calorific value was taken into account as 7.15 MJ/kg (6.51MJ/L) (Ejilah and Asere, 2008).

#### *2.2.2. Indirect energy inputs*

In the cultivation of wheat, the amount of energy that consumed for human labor, agricultural tools/machineries, chemical fertilizers and the seed production were considered as indirect energy inputs. Therefore,

$EI_{indirect} = HE + ME + EF + SE$ ...(7)

where;

$EI_{indirect}$ = Indirect energy input (MJ/ha),

$HE$ = Human labor energy (MJ/ha),

$ME$ = Indirect energy consumption for the usage of tools/machineries per field (MJ/ha),

$EF$ = The total energy input of fertilizer per unit area (MJ/ha) and

$SE$ = Seed energy per unit area (MJ/ha).

***2.2.2.1. Energy input of human labor***

Relating to these applications the human labor energy is determined as indirect energy consumption.

$HE = (NL \times WH / CA) \times EEL$ .....(8)

where;

$HE$ = Human labor energy (MJ/ha),

$NL$ = Number of laborer (person),

$WH$ = Working hours (h),

$CA$ = Cultivated area (ha) and

$EEL$ = Energy equivalent of labor (MJ/h).

***2.2.2.2. Indirect energy input regarding of agricultural tools/machineries***

The energy amounts that related to indirect energy consumption of agricultural tools/machineries usage were taken into account, as follows:

- The amount of energy that consumed for the manufacturing of tools/machineries, including to their disinterment of the raw materials, transportation and forge,
- The amount of energy that used for the materials from raw condition in factory/workshop to design of tools/machineries and their manufacturing processes,
- The amount of energy that used for the process of mending/maintenance of tools/machineries and
- The amount of energy that used for transportation and distribution of the tools/machineries

During the cultivation of wheat, the indirect energy consumption related to farming tools/machineries for each field application was determined as,

$$IDEM = \frac{PEM + MME + TDE}{EL \times CEW} \times NT \quad ...(9)$$

where;

$IDEM$ = The indirect energy consumption related to farming tools/machineries per area (MJ/ha),

$PEM$ = Cultivation energy of tools/machineries (MJ),

$MME$ = The mending/maintenance energy of tools/machineries (MJ),

$TDE$ = The amount of energy that used for transportation and distribution of the tools/machineries (MJ),

$EL$ = Economic life of the tools/machineries (h),

$CEW$ = The capacity of effective work (ha/h) and

$NT$ = The number transactions (quantity).

***2.2.2.3. Indirect energy input that related to usage of chemical fertilizer***

Relating to these applications, the indirect energy consumption of chemical fertilizer usage can be expressed as:

$$EF = \sum_{l=1}^{l=s} \Big[ \sum_{n=1}^{n=u} \frac{[N \times N_{eq}]_n}{FA} + \sum_{n=1}^{n=u} \frac{[P_2O_5 \times P_{eq}]_n}{FA} + \sum_{n=1}^{n=u} \frac{[K_2O \times K_{eq}]_n}{FA} \Big]_l \quad ...(10)$$

where;

$EF$ = The total energy input of fertilizer per unit area (MJ/ha),

$N$ = The applied amount of nitrogen fertilizer (kg),

$N_{eq}$ = The energy that consumed for the production of nitrogen fertilizer (MJ/kg),

$P_2O_5$ = The applied amount of phosphorus fertilizer (kg),

$P_{eq}$ = The amount of consumed energy for the production of phosphorus fertilizer (MJ/kg),

$K_2O$ = The applied amount of potassium fertilizer (kg)

$K_{eq}$ = The amount of energy that consumed for the production of potassium fertilizer (MJ/kg),

$FA$ = The fertilized area (ha) and

$n$ = The number of fertilizer application.

The production energy values of chemical fertilizers that used in wheat cultivation are given in **Table 1**.

***2.2.2.4. Indirect energy input related to the usage of seed***

Relating to these applications, the indirect energy consumption of the seed usage can be determined from

$SE = S\,(SPE + EPT)$ ......................(11)

where;

$SE$ = The seed energy per unit area (MJ/ha),

$S$ = Sowing ratio (kg/ha),

$SPE$ = The energy consumption for seed production (MJ/kg) and

$EPT$ = The energy consumption of packaging and transportation (MJ/kg).

The energy consumption for seed production and packaging/transportation equivalent was taken into account as 25 MJ/kg for determination of the seed energy per unit area (Ören and Öztürk, 2006).

***2.2.3. Total energy input for wheat cultivation***

In wheat cultivation, the direct and indirect energy inputs were taken into account as total energy input. Thus,

$TEI = EI_{direct} + EI_{indirect}$ ..........................(12)

where;

$TEI$ = Total energy input (MJ/ha),

$EI_{direct}$ = Direct energy input (MJ/ha) and

$EI_{indirect}$ = Indirect energy input (MJ/ha).

***2.2.4. Determination of energy output for wheat cultivation***

Two major outcomes were obtained, the wheat seed (grain) as a main product and the stem part of plant as a subsidiary product. The total amount of energy that obtained from at the end of wheat cultivation, including main and subsidiary products can be calculated as follows:

$TEI = (EMP \times E_{mp}) + (ESP \times E_{sp})$ .. ......................................................(13)

where;

*TEI* = Total energy input (MJ/ha),

*EMP* = The efficiency of the main product (kg/ha),

$E_{mp}$ = The energy equivalent of the main products (MJ/kg),

*ESP* = The efficiency of the subsidiary product (kg/ha) and

$E_{sp}$ = The energy equivalent of the subsidiary product (MJ/kg).

For the determination of the energy output in wheat cultivation, the energy equivalent were taken into account as 14.7 MJ/kg and for 12.5 MJ/kg for grain and wheat straw, respectively (Özkan *et. al*., 2004).

***2.2.5. Determination of energy efficiency for wheat cultivation***

The indicators that were used for the determination of energy efficiency in the cultivation of wheat with the applications of the different mechanization techniques are listed in **Table 2**.

## 3. Results and discussion

**3.1. The Energy Input-Output Relationships**

The energy equivalents of the input and output and indicators of energy efficiency in wheat cultivation are illustrated in **Table 3**. As can be seen from **Table 3**, the total energy used in various farm inputs was 17,159.5 MJ/ha for wheat cultivation. The results revealed that 7.6 h of machinery power per hectare were consumed to cultivate wheat in the research area. The human labour was 23.92 MJ/ha in wheat cultivation. The machine energy input was found to be of the order of 490.6 MJ/ha, while the man power 38.18 MJ/ha in wheat cultivation. Out of all the farm operations, seedbed preparation consumed the maximum energy followed by sowing and cultural practices, and harvesting.

In wheat cultivation, out of all the inputs, fertilizers have the biggest share in the total energy with a 43.8 %. Fertilizer energy input is followed by the diesel-oil energy. According to Muhadar and Hignet (1982), energy used in the production of fertilizers accounts for about 40 % of total energy used in agricultural production in developed countries. Most of this energy was consumed in the production of nitrogen, phosphorus and potassium fertilizers. In this study, nitrogen, phosphorus and potassium were considered as chemical fertilizer inputs. Results show that nitrogen is the most important energy source with a value of 6,714.5 MJ/ha, whereas phosphorus accounted for 801.42 MJ/ha. The diesel-oil energy was mainly used for operating tractor for performing the various farm operations. The results showed that the average yield in wheat production was 2,612.1 kg/ha and wheat cultivation consumed a total of 17,159.5 MJ/ha input energy. Therefore, in wheat cultivation the energy output/input ratio, specific energy, energy productivity and net energy efficiency were 2.21, 7.18 MJ/kg, 0.14 kg/MJ and 20,746.5 MJ/ha respectively. However, Canakci et.al., (2004) determined that the energy output/input ratio and specific energy for cultivating wheat were 2.8 and 5.24 MJ/kg in Antalya region of Turkey. Wheat is an energy rational crop, compared to most other food crops. The energy inputs for wheat production in various regions of the U.S. calculated by Krummel and Chick of Cornell University where it was reported that the energy output/input ratios were 0.43, 1.66, 2.21, 3.36 and 3.75 for wheat production in Texas, New Mexico, North Dakota, Ohio and Nebraska, respectively (Briggle, 1980).

## 4. Conclusions

The total mean energy inputs as direct and indirect forms were examined in the wheat cultivation. Considerable savings could be obtained in machinery energy inputs by adopting a reduced tillage method. The average values of estimated energy output/input ratio was 2.21 for cultivation of wheat. The low level of energy output/input ratio indicated that all the farmers were not fully aware of the right production techniques or did not apply them at the proper time in the right quantity. The diesel-oil and the level of fertilizer input particularly nitrogen, were two of the most significant determinants of the total energy input for wheat cultivation. These results indicate that wheat cultivation in Turkey heavily depends on fossil fuels which in turn lead to many environmental problems. Therefore, policies should emphasize development of new technologies and alternative energy resources aiming efficient use of energy. In addition to these, the results imply that Turkish field crop production might be considered as sensitive to changes in prices and availability of fossil fuels due to mainly its significant share in total consumed energy in field crop production. The results of this study can be used by policy makers and other relevant agencies for recommendations to farmers in order to use energy more efficiently. Proper

**Table 2** Indicators of energy usage efficiency in agriculture

| Indicators | Definition | Unit |
|---|---|---|
| Energy ratio | Total achieved energy amount/Total consumed energy amount | - |
| Specific energy | The amount of total consumed energy/The total amount of harvested product | MJ/kg |
| Energy productivity | The total amount of harvested product/ The amount of total consumed energy | kg/MJ |
| Net energy efficiency | Total achieved energy amount/ Total consumed energy amount | MJ/ha |

management of resources and their application at the right time can improve the efficiency of the farmers in the use of farm inputs.

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**Table 3** The energy use and efficiency for wheat cultivation.

| Input | Quantity per hectare | Total energy equivalent (MJ/ha) | Percentage of total energy input (%) |
|---|---|---|---|
| Human labour (h) | 16.6 | 38.18 | 0.22 |
| Seedbed preparation | 4.8 | 11.04 | |
| Sowing and cultural practices | 10.4 | 23.92 | |
| Harvesting | 1.4 | 3.22 | |
| Machinery (h) | 7.6 | 490.6 | 2.86 |
| Seedbed preparation | 4.8 | 209 | |
| Sowing and cultural practices | 2 | 145 | |
| Harvesting | 0.8 | 136.6 | |
| Diesel-oil (L) | 134 | 6,815.20 | 39.72 |
| Seedbed preparation | 80.52 | 4,228.20 | |
| Sowing and cultural practices | 33.55 | 1,620.80 | |
| Harvesting | 20 | 966.2 | |
| Chemical fertilizer (kg) | 183 | 7,515.90 | 43.8 |
| Nitrogen | 110.8 | 6,714.48 | |
| Phosphorus | 72.2 | 801.42 | |
| Chemicals (kg) | 1 | 161.1 | 0.94 |
| Insecticides | 0.1 | 19.9 | |
| Herbicides | 0.4 | 95.2 | |
| Fungicides | 0.5 | 46 | |
| Irrigation ($m^3$) | 1,587.30 | 1,000 | 5.83 |
| Seed (kg) | 227.7 | 1,138.50 | 6.63 |
| Total Energy Input (MJ/ha) | | 17,159.50 | 100 |
| Output (kg) | 2,612.10 | 37,906 | |
| Grain | 2,388.50 | 35,111 | |
| Straw | 223.6 | 2,795 | |
| Output/input ratio | | 2.21 | |
| Specific energy | | 7.18 | |
| Energy productivity | | 0.14 | |
| Net energy efficiency | | 20,746.50 | |

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# Design and Development of Cup in Cup Feed Metering Seed Drill for Seed Pattern Characteristics Study of Paddy Seeds


by

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## Abstract

Proper design of cup in cup feed metering seed drill is very important to enhance the performance of a seed drill. Earlier the cups used were of semi circular type. Due to vibration and shock, the seed retention and release for these cups were poor. So the cups were modified to cylindrical at top and conical at the bottom. An experimental test rig was developed in the laboratory in the Department of farm Machinery and Power, OUAT, Bhubaneswar, Odisha during the year 2009-10 to evaluate the best suitable dimensions of cup for the paddy variety pathara. Five different sizes of cups i.e. 14.83 mm, 11.71 mm, 9.48 mm, 7.84 mm and 6.58 mm depths with diameters of 8 mm, 9 mm, 10 mm, 11 mm and 12 mm respectively were prepared keeping the volume constant and were used for the study. The five different peripheral speeds of the cup discs were chosen to 6.28 m/min, 9.42 m/min, 12.55 m/min, 18.84 m/min and 23.56 m/min. The belt speed was calculated and maintained to study the seed rate deviation, seed distribution and seed damage. It was found that the dimensions of cup of 10 mm × 9.48 mm were found best with a permissible peripheral velocity up to 23.56 m/min. and an overall efficiency of 80.94 %. The above dimensions of the cup may be taken to develop a suitable seed drill for use in the field condition for sowing of paddy seeds.


## Introduction

The seed metering mechanism is the most vital component of the seed drill. The performance of a seed drill is mainly dependent on the type of metering device. In addition to this, the type of soil and field condition, preparation of seed bed, speed of operation and power source also affect the performance of the seed drill (Kepner *et al*., 2000). The crop yield is also affected by plant population, row spacing, plant to plant spacing, type and variety of seed and their emergence (Ojha and Micheal, 1978).

The fluted roller feed type metering device is very popular in India. This type of metering device is very much suitable for grain crops and not for large seeds. Moreover there is a concern for this type of metering device when the seed damage exceeds 3 % (Goel and Verma, 2000). Another metering device used was of cell feed type for manually operated seed drill. In this type of metering device, controlling of the seed rate was difficult. It was reported that the slightest displacement of brush contact varied the seed rate to a great extent under the field condition. In recent past, semi-circular type cups have been introduced for seed metering device in manufacturing of seed drill (Sahoo and Srivastava, 2000). Due to vibration and shock, the seed retention and release for these cups were poor. So the cups were modified to cylindrical at top and conical at the bottom for better retention of seeds.

The socio-economic conditions of Indian farmers do not permit them to have different seed drills for different crops. They are, therefore, bound to follow the traditional practice and face difficulty in intercultural operations and overall management of their crop. As the yield rate is low, farmers derive marginal benefit out of these crops. However the seed drills having cup feed metering mechanism can be suitably utilized for various crops only by changing the cups and with minor modifications (Garg and Dixit, 2003). Hence, the seed drill with cup type metering mechanism can be suitably used as a multi crop seeder for the crops like paddy, groundnut, green gram and black gram. So, studies on cup feed metering mechanism will help in developing a multi crop seeder for its versality in line sowing of various crops and enhancing the production and productivity.

Considering the above aspects, the present study was undertaken with the following objectives for sowing of paddy seeds.

1. To optimize the dimensions of the cup for sowing of paddy seeds
2. To optimize the peripheral speed of cup disc for the above mentioned seed
3. To evaluate the cup-feed metering device for seed-pattern characteristics considering seed rate deviation, seed distribution and seed damage for sowing of paddy

The spatial dimensions of the seed of the promising variety were measured. The dimensions of cup and peripheral speed of cup disc were optimized using the developed test rig (Goswami 2001) to achieve the desired seed pattern.

**Theoretical Consideration**

The suitable size of cup for the promising variety of paddy i.e. Pathara has been standardized using a test rig. This variety was selected as it is generally grown under upland conditions in Odisha with a yield potential of 30-35 quintals /ha. In order to develop and evaluate a multi crop seeder the standardized cups are used as cup feed metering mechanism and the cups are made replaceable. The details of theoretical aspects for the study are presented below;

***Thousand grain weight***

Thousand grain weight can be calculated taking approximately 500 grains from the sample at random. Subsequently thousand grain weight can be calculated using the following formula.

*The weight of 1000 grains on 'as is' basis = ((a × 1,000) / b) gm*;

*where*

*a* = weight of the whole grains, gm;

*b* = number of whole grains in the sample weighed

***Bulk density***

Bulk density of seed is defined as the total weight of the seeds per unit total volume.

*B.D.* = W / V;

*where*

*B.D.* = Bulk density, gm/cm³;

*W* = weight of seed sample, gm and

*V* = volume of seed sample, cm³

***Seed rate deviation***

The seed rate deviation was calculated using the following formula.

*Seed rate deviation, %* = ((-) Actual amount of seeds collected in 5 m length / Theoretical amount of seeds to fall in 5m length) × 100

The seed rate deviation was taken positive in all cases.

***Seed distribution***

The seed distribution was calculated using the following formula.

*Se = (1 - Y / d) × 100*;

*where,*

*Se* = Seed distribution, %;

*Y* = average numerical deviation of number of seeds per meter length of row from average number seeds per metre run;

*d* = average number of seeds per metre length of row

***Seed damage***

The seed damage was calculated taking nearly one kg of sample and using the following formula.

*Seed damage, % = (Weight of the damaged seeds from the sample / Weight of the sample) × 100*

The seeds before metering were tested to ensure their invisible damage and the seeds after passing through metering were tested for visible damage.

**Table 1** Physical properties and overall dimensions of selected seeds

| Seed variety | 1,000 grains weight (gm) | Moisture content (%) (w.b) | Bulk density (gm/cc) | Average length (L) (mm) | Average breadth (B) (mm) | Average thickness (T) (mm) | Average size (S) (mm) S = (LBT) ⅓ | Sphericit y = S/L | Spacing (cm) | Seed Rate (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| Paddy Pathara | 33.73 | 10.876 | 0.456 | 8.7 | 2.5 | 1.99 | 3.51 | 0.403 | 20 × 10 | 85 |

**Table 2** Calculation of dimensions of cup for selected seed

| Variety | Cup diameter (mm) | Cylindrical height (mm) | Cone height (mm) | Total height (mm) |
|---|---|---|---|---|
| Paddy: Pathara | 8 | 5.93 | 8.9 | 14.83 |
| | 9 | 4.68 | 7.03 | 11.71 |
| | 10 | 3.79 | 5.69 | 9.48 |
| | 11 | 3.14 | 4.7 | 7.84 |
| | 12 | 2.63 | 3.95 | 6.58 |

## Materials and Methods

The spatial dimension of paddy variety, Pathara, was studied (**Table 1**) and accordingly the cup dimensions were fixed (**Table 2**). The peripheral speed of cup disc was varied from 6.28 m/min to 23.56 m/min. The experiment was conducted using the test rig (**Fig. 1**) developed in the laboratory. The experimental test rig having hopper and cup feed

**Table 3** Peripheral speed of cup disc and belt speed for maintaining desired spacing

| Diameter of cup disc (cm) | Rpm of cup disc | Peripheral speed of cup disc (m/min) | No. of cups in cup disc | Canvas Belt speed (km/hr) | Spacing to be maintained (cm) |
|---|---|---|---|---|---|
| 10 | 20 | 6.28 | 8 | 0.97 | 10 |
| 10 | 30 | 9.42 | 8 | 1.44 | 10 |
| 10 | 40 | 12.55 | 8 | 1.92 | 10 |
| 10 | 20 | 6.28 | 10 | 1.21 | 10 |
| 15 | 40 | 18.84 | 12 | 2.4 | 10 |
| 15 | 50 | 23.56 | 12 | 3.6 | 10 |

**Fig. 1** Test rig for metering of seeds through sticky belt

seed metering mechanism was evaluated in the sticky belt. The design considerations for the sticky belt method are shown below.

1. A 2 HP electric motor with speed reduction unit was used for the drive mechanism.
2. The uniform speed of the canvass belt was maintained at 1 to 2.5 km/h with suitable belt pulley arrangement.
3. The endless canvass belt was prepared having 10.5 m length so as to take observations from top 5 m length.
4. The width of the belt should be at least 80 cm to evaluate four rows having spacing of 20 cm.
5. The canvass belt was graduated at the side so as to take observations easily.
6. A thin layer of grease was applied on the canvass belt so that the seeds would not be displaced after dropping.

**Details of Test Rig of Testing**

The test rig (**Fig. 2**) developed to evaluate the cup feed metering device consisted of two major sections. In the section one, the hopper, pickup chamber funnel in feed shaft with cup discs and 65 watts power source with suitable belt and pulley for power drive and variac were included. A stroke counter was used to measure the revolutions of feed shaft. In the section two, 1,492 watts power source with speed reduction unit, suitable belt and pulley for power drive, endless canvas belt 10.8 m length and 80 cm width, frame rollers and idler were included.

A thin layer of grease was applied to the belt so as to facilitate the proper embedding of seeds without any displacement. The belt used

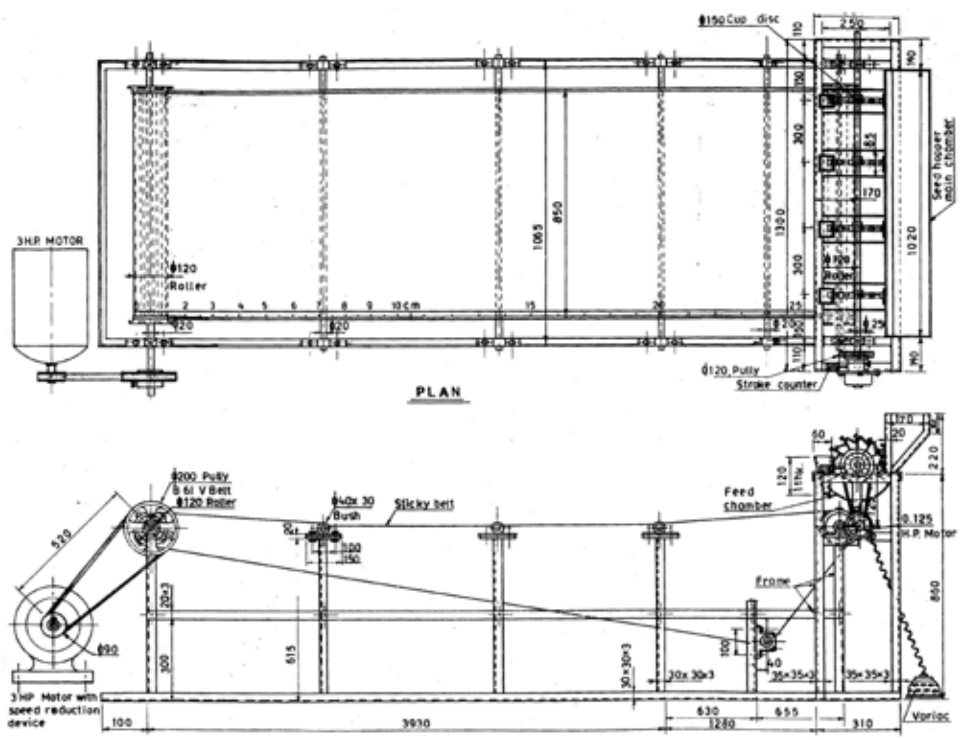


**Fig. 2** Test rig for performance evaluation of cup feed metering device

was demarcated for four rows and one side was marked in centimeters for easy reading. A stroke counter was used to measure the revolutions of driving shaft. The test rig was used to get the peripheral speed of cup disc from 6.28 m/min to 23.56 m/min with a belt speed from 0.97 km/h to 2.4 km/h to get the desired spacing as has been presented in **Table 3**. Five different sizes of cups i.e. 14.83 mm, 11.71 mm, 9.48 mm, 7.84 mm and 6.58 mm depths with diameters of 8 mm, 9 mm, 10 mm, 11 mm and 12 mm respectively were prepared keeping the volume constant and were used for the study. The five different peripheral speeds of the cup discs i.e. 6.28 m/min, 9.42 m/min, 12.55 m/min, 18.84 m/min and 23.56 m/min were chosen. The belt speed was calculated and maintained to study the seed rate deviation, seed distribution and seed damage.

**Table 4** Sample calculation for dimension of cup and hill spacing for paddy variety pathara

| | |
|---|---|
| A. Assumptions | |
| Seed rate | 85 kg/ha |
| Spacing | 20 cm × 10 cm |
| B. Calculation for dimension of cup | |
| No of hills per ha | 1000000 / 20 × 10 = 500000 |
| Amount of seeds to fall in each hill | 85000 / 500000 = 0.17 gm |
| Thousand grain weight | 33.73 gm |
| No. of seeds in each hill | 0.17 / 0.03373 = 5.04, or say 5 |
| Bulk density of seeds | 0.456 |
| Volume of seeds in each hill | 0.3728 c.c. |
| Additional 20% volume | 0.07456 c.c. |
| Total volume | 0.44736 c.c. |
| Cylinder volume, 1/3 of total volume | 0.14912 c.c. |
| Height of cylinder taking diameter 8 mm | 5.93 mm |
| Height of cone | 8.9 mm |
| Total height of cup | 14.83 mm |
| So for 8 mm diameter of cup, the cup height has been taken as 14.83 mm and with this cup dimensions 5 seeds are to fall in each hill. | |
| C. Calculations for hill spacing | |
| Diameter of cup disc | 10 cm |
| Cup disc, rpm | 20 |
| Peripheral speed of cup disc | 6.28 m/min |
| No. of cups in cup disc | 8 |
| Belt speed | 0.97 km/hr |
| Hill spacing | 0.97 × 100000 / 60 × 20 × 8 = 10.10 cm, or say 10 |

So with a belt speed of 0.97 km/hr hill spacing to be maintained is 10 cm

**Designs of Ground Wheel Diameter, Number of Cups and Cup Disc Diameter**

The ground wheel diameter of the seed drill was taken as 32 cm. The ground wheel of existing commercially available manually operated seed drill is only 25 cm. The larger diameter has been taken to rotate the ground wheel smoothly even if the seed bed was not prepared well. The ground wheel was fabricated from 2.5 cm M.S. flat and 18 pegs were provided on the periphery with the height of the pegs being 2.5 cm.

The number of cups can be calculated using the following formula:
$Z = \pi D / X.S$; where,
$Z$ = number of cups in the cup disc;
$D$ = ground wheel diameter;
$S$ =spacing in between the plants;
$N$ = seed metering shaft, r.p.m.;
$n$ = ground wheel, r.p.m.;
$X$ = gear ratio ; Assuming,
$D$ = 32 cm
$X$ = 1 and
$S$ = 10 cm;
$Z = \pi D / XS = 10.05 \approx 10$

Therefore the number of cups to be used in the cup disc was 10. In case of slow speed, the seeds were discharged from the cup by gravity. Under this condition, the guide plate was provided so that the seeds were directed to the seed funnel. In order to provide the guide plate, the peripheral distance between two cups should be at least 3.25 cm. So the cup disc dia = 32.5 / π = 10.34

Sample calculation for dimension of cup and hill spacing for paddy variety pathara has been mentioned in **Table 4**.

## Results and Discussion

The results of the different experiments conducted during the course of the studies are presented in this section. The experimental data collected from the test rig are presented in **Table 5**.

The seed rate deviation varied from 2.08 to 6.22 %. The results indicated that the minimum seed rate deviation occurred with cup No.3 having 10 mm diameter with a peripheral speed of 6.28 m/min. This may be due to improper filling of cup when the cup diameter was less than 10 mm and when the cup diameter was more than 10 mm seed retention was difficult because of the slippage. It was also found that the seed rate deviation was increasing with the increasing of peripheral speed. This may be due to improper filling at higher speed and scattering of seeds during centrifugal discharge due to the increase in kinetic energy of seeds.

The seed distribution efficiency varied from 82.76 to 85.46 %. It was found that the maximum seed distribution efficiency was found with cup No.3 with a peripheral speed of 6.28 m/min. It was also found that the seed distribution efficiency was decreasing with the increase in the peripheral speed. This may be due to scattering of seeds during centrifugal discharge as the seeds posses more kinetic energy.

The seed damage varied from 0.43 to 2.41 %. It was found that the minimum seed damage was attributed with cup No.3 with a peripheral speed of 6.28 m/min. It was found that the seed damage was increasing as the peripheral speed increased. This may be due to higher impact of the seeds. From the analysis of results it was found that the dimension of cup of 10 mm × 9.48 mm was found best with a permissible peripheral velocity up to 23.56 m/min. with an overall efficiency of 80.94 %. But the seed pattern observed for hill dropping was up to peripheral speed of 12.55 m/min and from 18.84 m/min to 23.56 m/min the seed pattern was of drilling the seeds.

## Conclusions

The dimensions of the cup i.e. 10 mm × 9.48 mm was found to be best and was used successfully up to a peripheral speed of 23.56 m/min with the desired seed rate deviation, seed distribution and seed damage. The seed pattern observed for hill dropping was up to peripheral speed of 12.55m/min and from 18.84 m/min to 23.56 m/min that was of drilling the seeds. These research findings would help in developing a multicrop seed drill using the cup feed metering device for the sowing of other major crops like groundnut, green gram, black gram etc. to promote line sowing to the benefit of the farmers.

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**Table 5** Evaluation of cup feed metering mechanism of paddy variety pathara

| Cup Dimensions | Peripheral speed of cup disc (m/min) | Seed rate deviations (%) | | | | Seed distribution (%) | | | | Breakage of seeds (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | R1 | R2 | R3 | Mean | R1 | R2 | R3 | Mean | R1 | R2 | R3 | Mean |
| 8 mm diameter and 14.83 mm depth | 6.28 | 4.61 | 4.32 | 4.16 | 4.36 | 83.82 | 83.62 | 83.54 | 83.66 | 0.8 | 1 | 0.7 | 0.83 |
| | 9.42 | 4.82 | 5.01 | 4.46 | 4.76 | 83.61 | 83.36 | 83.26 | 83.41 | 0.86 | 0.92 | 0.99 | 0.92 |
| | 12.55 | 5.12 | 5.1 | 4.82 | 5.01 | 83.42 | 83.16 | 83.02 | 83.2 | 0.89 | 0.98 | 1.11 | 0.99 |
| | 18.84 | 5.14 | 5.12 | 4.91 | 5.05 | 83.19 | 83.02 | 82.86 | 83.03 | 0.92 | 1.02 | 1.12 | 1.02 |
| | 23.56 | 5.21 | 5.16 | 5.11 | 5.16 | 83.01 | 82.83 | 82.53 | 82.79 | 1.61 | 0.82 | 1.29 | 1.29 |
| 9 mm diameter and 11.71 mm depth | 6.28 | 4.81 | 4.43 | 5.6 | 4.61 | 84.28 | 84.12 | 84.02 | 84.14 | 0.88 | 0.98 | 0.84 | 0.9 |
| | 9.42 | 4.91 | 4.98 | 4.8 | 4.89 | 84.09 | 83.92 | 83.76 | 83.93 | 0.9 | 0.89 | 1.15 | 0.98 |
| | 12.55 | 5.16 | 5.16 | 4.91 | 5.07 | 83.86 | 83.68 | 83.32 | 83.62 | 1.1 | 0.78 | 1.48 | 1.12 |
| | 18.84 | 5.26 | 5.21 | 4.98 | 5.15 | 83.64 | 83.49 | 83.13 | 83.42 | 1.12 | 0.99 | 1.43 | 1.18 |
| | 23.56 | 5.61 | 5.34 | 5.28 | 5.14 | 83.38 | 83.18 | 82.94 | 83.15 | 1.16 | 1.12 | 1.56 | 1.28 |
| 10mm diameter and 9.48 mm depth | 6.28 | 2.01 | 2.06 | 2.02 | 2.03 | 85.31 | 85.43 | 85.46 | 85.4 | 0.56 | 0.42 | 0.81 | 0.59 |
| | 9.42 | 2.24 | 2.16 | 2.2 | 2.2 | 85.02 | 85.13 | 85.18 | 85.11 | 0.48 | 0.92 | 0.59 | 0.66 |
| | 12.55 | 2.57 | 2.96 | 2.64 | 2.55 | 84.72 | 84.83 | 84.86 | 84.83 | 0.74 | 0.82 | 0.54 | 0.7 |
| | 18.84 | 2.96 | 2.81 | 2.74 | 2.83 | 84.41 | 84.52 | 84.53 | 84.43 | 0.82 | 0.88 | 0.98 | 0.89 |
| | 23.56 | 2.99 | 2.92 | 2.87 | 2.92 | 84.14 | 84.21 | 84.26 | 84.23 | 0.9 | 0.89 | 1.24 | 1.01 |
| 11 mm diameter and 7.84 mm depth | 6.28 | 5.1 | 5.01 | 4.92 | 5.01 | 84.26 | 84.36 | 84.28 | 84.3 | 0.9 | 1 | 0.92 | 0.94 |
| | 9.42 | 5.16 | 5.24 | 5.01 | 5.13 | 84.03 | 84.14 | 84.16 | 84.11 | 0.98 | 1.08 | 0.94 | 1 |
| | 12.55 | 5.28 | 5.42 | 5.71 | 5.29 | 83.78 | 83.96 | 83.98 | 83.93 | 1.04 | 1.09 | 0.97 | 1.03 |
| | 18.84 | 5.38 | 5.48 | 5.8 | 5.55 | 83.52 | 83.69 | 83.7 | 83.63 | 1.22 | 1.27 | 1.08 | 1.19 |
| | 23.56 | 5.82 | 5.79 | 5.98 | 5.86 | 83.3 | 83.46 | 83.53 | 83.43 | 1.28 | 1.86 | 1.84 | 1.66 |
| 12 mm diameter and 6.58 mm depth | 6.28 | 5.2 | 5.12 | 5.1 | 5.14 | 83.92 | 83.86 | 83.66 | 83.81 | 1.23 | 1.17 | 1.05 | 1.15 |
| | 9.42 | 5.28 | 5.21 | 5.24 | 5.24 | 83.71 | 83.58 | 83.42 | 83.57 | 1.24 | 1.23 | 1.21 | 1.22 |
| | 12.55 | 5.5 | 5.61 | 5.49 | 5.38 | 83.5 | 83.36 | 83.21 | 83.35 | 1.31 | 1.28 | 1.3 | 1.29 |
| | 18.84 | 5.81 | 5.89 | 5.89 | 5.86 | 83.26 | 83.16 | 83.01 | 83.11 | 1.84 | 1.98 | 1.92 | 1.91 |
| | 23.56 | 6.24 | 6.12 | 6.22 | 6.19 | 83.02 | 83 | 82.76 | 82.92 | 2.02 | 2.41 | 1.99 | 2.14 |

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# New Co-operating Editors

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# Development and Evaluation of Aloe Vera Gel Expulsion Machine


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## Abstract

An Aloe vera gel expulsion machine based on the principle of splitting leaf was designed and developed. Reduction of crushing force and minimization of contamination of gel with leaf rind compounds, Aloe vera leaf was split and expulsion of the inner gel carried out by passing split leaf between two rotating roller. The whole gel expulsion machine is divided into following two components: (a) Splitting unit and (b) Gel expulsion unit. The performance of the developed gel expulsion machine was evaluated at different speeds of roller and three thicknesses in terms of gel recovery, expulsion efficiency, output capacity and percentage of residual gel in leaf. The expulsed gel through the developed machine was evaluated for quality parameters like viscosity, optical density and refractive index. It was concluded that for getting maximum gel recovery, minimum residual gel percentage, highest expulsion efficiency and output capacity, the expulsion of Aloe vera leaves should be carried out at 75 rpm roller speed and 25 -30 mm thickness of leaves. The cost of gel expulsion for Aloe vera leaves by the developed machine was estimated to be $ 13.35 per tons as compared to $ 40 per tons by the manual method.


## Introduction

Aloe vera is a succulent that belongs to the liliaceae family. Aloe vera gel is the commercial name given to the fiber free mucilaginous exudate extracted from the hydroparenchyma of the succulent leaves of Aloe vera (*Aloe barbadensis Miller*). Aloe vera Gel (a clear, jelly-like material) is derived from tissue that comprises the inner portion of the leaves. It is slightly bitter and odourless. Aloe vera is used as an antiseptic, bactericidal, calming agent, detoxifiers, a natural cleanser and dilates capillaries in medical science, as moisturizer for skin care product and hair care product in cosmetics and over seventy-five nutritional compounds occur naturally within the plant, so it is used as aloe juice for nutrition purpose. Aloe vera gel also finds its application in the cosmetic and toiletry industries, where it is used as a base for the preparation of creams, lotions, soaps, shampoos and facial cleaners.

Hand filleting and whole leaf processing, the two types of Aloe vera gel extraction methods are prevalent. Only recently have processing methods using the entire whole leaf been perfected, so the undesirable elements can be selectively removed, while maximizing the desired constituents. Among the desirable constituents are the polysaccharides (glucomannans), glycoproteins and associated growth factors. The present hand filleting method for obtaining gel from the Aloe vera leaf with the help of sharp knife is very tedious and labour intensive, whereas in commercially available gel extraction machine, the whole leave is being processed, which may give the chance for the contamination of the leaf exudates to gel. This happened due to the presence of anthraquinones and their derivatives which may diffuse into the gel from the bundle sheath cells during pulping of whole Aloe vera leaf. Efforts have also been made to extract gel by squeezing the Aloe vera leaf between two rollers.

Squeezing of Aloe vera leaves between two roller, crush the leaf and the ingredients comes out and mixed up with the Aloe vera gel and also more compression force needed to extract gel without splitting the leaf. At the same time the residual gel amount will be more in roller squeezing. Considering these problems, a reciprocating knife type roller machine, which can split Aloe vera leaf into two halves, and easily expulsed the gel without contamination of exudates compounds with more purity and recovery will be design and develop which may useful for Aloe processing industry.

**Roller Method**

In the roller method of gel expulsion, the leaves are passed through rollers and the fillet "pops" out, same time more pressure is applied to the pericyclic tubules for gel expulsion. Bhubaneswar Centre of All India Coordinated Research Project (AICRP) on Post Harvest Technology, has developed a low cost gel extractor comprising of two roller having diameter 118 mm and length of 245 mm with one roller has continuous slope (Anonymous, 2008A). Similarly, low cost Aloe juice extractor has also developed by Jaipur Centre of AICRP on Post Harvest Technology (Anonymous, 2008B), where as AICRP Udaipur Centre has developed machine having two stainless steel roller rotated with chain and sprocket mechanism (Anonymous, 2008C). Aloe vera gel (fillet) extractor of 60-80 kg leaves/h capacity was designed and developed by providing adjustable gap in between the crushing rollers, so that only the gel is just extracted and over crushing of the leaves can be avoided (Anonymous, 2008D). Tumlinson (1985) had developed an apparatus for extraction of uncontaminated aloe vera gel from the leaves of aloe vera plants by passing through a number of crushing rollers arranged in a desired pattern. to extrude the gel from the leaf.

**Leaf Splitting Method**

Thompson (1983) had developed an apparatus for feeding an Aloe vera plant leaf to a cutting knife. The apparatus is designed to transport the leaf on an endless belt conveyor on which the leaf is laid down flat and lengthwise on the conveyor belt. A second endless belt conveyor travels in the same direction and at the same speed as the first endless belt conveyor but is disposed at a right angle to the first endless belt conveyor at the feed end of the apparatus. Cottrell (1984) had developed a method and apparatus for extracting gel from Aloe vera leaves without contaminating the gel with toxic juices. Mechanical filleting is the most commonly used method in the industry for gel extraction from the Aloe vera leaves, suggested by O'brien (2005). Danhof (2009) has suggested a method for processing of whole leaf in which the whole leaf is coarsely chopped and the rind particles are removed by passing through filters of various porosities. The anthraquinone are removed by using charcoal. This method produces a product rich in carbohydrates but also much higher in mineral salts than the other methods.

**Filet Machine**

The filet machine is a device, used to separate the rind from the inner gel of the leaf. The name comes from the resemblance of the inner gel to a fish fillet. An alternate of this machine is to hand filleting of the leaf. The advantage of using filet machine is the lower cost of operation but the yield may go down as compared to hand filleting. De gray (1986) had developed an elongated conveyor assembly on which an Aloe vera leaf is lengthwise disposed and advanced from one end of the conveyor to the other end. Huang (2000) had designed and developed an Aloe vera gel extracting apparatus, which consists of a body, transmission system, peeling device and a driving mechanism.

## Methodolgy

**Design Considerations**

The design of an efficient Aloe vera gel expulsion machine should embody the following special requirements and features:

1. The machine should be able to reduce handling time, labour and energy used.
2. The separated gel from Aloe vera leaves should have less contamination of aloin.
3. It should be suitable for large scale processing of Aloe vera leaves.
4. It should be able to expulse all the gel in Aloe vera leaf.
5. It should be cheaper as compared to traditional gel separating system.
6. The capacity of machine should be about 100 kg/h for Aloe vera leaf.
7. Each and every Aloe vera leaf should be split into two equal half in splitting unit.

**Mechanism of Aloe Vera Gel Expulsion Machine**

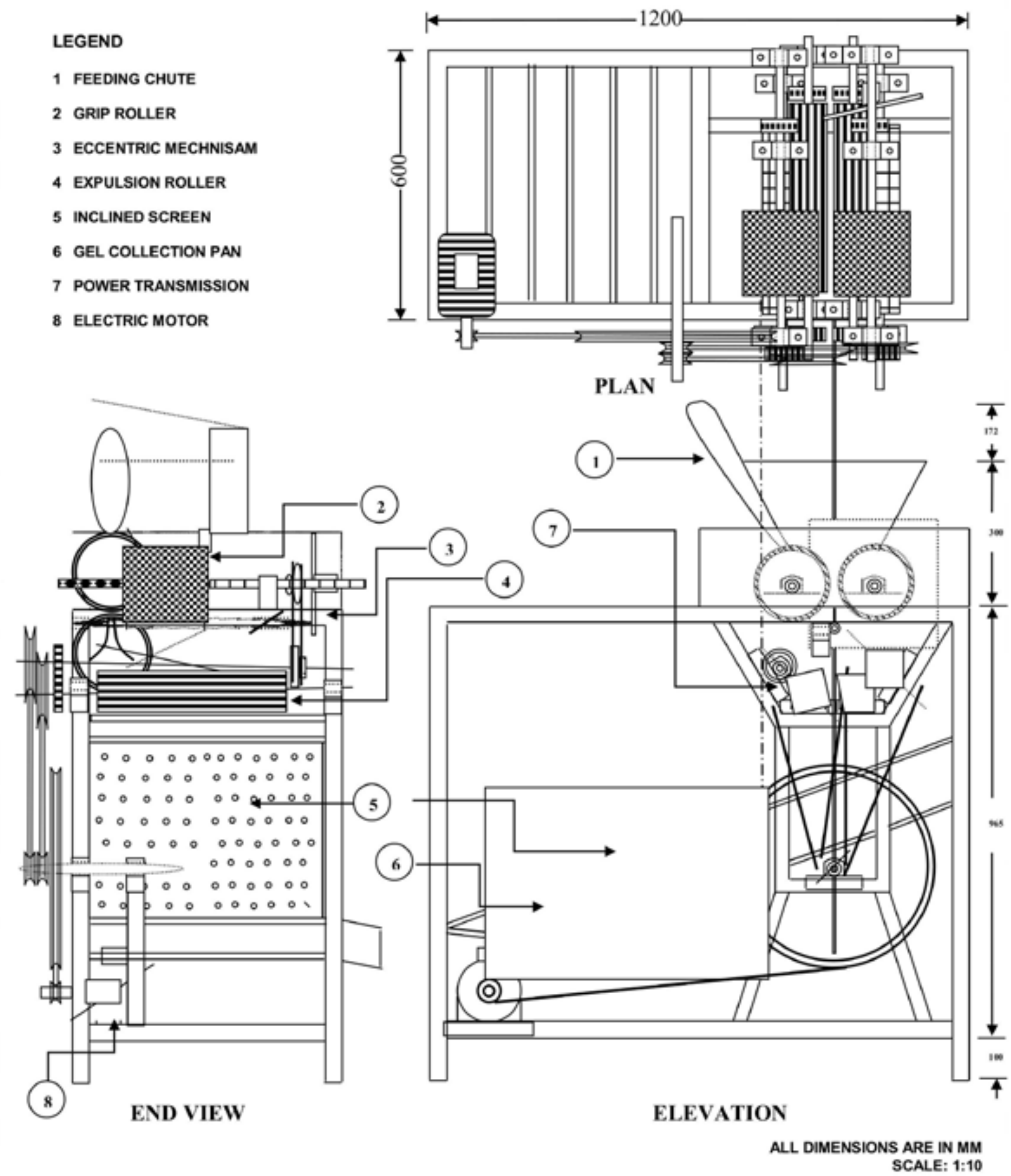
An Aloe vera gel expulsion machine based on the principle of splitting leaf to reduce crushing force and expulse the inner gel by passing split leaf between two rotating roller. The whole gel expulsion machine is divided into following two components: (a) Splitting unit and (b) Gel expulsion unit. The main components of the splitting unit are (1) Aloe vera leaf feeding chute assembly, (2) grip roller, (3) reciprocating cutting blade, (4) eccentric and (5) chain-sprocket power drive, whereas for gel expulsion unit are having (1) expulsion roller (2) expulsed gel collection unit, (3) inclined screen, (4) gear drive assembly and (5) power transmission system.

**Aloe Vera Gel Expulsion Process**

The Aloe vera leaf is dropped over the grip rollers from a feeding chute. The function of grip rollers is to hold the leaf in vertical position to split into two halves by the reciprocating blade of the splitting unit. The speeds of the splitting and gel expulsion units are kept same so that a single leaf is passed continuously and uniformly. The reciprocating blade is placed just near to the grip roller so that no single leaf can pass without splitting. The two halves of split leaf are then pass over to each pair of expulsion rollers, where by squeezing action gel is expulsed from the split leaf. The leaf is split individually by the splitting unit and gel expulsed from split leaf by crushing between pair of expulsion roller. The expulsed gel was collected at the bottom through openings of inclined screen and the rinds were collected down side through perforated screen. The gel adhering with the rinds also oozes out and collected from the discharge outlet.

The power from an electric motor is transmitted to main shaft of flywheel pulley to expulsion roller shaft through V-belt drives. Power is transferred with the help of gear drive to obtain opposite direction of pair of expulsion rollers. From expulsion unit, power is given to splitting unit through chain and sprocket drives. The power transmitted to reciprocating blade by rotary eccentric mechanism.

### Testing of Developed Aloe Vera Gel Expulsion Machine




Schematic diagram of developed aloe vera gel expulsion machine

View of developed aloe vera gel expulsion machine

The various components of the developed Aloe vera gel expulsion machine were installed on level ground with foundation. The electric motor was duly fitted with the machine. The preliminary trail runs were made by various components of the Aloe vera gel expulsion machine after it was installed. The operation of the machine showed initial troubles in fitting of the component, which were rectified and the smooth functioning of the components were ensured. The various components were inspected, which include the checking of the proper tension in the belt drive, alignment of the driven and driving shaft, reciprocating blade, movement of the Aloe vera leaves through grip roller and expulsion roller and movement of the leaf exudates on perforated screen. Alignment in power transmission through gears, V-belt and chain sprocket drive was checked.

The following desirable features were observed during the trial runs:

1. No vibration was observed during the operations it was properly fixed with the ground.
2. An irritating rattling sound was initially heard from the eccentric rotary disc plate. This was due to the contact point of reciprocating blade rod to the disc plate. However, providing grease and oil eliminated the sound.
3. The shaft was running smoothly and there was no marked rise in temperature of the bearings of the shaft.
4. No slippage of belts was observed during the test.
5. Flow of Aloe vera from the feeding chute to grip roller was found right.
6. The pointed portion of leaf should be fed to feeding chute to avoid blockage.
7. Minimum time required to feed leaf to feeding chute is 5 seconds.
8. The reciprocating blade cut the Aloe vera leaf passing through grip roller into two halves.
9. The expulsion roller removes all the gel adhered to split leaf.
10. The gel was collected in collection unit through screen.
11. The leaf exudates were getting collected downward by gravity flow.

## Results and Discussions

The developed Aloe vera gel expulsion machine was tested for its performance at seven levels of roller speeds and three levels of leaf thickness for gel recovery, expulsion efficiency, residual gel percentage and output capacity. The Aloe vera gel expulsion machine was operated at speeds of 45, 60, 75, 90, 105, 120 and 135 rpm. The Aloe vera leaf thickness was kept as less than 25 mm. 25-30 mm and more than 30 mm. The test data were analyzed by using analysis of variance techniques to determine gel recovery, expulsion efficiency, and residual gel percentage and output capacity at various operating parameters.

### Crude Gel Recovery

The crude gel recovery was calculated from the ratio of weight of extracted gel to the weight of leaf. During the experiment it was observed that the both roller speed and leaf thickness have considerable effect on crude gel recovery. The maximum gel recovery 39.14 % was found of at the speed of 75 rpm and 30 mm leaf thickness. The minimum gel recovery 26.95 % was found at 135 rpm speed and less than 25 mm leaf thickness. After considering both the factor, it may be concluded that for the maximum gel recovery the gel expulsion of Aloe vera leaves should be carried out at 75 rpm speed with leaf thickness of leaf 30 mm or more. The statistical analysis shows that results of combine effect of leaf thickness and roller speed found significant.

### Residual Gel Percentage

The residual gel percentage was obtained from the difference between theoretical and actual gel recovery. The minimum residual gel percentage i.e. 4.41 % was found at speed of 75 rpm and less than 25 mm leaf thickness, whereas the maximum residual gel percentage i.e. 15.30 % was found of at 135 rpm speed and 30 mm leaf thickness or more. After considering both factors, it may be concluded that the gel expulsion of Aloe vera leaves should be carried out at 75 rpm with 25-30 mm thickness of leaves for obtaining minimum residual gel percentage. The statistical analysis shows that results of combine effect of leaf thickness and roller speed found significant. Similar findings were also reported by the AICRP on Post Harvest Technology Centre, Jaipur (Anonymous, 2008 B) on the developed Aloe juice extractor. They have also reported the residual gel percentage in term of extraction loss i.e. 4.97 % with 50.9 juice extractability.

### Expulsion Efficiency

The expulsion efficiency is defined as the ratio of the actual gel recovery to the theoretical gel recovery. The actual gel recovery is the separation of gel from aloe vera leaf by the roller in closely separating the gel and leaf exudates and the theoretical gel recovery is the maximum amount of gel recovered manually. The expulsion efficiency may be affected by orientation of leaf in feeding, speed, leaf size & shape.

**Table 1** Effect of leaf thickness and speed on crude gel recovery

| Expulsion roller Speed (rpm) | Crude gel recovery (%) Leaf thickness | | | |
|---|---|---|---|---|
| | < 25 mm | 25-30 mm | >30 mm | Mean |
| 45 | 29.29 | 35.71 | 36.42 | 33.8 |
| 60 | 29.5 | 36.55 | 37.17 | 34.41 |
| 75 | 30.59 | 37.12 | 39.14 | 35.62 |
| 90 | 30.01 | 37.82 | 37.27 | 35.03 |
| 105 | 29.85 | 37.4 | 37.09 | 34.78 |
| 120 | 28.95 | 36.95 | 36.81 | 34.24 |
| 135 | 26.95 | 35.65 | 34.7 | 32.43 |
| Mean | 29.3 | 36.74 | 36.94 | |
| Factor | C.D. | S.Em. | C. V. % | Test |
| Leaf thickness | 0.157 | 0.055 | 0.16 | Sig. |
| Roller speed | 0.24 | 0.084 | 0.24 | Sig. |
| Leaf thickness x Roller speed | 0.415 | 0.145 | 0.42 | Sig. |

**Table 2** Effect of leaf thickness and speed on percentage of residual gel

| Expulsion roller Speed (rpm) | Residual gel percentage Leaf thickness | | | |
|---|---|---|---|---|
| | < 25 mm | 25-30 mm | >30 mm | Mean |
| 45 | 5.71 | 9.29 | 13.58 | 9.53 |
| 60 | 5.5 | 8.45 | 12.82 | 8.93 |
| 75 | 4.41 | 7.88 | 10.86 | 7.71 |
| 90 | 4.99 | 7.18 | 12.73 | 8.3 |
| 105 | 5.15 | 7.59 | 12.91 | 8.55 |
| 120 | 6.05 | 8.05 | 13.19 | 9.1 |
| 135 | 8.05 | 9.35 | 15.3 | 10.9 |
| Mean | 5.7 | 8.26 | 13.06 | |
| Factor | C.D. | S.Em. | C. V. % | Test |
| Leaf thickness | 0.157 | 0.055 | 0.61 | Sig. |
| Roller speed | 0.239 | 0.084 | 0.93 | Sig. |
| Leaf thickness x Roller speed | 0.415 | 0.145 | 1.61 | Sig. |

**Table 3** Effect of leaf thickness and speed on expulsion efficiency

| Expulsion roller Speed (rpm) | Expulsion efficiency (%) Leaf thickness | | | |
|---|---|---|---|---|
| | < 25 mm | 25-30 mm | >30 mm | Mean |
| 45 | 73.21 | 79.36 | 72.83 | 75.13 |
| 60 | 73.74 | 81.22 | 74.35 | 76.43 |
| 75 | 76.48 | 82.5 | 78.29 | 79.09 |
| 90 | 75.02 | 84.05 | 74.54 | 77.87 |
| 105 | 74.62 | 83.12 | 74.17 | 77.3 |
| 120 | 72.37 | 82.12 | 73.62 | 76.03 |
| 135 | 67.38 | 79.22 | 69.4 | 72 |
| Mean | 73.26 | 81.65 | 73.89 | |
| Factor | C.D. | S.Em. | C. V. % | Test |
| Leaf thickness | 0.341 | 0.119 | 0.22 | Sig. |
| Roller speed | 0.521 | 0.182 | 0.32 | Sig. |
| Leaf thickness x Roller speed | 0.903 | 0.315 | 0.55 | Sig. |

The highest gel expulsion efficiency 84.05 % was found at speed 90 rpm and 25-30 mm leaf thickness, whereas the lowest gel expulsion efficiency was 67.38 % at speed 135 rpm and leaf thickness 25 mm or less. After considering both the factor, it may be concluded that the gel expulsion of Aloe vera leaves should be carried out at 75 rpm with leaves having thickness ranging from 25 to 30 mm for highest gel expulsion efficiency. The similar results were also reported for Aloe vera gel extractor developed by the AICRP on Post Harvest Technology Centre, Udaipur (Anonymous, 2008C) and also confirmed the results for increase in speed initially and then reduction in gel expulsion efficiency at higher speed. They have also reported that the maximum gel recovery of 66.52 % and 75.28 % was obtained at 75 and 90 rpm of roller speed respectively. The AICRP on Post Harvest Technology Centre, Jaipur (Anonymous, 2008B) also showed the similarly findings for developed Aloe juice extractor.

### Output Capacity

The output capacity was calculated from the quantity of leaves processed per hour. The output capacity may affected by orientation of leaf in feeding, speed, leaf size & shape. The maximum output capacity was found 116.19 kg/h at speed 135 rpm and leaf thickness ranging from 25 to 30 mm, whereas the minimum output capacity was found 92.20 kg/h at speed 45 rpm and leaf thickness less than 25 mm. After considering both the factor, it may be concluded that the gel expulsion of Aloe vera leaves should be carried out at maximum speed and leaves having thickness 25-30 mm for getting maximum output capacity. The similar results have been reported by the AICRP on Post Harvest Technology Centre, Jaipur (Anonymous, 2008B) on developed Aloe juice extractor. The statistical analysis shows that results of combine effect of leaf thickness and roller speed on output capacity were found significant.

### Quality Parameters of Expulsed Gel

The quality of gel expulsed either manually or mechanically is depending on the several parameters. The results of various parameters like viscosity, refractive index and optical density, deciding the quality of gel expulsed through Aloe vera gel expulsion machine and manually expulsion process

Viscosity is the measure of biological activity and hence more will be the viscosity better will be the gel quality. The average values of viscosity of the expulsed gel manually and through mechanical expulsion machine were found 0.638 ±0.067 Stokes and 0.621 ±0.043 Stokes respectively. The refractive index determines the purity of the gel physically. The results of refractive index are presented in **Table 5**. The mean values of the gel expulsed manually and through mechanical expulsion machine were found to be 1.3359 ±0.0003 and 1.3364 ±0.0006 respectively. Optical density decides the clarity of the expulsed gel. The results data for optical density were found as 0.238 ±0.5299 for manual gel expulsion and 0.239 ±0.5297 for mechanical gel expulsion (**Table 5**).

### Cost Analysis of Aloe vera gel expulsion machine

Cost estimation for gel expulsion from aloe vera leaves was done to determine feasibility of the use of developed gel expulsion machine as compared to traditional gel expulsion system being followed by farmers and entrepreneurs. The total cost consisted of fixed as well as variable costs. Economics of the cost of operating the machine were computed adopting certain appropriate assumption. The following assumptions were made in the estimation of gel expulsion cost.

**Table 4** Effect of leaf thickness and speed on output capacity

| Expulsion roller Speed (rpm) | Output capacity (kg/h) Leaf thickness | | | |
|---|---|---|---|---|
| | < 25 mm | 25-30 mm | >30 mm | Mean |
| 45 | 92.2 | 104.58 | 93.86 | 96.88 |
| 60 | 94.2 | 106.99 | 96.88 | 99.36 |
| 75 | 98.88 | 108.17 | 96.91 | 101.32 |
| 90 | 99.53 | 109.85 | 97.77 | 102.38 |
| 105 | 101.89 | 111.14 | 99.85 | 104.29 |
| 120 | 104.27 | 113.54 | 99.5 | 105.77 |
| 135 | 104.59 | 116.19 | 102.44 | 107.74 |
| Mean | 99.37 | 110.07 | 98.17 | |
| Factor | C.D. | S.Em. | C. V. % | Test |
| Leaf thickness | 0.62 | 0.217 | 0.21 | Sig. |
| Roller speed | 0.948 | 0.331 | 0.32 | Sig. |
| Leaf thickness x Roller speed | 1.641 | 0.573 | 0.56 | Sig. |

### Assumptions

Useful life of machine
= 10 years.
1. Total working time
= 300days/year @ 8 hours/day.
2. Depreciation cost of machine
= @ 10% salvage value.
3. Interest on capital investment
= @ 12 % of initial cost/year.
4. Repair and maintenance cost
= @ 3 % of initial cost/year.
5. Cost of housing shed
= 1 % of equipment cost
6. Labour charges
= $ 2 /man /day.
7. Electricity charges
= $ 0.14 /unit

The cost of the machine was estimated by adding the costs of different materials used in the fabrication of the Aloe vera gel expulsion machine. The fabrication cost is considered 30 % of total material cost. The overhead cost was assumed 10 % of total cost of material and fabrication work. Thus, the total cost of the Aloe vera gel expulsion machine developed was estimated to be about $ 500.

### Manual Gel Expulsion Cost

One labour can manually expulsed gel from aloe vera leaf about 50-100 kg of aloe vera leaves in one day, with the labour charge @ $ 2 per day per person. The cost of manual gel expulsion is carried out for one tons of Aloe vera leaves. As in case of the manual gel expulsion considering an average time of 5 minutes for single leaf and 8 working hour, one labour can separate gel from the 96 leaves i. e. 50 kg of Aloe vera in one day. It was considered the prevailing wages of $ 2 for unskilled labour per day for cost analysis; the cost of manual gel expulsion comes as;
= 2 / 50
= $ 0.04 / kg
The manual gel expulsion cost for 1 tons Aloe vera leaves
= $ 40

The comparative cost analysis is presented in the **Table 6** for manual gel expulsion and mechanical gel expulsion of Aloe vera leaves. It has been found that the cost for gel expulsion for 1 tons of Aloe

**Table 5** Quality parameters for extracted crude gel

| Quality parameters | Aloe vera gel expulsion | |
|---|---|---|
| | Manual gel expulsion | Mechanical gel expulsion |
| Viscosity, Stokes | 0.638 | 0.621 |
| Refractive index | 1.3359 | 1.3364 |
| Optical density, abs | 0.238 | 0.239 |

**Table 6** Comparative cost for machine and manual gel expulsion of Aloe vera leaves

| S. No. | Particulars | Specifications | Rate ($) | Total Cost ($) |
|---|---|---|---|---|
| I | Manual gel expulsion | | | |
| | Labour charges per day | 1 No. @ $ 2 per 8 man hour | 2 | |
| | Capacity of gel expulsion | Average 96 leaves i.e. 50 kg per 8 man hour | | |
| | Total cost of manual gel expulsion $ /tons | | | 40 |
| II | Mechanical gel expulsion | | | |
| | Initial cost of Aloe vera gel expulsion machine $ | | 500 | |
| A | Fixed cost | | | |
| | Depreciation of the Aloe vera gel expulsion machine | 10 years useful life, 20% salvage value | 40 | |
| | Interest on investment | @12% on initial cost of Aloe vera gel expulsion machine | 60 | |
| | Repair and maintenance | @10% of initial cost of Aloe vera gel expulsion machine | 50 | |
| | Total fixed cost $/year | | 150 | |
| | Fixed charges $/day | 300 working days/year | 5 | 5 |
| B | Variable cost | | | |
| | Labour charges per day | 2 No.@ $ 2 per 8 man hour | 4 | |
| | Electricity charges | 12 KWH @ $ 0.14 per unit | 1.68 | |
| | Total variable cost $/day | | | 5.68 |
| | Capacity of expulsion, kg/day | 800 kg/day | | |
| | Total variable cost $/ tons | | | 7.1 |
| | Total cost of gel expulsion/day | | (A+B) | 10.68 |
| | Total cost of gel expulsion `/tons | | | 13.35 |
| | Ratio of cost for manual to mechanical gel expulsion | | | 2.99:1 |

Note : ` = Indian rupees
Currency conversion 1U.S. Dolor $ = 50 Indian rupees

vera leaves using the developed gel expulsion machine comes to be $ 13.35. This facilitated a saving of about $ 26.65 per tons for gel expulsion of Aloe vera leaves using the developed Aloe vera gel expulsion machine over the manual operation. The ratio of cost for manual to mechanical gel expulsion comes to around 3.0.

## Conclusions

It may be concluded that, for getting maximum gel recovery, minimum residual gel percentage, highest expulsion efficiency and output capacity, the expulsion of Aloe vera leaves should be carried out at 75 rpm roller speed and 25 - 30 mm thickness of Aloe vera leaves. The cost of gel expulsion for Aloe vera leaves by the developed machine was estimated to be $13.35/tons as compared to $ 40/tons by the manual method, resulting in cost reduction of processing about $ 26.65 per tons for gel expulsion of Aloe vera leaves.

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## News

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# A Review on Status of Gum Tapping and Scope for Improvement

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## Abstract

Natural gums are among the important non timber forest products and are produced from a wide range of plants. The gums may be found in any part of the plant or may occur only in the inner tissues and are extracted from the trees by tapping. Gum is tapped by exposing the gum ducts by making suitable incision on the stem of trees. The gum exudes from the gum canals where incision is made and is collected. Most of the natural gums are collected in small quantities by forest dwellers adopting traditional tapping methods. The tapping methods used are brutal and injurious to the plants, often leading to their death. The technology available is traditional and innovations are essential for sustainable yield and quality control. Concerted efforts by researchers and agencies such as research institution, universities and non-governmental organizations are urgently needed to improve method of tapping and collection for sustainable production of gums.

## 1. Introduction

In India, Non-Timber Forest Products (NTFPs) provide 50 % of total forest revenues, 55 % of forest based employment and 70 % of forest based export earning. National average value of NTFPs is 36.11 US dollars per ha and the gross value of NTFPs harvested in India is 905.00 million US dollars. Similarly, NTFPs based industries provide 1.6 million employments per year in India (Behera, 2009). The gross value of goods and services provided by the forestry sector is estimated as an average of 5285.63 million US dollars (2.37 % of GDP) comes from this sector. Forest and sub forest area provides 50 million employments to population inhabiting forest while minor forest produce contribute about 70 % employment (Giri *et al*., 2008).

Gums occupy a prime place among Non Wood Forest Produce (NWFP) and are known to mankind since time immemorial. These are perhaps the most widely used and traded NWFPs other than items consumed directly as food, fodder and medicine. Use of gums for domestic consumption and sale to earn some cash is very common among the forest dwelling communities, particularly tribals in India. Thousand of forest dwellers particularly in the central and western Indian states depend on gums as a viable source of income. Gums, commonly used in every day life, are having ample importance as Non-Timber Forest Produce.

Indonesia and China are among the world's major producers of gums and resins. India is rich centre of plant bio-diversity having more than 45,000 plant species including about 120 gum and resin yielding plants. It produces 246,900 tonne gum and 16,606 tonne of gum-resins during the year 2007-2008. Average annual export of gum and gum resin during 2013-14 was 473,095 tonne and 1,277 tonne of value Rs. 115,549 million and 408 million, respectively (Yogi *et al*., 2014).

In India, natural gums are derived from the selected tree species. Gum sector is one of the most important sources of livelihood support of more than 50 million population inhabiting forest and sub forest area besides being a major source of employment. The gums are produced by plants in the form of nodules spontaneously. It is also collected by making incisions in the bark of the tree trunk. In recent years, due to 'back to the nature' trend, there has been a revival of interest in natural gums collected from forests by rural and tribal people who depend on these resources to sustain their livelihood. The natural gums are non-toxic, biodegradable and eco-friendly for use in various industries. Therefore, there is tremendous potential to develop the sector further. It is admitted fact that neither the forest nor the tribals and poor inhabiting forest should be removed for environmental protection.

Generally, the weaker sections of society particularly tribals are involved in the collection of NTFPs. They collect these produce to sustain their livelihood. In India over 5 million tribal depend on NTFPs for their employment and household income from the forests (Rawat and Jishtu, 2006). Tribal groups inhabit on varying ecological and geo-climatic conditions (hilly, forest, desert etc) in different concentrations throughout the country with different cultural and socio-economic backgrounds. Historically, the economy of most tribes was subsistence agriculture or hunting and gathering. A large number of tribals in rural areas are still dependent on forests for their livelihood. In the forest based tribal economy provisions for basic necessities like food, fuel, housing material are made from the forest produce.

The tapping methods used are brutal and injurious to the plants, often leading to their death. The technology available is old and the innovations are essential for sustainable yield and quality control. A concerted effort by researches and agencies such as research institution, Universities and non-governmental agencies is urgently needed to improve all aspects of the industry such as tapping, collection, processing, grading, classification and marketing. Gum industry can provide employment and a steady additional income to rural people and thereby stop their migration into the towns and cities.

Most of the natural gums are collected in small quantities by forest dwellers by adopting traditional tapping methods. Benefit mainly depends on the quality of the produce. The existing techniques and devices of gum tapping is traditional and location specific. The techniques and devices which are in vogue are less efficient and time consuming and having problem in handling and its operation. Different methods followed for tapping and collection of some gums have been reviewed in this paper.

## 2. Gum Tapping

The gum exudes from the trees by tapping of blazes made by stripping off the bark. The quantity of gum exudes varies from tree to tree, depending upon its genetic character and climatic conditions. There are various views about the function of gum in the plant. Some believe that the gum is part and parcel of normal metabolism of the plant. In some cases the production of gum has been attributed to fungi attacking the plant. The fungi are being responsible for enzymes that penetrate the tissues and transform the cellulose and hemicelluloses of the cell wall into gum. In some cases it is believed that certain bacteria cause exudation of gum while in *Astragalus spp.* (true tragacanth) the gum is produced inside the plant by the transformation of cell walls and adjacent layers of medullary rays and the pith into gum. This readily absorbs water, causing it to swell and exerts pressure on the surrounding tissue. As a result, gum oozes from the stem of its own accord or due to injury (Krishinamurthy, 1993). It was estimated that, some trees yield maximum 100 g per blaze during peak season and 20 to 30 g per blaze in off-season in low gum yielding trees. However, the tree exudes 500 to 750 g per blaze during peak season in high gum yielding trees. The details regarding various gums tapping is discussed in detail as under:

### 2.1 Gum

#### *2.1.1 Frankincense (Gum from Boswellia caraterii)*

Gum (Frankincense) exudes from cracks in the bark of wild trees (Boswellia caraterii). In Africa (Euthopia), it is regularly tapped from trees, which are about six years old by making narrow transverse incisions in the bark of stems and branches. In about a month, tears of gum form on the surface are gathered.

In Ethiopia, harvesting of natural gums is done manually by labour intensive traditional methods of tapping (**Fig. 1**). Tapping and collection of frankincense is carried out following a specific pattern. The technique of tapping usually involves the shaving of a very thin, *i.e*. 2 mm deep and 4-8 mm wide, external circular layer of the bark starting at 0.5 m from the base of the stem using a hand tool, locally known as *'Mingaf'* (Girmay, 2000). Once the first tapping is done, the second tapping takes place after 30-40 days, and involves a moderate widening of the wound, which is started during the first tapping.

This tapping process continues for three to four months until the wound reaches 4 cm in width. Usu-


**Fig. 1** Frankincense gum tapping tool (Mingaf) and collection

**Fig. 2** View of different tapping tools (from left makmak, axe, mofar and sonkey)

ally three such tapping spots are made on each side of the plant, but they could also be four in some cases. Thus, six to eight tapping spots are made as a whole on each plant depending on its size (Girmay, 2000). After each wounding/incision, the exudate starts to ooze and becomes dry in two to three weeks when it is ready for collection. The wound is renewed immediately while collecting the gum to prevent the hole through which the exudate comes out from drying. On an average single tapper collects 500 g frankincense from individual trees and a total of 10-12 quintals within 9 months from October - June per season (Tadesse *et al*., 2007).

### *2.1.2 Talh Gum (Gum from Acacia seyal var. seyal)*

Two experiments were conducted in Sudan at Umfakarin forest reserve (South Kordofan) to investigate the effect of different tapping tools *viz. makmak, axe, mofar* and *sonkey* and tapping positions on *talh* gum yield of *A. seyal* var. *seyal* (Kamal *et al*., 2004). In the first experiment, four different tapping tools *makmak, axe, mofar* and *sonkey* were used (**Fig. 2**). All trees were tapped at the middle stem position. In the second experiment, trees were tapped on four different positions (low stem, middle stem, high stem and branches) using the *makmak*. In both experiments trees were tapped on the 1st of November, and gum was collected four times (1st December, 1st January, 1st February and 1st March). The yield of each tree in both experiments was determined by weighing the gum directly after every collection.

The removal of bark to expose the wood surface stimulated gum excretion on *A. seyal* var. *seyal* in both experiments. The results of the first experiment clearly show that the tapping tool had a great influence on the amount of *talh* gum production of *A. seyal* var. *seyal*. Over the season, trees produced more gum when they were tapped with the *makmak* and the lowest when tapped with the *sonkey*. In comparison to trees tapped with *makmak*, trees tapped with *axe*, *mofar* or *sonkey* produced 58, 59, 75 % less gum, respectively.

In the second experiment, the different tapping positions on *A. seyal* var. *seyal* lead to different gum yields. The middle stem tapping caused the highest gum secretion with a total yield of 275 g/tree. With the low stem tapping, the high stem tapping and the branch tapping, gum yield was reduced by 26, 57 and 41 %, respectively.

In both experiments there were variations in the amount of gum secretion from different trees within the treatments. The experiments clearly showed the possibility of *talh* gum production by tapping *A. seyal* var. *seyal*. The use of four different tapping tools in the first experiment indicates that the *makmak* was the best tapping tool for high gum production. The reasons can be the wide edge on the top of the *makmak* tool, which allows one to remove a big piece of the bark. The lowest gum yield was obtained from trees which were tapped with the *sonkey* (Kamal *et al*., 2004). In the second experiment, the middle stem tapping caused the highest gum exudation. It was also a suitable height for easy gum collection. Tapping the branches gave the lowest gum yield per tree and is not recommended for *talh* gum production. In contrast, A. senegal is often tapped on its branches due to the small tree size and its highly branched stem. Reasons for the monthly variation in gum production in both experiments can be seen in the different metabolic activities of the trees during the season (Harsh *et al*., 2003).

### *2.1.3 Gum Arabic (Gum from Acacia Senegal)*

Gum is exuded from Acacia senegal and other acacia trees in the form of tears or nodules of 20-50 mm diameter (**Fig. 3**). There is no doubt that manual collection and sorting of gum into the varieties (“clean amber”, “handpicked products” and “siftings”) is costly and time consuming. Collection takes place at intervals during the dry season from November to May and two main harvests are taken in December and April, in the major gum producing areas of the northern hemisphere. In general, higher the average temperature, greater is the production of gum. However, the natural yield of gum from each tree rarely exceeds 10-100 g per harvest. Hence, for commercial production of the gum, stripping of 2 ft by 2 inch section of the bark from the tree trunk is carried out. In 4-8 weeks the dried gum harvested in this way can amount to 200g per tree. High rainfall during the growing season and the higher temperature during dry season give the higher gum yield (Mathur and Mathur, 2008).

The gum exudes from the cracks on the bark of the tree under difficult conditions such as heat, dryness, wounds and diseases. The gum flows naturally from the bark of the trees in the form of a thick and rather frothy liquid, and speedily concretes in the sun into tears. To accelerate exudation and to improve and regulate gum production, Acacia trees are tapped by means of incisions (60 cm × 5 cm) made in the branches some weeks ahead of tapping time. Usually mature trees, 4.5-6.0 m high and 5-25 years old, are tapped by making incisions in the branches and stripping away bark. The gum starts to collect in the wound within 3-8 weeks, but this depends on the weather conditions. The gum dries into rough spheres, which are manually collected (**Fig. 4**). Gum droplets are about 0.75-3.0 cm in diameter and they gradually dry and harden on exposure to the atmosphere (Giri *et al*., 2008).

**Fig. 3** Exuded gum Arabic from Acacia Senegal

**Fig. 4** Collection of Gum Arabic

In Ethiopia, gum arabic is collected both from naturally oozing (Southern part of Ethiopia) and by tapping (Northern part). Yields of gum Arabic from individual trees are quite variable. A figure of 250 g of gum per tree per season is often cited as an average yield from individual trees (Dagnew, 2006).

*Acacia Senegal, Acacia tortilis, Anogeissus rotundifolia, Cordia rothii, Boswellia serrata* and *Combiphora weightii* are the main gum producing species in arid zone of India. In arid western Rajasthan, Acacia senegal grows abundantly in different habitat like rocky, semi-rocky, sandy plains and dunes of old formation in Jodhpur, Barmer, Jalore, Jhunjhunu, Churu, Sikar, Bikaner and Ajmer districts. Inspite of its wide distribution in India, the gum production from this species is abysmally low.

To produce and enhance gum Arabic production from Acacia senegal tree, a small size hole (25 mm × 06 mm) diameter with $45^0$ inclination towards inner side (Mertia *et al*., 2007) is made on the tree trunk about 45-50 cm above the ground and ethepon (780 mg/4 ml) is injected in the hole (Harsh *et al*., 2003) through syringe. The hole is plugged with the clay soil or bee wax. This process of gum production is known as CAZRI's technology. The trees are treated once in a year in the month of March. The depth of the hole is kept smaller because the gum contents are higher in bark and outer wood, while the inner wood contains less gum (Seif-El-Din, 1981). After 7-10 days, gum exudes from whole plant in the form of gum tears and all the tears are collected manually. Without treatment, gum production ranges from 10 to 100 g per tree whereas with CAZRI's technology it ranged from 100 to 2,000 g per tree with an average of 500 g per tree. Using CAZRI's technology, gum production ranges from 4 to 17 kg/ha if the tree density is between 10 to 50 trees per ha (Yadev *et al*., 2008).

In some countries gum from *Acacia senegal* is obtained by tapping the trees while in others, natural exudation occurs. *A. seyal* gum comes entirely from natural exudation but in small tears or driblets, making their collection time consuming. Tapping begins when the trees begin to shed their leaves. A specially designed tool with a pointed metal head is pushed tangentially into the stem or branch so as to penetrate just below the bark, and then pulled up so as to strip a small length of bark longitudinally from the wood. Damage to the wood should be minimal. Several branches are treated in a similar manner at one taping. The tears of gum which form should be picked by hand when they have dried and hardened. Importance is laid on maintaining the harvested gum clean and dry. Mixtures of various Acacia species should be avoided to prevent lowering the quality of the gum. Traders undertake the process of cleaning and grading the gum. Kibbling or powdering the gum for easier use is normally undertaken in the consumer countries (Baldascini, 2002).

#### *2.1.4 Gum Karaya (Gum from Sterculia urens Roxb.)*

Gum Karaya is commercially tapped through blazing, peeling or by making deep cut in the base of the tree trunk with an *axe*. A simple and safe technique of tapping with substantial increase in the yield is developed using ethephon to enhance gum yield and wound healing. Optimum concentrations of ethephon to induce maximum production of gum with minimum injury to the tapped trees are studied using a specially devised knife (**Fig. 5**). Holes of 5 mm diameter and 20-35 mm depth (based on the thickness of the bark) are made on the tree trunk of 200 to 300 mm distance at 100 mm above the ground (**Fig. 6**). The holes are angled towards the base of the tree to prevent the back flow of the introduced solutions. One hole in each tree is maintained as the distilled water control and rest of them are treated with ethephon (2-chloroethyl phosphonic acid). One ml of ethephon containing 190/285/390 mg of active substance (one ml of distilled water for controls) is dispensed into each hole.

A preliminary observation showed that ethephon enhances gum formation and wound healing in Sterculia urens (Nair *et al*., 1995). The gum started oozing out after 4 hours in treated holes. After couple of weeks the exuded gum appears as stalactic mass. The first collection of gum produced in the control and treated holes were made after 15 days. The succeeding 3 collections were done after every 10 days. Trees treated with 285 mg of active substance of ethephon yielded highest amount of gum.

The ethephon treatment showed an increase in gum karaya yield of 40 to 85 times than the control. The gum karaya obtained through ethapon treatment is of high quality (first grade).

The normal practice in Raipur for gum karaya tapping is making blaze (**Fig. 7**) with the help of an *axe* or "Kulhadi" on the tree trunk. During the survey, three types of blazing have been observed (Shaw *et al*., 2010). First type of blazing for tapping gum karaya involves making 2-3 blazes of around 10 cm × 20 cm size on the tree at different places at a time and collection of gum begin after 7-8 days. In continuation of the process of tapping another 2-3 or more blaze are made. In second type gum tapping, around 10-20 cuts are made on the tree trunk at a time and collection of gum start after 7-8 days. Similarly another 10-20 cuts are again made on the tree trunk. In third type of gum tapping, a big blaze is made and collection of gum starts after 7-8 days (**Fig. 8**). In similar fashion another blaze is made just after leading to girdling.

As gum karaya is vital for the tribal economy and its trade value is substantial there is a pressing need to develop a scientific and sustainable tapping method to increase the yield and to ensure the survival of the tapped trees.

***2.1.5 Gum Ghatti (Gum from Anogeissus latifolia)***

The trees are not usually tapped for gum. The gum oozes out naturally from the bark through injuries and wounds mostly in summers and is collected manually. In some places artificial incisions are made in the tree bark to increase the gum yield. These incisions are made carefully so as not to permanently injure or kill the tree (Giri *et al*., 2008).

***2.1.6 Palosa Gum (Gum from Acacia modesta)***

Gum collected from trees of *Acacia modesta* is locally known as "palosa". Palosa gum is eaten by women as a sweet. It is believed to restore vitality, particularly after child birth.

The tree grows in sub-mountainous tracts up to altitude of 1,200 m. It starts producing gum after 4 or 5 years, when it yields about 0.06 kilograms of gum. Production increases with age until about 20 years, when it stabilizes at about 0.25 kilograms per tree per year. The gum oozes spontaneously from the stems and main branches in October and November and is then collected by hand (Iqbal, 1991).

***2.1.7 Tragacanth Gum (Gum from A. Microcephalus)***

During gum collection, plants are generally incised with a sharp blade and the gum exudes spontaneously and rather quickly from the wounds and dries in curled ribbons or in some species as flakes. Bushes are scattered and grow low to the ground. After tapping, they are left for several weeks until the hardened gum can be collected by hand. Hand collection is a time consuming and laborious task. Ribbons are white to off white and 50-150 mm or more in length. The highest grades of gum are milky white; lower grades are some what glossy and translucent with low viscosity (Sagta and Nauti-

**Fig. 7** View of blaze for gum karaya tapping

**Fig. 5** Tool for tapping gum Karaya

**Fig. 6** Tapping of gum Karaya

**Fig. 8** View of gum karaya exudate

yal, 2003).

### *2.1.8 Locust Bean (Carob) Gum (Gum from Ceratonia siliqua)*

The first commercial fruit can be harvested after about 5-7 years. After flowering, the pods take approximately 6-8 months to mature, turning from green to chocolate brown in late summer. They are usually harvested by knocking them off with long poles, preferably aimed at the cluster of pods rather than by hitting the branches indiscriminately. Passing them through mechanical rollers, sometimes after a dilute acid pretreatment, dehusked seeds are then split in half lengthwise by metal rollers, and the germ is separated from the endosperm through differential grinding. An alternative process is oven dehulling in which the seeds are heated to high temperatures for about 45 seconds and than passed through a series of roller mills to remove the husk and germ simultaneously. It is important that a clean endosperm separation is achieved, since incomplete husk removal leaves specks in the gum and any remaining enzyme activity of a residual germ can cause viscosity loss over time in prepared gum solutions. The endosperm is finally milled, classified, sized and blended to a nearly white powder of various mesh sizes. Various grades are available. The highest grades are those which are most speck free and have the highest viscosity (Sagta and Nautiyal, 2003).

**Fig. 9** Exudation of oleo-gum resin from Guggul stem

### *2.1.9 Tara Gum (Gum from Caesalpinia spinosa)*

Most seeds are harvested from wild trees subjected to simple pruning operations. The seeds consists of germ 40 %, hull 38 % and endosperm 22 %. Tara gum is manufactured by milling the endosperm portion of the seed into the flour. Processes for separation of the Tara endosperm from the hull and the germ are the same as those employed for guar and locust bean kernels. Pure Tara gum is a white to cream coloured powder. Incomplete removal of the dark brown hull however will result in tan coloured gum (Sagta and Nautiyal, 2003).

### *2.1.10 Mesquite Gum (Gum from P. juliflora)*

The ground endosperm of mesquite seed consists mainly of galactomannan-type polysaccharides, similar to those in locust bean and guar gums. Mesquite gum is not yet produced on a commercial scale, but *P. juliflora* is widely grown as a source of animal feed, fodder and fuel in some countries such as Brazil and India. As with other seed gums, the galactomannan component of mesquite seed is contained in the endosperm, which constitutes about 30 % of the seed by weight. The seeds themselves are embedded in a hard endocarp and represent about 10 % of the pod weight.

The term "mesquite gum" is used to denote the ground endosperm of the seed from *Prosopis* spp., in particular *P. juliflora*, a leguminous tree native to Central America, but now widely distributed elsewhere. An exudate gum, similar in composition to gum arabic, can also be obtained by making incisions into the trunk of the tree, but yield is poor.

A major obstacle to the economic recovery of the seed gum is the toughness of the seed pod and the difficulty, firstly, of separating the seeds from the surrounding pulp and, secondly, splitting and cleanly separating the endosperm from the germ. (One consequence of the hardness of the seed - which contributes to the ability of *Prosopis* to spread so easily - is that it remains intact during ingestion of the pod by browsing animals and emerges later in a suitable state for germination). Yields of 10 tonnes/ha of pods have been reported from cultivated mesquite in Brazil, equivalent to a yield of about 1 tonne/ha of seeds or 300 kg/ha of gum (endosperm). Elsewhere, 2.3 tonnes/ha/year of pods have been reported from a density of 118 trees/ha, equivalent to a yield of about 20 kg/tree (Schmincke, 1995).

## 2.2Gum - Resin

### *2.2.1 Guggul Gum-Resin (Gum-Resin from Commiphora wightti)*

Generally the gum resin is collected by tribal people using traditional tapping methods involving making several deep incisions on the stem to extract the maximum amount of gum.

They then apply a paste consisting of horse or wild ass urine, oleo gum resin and copper sulphate around the incision. Whilst this crude method increases the amount of gum three to four times over that obtained under normal tapping procedures, the shrub becomes subsequently unfit for tapping for the next couple of years and ultimately plants may die due to the injurious effect of copper sulphate (Kshetrapal & Sharma 1993). It is now believed that such tapping methods to increase gum yield causes mortality of plants (Soni, 2010).

Usually 1.5 cm deep circular incisions are made on the main stem for tapping guggul (**Fig. 9**), not beyond the thickness of the bark. Guggul gum-resin ooze out from these incisions as pale yellow, aromatic fluid that quickly solidifies to form a golden brown or reddish brown agglomerate of tears or stalactic prices (Giri *et al*., 2008).

In Gujarat, normally a blaze is

made in the middle of the stem with the help of a sharp half circular knife applying curd or such other stimulating material (Anonymous, 2007). The oozing of gum starts and continues till exhaust. Due to a cut across the stem the trees gets infected and gradually die. Thus the traditional system of gum tapping leads to mass killing of guggul trees. Hence, silvicultural operations require some restrictions. Proper technique of gum tapping needs to be evolved, so that the periodical extraction can be done and such trees can survive for its total life span.

An improved tapping technique, using 'Mitchie Golledge' knife, coupled with ethapon application has been devised. This method can enhance guggul production by about 22 times over the control. The technique is safe but expensive and requires no specialized skills and can easily be taught to the tribals. April and May are peak months for guggul tapping as established by localization of resin in the sanctioned material using bright field and epifluorescence microscopy.

***2.2.2 Asafoetida Gum (Gum-Resin from Ferula northex)***

The gum resin is obtained from incisions in the roots and rhizomes of the plants. Usually plants of four to five years old develop very thick and fleshy carrot shaped roots. The upper part of the root is laid bare and the stem is cut close to the crown. The exposed surface is covered by a dome shaped structure made of twigs and earth. A milky juice exudes from the cut surface which soon coagulates when exposed to air. After some days, the exudate gum-resin is scraped off and a fresh slice of the root is cut (Giri *et al*., 2008).

***2.2.3 Salai Gum (Gum from Boswellia serrata)***

Usually trees of 90 cm girth and above at breast height are tapped. A thin band of bark of about 30 cm in length and 20 cm wide is shaved from the trunk of the tree at a height of 0.75 meter from the ground. The blaze is freshened after every fourth or fifth day. Collection is done by a scraper keeping a tray having a semi circular edge around the blazed surface (Giri *et al*., 2008).

## 3. Conclusions

- Present practices of gum tapping from selected trees are traditional, location specific, require more time and worker, less efficient and gum yield is less with more injury to the trees involving problem of drudgery for pickers/collectors.
- Concerted efforts by researchers and agencies such as research Institutions, Universities and Non Government Organizations (NGOs) is urgently needed to improve all aspects of gum tapping, collection, processing, grading, classification and marketing.
- Gum tapping could be promoted and migration of gum pickers/collectors could be minimized with reduction in drudgery and increase in efficiency with little improvement in the existing techniques and devices. Hence, increase in sustainable livelihood of rural and tribal people might be possible with adoption of the gum sector.

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# Design, Manufacturing and Field Test of Animal-drawn Ground Nuts planting Machine for Rural Farming in Northern Kordofan (Sudan)

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## Abstract

An animal drawn ground nut planting machine was designed and manufactured from local materials in Elobeid town, Nothern Kordofan state, west of Sudan. The machine was developed from seed box, metering device, furrow openers, driving wheels and an iron frame for linking with the animal. The developed animal drawn machine was tested in the field with three animals (donkey, mule and horse) and compared with manual planting. The results showed that the highest total field time was recorded by manual sowing (5,828.3 sec/plot), while the lowest total field time was recorded by machine with mule (1,341.8 sec/plot) The average operating speed of the three animals (80m/sec) was higher than the manual by 77 %. The difference between treatments were highly significant at $P \leq 0.01$. The rate of work of manual sowing (0.032 ha/h) was lower than the average rate of work of animal drawn machine by 75 %. The average plant density when using the animal drawn machine was 13 plants/m$^2$, while in case of manual sowing it was 19 plants/m$^2$. Statistical analysis showed no significant difference between the three animals, but compared to manual planting, the difference was highly significant at $P \leq 0.01$.

## 1. Introduction

There are three main sources of power in agriculture, human, animal and motorized power. In the rural areas of developing countries like Sudan, Nigeria and India, farmers use simple implements and tools utilizing human and animal power, therefore their production is low. In spite of many trials for mechanizing and using large machinery for small- scale and traditional farming agriculture, the general recognition is that sophisticated and expensive technology will never be a suitable solution for small farmers (Milles, 1982). Introduction of animal-drawn implements as intermediate technology for small farmers is becoming increasingly necessary, especially for some critical operations like planting and weeding (Hetz 1988, Rahma 1993, Awadhawal 1994, Wohab *et.al.* 1997). Animal draught implements compared to manual tools have positively affected the crop production factors through improving field efficiency and capacity, increasing crop yield and reducing costs of production (Stevens , 1992, Atu, 1998, Dosh, 1998, Dahab and Hamad, 2003).

In western Sudan, farmers grow different types of crops such as millet, sorghum, groundnuts (G/N), water melon and cowpeas in small holdings as traditional agriculture (Edward, 1981). They use many types of small farming tools and implements at different stages of crop production. Animal drawn implements are used by some farmers mainly for weeding of G/N (the most important cash crop in the area). This practice was observed to increase the cultivable land, reduce the cost of production and improve the general standard of living of the people (Starkey 1992, Dahab and Hamad, 2003). Therefore, selection and introduction of appropriate farming technology for rural agriculture like animal traction implements may affect positively crop production factors and increase the final yield. The main objectives of this study are:

1. To design and fabricate animal drawn G/N planting machine using local materials
2. To evaluate the field performance of the developed machines drawn by donkeys, mules, and horses compared to manual sowing through measuring productive, turning and total field time, operating speed, field efficiency and capacity and plant density.

## Materials and Methods

**Materials**

The experimental work was conducted at FaragAlla village, north Elobied town which is characterized by sandy soil whose physical properties are shown in **Table 1**.

Materials used in this study for manufacturing the planting machine are given in Table 2. Other materials used were three animals (donkey, mule, horse) for pulling the machine and one labour for manual sowing.

**Table 1** Soil physical properties of the experimental areas

| Parameter | Value |
|---|---|
| Soil bulk density | 1.1 gm/c |
| Soil cohesion | 0 |
| Soil-steel adhesion | 26.3 kPa |
| Soil internal angle of friction | $42^0$ |
| Soil-steel angle of friction | $22^0$ |
| Soil-steel friction coefficient | 0.41 |

**Methods**

***Fabrication of the planting machine:***

The machine was fabricated in a workshop in Elobied town. Three winged type furrow openers were manufactured each with $45^0$ rake angle, two winged type covering devices were made to perform weeding operation and cover the seeds simultaneously. The frame of the machine was constructed with seed box supported by two ground rubber wheels. The seed box was composed of three separated units to prevent accumulation of the seeds in one side of the box. The machine metering device was composed of three steel plates each with five holes for seed placement through a seed pipe; each plate was supplied with a brush to prevent the seeds holes to be clogged with seeds. The rotational motion was transmitted to the plate by meshed bevel gears welded on a rectangular steel rod. One end of the rod was supplied with a toothed gear which receive the motion from other toothed gear fixed on a rear rubber wheel through a steel chain. The rear wheel was connected to the frame by two bars in a way that it could be idle when the machine was not in operation. A cylinder to be filled with soil for ballasting purposes was connected vertically to bars. The motion wheel in the present machine was placed behind the supporting wheels.

**Table 2** Materials used for machine manufacturing

| Items | Number |
|---|---|
| Angle bar | 3 |
| Steel beam | 2 |
| Medium carbon steel sheet | 3 |
| Rubber wheel | 3 |
| Steel wheel | 3 |
| Plastic hoses | 3 |
| Steel tubes | 3 |
| Steel bases | 3 |
| Transmission gears | 2 |
| Bevel gears | 6 |
| Steel chains | 2 |
| Bearings | 5 |
| Pivot gears | 3 |
| Rectangular section steel rod | 4 |
| Steel pipes | 2 |
| Box cover bolt and lock | 1 |
| Pins and bolts | - |
| Weights | 5 |
| High carbon steel sheet (for ridgers) | 3 |
| High tensile springs | 5 |
| Rectangular rod (for stands and base frame) | 5 |
| Steel discs (for metering device) | 3 |

***Field performance test of the planting machine***

The field performance evaluation of the planting machine was conducted and the parameters measured included field time, operating speed, theoretical field capacity, effective field capacity, field efficiency and plant density.

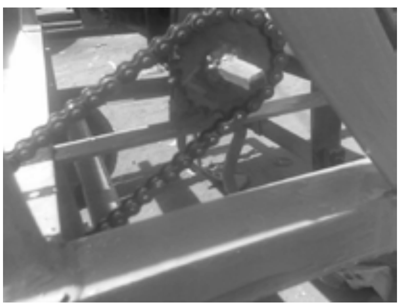
The experimental area was 0.86 ha, and it was divided into 16 plots each 5.4 m × 100 m. A completely randomized plot design (CRD) was used. The treatments were distributed randomly in the experimental plots and replicated four times. Seeding operation was performed using four treatments namely:

i- Planting machine drawn with

(a) Front view

(b) Rear view

(c) Side view



(d) Motion transmission chain

**Fig.1** The manufactured ground nut planting machine

**Table 3** Planting machine specifications

| Parameter | Value |
|---|---|
| Number of furrow openers | 3 |
| Operating width | 0.54 m |
| Operating depth | 0.12 m |
| Furrow opener rake angle | 45° |

donkey.

ii- Planting machine drawn with mule.

iii- Planting machine drawn with horse.

iv- Manual seeding.

***Measurement of field times***

Time for each stroke to cover 100 m, the length of the plot was recorded as a productive time. Time for each turn at the end of the plot was determined. Total time required to cover the plot was computed as follows:

Total time (sec) = $\Sigma PT + \Sigma TT$.........(1)

Where,

$PT$ = productive time, (sec).

$TT$ = time of turns, (sec).

***Determination of operating speed***

The operating speed was computed as follows:

$S = L / t$.............................................(2)

Where,

S = operating speed, (m/sec).

$L$ = length of the plot, (m).

$t$ = time required to cover one stroke, (sec).

***Determination of theoretical and effective field capacities***

Theoretical field capacity was calculated as follows:

$TFC = (W \times S) / C$...........................(3)

Where,

$TFC$ = theoretical field capacity, (ha/h).

$W$ = machine width, (m).

$C$ = conversion factor.

Effective field capacity was calculated as follows:

$EFC = A / C \times T$.............................(4)

Where,

$EFC$ = effective field capacity, (ha/h)., A = plot area, ($m^2$).

$T$ = total time required to cover the plot, (sec).

***Determination of Field efficiency***

$FE = (EFC / TFC) \times 100$ ..............(5)

Where,

$FE$ = field efficiency, (%).

***Determination of plant density***

Number of plants per meter square was counted at randomly selected locations in each plot.

## Results and Discussion

**The Manufactured Planting Machine**

The specifications of the developed planting machine are shown in **Fig. 1** and given in **Table 3**.

**Field Performance Evaluation of the Planter**

***a) Field times measurement***

Means separation between different treatments effect on field times (Productive, turning and total times) are demonstrated in **Table 4** and presented in **Fig. 3**.

It can be observed that the average productive time of the machine when drawn with any of the three animals was 1,279.6 seconds while in case of manual sowing its time was 5,828.3 seconds which was the highest productive time used. The difference in the productive time between the machines with the three animals showed no significant difference at $P \leq 0.01$ (**Table 7**), while when compared with manual the difference was highly significant.

In case of turning and other loss time, it was observed that there was significant difference between machine drawn with the animals and manual sowing (**Table 4**). The total

**Table 4** Means separation for field times

| Treatment | Productive time (sec) | Turning + loss time (sec) | Total time (sec) |
|---|---|---|---|
| Machine X Donkey | 1,267.0 ±50$^{ab}$ | 274.8 ±12$^{a}$ | 1,541.8 ±59$^{a}$ |
| Machine X Mule | 1,097.5 ±13$^{b}$ | 224.0 ±8$^{a}$ | 1,341.5 ±16$^{a}$ |
| Machine X Horse | 1,474.3 ±65$^{a}$ | 452.3 ±17$^{b}$ | 1,926.5 ±76$^{b}$ |
| Manual | 5,823.3 ±77$^{c}$ | 3,790 ±146$^{c}$ | 5,828.3 ±77$^{c}$ |

Each value is mean  standard error.

Means in column share same superscript letters showed no significant differences at.

**Fig. 2** Groundnut planting machine in operation

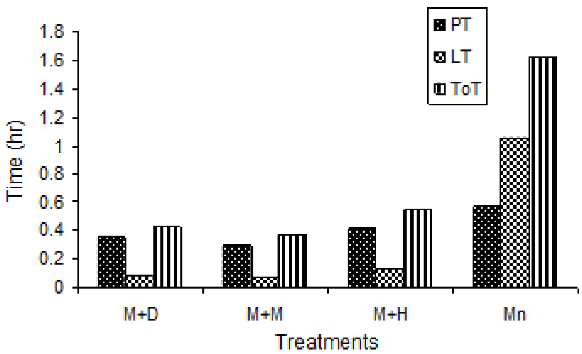



**Fig. 3** Effect of treatments on different times during plot sowing

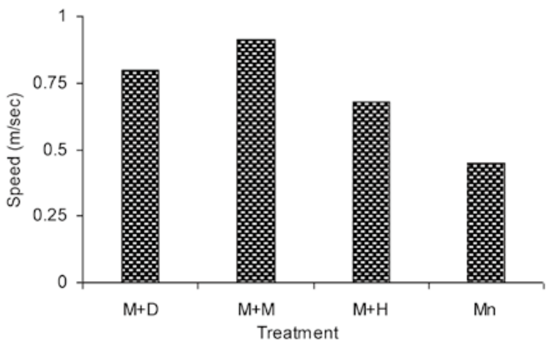



**Fig. 4** Operation Speed for different treatments during plot sowing

**Table 5** Means of speeds, field capacities and efficiencies

| Treatments | Speed (m/sec) | Theoretical field capacity (ha/h) | Effective field capacity (ha/h) | Field efficiency (%) |
|---|---|---|---|---|
| Machine X Donkey | 0.80 ±0.04$^{ac}$ | 0.155 ±0.005$^{a}$ | 0.128 ±0.005a | 82.3 ±1.6$^{a}$ |
| Machine X Mule | 0.91 ±0.01$^{a}$ | 0.175 ±0.003$^{b}$ | 0.147 ±0.003$^{b}$ | 84.3 ±1.3$^{a}$ |
| Machine X Horse | 0.68 ±0.03$^{c}$ | 0.130 ±0.006$^{c}$ | 0.105 ±0.002$^{c}$ | 80.9 ±1.4$^{a}$ |
| Manual | 0.45 ±0.03$^{d}$ | - | 0.032 ±0.001$^{d}$ | 35.0 ±0.2$^{b}$ |

Each value is mean ±standard error.

Means in column share same superscript letters showed no significant differences at.

loss time of manual was four times higher than the machine drawn by the three animals.

The highest total field time was recorded by manual sowing (5,828.3 seconds), while the lowest total field time was recorded by machine with mule (1,341.8 seconds) and the difference between the donkey and mule was not significant at $P \leq 0.01$ (**Table 4**). These values indicated that the animals drawn machine was faster than the manual sowing and uses less time in the field. **Fig. 2** shows the animal drawn machine operating in the field.

***b) Operating speeds, field capacities and efficiencies***

The means of operating speeds, theoretical field capacity, effective field capacity and field efficiency are given in **Table 5**. It is clear that the highest operating speed was recorded by machine with mule (0.91 m/sec), while the lowest speed was recorded by manual sowing (0.45 m/sec). The average operating speed of the three animals was higher than the manual by 77 % (**Fig. 4**), which means less time in the field.

The highest effective field capacity was given by machine drawn with mule (0.147 ha/h), followed by machine drawn with donkey (0.128 ha/h), while the lowest effective field capacity was recorded by manual sowing (0.032 ha/h). The difference between treatments was highly significant at $P \leq 0.01$ (**Table 7**). The rate of work of manual was lower than the average rate of the machine with the three animals by

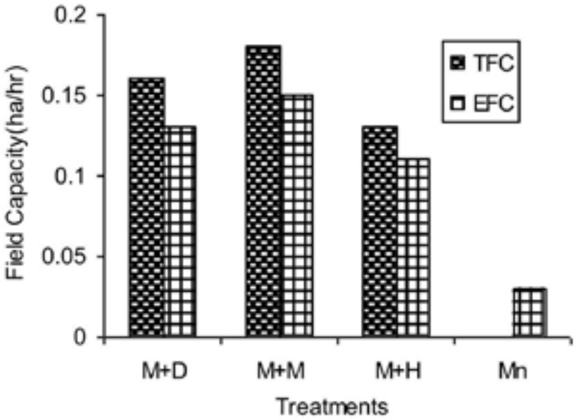



**Fig. 5** Effect of treatments on field capacities during sowing the plot

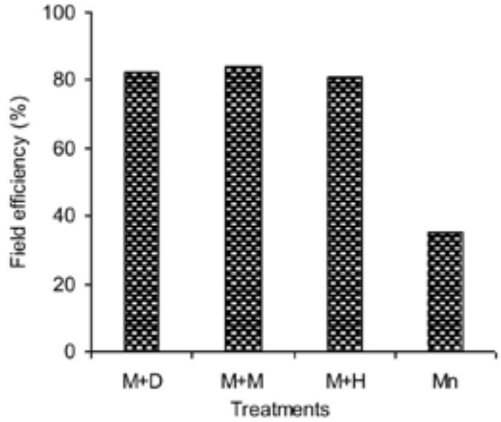
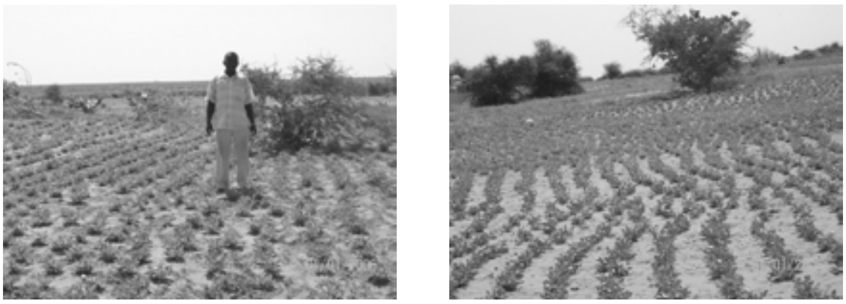



**Fig. 6** Effect of treatments on field efficiency during sowing the plot



(a) Plant density in plots sown by planting machine

(b) Plant density in plots sown manually

**Fig. 7** Plant density

75 %, which means more time for carrying out the operation (**Fig. 5**).

There was no significant difference between the field efficiencies of the machine with the three animals (**Table 9**). The average field efficiency of the three animals was 82.5 % while that recorded by the manual method of sowing 35.2 % (**Fig. 6**).

***c) Plant density***

The mean plant density of the treatments is given in **Table 6**. Analysis of variance for different parameter showed no significant difference between the three animals, but compared to the manual the difference was significant at $P \leq 0.01$ (**Table 7**). **Table 8** showed that the average plant density when the machine drawn with the three animals was 13 plants/ $m^2$, while in case of manual sowing it was 19 plants/$m^2$. **Fig. 7a** and **Fig. 7b** shows the differences in plant density between the machine drawn by animals and manual planting.

**Table 6** Mean plant density for different treatments

| Treatments | Plant density (plants/$m^2$) |
|---|---|
| Machine X Donkey | 13.0 ±0.3$^a$ |
| Machine X Mule | 13.0 ±0.6$^a$ |
| Machine X Horse | 13.0 ±0.4$^a$ |
| Manual | 19.0 ±0.8$^b$ |

Each value is mean  standard error.

Means in column share same superscript letters showed no significant differences at $P \leq 0.01$.

## Conclusions

1. The planting machine which was developed locally showed higher field performance parameters compared to manual sowing.
2. Although manual sowing was slow and less efficient, it demonstrated higher plant density as compared with the animal drawn machine.

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**Table 7** Analysis of variance for the different measured parameters

| Parameters | Source of variation | DF | SS | MS | F-value | P |
|---|---|---|---|---|---|---|
| Productive time | Between treatments | 3 | 2,011,556.50 | 670,518.80 | 34.3 | P < 0.001 |
| | Residual | 12 | 234,624.50 | 19,552 | | |
| | Total | 15 | 2,246,181 | | | |
| Turning + loss time | Between treatments | 2 | 36,147,493.40 | 12,049,164.50 | 553 | P < 0.001 |
| | Residual | 12 | 261,445.50 | 21,787.10 | | |
| | Total | 15 | 36,408,939 | | | |
| Total time | Between treatments | 3 | 54,259,018.50 | 18,086,339.50 | 1,174.9 | P < 0.001 |
| | Residual | 12 | 184,725.50 | 15,393.80 | | |
| | Total | 15 | 54,443,744 | | | |
| Operating speed | Between treatments | 3 | 0.469 | 0.156 | 52.45 | P < 0.001 |
| | Residual | 12 | 0.036 | 0.003 | | |
| | Total | 15 | 0.505 | | | |
| Theoretical field capacity | Between treatments | 2 | 0.004 | 0.002 | 22.9 | P < 0.001 |
| | Residual | 9 | 0.0008 | 0.00009 | | |
| | Total | 11 | 0.005 | | | |
| Effective field capacity | Between treatments | 3 | 0.031 | 0.0102 | 261.8 | P < 0.001 |
| | Residual | 12 | 0.0005 | 0.00004 | | |
| | Total | 15 | 0.031 | | | |
| Field efficiency | Between treatments | 3 | 6,801 | 2267 | 220.3 | P < 0.001 |
| | Residual | 12 | 123.5 | 10.3 | | |
| | Total | 15 | 6,924.5 | | | |
| Plant density | Between treatments | 3 | 111.18 | 37.06 | 31.21 | P < 0.001 |
| | Residual | 12 | 14.25 | 1.19 | | |
| | Total | 15 | 125.44 | | | |

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference at (P = < 0.01).

# Research and Application of Osmotic Dehydration Technique in Preservation of Fresh Guavas (Psidium guajava L.)

by

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## Abstract

The consumer demand for high quality products with fresh-like characteristics has promoted the development of a new technology of osmotic dehydration. Osmotic dehydration done only as soaking process requires long time for osmotic equilibrium achievement. Vacuum pulse technique, solutions temperature and concentration can enhance mass transfer process of solution's solids. The effects of those parameters on mass transfer of different geometrical shapes of minimally processed Guavas (plate slices, cylinder and sphere) were investigated. Weight reduction, water loss and gain solids were obtained using sucrose solutions at 45, 57 and 65 °Brix at solution's temperatures of 30, 48 and 58 °C and vacuum pulse of 0, 50 and 100 mbar for 10 and 20min at the process beginning. Higher solutions concentrations, temperatures and the vacuum pulse application caused an increase on water loss of osmotically dehydrated Guavas. The highest water loss reached was 69.17 % at 65 °Brix, 58 °C and 100 mbar at 20 min. The gain solids was reduced by the increase in osmotic solutions concentration; and raised up by vacuum pulse application and solutions temperature. Maximum gain solids achieved was 25.93 % at 45 °Brix, 48 °C and 100 mbar at 20min. Osmotic dehydrated Guavas' plates have the optimum mass transfer characteristics of gain solids and water loss due to its higher surface area to volume ratio of 520 $m^{-1}$. Kinetics diffusion model of Fick's law, for the three different geometrical shapes, was tested obtaining diffusivity and to compare favored shape. The effective diffusivity determined by the model well represented the effect of osmotic dehydration process treatments on mass transfer and showed a better agreement to the experimental data. The quality of investigated Guavas (*Psidium guajava L.*) pulsed osmotically dehydrated and packaged under passive modified atmosphere conditions, was evaluated during four weeks of storage. Passive modified atmosphere applied with polyethylene terephthalate containers had the highest potential on preserving and maintaining weight loss of 13 % and respiratory quotient of 1.40 ±0.97.

***Keywords:*** osmotic dehydration process, shelf-life extension, vacuum pressure technique, guavas preservation, mass transfer.

## Introduction

Guava fruits have a short shelf-life, which varies with the cultivar and the rate of ripening of fruits. It is, therefore, important to find ways of extending the postharvest shelf-life of Guava fruits to improve their marketability as fresh fruits, as well as to regulate supply to the processing plants. Mature Guavas do not keep well and are transported rapidly to the fruit processing factories. Guava fruits are usually shipped in small boxes rather than in bigger crates, as these fruits are easily crushed or bruised as the damaged fruit deteriorates fast. Fully mature fruits can be refrigerated during shipment. Guavas, like most other tropical fruits, are highly chill sensitive. Varietal differences in shelf-life of Guava fruits during cold storage are reported (Sidhu, 2006 and Singh *et al*., 1990). The research and development on food preservation methods concentrates on processes during which the structure of the product does not deteriorate and its nutritional value is maintained. Osmotic dehydration is one of such mild processes that help to diminish the detrimental changes that can take place during the processing or storage of plant tissues. Osmotic dehydration has been previously used in the dehydration of fruits to produce candy pineapple with non-thermal treatments (Barat *et al*., 2002) and coconut (Pereira da Silva *et al*., 2014). Likewise, some authors proposed that in osmotic dehydration processes, sucrose acts lowering the water activity in the sample (Panagiotou *et al*., 1998); in this sense, sugar concentration has a greater effect than the temperature in the preservation of the product for longer periods of time.

Osmotic dehydration is based on the removal of water from the material of interest without a change in phase (Fito *et al*., 2001 and Lenart, 1990). This water removal process leads into concentrated solutions of soluble solids having higher osmotic pressure and lower water activity (Kaymak-Ertekin and Sultanoglu, 2000). During osmotic dehydration, the water flows from the fruit to the osmotic solution, while osmotic solute is transferred from the solution into the product, providing an important tool to impregnate the fruit with protective solutes or functional additives. Syrup is considered a better protecting agent than dry sugar. Sucrose is the osmotic agent most suitable for fruits although other substances, including sucrose, glucose, fructose, lactose, L-lysine, glycerol, polyols, maltodextrin, starch syrup, or combinations of these solutes can be used (Bing and Da-Wen, 2002 and Zhao and Xie, 2004). The water loss and gain solids are higher in the beginning of the vacuum pulse application process, when the hydrodynamics mechanism takes place, than in the osmotic dehydration process (Chafer *et al*., 2003 and Giraldo *et al*., 2003). The hydrodynamics mechanism is a consequence of the pressure gradients, resulting from the combined action of capillary flow and pressure changes imposed on the porous structures of vegetable or fruit tissue. It is controlled by the presence of gas or liquid occluded in the intercellular spaces. By applying vacuum pressure, an outflow of internal gas or liquid from the tissue and the entrance of external solution are established that promotes water loss and the uptake of external solutes (Chiralt *et al*., 2001; Chiralt and Talens, 2005; Fito and Chiralt, 1997 and Rastogi *et al*., 2002). Temperature, osmotic solution concentration, vacuum time and total processing time are the most important variables in the osmotic process. Increasing the osmotic solution concentration induces an increase in the mass transfer (Barat *et al*., 2001; Giraldo *et al*., 2003; Ito *et al*., 2007; Madamba and Lopez, 2002 and Panades *et al*., 2006). The vacuum pulse results in a higher mass transfer, but the influence of the vacuum application time could be function of the product's biological characteristics (Escriche *et al*., 2000 and Panades *et al*., 2006). The mathematical models employed to describe the osmotic dehydration process are usually based on Fick's diffusion law (Falade and Igbeka, 2007; Rastogi *et al*., 2002 and Rastogi and Raghavarao, 2004). However, the consideration of the hydro-

Nomenclature

| | |
|---|---|
| M | moisture content, % w.b. |
| W | sample weight, kg |
| S | solids content, kg |
| WL | water loss, % |
| GS | gain solids, % |
| WR | weight reduction, % |
| $CR_{o_2}$ | oxygen consumption rate, *mL*/kg.h |
| $RR_{CO_2}$ | respiration rate of Guavas in terms of $CO_2$, *mL*/kg.h |
| RQ | respiratory quotient, decimal |
| ODMAP | osmotic dehydrated Guavas modified atmospheric packaging |
| FMAP | fresh Guavas modified atmospheric packaging |
| ODAIR | osmotic dehydrated Guavas atmospheric air packaging |
| FAIR | fresh Guavas atmospheric air packaging |
| $D_{eff_{w\ or\ s}}$ | effective diffusivity of the water loss or solids' gain, $m^2s^{-1}$ |
| L | the characteristic length (sample half-thickness), m |
| T | time, s |
| $W_{w\ or\ s}$ | the dimensionless water or solid content |
| r | diffusion radius of sphere or cylinder, m |
| R | whole radius of sphere or cylinder, m |
| H | half cylindrical height, m |
| $R^2$ | coefficient of determination |
| RMSE | root mean square error |
| $\chi^2$ | chi-square |
| N | number of samples |
| EXP | experimental data |
| CAL | calculated data |
| **Subscripts** | |
| 0 | initial |
| f | final |
| t | at time t, s |
| eq | equilibrium |

dynamics mechanism coupled with Fick's diffusion law can promote a better representation of the mass transfer phenomenon in the pulsed vacuum osmotically dehydration process (Corrêa *et al*., 2010).

The main goal of this research work was to investigate the effects of the vacuum pulse with different periods of vacuum pulse application at the beginning of the osmotic dehydration process; sucrose solution's concentration and solution's temperature on mass transfer characteristics of Guavas with different geometrical shapes (plate, sphere and cylinder). This was performed by: (1) determining the osmotic dehydration kinetics of water loss and gain solids; (2) studying the influence of both osmotic dehydrated Guavas and passive modified atmosphere packaging on its shelf-life quality parameters (weight reduction and respiration rate) and (3) calculating the effective diffusivity for different geometrical shapes of Guavas by the use of Fick's model, a diffusional model, of minimally processed Guavas.

## Materials and Methods

### Raw Material and Sample Preparation

The Guavas (*Psidium guajava L.*) was purchased from a local market in Kafr Elsheikh city, Egypt during the period from August to October 2014 and selected according to a similar ripeness degree (around 8 °Brix and 90 % skin yellowness), and with a 55-60mm diameter. The solution concentration of Guavas fruit juice was measured by a digital refractometer Hanna Brix meter model HI96801 and the fruit color was determined by a Hunterlab colorimeter (Reston, Va., U.S.A.). The Guavas were washed with tap water and manually peeled; each fruit was formed according to the required geometrical shape (sphere, plate slices and cylinder), **Fig. 1**. For plate slices' formation; the fruit was cut into two halves. From each half, two slices of 0.050 × 0.025 m (length × width) were obtained, keeping the slices thickness of 0.005 m. The Guavas' fruit geometry (configuration and size) was selected to be appropriate as a semi-infinite plate in the unidirectional diffusion model (Corrêa *et al*., 2010 and Panades *et al*., 2008). The sphere's and cylinder's radius of Guavas are 5 cm for both and the cylinder height is 5 cm. Fresh fruit was characterized measuring the moisture and soluble solids content.

### Experimental Procedure and Equipment

The osmotic treatment was carried out in two steps; in the first one, a vacuum pulse was applied to the samples immersed in different osmotic solutions and in the second step, the samples were placed in a concentrated solution and held there to attain the osmotic equilibrium, as shown in **Fig. 2**. The Guava fruits were immersed in three different sucrose solutions (45, 57 and 65 °Brix). Guava slices were soaked in the osmotic solution at different temperatures (30, 48 and 58 °C) using a mass ratio of product to solution of 1:10 (Argandoña, 1999). Two different vacuum pulses of 50 and 100 mbar were applied for 10 and 20 minutes, after which the atmospheric pressure was restored suddenly. The equipment used in the osmotic dehydration experiments consisted of a jacketed stainless steel chamber designed to work at atmospheric pressure and/or under vacuum (Ito

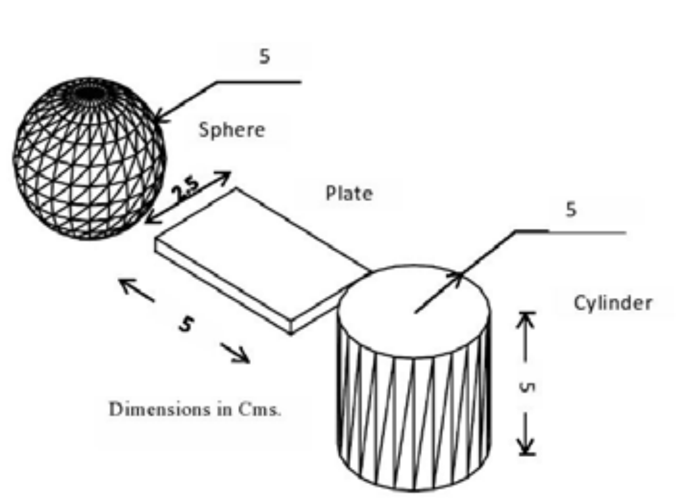



**Fig. 1** Configuration of Guavas' geometrical shapes.

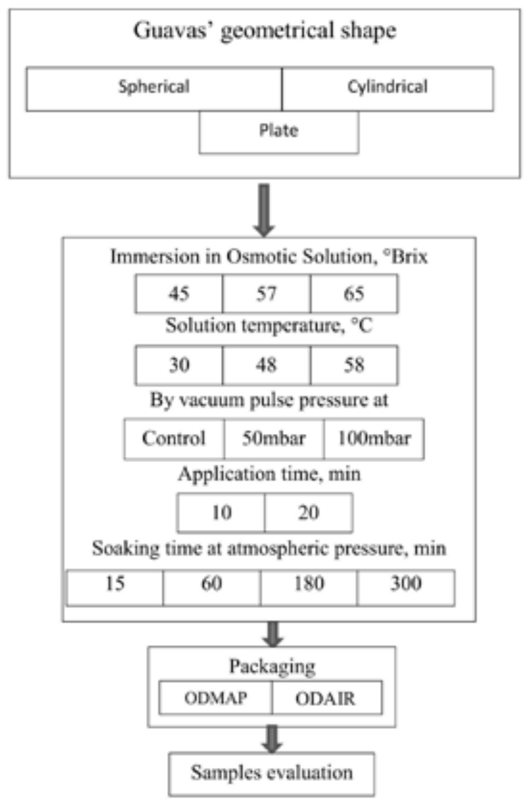


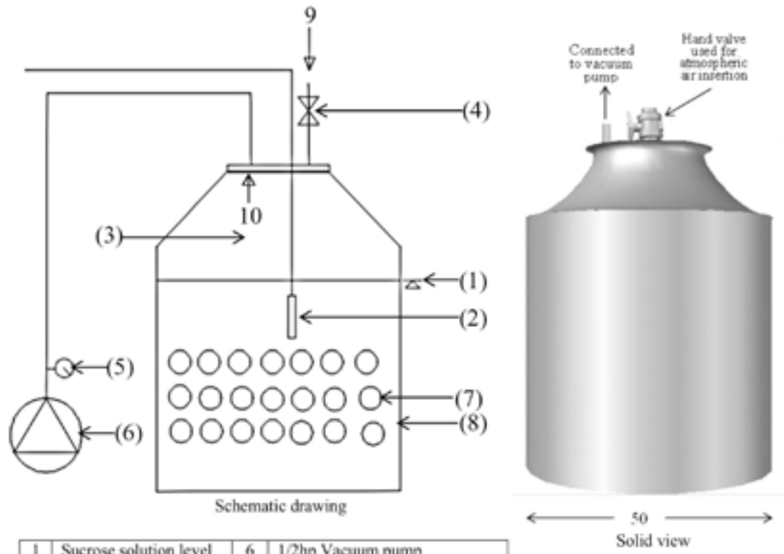

**Fig. 2** Experimental procedure flowchart.

*et al*., 2007 and Vivanco-Pezantes *et al*., 2004). The chamber, as illustrated in **Fig. 3**, presented internal diameter of 0.460 m and height of 0.450 m with a useful volume of around 60 liters. The osmotic solution temperature was controlled using an electrical immersed heater of 1kW. Vacuum was obtained by using a vacuum pump of 350 W. The experimental data were acquired by a data acquisition system which located in physics laboratory, Kafrelsheikh University. Following the vacuum pulse application, the atmospheric pressure was restored. At predetermined times (15, 30, 60, 120, 180 and 300 min) the samples were removed, rinsed with water and placed on absorbent paper to remove excess solution. The overall time used was chosen in accordance to other osmotic dehydration studies (Fermin and Corzo, 2005; Ito *et al*., 2007; Moraga *et al*., 2009; Park *et al*., 2002; Corrêa *et al*., 2010).

All the investigated treatments are indicated in **Table 1**. Subsequently two different packaging systems for the stored Guavas were used as follows:

Packaging in polyethylene terephthalate (PET) containers (jars) to develop a passive modification of the atmosphere around the product. The treated Guavas were then named osmotic dehydrated Guavas modified atmospheric packaging (ODMAP) and compared with fresh Guavas modified atmospheric packaging (FMAP). The same packaging material was used by Mattiuz *et al*., 2000 and Carlos *et al*., 2000 to modify the gas composition around fresh Guavas.

Packaging in perforated (5holes of 10mm in diameter each) polyethylene terephthalate trays wrapped by a perforated PVC (polyvinyl chloride) stretch film. The treated Guavas were then named osmotic dehydrated Guavas atmospheric air packaging (ODAIR) and compared with fresh Guavas atmospheric air packaging (FAIR).




| | | | |
|---|---|---|---|
| 1 | Sucrose solution level | 6 | 1/2hp Vacuum pump |
| 2 | Automatic electrical immersed heater | 7 | Guava fruits |
| 3 | Over head space | 8 | Stainless steel vessel |
| 4 | Hand valve | 9 | Atmospheric air insertion point |
| 5 | Manometer | 10 | Space air suction point |

**Fig. 3** Experimental setup equipped with a vacuum pulse treatment unit.

Guava plates, weighing approximately 70 g, were used in each packaging system. The samples were stored at room temperature of 23 °C for four weeks without exposition to light (Artés *et al*., 1999). The Guavas were evaluated with respect to respiration rate and weight reduction after 0, 7, 10, 14, 21, and 28 days of storage. The $CO_2$ and $O_2$ levels inside the packages were also verified by an oxygen/carbon dioxide analyzer dual head space analyzer (Model 650, Mocon, Minneapolis, Minn., U.S.A.). All measurements were carried out in triplicate and the mean values reported. The moisture and soluble solids content of the Guavas samples were analyzed at the end of the osmotic treatment. The moisture content was measured by an oven set at 65 °C for 71h as recommended by (Karathanos, 1999); and the weight was determined by a digital balance with a precision of 0.01 g.

## Quality Indicators

***a. Osmotic dehydration experimental analysis***

Sampling was done in triplicate. The samples were then weighed and analyzed in terms of the water loss (WL), the gain solids (GS) and the weight reduction (WR). These parameters were calculated according to the following equations (Corrêa *et al*., 2010):

$$WL, \% = \{(M_0\ W_0 - M_f\ W_f) / W_0\} \times 100 \quad \text{.......(1)}$$

$$GS, \% = \{(S_f W_f - S_0) / W_0\} \times 100 \quad \text{.......(2)}$$

$$WR, \% = \{(W_0 - W_f) / W_0\} \times 100 \quad \text{...(3)}$$

Where $M_0$ initial moisture content, (%w.b.); $M_f$ final moisture content, (%w.b.); $W_0$ initial sample weight, kg; $W_f$ final sample weight, kg; $S_0$ initial solids was determined according to the AOAC, 2002.

***b. Product storing experimental analysis***

***Respiration rate determination***

Fruit respiration rates of fresh and osmotically dehydrated Guavas were measured to evaluate the effect of the osmotic treatment on product respiration. The Guava slices (around 70 g) were placed in 330 milliliters gas-tight glass jars and the increase in carbon dioxide level in the headspace measured 60min after closing the jars, maintaining the temperature at 23 °C (Artés *et al.*, 1999). This sampling time allowed a change in $CO_2$ jar concentration without affecting the respiration rate of fruits. Gas samples were taken from the headspace using a gas tight syringe and $CO_2$ concentrations were determined using a gas chromatograph (SRI Instruments Inc., California, U.S.A.; Model-8610A) equipped with a thermal conductivity detector located at Department of Physics, Faculty of Science, Kafrelsheikh University, Egypt. The respiration rate of Guavas in terms of $CO_2$ evolution ($RR_{CO2}$), $O_2$ consumption rate ($CR_{O2}$) and respiratory quotient (RQ) were calculated in accordance with Palanimuthu *et al.*, 2009 as follows:

*Respiration rate ($RR_{CO2}$) ,ml / kg.h = {Change in $CO_2$ concentration in head space (%v / v) × Free volume (ml)} / {Fruit mass (kg) × Duration of respiration (h)}* ......(4)

*Consumption rate ($CR_{O2}$), ml / kg.h = {Change in $O_2$ concentration in head space (%v / v) × Free volume (ml)} / {Fruit mass (kg) × Duration of respiration (h)}* .....(5)

*Respiratory quotient (RQ), decimal = Respiration rate ($RR_{CO2}$) / Consumption rate ($CR_{O2}$)* .................(6)

**Kinetics Models - Diffusion Coefficients**

The experimental data were fitted to a mathematical model to estimate the water loss and gain solids diffusion coefficients. The model is unidirectional (Z direction) diffusion model, (Fick's model) Crank, 1975, **Fig. 4**.

Non-steady state diffusion equation initially uniform concentration and initial distribution is constant. The theoretical model of plane sheet is unsteady diffusion in semi-infinite medium, but the sphere shape and solid cylinder models are unsteady diffusion in a finite medium.

***a. Infinite plane sheet (slices):***

A plate of thickness 2 L with uniform initial amount of water or solids $M_0$, submitted to osmotic dehydration at constant conditions, can be described by Fick's unidirectional diffusion equation 7, Crank, 1975.

$\partial M(t) / \partial t = \partial / \partial z \{D_{eff} (\partial M(t)) / \partial z)\}$ ........................................................(7)

Using the following initial and boundary conditions:

- Uniform initial amount $M(z, 0) = M_0$;
- Symmetry of concentration $\partial M(t) / \partial z \mid t = 0$;
- Equilibrium content at surface $M(L,t)=M_{eq}$

And applying equation 8:

$$M_t = \frac{1}{L}\int_0^L M\ (z,t)dz \quad ..................(8)$$

It becomes, in one dimension (Crank, 1975) equation 9:

$$M_t = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2} exp\left\{-D_{eff_{w\ or\ s}}(2n+1)^2\pi^2\frac{t}{4L^2}\right\} \quad ........................................................(9)$$

Where $D_{eff_{w\ or\ s}}$ is the effective diffusivity of the water loss or the solids' gain, n is the number of series terms, L is the characteristic length (sample half-thickness), t is the time and $W_{w\ or\ s}$ is the dimensionless water or solid content. This is valid for a transient operation.

***b. Solid finite cylinder:***

$$\frac{\partial M(t)}{\partial t} D_{eff}\left(\frac{\partial^2 M(t)}{\partial r^2} + \frac{1}{r}\frac{\partial M}{\partial r} + \frac{\partial^2 M}{\partial z^2}\right) \quad ......................................................(10)$$

(t>0; 0<r<R; -h<z<+h)

- Initial conditions: $M(r,z,0) = M_0 = const$

**Table 1** Treatments details which are executed during the experimental run.

| Treatment No. | Solution concentration, °Brix | Solution Temperature, °C | Pulse pressure, mbar | Application time, min | Treatment No. | Solution concentration, °Brix | Solution Temperature, °C | Pulse pressure, mbar | Application time, min |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 45 | 30 | 0 | 0 | 23 | 57 | 48 | 50 | 10 |
| 2 | 45 | 48 | 0 | 0 | 24 | 57 | 48 | 50 | 20 |
| 3 | 45 | 58 | 0 | 0 | 25 | 57 | 48 | 100 | 10 |
| 4 | 45 | 30 | 50 | 10 | 26 | 57 | 48 | 100 | 20 |
| 5 | 45 | 30 | 50 | 20 | 27 | 57 | 58 | 50 | 10 |
| 6 | 45 | 30 | 100 | 10 | 28 | 57 | 58 | 50 | 20 |
| 7 | 45 | 30 | 100 | 20 | 29 | 57 | 58 | 100 | 10 |
| 8 | 45 | 48 | 50 | 10 | 30 | 57 | 58 | 100 | 20 |
| 9 | 45 | 48 | 50 | 20 | 31 | 65 | 30 | 0 | 0 |
| 10 | 45 | 48 | 100 | 10 | 32 | 65 | 48 | 0 | 0 |
| 11 | 45 | 48 | 100 | 20 | 33 | 65 | 58 | 0 | 0 |
| 12 | 45 | 58 | 50 | 10 | 34 | 65 | 30 | 50 | 10 |
| 13 | 45 | 58 | 50 | 20 | 35 | 65 | 30 | 50 | 20 |
| 14 | 45 | 58 | 100 | 10 | 36 | 65 | 30 | 100 | 10 |
| 15 | 45 | 58 | 100 | 20 | 37 | 65 | 30 | 100 | 20 |
| 16 | 57 | 30 | 0 | 0 | 38 | 65 | 48 | 50 | 10 |
| 17 | 57 | 48 | 0 | 0 | 39 | 65 | 48 | 50 | 20 |
| 18 | 57 | 58 | 0 | 0 | 40 | 65 | 48 | 100 | 10 |
| 19 | 57 | 30 | 50 | 10 | 41 | 65 | 48 | 100 | 20 |
| 20 | 57 | 30 | 50 | 20 | 42 | 65 | 58 | 50 | 10 |
| 21 | 57 | 30 | 100 | 10 | 43 | 65 | 58 | 50 | 20 |
| 22 | 57 | 30 | 100 | 20 | 44 | 65 | 58 | 100 | 10 |
| | | | | | 45 | 65 | 58 | 100 | 20 |

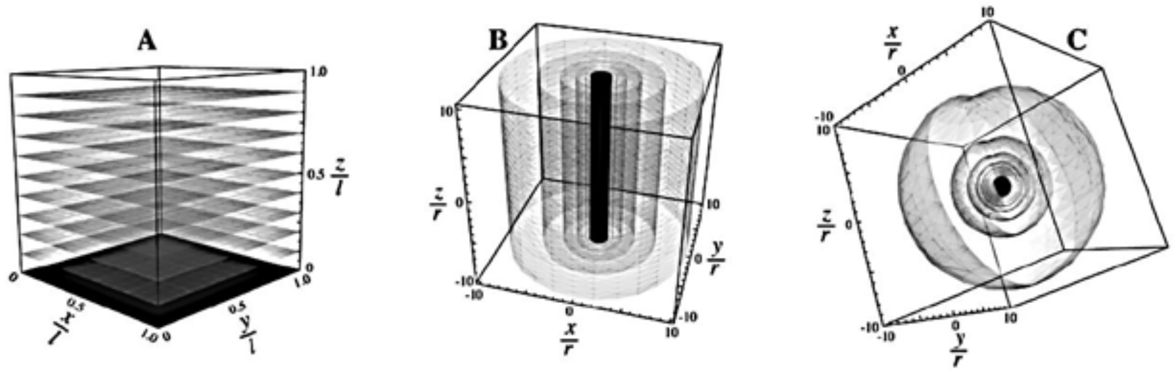



**Fig. 4** Three different diffusion bases of Fick's models used for the three geometrical shapes of Guavas
(A) infinite plane model for plate slices shape; (B) finite cylinder model for cylindrical shape and (C) finite sphere model for spherical shape.

• Boundary conditions:

$M(R,z,t) = M_{eq} = const$

$$\frac{\partial M(0,z,t)}{\partial r} = 0, M(0,z,t) \neq \infty$$

$M(r,h,t) = M_e = const$

$(\partial M(r,0,t)) / \partial z = 0$

If the concentration is initially uniform throughout the cylinder and initial distribution is constant:

$$M_t = \frac{32}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{\mu_n^2}\exp\left(-D_{\text{eff}}\frac{\mu_n^2\, t}{R^2}\right)$$

$$\sum_{m=0}^{\infty}\frac{1}{(2m+1)^2}exp\left[-\frac{\pi^2(2m+1)^2}{4}\frac{D_{\text{eff}}t}{h^2}\right]$$

.......................................................(11)

Where the μ_n are the positive roots of Bessel function of the first kind of order zero. Roots are tabulated in tables of Bessel functions;

$J_0\,(a \propto_n) = 0$

and m is mass and h is half of cylinder height, R is the whole cylindrical radius.

Solid finite sphere

$$\frac{\partial M(t)}{\partial t} = D_{eff}\left(\frac{\partial^2 M(t)}{\partial r^2} + \frac{2}{r}\frac{\partial M}{\partial r}\right)$$

.......................................................(12)

(t>0; 0<r<R)

• Initial conditions:

$M\,(r,0) = M_0 = const$

• Boundary conditions:

$r = R\ M\,(R,t) = M_{eq} = const$

$r = 0\ \{\partial M(0,t)\} / \partial r = 0$

$$M_t = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}exp\left(-D_{eff\,w\,or\,s}\frac{n^2\pi^2 t}{R^2}\right)$$

.......................................................(13)

Where, R is the whole sphere radius.

Water loss and gain solids calculations

The calculation of effective diffusivity for water loss and gain solids can be based on the dimensionless amount of water loss ($W_w$) and gain solids($W_s$), equation 14:

$W_{w\,or\,s} = (M_t - M_{eq}) / (M_0 - M_{eq})$

.......................................................(14)

The dimensionless water or solid content is given by one of the most useful empirical models of Page's equation (Page, 1949):

$W_{w\,or\,s} = exp(-At^B)$......................(15)

In which, A and B are Page's water loss or gain solids parameters; and t is the time. The model constants were estimated using Microsoft Excel 10 software. Three parameters such as coefficient of determination ($R^2$), chi-square ($\chi^2$), and root mean square error (RMSE) were used to evaluate the fit of tested models to the experimental data. The models were used for describing the osmotic dehydration characteristics of Guavas under different treatments. Statistical parameters were defined with the following equations:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(EXP - CAL)^2}{\sum_{i=1}^{n}(\overline{EXP} - CAL)^2}$$

.......................................................(16)

$$\chi^2 = \sum_{i=1}^{N}\frac{(EXP - CAL)^2}{EXP}$$

.......................................................(17)

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(EXP - CAL)^2}{N}}$$

.......................................................(18)

## Results and Discussion

**Water Loss and Gain Solids**

The osmotic dehydration process was considerably influenced by the vacuum pulse pressure, application time of vacuum pulse, solution temperature and osmotic solution concentration. The kinetics of water loss from Guava slices, subjected to different osmotic treatments, is shown in **Fig. 5**. From **Table 1**, treatments No. 1, 20, 30 and 45 (solution concentration of 45 °Brix; solution temperature of 30 °C and pulse pressure of zero mbar), (solution concentration of 57 °Brix; solution temperature of 30 °C; pulse pressure of 50 mbar and application time of 20 min), (solution concentration of 57 °Brix; solution temperature of 58 °C; pulse pressure of 100 mbar and application time of 20 min) and (solution concentration of

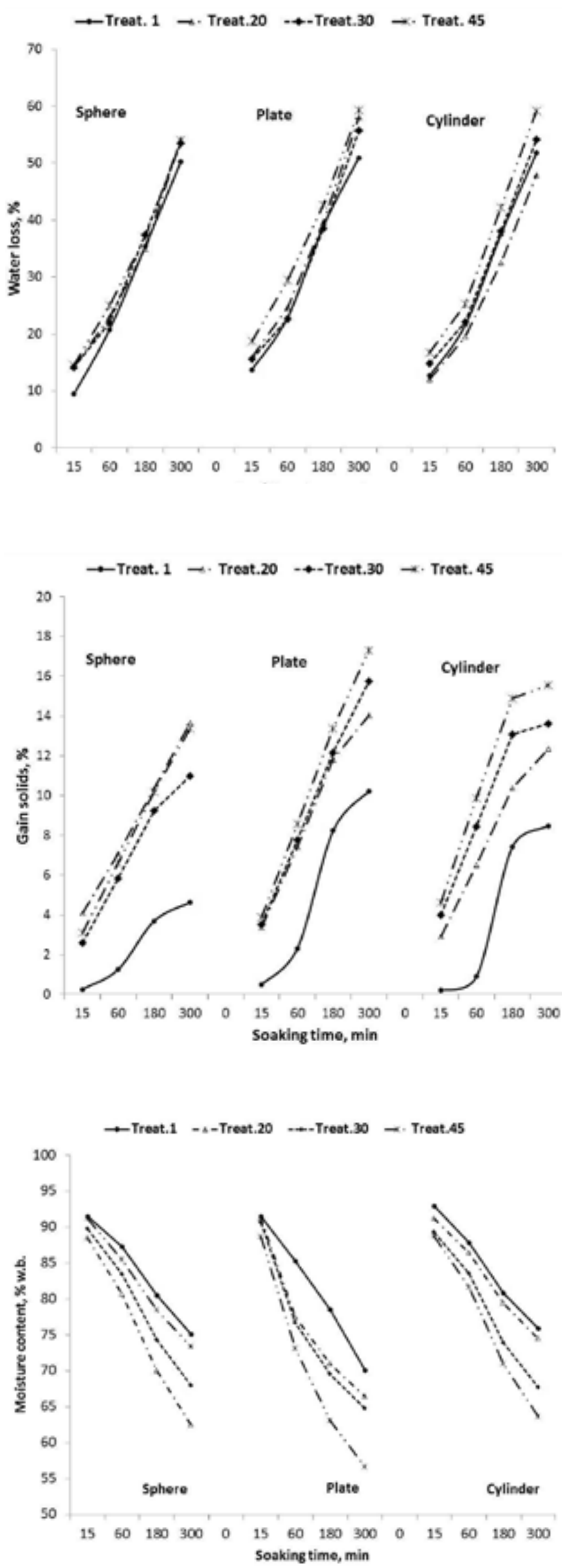



**Fig. 5** Kinetics of water loss, gain solids and moisture content of different geometrical shapes of osmotically dehydrated Guavas

65 °Brix; solution temperature of 58 °C; pulse pressure of 100 mbar and application time of 20 min), respectively, are selected from among the other treatments to generally elucidate the effect of geometrical shape on mass transfer characteristics of Guavas, **Fig. 5**. Treatment No. 1 was selected to represent the control study and treatments No. 20, 30 and 45 were chosen to characterize different study of vacuum pulses and solution temperatures. It is observed that there are no significance differences in water loss among the three geometrical shapes, but they are at both of gain solids and moisture content, $p<0.05$. Plate shape, at all treatments, records nearly higher gain solids and lower moisture content than other geometrical shapes, due to its higher surface area to volume ratio of 520 $m^{-1}$, that is roughly four times greater than that of sphere and cylindrical shapes of 120 $m^{-1}$. The maximum gain solids obtained by plate shape of 17.32, 15.70 and 14.03 % for treatments No. 45, 30 and 20, respectively; and for control treatment (Treatment No. 1) of 10.22 % after 300 minutes of soaking time. On the other side, gain solids and Guavas' moisture content is related inversely, due to the interchange between solids and moisture. Higher solids that the Guavas contain gradually based on soaking duration affect relatively on moisture migration from Guavas cells to the solution until obtaining equilibrium state. The moisture content of plate shape is reduced from 89.20 to 56.59 %w.b. during 300 minutes as gain solids increased for treatment No. 45. The use of osmotic solutions at higher sucrose concentrations causes an increase in the water loss of Guavas osmotically dehydrated at atmospheric conditions (treatments No. 1, 2, 3, 16, 17, 18, 31, 32 and 33). The vacuum pulse of 50 mbar (treatments No. 4, 5, 8, 9, 12, 13, 19, 20, 23, 24, 27, 28, 34, 35, 38, 39, 42 and 43) and 100 mbar (treatments No. 6, 7, 10, 11, 14, 15, 21, 22, 25, 26, 29, 30, 36, 37, 40, 41, 44 and 45) are applied at the beginning of the osmotic process also causes an increase in the water loss of Guavas, and this result was intensified by the vacuum pulse application time especially at vacuum pressure of 100 mbar (**Figs. 6** and **7**). However, for Guavas treated at 45 °Brix, a relevant effect of the pressure conditions was verified with the application of 100 mbar of the vacuum pulse only, **Fig. 6**. Similar behavior of the water loss was observed for the weight reduction or moisture content (% wet basis). Solution temperature has a proportional effect on both of water loss and gain solids (sugar) for all vacuum pulse application levels, **Fig. 6**. The water loss was favored by higher solution concentrations (see **Fig. 7**), increased from 50.20 to 51.70 % at atmospheric conditions, and from 59.35 to 69.17 % at 100 mbar and 58 °C due to the increase of the osmotic gradient between the food material and the osmotic solution. The presence of a large amount of solute causes a higher osmotic pressure that makes the water loss easier. These results cor-

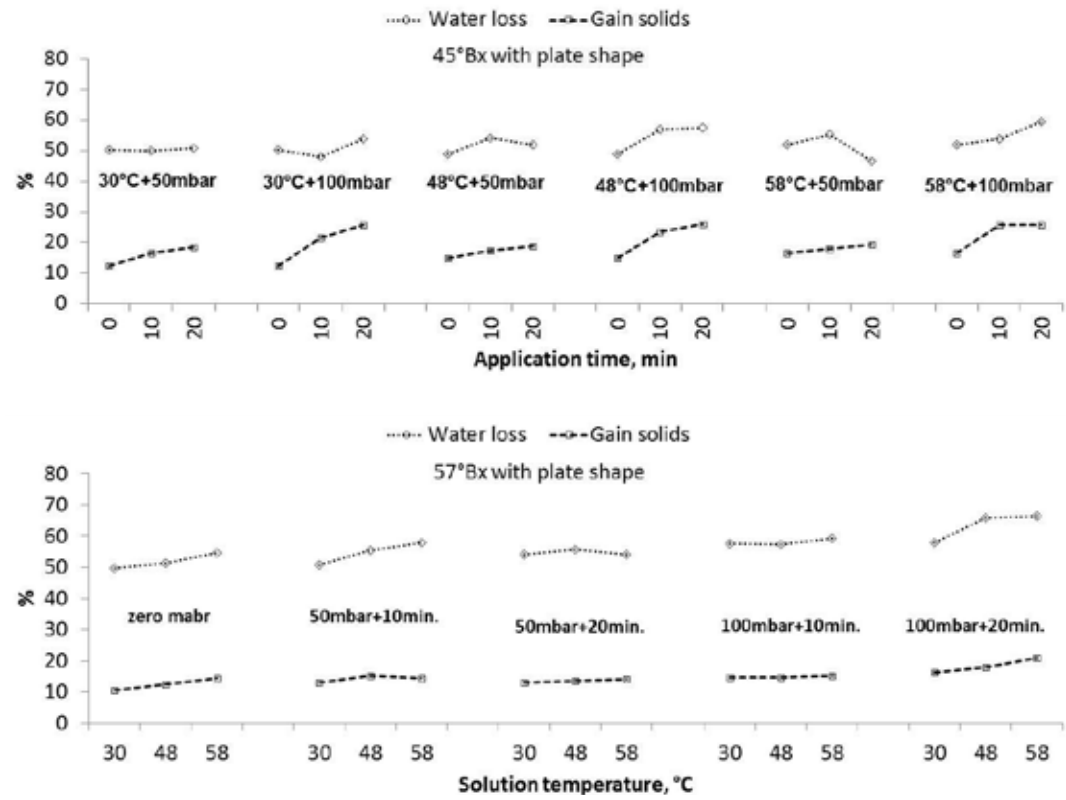



**Fig. 6** Water loss and gain solids of Guava slices osmotically dehydrated in sucrose solution at 45 and 57 °Brix of plate shape after soaking period of 300 minutes

roborate those obtained by Fermin and Corzo, 2005 and Ito *et al.*, 2007 in the vacuum pulse application of cantaloupe cylinders and mango slices, as well as the results from Madamba and Lopez, 2002 and Mastrantonio *et al.*, 2005 in the osmotic dehydration of mango slices and Guava halves. The increase of the water loss of Guavas with the application of a vacuum pulse can be explained by the hydrodynamics mechanism that is verified at the beginning of the osmotic process. With the application of the vacuum conditions, the gas occluded in the intercellular spaces of the fruit tissues is removed and when the atmospheric pressure condition is restored, the pores of the food material are filled by osmotic solution. This increases the available mass transfer surface area. Similar trends were also observed in other studies (Deng and Zhao, 2008; Fermin and Corzo, 2005; Fito, 1994; Panades *et al.*, 2006).

The influence of the vacuum pulse was more effective on fruits treated with higher osmotic solution concentrations (100 mbar with application time of 20 minutes and 55 °C). This suggests an interactive effect

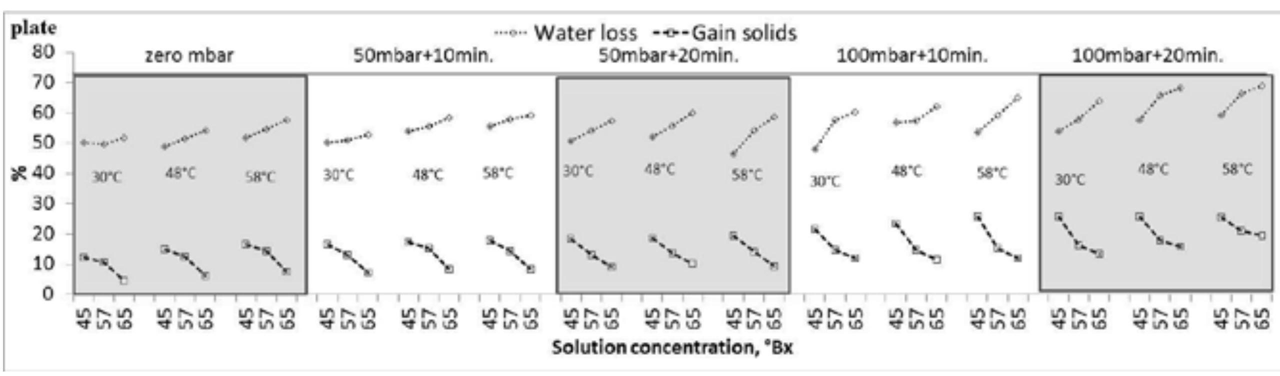



**Fig. 7** Water loss and gain solids of Guava slices osmotically dehydrated under different sucrose solutions after soaking period of 300 minutes.

of these three variables on the water loss of Guavas. The use of osmotic solutions at higher sucrose concentrations caused a decrease in the gain solids of Guavas osmotically dehydrated at atmospheric conditions and with the vacuum pulse application, as shown in **Fig. 7**. It is observed that the average raising of water loss as a result of the sucrose concentrations increment from 45 to 57 to 65 °Brix is 8.18, 12.42 and 18.30 % of atmospheric conditions (zero mbar), vacuum pulse of 50 and 100mbar, respectively. The concentrated solutions may have promoted the formation of a dense layer of solutes at the surface of the osmotic dehydrated Guavas. This layer acts as a barrier against penetration of the solutes into the food and makes solutes mass transfer more difficult, which results in a lower solids uptake in fruits tissue. According to Mujica-Paz *et al*., 2003, diluted solutions penetrate better into the fruit tissue than concentrated solution. With the increase of sugar concentration, the osmotic solution becomes more viscous, that makes the solutes penetration more difficult. Similar behavior was also observed by Barat *et al*., 2001; Ito *et al*., 2007; Madamba and Lopez, 2002 and Mastrantonio *et al*., 2005. The application of the vacuum pulse influenced the kinetics of gain solids of Guava slices in a similar way as the changes observed in kinetics of water loss. The use of the vacuum pulse at the beginning of the osmotic dehydration process caused an increase in the gain solids of Guavas as depicted in **Fig. 7**, and this behavior was intensified with the increase of vacuum pulse application time. However, for Guavas treated at 57 °Brix, the effect of the pressure conditions was noted with 10 minutes of the vacuum pulse application. Similar to the effect seen in the water loss, with the use of the vacuum pulse, the gas that was occluded in the fruit pores was removed and the intercellular spaces of the food material were filled with the osmotic solution causing a greater solid uptake in the fruit tissue. A similar effect of the vacuum pulse on solid incorporation of osmotically dehydrated fruits was also observed by Deng and Zhao, 2008; Ito *et al*., 2007 and Panades *et al*., 2006. Despite the results presented here, Shi *et al*., 1995 reported that the vacuum treatments are effective in increasing water loss but with no influence on the sugar gain of fruits in the osmotic dehydration process. It can be inferred that as the sugar gain is closely related to the porosity of fruits, the different behaviors among osmotically dehydrated fruits can be attributed to the biological characteristic of fruit tissues. Ito *et al*., 2007 reported that the main influences of the vacuum pulse and the osmotic solution concentration are observed only after 300 minutes of treatment for the water loss and gain solids. In the present study, the same influences were observed from the beginning of the osmotic dehydration process.

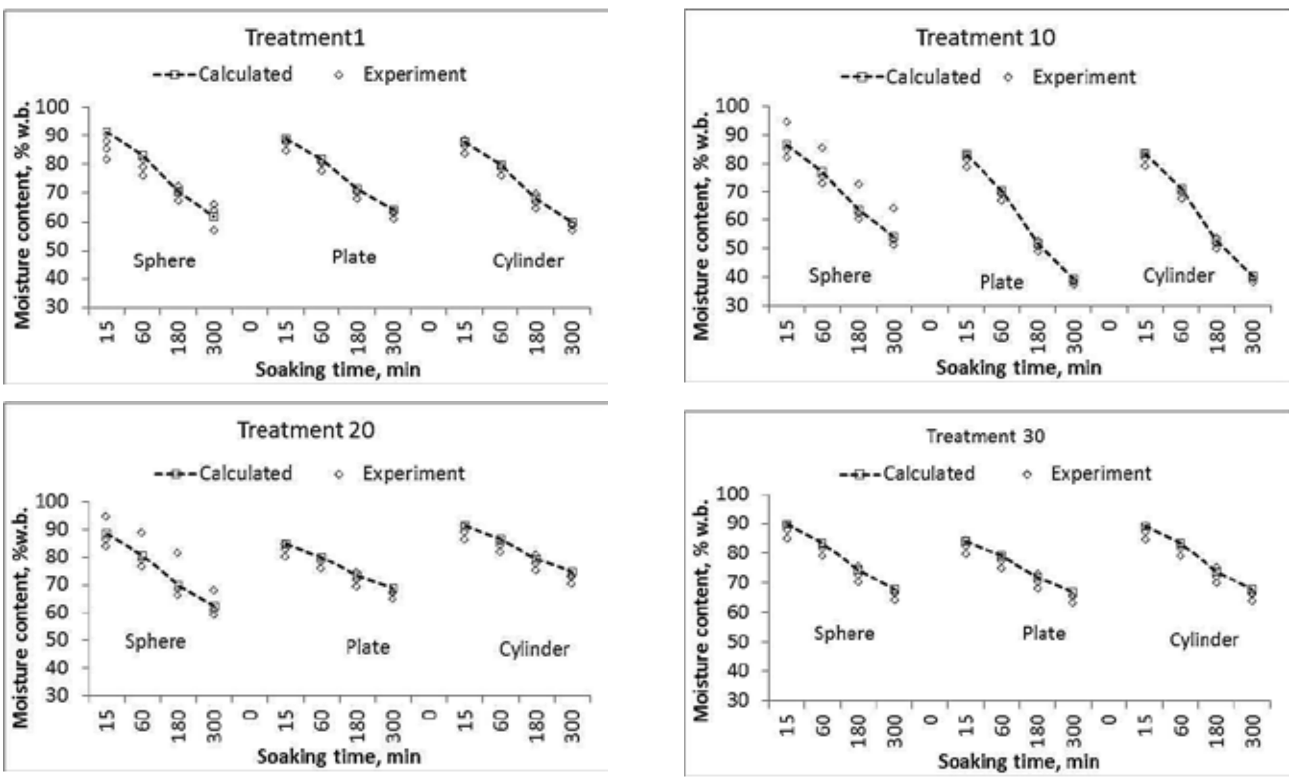



**Fig. 8** Experimental and diffusion model of osmotic dehydration curves of fresh Guavas under different treatments.

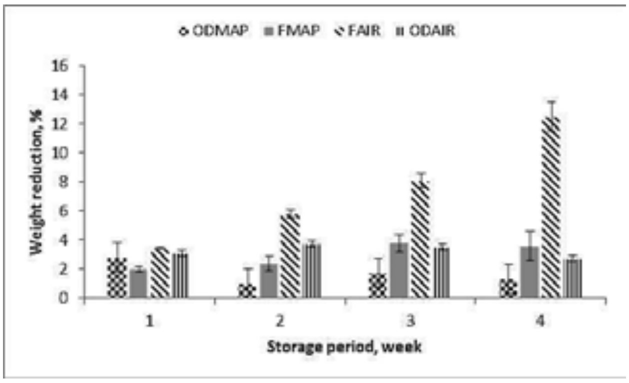



**Fig. 9** Guavas weight reduction during storage of osmotic dehydrated Guavas stored under modified atmospheric packaging conditions (ODMAP), fresh Guavas stored under modified atmospheric packaging conditions (FMAP), fresh Guavas stored at ambient conditions (FAIR), osmotic dehydrated Guavas stored at ambient conditions (ODAIR).

**Table 2** Effective diffusivities for the water loss and gain solids obtained.

| Treatment No. | $D_{effw}$ x $10^{-10}$ ($m^2s^{-1}$) | $R^2$ | $\chi^2$ | RMSE |
|---|---|---|---|---|
| Infinite plane | | | | |
| 1 | 0.97 | 0.9995 | 0.00087 | 0.0075 |
| 10 | 2.07 | 0.9939 | 0.00143 | 0.00929 |
| 19 | 0.8 | 0.9893 | 0.00149 | 0.00748 |
| 31 | 0.69 | 0.9889 | 0.00967 | 0.03806 |
| 34 | 0.54 | 0.9874 | 0.00203 | 0.00787 |
| 37 | 0.46 | 0.987 | 0.00105 | 0.00791 |
| 40 | 0.84 | 0.975 | 0.0025 | 0.01056 |
| 45 | 0.61 | 0.9718 | 0.00431 | 0.01516 |
| Solid finite cylinder | | | | |
| Treatment No. | $D_{effw}$ x $10^{-10}$ ($m^2s^{-1}$) | $R^2$ | $\chi^2$ | RMSE |
| 1 | 1.19 | 0.9918 | 0.0002 | 0.0032 |
| 10 | 3.86 | 0.9926 | 0.00065 | 0.00672 |
| 19 | 1.34 | 0.9941 | 0.00028 | 0.00434 |
| 31 | 0.95 | 0.97 | 0.00171 | 0.01089 |
| 34 | 1.3 | 0.977 | 0.00008 | 0.00211 |
| 37 | 0.95 | 0.9772 | 0.00008 | 0.00213 |
| 40 | 1.56 | 0.9568 | 0.00081 | 0.00735 |
| 45 | 1.3 | 0.949 | 0.0035 | 0.01564 |
| Solid finite sphere | | | | |
| Treatment No. | $D_{effw}$ x $10^{-10}$ ($m^2s^{-1}$) | $R^2$ | $\chi^2$ | RMSE |
| 1 | 1.54 | 0.9966 | 0.00054 | 0.00535 |
| 10 | 3.68 | 0.9932 | 0.00104 | 0.00801 |
| 19 | 0.58 | 0.9917 | 0.00089 | 0.00591 |
| 31 | 1.4 | 0.9794 | 0.00569 | 0.02448 |
| 34 | 1.34 | 0.9925 | 0.00106 | 0.00499 |
| 37 | 0.93 | 0.9921 | 0.00057 | 0.00502 |
| 40 | 1.48 | 0.9759 | 0.00166 | 0.00896 |
| 45 | 1.24 | 0.9604 | 0.00391 | 0.0154 |

The different results observed in these studies can also be explained by the differences in biological structural characteristics of the fruits studied, since the vacuum effect depends on the porosity of the specific fruit. Generally, it could be observed that the application of a 10 minutes vacuum pulse at the beginning of the osmotic dehydration process had a minor influence on the water loss behavior and the gain solids of osmotically dehydrated Guavas with respect to atmospheric pressure conditions. However, the effect of a 20 minutes vacuum pulse application at the beginning of the process was clearly observed on the mass transfer of osmotically dehydrated Guavas. For the studied process conditions, it was also observed that the osmotic solution concentration had a greater influence than the vacuum pulse on the kinetics of osmotically dehydrated Guavas.

**Modeling of Osmotic Dehydration Process**

The results of model fitting criteria showed that all models had good fitness to the experimental data under all osmotic dehydration conditions. For all the employed models, the $R^2$, $\chi^2$ and RMSE are higher than 0.94, lower than 0.03 and 0.05, respectively. To determine the overall fitness of each model for all experimental treatments, the average values of the $R^2$, $\chi^2$ and RMSE are calculated and reported in **Table 2**. The diffusion models had a good fitness to the experimental data for vacuum pulse dehydration. The predicted data using the diffusion models are shown in **Fig. 8**. The good fitness might be because the configured Guavas that have different geometrical shapes their surface skin removed or are cut into slices give a good chance for the solution to diffuse through the cells freely.

**Weight Reduction**

Both of ODMAP and FMAP in polyethylene terephthalate (PET) containers showed less weight reduction, which does not change during the 28 days of storage ($P < 0.05$). However FAIR using the perforated PVC film, presented an increase in weight reduction, reaching values of around 13 % at the end of storage, **Fig. 9**. These results demonstrated that the rigid PET packages were essential for weight reduction prevention, supporting the moisture barrier characteristic that keeps high values of relative humidity in the environment, thus avoiding dehydration of the cut surfaces because tissue respiration is substantially increases after processing.

**Respiration Rate**

Oxygen consumption rate of osmotically dehydrated and fresh Guavas showed 356.88 ±110.676 and 332.24 ±76.2 $mlO_2$/kg.h, respectively. The increase of oxygen consumption rate caused by osmotic dehydration was probably a consequence of reactions between the sugar

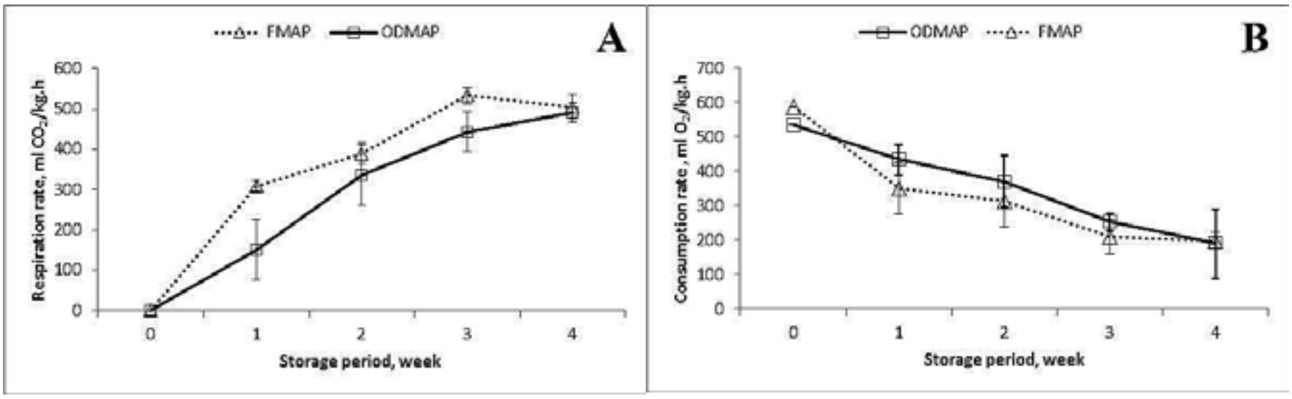



**Fig. 10** Evolution of respiration rate (A) and consumption rate (B) inside the Guavas packages during storage

obtained intercellular and the cell wall occurring during the storing. The osmotically dehydrated and fresh Guavas showed respiration rates of 284.54 ±150.16 and 347.40 ±104.13 ml$CO_2$/kg.h, respectively. The increase in $CO_2$ caused by fresh Guavas was due to higher moisture content they have 88 % w.b. than osmotic dehydrated Guavas have 60 % w.b. The PET containers used to package both of fresh (FMAP) and osmotically dehydrated (ODMAP) Guavas provided a passive modification of the atmosphere around the product and the oxygen and carbon dioxide concentrations reached levels of about 6.8 % and 17.3 % (volumetric), respectively, at the end of storage, **Fig. 10.** This atmosphere inside the packages was obtained due to the oxygen and carbon dioxide transmission rates shown by the PET containers in combination with the Guavas respiration rate. The PVC perforated film used for fresh Guavas storage (FAIR), exhibited an internal atmosphere similar to that of air. Respiratory quotient of FMAP (1.81 ±0.87) is higher than ODMAP (1.40 ±0.97), **Fig. 11**. These results are in accordance to Palanimuthu *et al.*, 2009 investigating the respiratory quotient of the cranberry treated with high voltage electric fields in the range of 1.69-2.21 at the end of the third week. The authors Palanimuthu *et al.*, 2009 and Sidhu, 2006 related the higher respiratory quotient for its greater organic acid content. Also Pereira *et al.*, 2004 related a higher $CO_2$ production to a consequence of mechanical damage occurring during the configuration process.

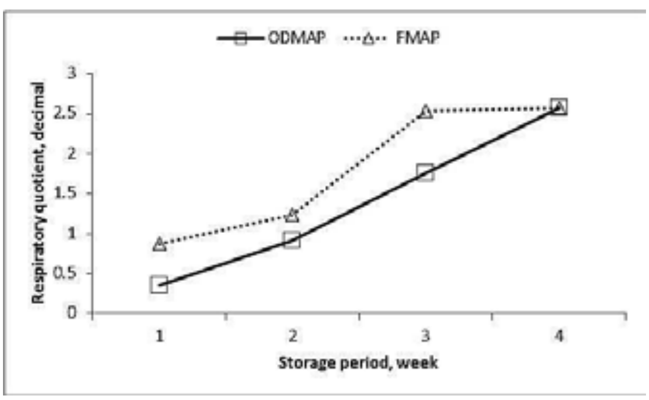



**Fig. 11** Evolution of respiratory quotient of osmotic dehydrated Guavas ODMAP and fresh Guavas FMAP inside the packages during storage.

## Conclusions

The effect of geometrical shape on mass transfer characteristics of Guavas clarified that there are no significance differences in water loss among the three geometrical shapes. Plate shape records higher gain solids and lower moisture content than other geometrical shapes, due to its higher total surface area to volume ratio of 520 $m^{-1}$. Mass transfer characteristics of Guavas osmotically dehydrated in sucrose solutions were greatly affected by sucrose concentration, solution temperature and vacuum pulse application at the beginning of the osmotic dehydration process. Higher sucrose solution concentrations and the vacuum pulse application caused an increase on water loss of osmotically dehydrated Guavas. However, the gain solids were reduced by the increase on osmotic solution concentration, although solid uptake was favored by vacuum application and solution's temperature. The behavior of weight reduction was similar to the water loss. In a general way, the effects of pressure conditions on the mass transfer kinetics were clearly observed with the application of the vacuum pulse of 100 mbar during 20 minutes and at sucrose concentration of 45 °Brix at solution temperatures between 48 and 58 °C at the beginning of the process. Furthermore, for the process conditions studied, the osmotic solution concentration seems to have a greater influence on the kinetics of osmotically dehydrated Guavas than the vacuum pulse especially water loss. Passive modified atmosphere packages provide intermediate $O_2$ and high $CO_2$ levels avoiding weight reduction during storage process of osmotic dehydrated Guavas when compared with the fresh Guavas in modified atmosphere packaging. The combination of modified atmosphere packaging, and the osmotic dehydration process maintained the quality of the Guavas during four weeks. The one-dimensional diffusional model demonstrated a better agreement to the experimental data presenting determination coefficients ($R^2$) values between 0.94 and 0.99 and an estimated standard error lower than 0.03. The effective diffusion coefficients behavior reflected the influence of osmotic dehydration process variables on mass transfer kinetics.

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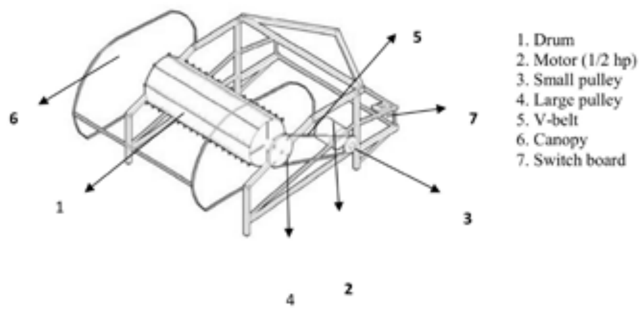
# ABSTRACTS

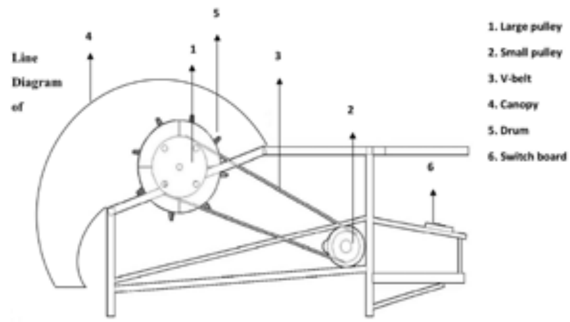
The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

**1410**

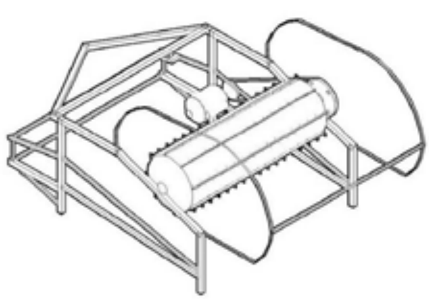
**Design, Fabrication and Performance of Drudgery Free Paddy Thresher for Farmers of Hills of Himalayas:** **Divya Singh,** Department of Family Resource Management, College of Home Science, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar U.S.Nagar Uttarakhand -263145 INDIA; **Deepa Vinay,** Professor and Head, same, singhdivya546@gmail.com




Line Diagram of Paddy Thresher




Various parts of Paddy thresher



Top view

Front view

Paddy threshing by manually operated paddy thresher is popular among the farmers since more than 60 % of the cultivated land in hill area is under the category of small and marginal farmers in India. In manual beating operation the operator had to sit in a bent position, which was ergonomically not appropriate for long-time operation, since wrong posture may cause serious injury. Hence need was felt to design and develop a small motorized thresher especially for hill region which should be user friendly and more efficient New developed thresher was a low cost motorized machine for threshing paddy crops. The machine runs on ½ hp and operated by an electric motor. Due to the mechanical process, drum speed increased and it reduced the energy expenditure and threshing time of the users. Optimization process was carried out using design software. The goal was fixed to maximize the production and minimize the energy expenditure and Musculoskeletal disorder. On this basis, a new motorized paddy threshing unit, having a height 755 mm, time 5.1 minutes and load density 1 ½ kg gives production.i.e. 16.69 kg with 9.6 kj/min energy expenditure, and 299 beats Tccw, 127 beats/ min. heart rate, 20.94 % MSD and 20.86 % RPE and overall desirabillty were found to be .73 percent.

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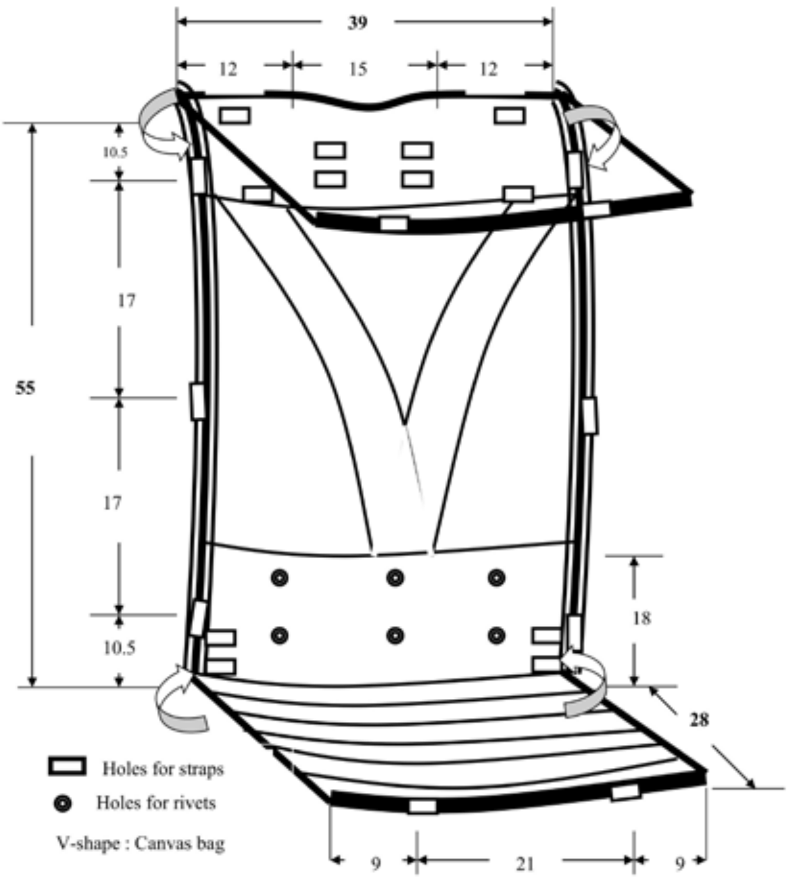
**1415**

**Ergonomic Design of an External Frame Backpack for Carrying Loads by Hill Women:** **Vijayshree Dhyani,** Ex-Ph.D. Scholar, College of Home Science, G.B. Pant University of Agriculture and Technology, Pantnagar-263 145, Uttarakhand, INDIA, vsdhyani@gmail.com; **Promila Sharma,** Professor, same, Promila34@gmail.com; **T.C. Thakur,** ICAR National Professor, College of Technology, same, drtcthakur@yahoo.com

An ergonomically designed external frame backpack was developed for carrying loads by hill women. The 'Case Selection Method' was used for selecting the critical dimensions of backpack, viz. length (sitting shoulder height) and width (shoulder breath) which were fixed at 55 cm and 39 cm, respectively based on the 90th percentile of anthropometric measurements of one hundred hill women subjects. The backpack was fabricated from L-shaped aluminium frame and high quality canvas (10 oz) and weighed less than 2 kg. The developed backpack alongwith a traditional backpack was tested for carrying loads (15, 20 and 25 kg) on the basis of changes in Heart Beat Rate (HR), Oxygen Consumption Rate (OCR), Energy Expenditure Rate (EER), Rate of Perceived Exertion (RPE) and Body Part Discomfort Score on a treadmill in the laboratory condition and for carrying grass and wood under field condition. The OCR with developed backpack varied from 0.44 to 0.63 *l*/min as against 0.62 to 0.77 *l*/min with traditional backpack when carrying loads from 15 to 25 kg, respectively. Accordingly, the RPE was found to vary from 1.0 (very weak) to 2.0 (weak) with the developed backpack as against 2.0 (weak) to 4.0 (some-what weak) for traditional backpack. The developed backpack not only brought down the physiological cost of carrying loads but also had no pinch or pressure points on the body which resulted in more comfort to the subjects.

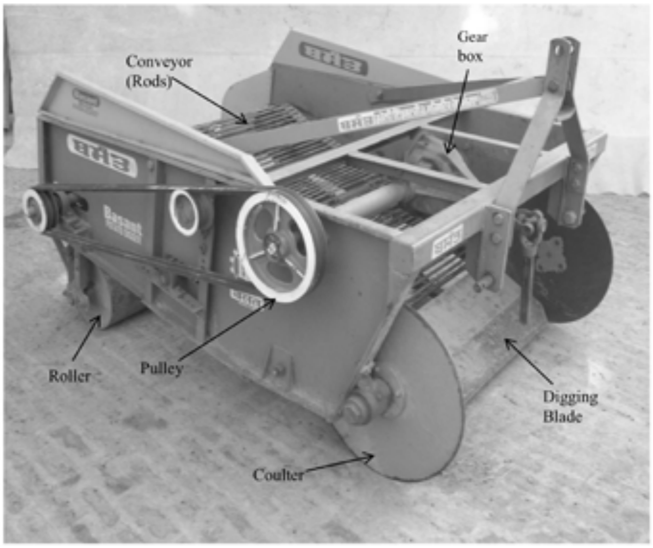



All dimensions in cm.
Note: Arrows show the hinge points to fold the pack at its top and bottom
Fig: Developed external frame backpack

Fig: Developed backpack

**1414**

**Performance Evaluation of Root Crop Digger in Potato, Carrot and Onion Crops:** **Narender,** M. Tech., Department of Farm Machinery & Power Engineering, COAE&T, CCSHAU, Hisar, Haryana, INDIA, narender4ever@gmail.com; **Vijaya Rani,** Assistant Prof., same; **Anil Kumar,** Assistant Prof., same; **S. Mukesh,** Assistant Agril. Engr., same; **Ajit Singh,** Research Associate, Department of Horticulture, College of Agriculture, CCS HAU, Hisar, Haryana, INDIA




A view of root crop digger

In vegetables, potato, onion and carrot are important root crops. The harvesting of root crops is presently carried out manually in India. The harvesting of root crops is highly labour intensive and costly process. Diggers were developed and available for different crops independently, but they are not much accepted by the farmers. Therefore, it was proposed to evaluate the tractor drawn multi-root crop digger designed by Punjab Agricultural University which was designed to dig different crops namely potato, onion, carrot, turmeric, garlic etc. Four parameters i.e. exposed percentage, cut percentage, bruised percentage and digging efficiency of digger were studied at three different forward speeds and blade angle to evaluate the performance of multi root crop digger for potato, carrot and onion crops. The root crop digger performed the best at speeds of 2.3, 2.2 and 2.5 km $h^{-1}$ and blade angles of $23^0$, $23^0$ and 170 with digging efficiency of 97.90 %, 100 % and 100 %, cut percentage of 1.71, 7.53 and 0.00, bruised percentage of 2.48, 2.28 and 3.39 and exposed percentage 90.62, 92.12 and 96.62 for potato, carrot and onion crops, respectively. The field capacity of multi root crop digger was 0.21, 0.18 and 0.25 ha $h^{-1}$ in potato, carrot and onion crops, respectively. There was saving of Rs 8384, Rs 7359 and Rs 5615 per hectare in potato, carrot and onion crop, respectively.

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# EVENT CALENDAR

◆ **AGRICONTROL 2016**
—The 5th IFAC Conference on Sensing, Control and Automation for Agriculture—
*August 14-17, 2016,* Seattle, Washington, USA
http://ifac.cahnrs.wsu.edu/

◆ **The 4 th Edition of INAGriTech 2016**
*August 25-27, 2016,* Jakarta INDONESIA
http://www.inagritech-exhibition.net/#axzz3zFynVBGC

◆ **3rd Conference Biogas Science 2016**
*September 2016,* Szeged HUNGARY

◆ **The World Food Prize**
*October 12-14, 2016,* Des Moines, Iowa, USA
https://www.eventbrite.com/e/2016-borlaug-dialogue-and-global-youth-institute-oct-12-15-registration-26211502309

◆ **10th CIGR Section VI Symposium**
—Food: the tree that sustains life—
October 24-27, 2016, BRAZIL
http://www.ufrgs.br/sbctars-eventos/xxvcbcta/en/

◆ **ICAS VII**
—International Conference on Agricultural Statistics (FAO)—
*October 26-28, 2016,* Roma, ITALY
http://icas2016.istat.it/

◆ **CIAME 2016**
—China International Automotive Manufacturing Technology & Equipment Exhibition—
*October 28-30, 2016,* Wuhan, CHINA
http://www.ciame.net/

◆ **EIMA International 2016**
*November 9-13, 2016,* Italy, BOLOGNA
www.eima.it

◆ **BICET 2016**
—6th Brunei International Conference on Engineering and Technology 2016—
*November 14-16, 2016,* Bandar Seri Begawan,
NEGARA BRUNEI DARUSSALAM
http://www.itb.edu.bn/bicet2016/

◆ **KISAN SHOW**
—India's Largest Agri Show—
*December 14-18, 2016*, Pune, INDIA
http://pune.kisan.in

◆ **ETAE 2016**
—Emerging Technologies in Agricultural and Food Engineering—
*December 27-30, 2016,* The Indian Institute of Technology, Kharagpur, INDIA
http://www.etae2016.in/

◆ **AGRITECHNICA ASIA 2017**
*March 15-17, 2017,* BITEC, Bangkok, THAILAND
https://www.agritechnica.com/en/press/?detail/agritechnica2015/10/2/8554

◆ **XIX. World Congress of CIGR**
*April 22-25, 2018,* Antalya, TURKEY
http://www.cigr2018.org/

◆ **XXXVII CIOSTA & CIGR Section V Conference**
*June, 13-15, 2017,* Palermo, Italy
http://www.aidic.it/ciosta2017

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# NEWS

## ◇ YOSHISUKE KISHIDA AWARDED THE DECORATION

In spring conferment, Yoshisuke Kishida, president of Shin-Norinsha and Farm Machinery Industrial Research Corp., which publishes AMA and he serves as chief editor, was awarded the decoration of KYOKUJITSU SHOUJUSHOU (THE ORDER OF THE RISING SUN, GOLD RAYS WITH ROSETTE) from Emperor of Japan. He, with his wife, attended the awarding ceremony held at National Theater and Imperial Palace on May 12th, 2016. Yoshisuke Kishida was awarded the decoration for his distinguished long service in the field of press and publishing. Through media communication, he made significant contributions to promote agricultural mechanization in Japan and the world. On this honorable event, he commented, “Unexpectedly being awarded, I deeply appreciate for that. I would like to make continuous effort for the development of agriculture in my remaining life.”

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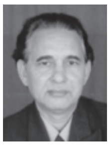
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# Back Issues

**AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA**

(Vol.45, No.4, Autumn, 2014-)

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**Vol.47, No.1, Winter 2016**



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**Vol.47, No.2, Spring 2016**



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# INSTRUCTIONS TO AMA CONTRIBUTORS

The Editorial Staff of the AMA requests of articles for publication to observe the following editorial policy and guidelines in order to improve communication and to facilitate the editorial process:

## Criteria for Article Selection

Priority in the selection of article for publication is given to those that –

a. are written in the English language;
b. are relevant: to the promotion of agricultural mechanization, particularly for the developing countries;
c. have not been previously published elsewhere, or, if previously published are supported by a copyright permission;
d. deal with practical and adoptable innovations by, small farmers with a minimum of complicated formulas, theories and schematic diagrams;
e. have a 50 to 100-word abstract, preferably preceding the main body of the article;
f. are printed, double-spaced, under 3,000 words (approximately equivalent to 6 pages of AMA-size paper) ; and those that
g. art: supported by authentic sources, reference or bibliography.
h. written on CD-R.

## Rejected/Accepted Articles

a. As a rule, articles that are not chosen for AMA publication are not returned unless the writer(s) asks for their return and are covered with adequate postage stamps. At the earliest time possible, the writer(s) is advised whether the article is rejected or accepted.
b. When an article is accepted but requires revision/modification, the details will be indicated in the return reply from the AMA Chief Editor in which case such revision/modification must be completed and returned to AMA within three months from the date of receipt from the Editorial Staff.
c. The AMA does not pay for articles published.
d. Complimentary copies: Following the publishing, three successive issue are sent to the author(s).

## Procedure

a. Articles for publication (original and one-copy) must be sent to AMA through the Co-operating Editor in the country where the article originates. (Please refer to the names and addresses of Co-operating Editors in any issue of the AMA). However, in the absence of any Co-operating Editor, the article needs to be sent to Co-operating Editor in the writer's neighboring country.
b. Contributors of articles for the AMA for the first time are required to attach a passport size ID photograph (black and white print preferred) to the article. The same applies to those who have contributed articles three years earlier. In either case, ID photographs taken within the last 6 months are preferred.
c. The article must bear the writer(s) name, title/designation, office/organization, nationality and complete mailing address.

## Format/Style Guidance

a. Article must be sent on CD-R with MS DOS format (e.g. Word Perfect, Word for DOS, Word for Windows... **Absolutely necessary TEXT FORMAT**) along with two printed copys (A4). Or it must be sent by E-mail with Word File and PDF File attached.
b. The data for graphs and photographs must be saved into piecemeal data and enclosed (attached) with the article.
c. Whether the article is a technical or popular contribution, lecture, research result, thesis or special report, the format must contain the following features:
   (i) brief and appropriate title;
   (ii) the writer(s) name, designation/title, office/organization; and mailing address;
   (iii) an abstract following ii) above;
   (iv) body proper (text/discussion);
   (v) conclusion/recommendation; and a
   (vi) bibliography
d. The printed copy must be numbered (Arabic numeral) successively at the top center whereas the disc copy pages should not be number. Tables, graphs and diagrams must likewise be numbered. Table numbers must precede table titles, e.g., "Table 1. Rate of Seeding per Hectare". Such table number and title must be typed at the top center of the table. On the other hand, graphs, diagrams, maps and photographs are considered figures in which case the captions must be indicated below the figure and preceded by number, e.g., "Figure 1. View of the Farm Buildings".
e. **The data for the graph must also be included. (e.g. EXCEL for Windows)**
f. Tables and figures must be preceded by texts or discussions. Inclusion of such tables and figures not otherwise referred to in the text/discussion must be avoided.
g. Tables must be typed clearly without vertical lines or partitions. Horizontal lines must be drawn only to contain the sub-title heads of columns and at the bottom of the table.
h. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
i. Indicate by footnotes or legends any abbreviations or symbols used in tables or figures.
j. Convert national currencies in US dollars and use the later consistently.
k. Round off numbers, if possible, to one or two decimal units, e.g., 45.5 kg/ha instead of 45.4762 kg/ha.
l. When numbers must start a sentence, such numbers must be written in words, e.g., Forty-five workers..., or Five tractors..."instead of 45 workers..., or, 5 tractors.

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