COMPARATIVE PERFORMANCE EVALUATION OF DIFFERENT TYPES OF ONION DIGGER IN CHHATTISGARH

M. Tech. (Agril. Engg.) Thesis

by

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Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

Biswajit Nayak

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CERTIFICATE-I

This is to certify that the thesis entitled **"Comparative performance evaluation of different types of onion digger in Chhattisgarh"** submitted in partial fulfilment of the requirements for the degree of the **Master of Technology in Agricultural Engineering** of Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of bonafide research work carried out by **Biswajit Nayak** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigation have been duly acknowledged.

Chairman 21/7/2022

Date: 21/07/2022

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CERTIFICATE-II

This is to certify that the thesis entitled **"Comparative performance evaluation of different types of onion digger in Chhattisgarh"** submitted by **Biswajit Nayak** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfilment of the requirement for the degree of **Master of Technology in Agricultural Engineering** in the Department of **Farm Machinery and Power Engineering** has been approved by the external evaluator and Student's Advisory Committee after oral examination, under the chairmanship of Head of Department/Dean (in case of outcampii).

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Biswajit Nayak

(Biswajit Nayak)

Place: Raipur

Date: 21/07/2022

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LIST OF NOTATIONS/SYMBOLS

Notations	Description
%	Percent
₹	Rupees
°	Degree
^0C	Degree Celsius
db	dry basis
Fig.	Figure
h	hour
ha	hectare
hp	horse power
hp	horse power
kg	kilogram
km	kilometer
kPa	kilo Pascal
kW	kilo Watt
l	liter
m^2	meter square
mm	millimeter
MT	Metric Tonne
No.	Number
S	Speed of operation
t	ton
W	Weight
wb	wet basis
$kg\ m^{-3}$	kilogram per cubic meter
$ha\ day^{-1}$	hectare per day
$ha\ h^{-1}$	hectare per hour
$kg\ h^{-1}$	kilogram per hour
$kg\ ha^{-1}$	kilogram per hectare
$km\ h^{-1}$	kilometer per hour
$l\ h^{-1}$	liter per hour
$m\ s^{-1}$	meter per second
$m^2\ h^{-1}$	meter square per hours
$q\ ha^{-1}$	quintal per hectare
$t\ ha^{-1}$	tons per hectare

LIST OF ABBREVIATIONS

Abbreviations	Full name
Agri.	Agriculture
Agril. Engg.	Agricultural Engineering
ASAE	American Society of Agricultural EngineersChhattisgarh
B.Tech.	Bachelor of Technology
C.G.	Chhattisgarh
EFC	Effective Field Capacity
et al.	*Et alibi*
etc.	Et cetera
FAE	Faculty of Agricultural Engineering
Fig.	Figure
FMPE	Farm Machinery and PowerEngineering
ICAR	Indian Council of Agricultural Research
IGKV	Indira Gandhi Krishi Vishwavidyalaya
IS	Indian Standard
M.Tech	Master of Technology
Max.	Maximum
Min.	Minimum
rpm	Revolution per minute
S.No.	Serial Numbers
TFC	Theoretical Field Capacity

THESIS ABSTRACT

Title of the Thesis	:	Comparative performance evaluation of different types of onion digger in Chhattisgarh
Full name of the student	:	Biswajit Nayak
Major Subject	:	Farm Machinery and Power Engineering
Name and Address of the Major Advisor	:	Dr. R.K. Naik (Associate Professor) Department of FMPE, SVCAET and RS, FAE, IGKV, Raipur (Chhattisgarh)
Degree to be Awarded	:	Master of Technology in Agricultural Engineering

Signature of Major Advisor

Signature of student

Date: 21/7/2022

Signature of Head of the Department

ABSTRACT

Onion is produced in all over the world however India is the second largest producer of onion after the China. Onion is mainly grown in *rabi* season. Harvesting of onion by manual method is an expensive, time consuming and labour intensive operation. The various tools used for the digging of onion crop are spade, *khurpa* and hoe. Various types of tractor operated onion digger were developed in the country but no one is still tested in Chhattisgarh. The present study was conducted to evaluate the comparative performance of different tractor operated onion diggers available in Chhattisgarh. Three types of onion diggers *viz.* tractor operated onion digger (M1), vibro onion digger (M2) and duck foot type onion digger (M3) were selected for the comparative evaluation. The major crop parameters such as size, shape, aspect ratio and some of the soil parameters i.e., bulk density and moisture content were studied for evaluation of harvesters for onion crop.

A two factorial randomized block design using three type of diggers as the first parameter and three speed of operation as the second parameters was taken for performance evaluation of the digger. The lowest damage percentage was found as 2.16 % for vibro onion digger (M2) and highest exposure percentage was observed for vibro onion digger (76.32 %).

The highest separation index was found as 75.81 per cent for vibro onion digger (M2) whereas, highest digging efficiency was found to be 93.62 per cent for vibro onion digger.

A detailed study was done by selecting vibro onion digger as the best digger for Chhattisgarh region as the digger has highest exposure percentage, highest digging efficiency and lowest damage percentage. Split plot experimental design with speed as main plot i.e., speed of operation 2.5 km h^{-1} (S1), 3.0 km h^{-1} (S2) and 3.5 km h^{-1} (S3) and blade angle as sub plot i.e., 15°(B1), 20°(B2) and 25°(B3). The lowest damage percentage was observed as 1.98 per cent for speed of operation 3.0 km h^{-1} and blade angle 20°. The highest exposure was found 97.22 per cent at 3.0 km h^{-1} speed of operation and 25° blade angle. The separation index was found to be highest (57.87 %) for speed of operation 2.5 km h^{-1} and blade angle of 15°. The highest digging efficiency (94.81%) was found at speed of operation of 3.0 km h^{-1} and having blade angle of 20°. Vibro onion digger was found to work efficiently at speed of operation of 3.0 km h^{-1} and having blade angle of 20°.

The average operation cost for onion digger, vibro onion digger and duck foot onion digger were found to be ₹ 178.99 h^{-1}, ₹ 170.71 h^{-1} and ₹ 101.71 h^{-1} respectively. The breakeven points were found to be 551.97 h $year^{-1}$, 535.15 h $year^{-1}$ and 336.05 h $year^{-1}$ respectively. The payback period were found to be 9.81 year, 9.51 year and 5.97 year respectively.

शोध सारांश

शोध का शीर्षक	:	छत्तीसगढ़ में विभिन्न प्रकार के प्याज खोदने वालों का तुलनात्मक प्रदर्शन मूल्यांकन
छात्र का पूरा नाम	:	विस्वजीत नायक
प्रमुख विषय	:	कृषि यंत्र एवं शक्ति अभियांत्रिकी
प्रमुख सलाहकार का नाम एवं पता	:	डॉ. आर.के. नायक (सह -प्राध्यापक) कृषि यंत्र एवं शक्ति अभियांत्रिकी इं. गाँ. कृ. वि. वि. रायपुर (छ.ग.)
प्रदान की जाने वाली डिग्री	:	कृषि अभियांत्रिकी में स्नातकोत्तर (मास्टर ऑफ टेक्नोलॉजी)

21/7/2022

प्रमुख सलाहकार के हस्ताक्षर

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छात्र के हस्ताक्षर

दिनांक: 21/7/2022

विभागाध्यक्ष के हस्ताक्षर

सारांश

दुनिया भर में प्याज का उत्पादन होता है लेकिन चीन के बाद भारत प्याज का दूसरा सबसे बड़ा उत्पादक है। प्याज मुख्य रूप से रबी मौसम में उगाया जाता है। मैन्युअल तरीके से प्याज की खुदाई एक महंगा, समय लेने वाला और श्रमसाध्य कार्य है। प्याज की फसल की खुदाई के लिए इस्तेमाल किए जाने वाले विभिन्न उपकरण खुरपा और कुदाल हैं। देश में विभिन्न प्रकार के ट्रैक्टर चालित प्याज खोदने वाले मशीन विकसित किए गए लेकिन छत्तीसगढ़ में अभी भी किसी का परीक्षण नहीं किया गया है। वर्तमान अध्ययन छत्तीसगढ़ में उपलब्ध विभिन्न ट्रैक्टर संचालित प्याज खोदने बाले मशीनों के तुलनात्मक प्रदर्शन का मूल्यांकन करने के लिए आयोजित किया गया है। तीन प्रकार के प्याज खोदने वाले अर्थात। तुलनात्मक मूल्यांकन के लिए ट्रैक्टर चालित प्याज डिगर (M1), वाइब्रो प्याज डिगर (M2) और डक फुट टाइप प्याज डिगर (M3) का चयन किया गया। प्याज की फसल के लिए हार्वेस्टर के मूल्यांकन के लिए मुख्य फसल मापदंडों जैसे आकार, पहलू अनुपात और कुछ मिट्टी के मापदंडों यानी

थोक घनत्व और नमी की मात्रा का अध्ययन किया गया है। एक दो फैक्टोरियल रैंडमाइज्ड ब्लॉक डिज़ाइन लिया गया जिसमे पहले पैरामीटर के रूप में तीन प्रकार के डिगर्स और दूसरे पैरामीटर के रूप में ऑपरेशन की तीन गति को डिगर के प्रदर्शन मूल्यांकन के लिए लिया गया। वाइब्रो प्याज डिगर (M2) के लिए सबसे न्यूनतम नुकसान प्रतिशत 2.16 प्रतिशत पाया गया और वाइब्रो प्याज खोदने वाले डिगर के लिए उच्चतम जोखिम प्रतिशत 76.32 प्रतिशत देखा गया। ट्रैक्टर संचालित प्याज खोदने वाले के लिए अधिकतम पृथक्करण सूचकांक 75.81 प्रतिशत पाया गया, जबकि वाइब्रो प्याज खोदने वाले के लिए अधिकतम खुदाई दक्षता 93.62 प्रतिशत पाई गई।

छत्तीसगढ़ क्षेत्र के लिए सबसे अच्छा डिगर के रूप में वाइब्रो प्याज डिगर का चयन किया गया और एक विस्तृत अध्ययन किया गया क्योंकि इस डिगर में अधिकतम एक्सपोजर प्रतिशत, अधिकतम खुदाई दक्षता और न्यूनतम क्षति प्रतिशत है। स्प्लिट प्लाट एक्सपेरिमेंटल डिज़ाइन मै गति को मैन प्लाट और ब्लेड कोण को सब प्लाट को लिया गया। ऑपरेशन की गति 3.0 किमी प्रति घंटा और ब्लेड कोण 20 डिग्री के लिए सबसे कम क्षति 1.98 प्रतिशत के रूप में देखा गया था। उच्चतम जोखिम 97.22 प्रतिशत 3.0 किमी प्रति घंटा गति और 25° ब्लेड कोण पर पाया गया। संचालन की गति 2.5 किमी प्रति घंटा और ब्लेड कोण 15° के लिए पृथक्करण सूचकांक उच्चतम 57.87 प्रतिशत पाया गया। उच्चतम खुदाई दक्षता 94.81 प्रतिशत 3.0 किमी प्रति घंटा के संचालन की गति और 20 ° के ब्लेड कोण वाले होने पर पाई गई। विब्रो प्याज खोदने वाला 3.0 किमी प्रति घंटा की संचालन की गति और 20 डिग्री के ब्लेड कोण से कुशलता से काम करता पाया गया।

ट्रैक्टर ड्रेन प्याज डिगर, वाइब्रो प्याज डिगर और डक फुट प्याज डिगर की औसत संचालन लागत क्रमशः ₹ 178.99 प्रति घंटा, ₹ 170.71 प्रति घंटा और ₹ 101.71 प्रति घंटा पाई गई। ब्रेक ईवन अंक क्रमशः 551.97 घंटा प्रति वर्ष, 535.15 घंटा प्रति वर्ष और 336.05 घंटा प्रति वर्ष पाए गए। पेबैक अवधि क्रमशः 9.81 वर्ष, 9.51 वर्ष और 5.97 वर्ष पाई गई।

CHAPTER-I
INTRODUCTION

Onion (*Allium cepa* L.) is one of the oldest bulb crops, known to mankind and also known as queen of kitchen. The onion plant has been grown and selectively bred in cultivation for at least 7,000 years. India is the world's second largest producer of onion after China and it is one of the most important bulbs as well as cash vegetable crop belongs to family Alliaceous. It generally used as spices, vegetables and salad in daily life and every kitchen. In India onion is grown in three crop seasons, namely *rabi* (April – May), late *kharif* (January-February) and *kharif* (harvested in October-November). *Rabi* season crops contribute for over 60% of yearly production while *kharif* and late *kharif* contributing for approximately 20% each. Maharashtra was the major producer of onion followed by Madhya Pradesh and other states like Chhattisgarh, Rajasthan, Karnataka, Bihar, Haryana, Andhra Pradesh, West Bengal, Uttar Pradesh, Odisha, Tamil Nadu, Telangana and Jharkhand are also contributing to the country's onion production.

Onion is cultivated on 5.30 million hectares worldwide with a total production of 88.48 million tonnes with a productivity of 16.69 tonnes per hectare. In India, onion crop is grown in about 1.91 million-hectare area with an annual production of 31.13 million tonnes with productivity 16.26 tons per hectare (Anonymous, 2021 a). The total area under onion cultivation in Chhattisgarh is 23310 ha with a production of 365740 MT (2021-22) with a productivity of 15.69 tons per hectare. As per the report of Horticulture Department of Chhattisgarh, Raipur district is one of the major producers of onion with an area of 2862 ha having production of 50,327 MT and productivity of 17.58 tons per hectare which is greater than India as well as world productivity (Anonymous, 2021 b). Durg, Raigarh, Kanker and Surajpur are the top four onion producer districts in Chhattisgarh.

Onion is considered a perennial plant and it can be grown under a wide range of climatic conditions such as tropical, temperate and subtropical climate. The best results may be obtained in warm conditions without extremes of cold and heat as well as excessive downpour. Lower temperatures and shorter photoperiods are necessary for vegetative growth but higher temperatures and longer photoperiods are required for bulb development and maturity.

Table 1.1 Selected state-wise area, production and productivity of onion in India

States/UTs	Area (In ' 000 Hectare)	Production (In ' 000 Tonne)	Productivity (In MT/Hectare)
Andhra Pradesh	44.60	722.90	16.21
Assam	8.32	92.32	11.1
Bihar	58	1375	23.71
Chhattisgarh	**23.31**	**365.74**	**15.69**
Delhi	0.88	16.58	18.88
Gujarat	99.60	2554.70	25.65
Haryana	24.10	514.00	21.33
Himachal Pradesh	3.41	74.83	21.94
Jammu & Kashmir	4.32	77.84	18.03
Jharkhand	18.61	295.04	15.86
Karnataka	231.80	2779.50	11.99
Kerala	0.00	0.04	10.79
Madhya Pradesh	196.70	4740.60	24.10
Maharashtra	925.20	13301.70	14.38
Manipur	0.54	5.19	9.63
Meghalaya	0.57	5.12	9.00
Mizoram	0.27	1.80	6.67
Nagaland	0.60	5.61	9.34
Odisha	30.78	359.46	11.68
Puducherry	0.01	0.05	7.67
Punjab	10.35	246.52	23.83
Rajasthan	91.90	1447.90	15.76
Sikkim	0.27	1.67	6.14
Tamil Nadu	52.80	555.70	10.52
Telangana	9.10	172.00	18.90
Tripura	0.17	1.11	6.43
Uttar Pradesh	30.00	508.90	16.96
Uttarakhand	4.49	45.74	10.19
West Bengal	43.55	861.35	19.78
India	**1914.23**	**31128.90**	**16.26**

Source: Ministry of Agriculture & Farmers Welfare, Govt. of India.(2021-22)

Fig 1.1 Onion plants, uprooted plants and cleaned plants with leaves

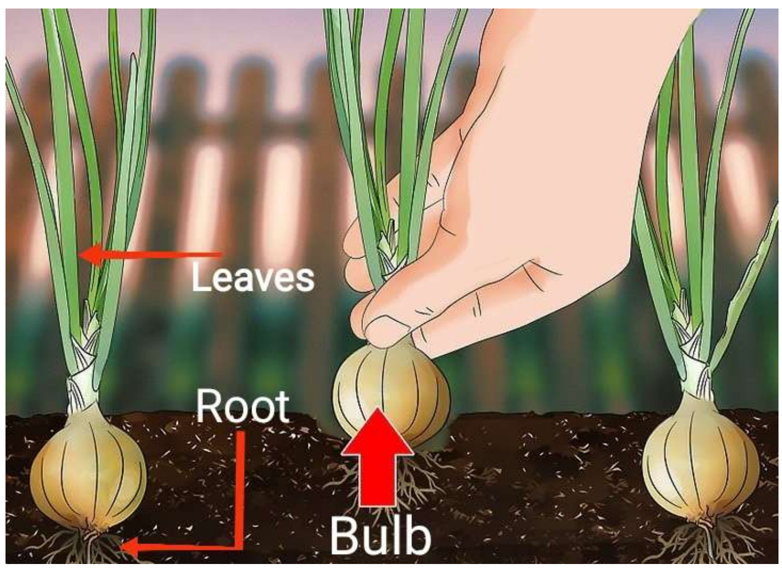


Fig. 1.2 View of parts of onion plants

Onion plant consists of the following two main parts: the bulb and the vegetative growth tubular leaves (Fig 1.1). The cross sectional of a onion plant is shown in Fig 1.2. Generally bulbs or seedlings are planted with row to row distance of 200 mm and plant to plant distance of 120 mm (Annon, 2021). Onion may very well be cultivated in a wide range of soil types including clay loam, sandy loam, heavy soils and silt loam. Deep, friable loam and alluvial soils with good drainage, sufficient organic matter and moisture holding capacity is considered as the ideal soils for effective onion growing.

Onion harvesting is carried out when the bulbs that grow from the leaf bases of onions are fully developed, the leafy green tips begin to yellow and finally collapse at a point a little above the top of the bulb leaving an erect short neck. Onion top don't fall during *kharif* season so bulbs are collected shortly after the colour of the leaves change to slightly yellow and red pigmentation on bulbs develops. Harvesting of onion crop at proper time is essential to decrease the post harvest losses and increase its shelf life of onion bulb. Infection of onion bulb due to microorganism occurs at late harvest of bulbs. The others parameters like sizing and yield also decreases at early harvest. Hence, timely harvest of onion bulb is essential to overcome the above problems.

Manual harvesting is accomplished by use of hand pulling the matured plants or by digging by use of mechanical tools like *khurpa,* spade or hoe. Manual harvesting of onion bulb required 80-300 man hour per hectare, depending upon the soil type (Akdemir *et al.*, 2005). The digging operation there are some tractor operated and power tiller operated onion diggers are available in India and abroad. The available tractor and power tiller operated was able to dugout onion and some even capable of collecting onions from soil, but their capital was very high and huge in size.

Due to unavailability of labour the harvesting works is not completed in time and huge loss was observed by the grower. The timeliness completion of harvesting is one of the major issues in onion cultivation. In order to extend shelf life and minimize damages of onion bulb it requires careful handling. (Maw *et al.*, 1996). In Chhattisgarh till now very little works were conducted for harvesting of onion.

The present study is conducted to minimize damage to onion bulbs, efficient in digging, minimizing the labour, reduction in drudgery carried out with following objectives:

i. To study the physical and engineering properties of onion crop at the time of harvesting
ii. To test and evaluate the performance of onion diggers in actual field conditions
iii. To select suitable tractor drawn onion digger for Chhattisgarh

CHAPTER-II
REVIEW OF LITERATURE

Harvesting is a crucial process in the onion bulb production and appropriate machinery for harvesting is now essential. It is critical in harvesting to have a machine that can do the work at a low cost and with a high output. Previous work conducted by various harvesters /diggers in India and overseas in relation to the design, development, and performance evaluation of onion diggers is examined and presented:

- Physical and engineering properties of onion bulbs
- Design parameters for development of onion digger
    - Crop parameters for designing an onion digger
    - Mechanical harvesting of onion
- Performance evaluation of onion digger, energy and cost economics
- Study of some other crop digger/ harvester

2.1 Physical and Engineering Properties of Onion Bulbs

Engineering considerations play a crucial role in determining the best digger for harvesting/digging. Some of the physical and mechanical characteristics of the onion bulb have been examined and are depicted below.

Bahnasawy *et al.* (2004) investigated physical and mechanical properties of three most popular onion cultivars in Egypt (Giza 6 (white), Beheri (red) and Giza 20 (yellow), which were very important to make important data-based decisions and understand the behavior of the product during post-harvesting operations such as harvesting, transporting, sorting, grading, packaging, and storage processes The physical attributes were equatorial and polar diameters, shape index, volume, density, mass, and surface area. The mechanical attributes were the rolling angle, coefficient of friction, crushing load, and penetration resistance.

Khura *et al.* (2011) conducted an experiment to examine the biometric and mechanical characteristics of the onion crop, which are crucial in the design of various harvesting machine components. According to the percentage distribution of onion bulbs beneath the ground surface it was found that the length of the onion crop varied from 11.0 to 32.0 cm with an average of 17.76 cm and row-to-row spacing of 14 cm. Mean equatorial diameter and polar diameter of small onions, medium and large onions, had values of 34.5, 33.8 mm and 49.82, 41.41, and 64.68, 53.20, respectively. Small, medium and big onion bulbs with leaves has average weights of 21, 52, and 112g, respectively,, while the bulk density was found to be 180, 260, and 290 kg m^{-3}. This aids in estimating how much material is handled by the onion digger's elevator. The information collected is quite helpful and might be used to construct various onion digger components.

Ghaffari *et al.* (2013) studied the physical attributes of three types of Iranian onion and measured dimensions, coefficient of friction, true density, rolling angle, and shape index. The equatorial diameter ranges between 46.63-59.82 mm and the polar diameter ranges between 46.93-59.82 mm. The mean shape Index for red *Azarshahr*, white *Kashan* and yellow *Isfahan* onion bulb varieties was obtained to be 1.004±0.023, 1.001±0.027 and 1.099±0.119 respectively. As a result, the three cultivars have a spherical shape. On plywood, galvanized, rubber, and P VC surfaces, the coefficients of static friction ranged from 0.243 to 0.821, 0.195 to 0.916, 0.852 to 1.186, and 0.909 to 1.250, respectively. The rolling angle varies between 11.13 and 15.87 degrees.

Bhanupriya *et al.* (2015) investigated the physical, frictional, and textural qualities of onion in order to set up grading, sorting, and packing systems and created a database. Equatorial diameter, polar diameter, geometric mean diameter (D_{gm}), arithmetic mean diameter (D_{am}), frontal surface area (A_{fs}), cross-sectional area (A_{cs}), mass, volume, density, co-efficient of friction, cutting strength, and TSS of 50 samples were measured. The form index of the bulbs is spherical although the physiology of Bellary onions and small onions (CO-3) differs from each other. The geometric mean is used to compute the study's normalized mean. The cutting strength of CO-3 onions and Bellary onions was 62.71±15.18 and 129.52±33.65 N. Co-efficient of friction and rolling angle ranged from 0.25±0.05 to 0.27±0.06 and 11.13±1.23 to 11.98±3.15; CO-3 onions have a total soluble solids content of 15° Brix, which offers them better storage properties than Bellary onions, which have a soluble solids content of 12° Brix. The redness value of the onions was not significantly different forboth and ranged between 12.24±2.40 to 14.84±1.43.

Kaveri and Thirupathi (2015) investigated the geometrical and physical features of CO-4 onion bulbs and discovered that the average moisture content was 83.45±1.10 per cent (wb) for the fresh onion bulbs and 81.82 ±1.01 per cent (wb) for three months preserved onion. Fresh onion bulbs had an average bulk density of 547.48 ± 26.30 where as three months preserved onion bulbs had an average bulk density of 408.53 ± 8.86 kg m^{-3}. Fresh and three-month-old onion bulbs had an average true density of 0.970±0.08, 0.930±010 g cm^{-3} respectively.

Gautam *et al.* (2016) conducted an experiment for studying the physical properties of pelleted and un-pelleted onion seed. The variety used was Punjab Naroya (PN) throughout the experiment. The important parameters were size, shape, thousand grain weight, angle of repose, bulk density and coefficient of static friction from engineering point of view in three different categories seed were got pelletized i.e. the ratio of seed to coating material was 1:1, 1:2 and 1:3. The geometric mean diameter was measured for the three categories are 2.45, 2.82, and 3.07 mm. In comparison, the geometric mean diameter for un-pelleted seed was 2.00 mm. In the laboratory, the average angles of repose for the cultivars under study were 29.50°, 24.78°, and 23.70° for pelleted 1:1, 1:2 and 1:3 onion seeds, respectively. Un-pelleted seed, on the other hand, had an average angle of repose of 31.61°. The porosity of un-pelleted to 1:1, 1:2, and 1:3 pelleted seeds rapidly dropped, although the porosity of 1:3 pelleted seed was 41.84 per cent, the lowest among the other cultivars. Un-pelleted seed has the maximum porosity (53.3 per cent).

Dabhi *et al.* (2017) determined the physical and mechanical properties of the onion crop for the Talaja Red variety. The polar and equatorial diameters including the weight of the bulbs were discovered to be linearly related. The shape of the onion crop varies from oval to spherical. The onion crop's shape ranges from oval to spherical. The mean bulk density of onion was 548 kg m^{-3}. Galvanized iron, mild steel, aluminum, and plywood all had friction coefficient 0.42, 0.39, 0.45, and 0.32 respectively. In addition, the angle of repose for galvanized iron, mild steel, aluminum, and plywood were discovered to be 23, 21, 24, and 17 respectively.

Other physical and mechanical properties were equatorial and polar diameters, bulk density, angle of repose, shape index, mass and coefficient of friction respectively. The equatorial and polar diameter varies from 36.67 to 74.96 and 29.32 to 60.05 respectively, with CV of 18.79 per cent and 16.55 per cent.

2.2 Studies on Parameter of Onion Harvester/Digger

Onion harvester/diggers performance depends upon many parameters such as agronomical (Bulb size, plant height, leaf height and cultivar type, etc) as well as mechanical parameters like (angle of repose, coefficient of friction and crushing load, etc).It was necessary for selecting appropriate parameters for digger/harvester according to requirement of crop. Many researchers were worked on these issues and are given as below:

2.2.1 Crop parameter for selecting appropriate onion digger

Tekle (2015) studied onion management strategies in Tigray's central zone. It was discovered that poor spacing and soil fertility played a significant effect in onion bulb output. From October to March 2014, a field experiment was undertaken to investigate the effect of varied row spacing (2.5, 5, 7.5, 10, and 12.5cm) and nitrogen rate (0, 41, 82, and 123 kg N ha^{-1}) and nitrogen rates (0, 41, 82, and 123 kg N ha^{-1}) on onion growth, bulb output, and quality in the Axum district of Tigray’s central zone. Factorial randomized complete block design (RCBD) with three replications of each treatment was used for statistical analysis.

Rajput *et al.* (2018) analyzed the performance of a dark red variety to that of a commonly cultivated seed onion in a front-line demonstration conducted in the years 2012-13 and 2013-14 in several areas in Chhattisgarh's Janjgir - Champa region. The primary goal of the research was to maximize productivity per unit area and collect farmer opinion on several types. It was observed that Agri-found variety yielded higher (0.21 t ha^{-1}) than local variety but fell short of its potential yield (0.25 t ha^{-1}). In addition, the Agri-found dark red cultivar had better net return, B:C ratio, and gross return. Agri-found Dark Red variety outperformed local in the technology index and its adoption index performance.

2.2.2 Mechanical harvesting of onion

Bendix and Krier (2002) studied mechanical harvester for harvesting, topping and sacking bulb crops, such as onions. The harvester removes the onions from the ground and conveys them backward to a cutting assembly via a conveyor system that drops little onions, mud, rocks, and debris. The cutting assembly is made up of a series of elongated cutting blades that work together to receive and sever the bulb's leaves and roots. Gravity aids in the offal falling away from the harvester and onto the ground. The onions were sliced before being transported to an inspection assembly for inspection, sorting, grading, and distribution. The onions were then moved backward to a bagging assembly to be placed into sacks, a chute mechanism to return the onions to the ground, or a conveyor system to be transferred to a side by truck. Platforms on the sides and ends of the harvester make the above possible.

Waszkiewicz *et al.* (2005) assessed crop damage, losses, and contamination during mechanized onion harvesting using one row combine harvester ground speed (0.43, 0.50, 0.62, 0.75 m s^{-1}), separating web speed (1.37, 1.78, 2.30, 2.73 m s^{-1}), at three positions of mechanical separator scraper. They discovered that differentiating web speed has a considerable impact on onion losses on this site. The arrangement of the separator scraper determined the plant losses on mechanical separators as well as overall losses. The examined parameters had no significant impact on the values of onion damage and contamination. The average overall loss was 2.60 per cent, with damage accounting for 0.99 per cent and contamination accounting for 0.49 per cent (mainly with soil clods). It was discovered that onion plantations should be adequately prepared for mechanical harvesting in order to obtain the correct quality standards, since losses and damage were shown to be directly related.

Khura *et al.* (2011) developed the tractor-drawn onion harvester and its primary components were digging, transporting, and sorting units. Six different shapes of digging blades were examined for digging effectiveness. The lowest mean draught was 625.6 N for the inverted v-shaped blade. The best design parameters for elevator length, speed ratio, and slope were discovered to be 1.2 m, 1.25:1, and 15°, respectively. During field testing, the prototype onion digger with the aforementioned design parameters performed as predicted, with 97.7 per cent digging efficiency, 79.1 per cent separation index, 3.5 per cent bulb damage, 4.10 l h^{-1} and draught of 10.78 kN. When compared to manual digging, the cost of onion digging per hectare saved by employing the created digger was determined to be ₹ 1170 per hectare.

Massah *et al.* (2012) worked on onion harvester It was discovered that the blade was normally positioned at an angle on the head of the onion harvester in order to extract the bulbs from the soil. The harvester's efficiency and the proportion of damaged onion bulbs are both affected by the harvester's blade angle and harvesting depth. The blade angle was changed using a four-bar mechanism. The tests were carried out at vehicle speeds of 1.8, 2.4 and 3 km h^{-1} with blade angles 12, 15 and 20°. A factorial experiment was conducted based on a randomized complete design. The harvester performed best at a vehicle speed of 1.8 km h^{-1} at a blade angle of 20°. The harvester caused a lower percentage of damaged bulbs than the manual. Based on the damage of the harvested onions, a vehicle speed 2.4 km h^{-1} and blade angle of 20° were chosen for harvesting process.

Hong *et al.* (2014) developed a tractor-mounted Welsh onion harvester. The performance of the onion harvester was assessed at tractor running speeds of 50 mm s^{-1}, 114 mm s^{-1}, and 158 mm s^{-1} by comparing the operating efficiency, harvest rate, and damage rate. The harvester's performance was recorded as per the tractor operating speed. The harvesting efficiency was increased with the increasing of the operating speed. Damage rate of the harvested Welsh onions at running speeds 5.0 cm s^{-1}, 11.4 cm s^{-1} and 15.8 cm s^{-1} increased correspondingly and proportionally to speeds from 4.55% to 6.53% and to 11.29%. The remaining quantity of dirt on the harvested Welsh onions was approximately 0.24 per cent of their weight, demonstrating the harvester's exceptional soil-removal efficiency.

Khambalkar *et al.* (2014) developed an onion harvester for tractors within range of 15 to 20 horsepower. The crop's agro-technical qualities influenced the harvester's size. The operating width of the harvester was calculated to be 60 cm, the depth of operation was determined to be 10 cm, and the width-to-depth ratio was 6:1, which was adequate for the design. The harvester's soil mass load was calculated to be 1.35 N cm^{-2}. For a travel speed of 3.0 km h^{-1} the volume of soil discharge per second on the web has been estimated to be 0.023 m^3 s^{-1}. Both the blade bending moment and the onion crop harvester were safe to use in black cotton soil. According to the suggested technical drawing, the total weight of the machine is 44.38 kg. The expected cost of the onion harvester was assessed to be ₹7354.00.

Mozaffary and Kazmeinkhah (2014) developed, manufactured, and tested an onion harvester in East Azerbaijan to solve challenges associated with manual harvesting. They initially constructed and tested the topping mechanism, and then they devised and built the undercutting mechanism. Three varieties of onion toppers were created and an experiment was carried out to determine the best topper. The collected data set was statistically analyzed using factorial RBD having two factors (topper prototype; flail, rotary, and roller topper and mechanism rotational speed of mechanism; 1500, 1700, and 2000 rpm) and three replications. The test was done in two stages, using characteristics including acceptable top percentage, not acceptable top percentage, not topped percentage, and damaged bulbs percentage.

Singh (2014) evaluated the performance of a newly constructed onion digger. The main component was a high carbon steel (EN 45) blade with dimensions of 1430 mm x 70 mm x 15 mm. Depth control wheels were provided to adjust the blade's depth of cut. Field test were carried out to compare the performance of an onion digger with manual labour. The digger was operated at speeds ranging from 3.76 to 4.83 km h^{-1} with minimal losses at 4 km h^{-1} in first high gear with a field capacity of 0.46 ha h^{-1}. The developed digger's average operational depth of 7.62 cm proved sufficient, with almost minimal damage to the onion bulbs. The digger's operational time, including and excluding turning time, was 3.10 h ha^{-1} and 2.38 h ha^{-1}, respectively. The plant density at harvest was 2,76,700 bulbs per ha and the output was 15.2 t ha^{-1} with 94.9 per cent lift, 89.8 per cent mean digger efficiency, and 5.1 per cent damage. Labor and cost reductions of 58 per cent and 49 per cent, respectively, were observed.

Mehta and Yadav (2015) developed an onion harvester that could dig the onion plants with blub and lay them unevenly on the bed surface. The theoretical field capacity of the harvester was 0.57 ha h^{-1}, whereas the actual field capacity was 0.45 ha h^{-1}, with a field efficiency of 78.95 per cent When compared to manual harvesting, the time, energy, and cost of harvesting onions were reduced by 87.64 per cent, 46.23 per cent, and 78.86 per cent, respectively, as compared to manual harvesting. The developed harvester had an average depth of cut of 6.0 cm, a width of cut of 1.80 m. The draft required for operating the onion harvester was 470 kg at a speed of 2.52 km h^{-1} and the power requirement was 4.39 hp (3.27 kW) with the fuel consumption of 2.53 l h^{-1}.

Rane *et al.* (2015) investigated a dependable solution for onion crop harvesting. The harvester's size was determined by the crop's agro technical properties. It was anticipated that the onion harvester will require 8 horsepower. According to the proposed CAD model the total weight of machine was found to be around 640kg. According to the agro-technical requirements the depth of operation was decided while machine width was determined by the power availability controlled. The PTO power requirement of the harvester at an operating speed of 1.0 km h^{-1} was expected to be in the 11 to 13 hp range.

Pavani (2017) designed, developed and evaluated the performance of a tractor operated onion digger. The number of leaves, equatorial diameter, polar diameter, depth of crop, true density, and bulk density of onion crop were determined to be 63, 45.1 mm, 42.77 mm, 80.16 mm, 944.35 $kgm^3$and 548.15 kgm^3, respectively. Harvesting efficiency was found to be 100 per cent regardless of rake angle or speed of operation. The draught demand and damage percentages were 550 N and 2.3 per cent, respectively at a rake angle of 20 ° and a forward speed of 2 kmh^{-1}. The actual field capacity, field efficiency and minimum power requirement of the machine was 0.19 ha h^{-1}, 82.2% and 3.03 kW and at the same combination the machine's actual field capacity, field efficiency, and minimum power requirement were 0.19 ha h-1, 82.2 per cent, and 3.03 kW. The cost of operation was found to be ₹19190 ha^{-1} compared to hand harvesting ₹21125.00 ha^{-}

^{1}, and the machine's breakeven point was 23.6 hours, or 47.5 per cent of yearly utility. The tractor-operated onion digger has a payback period of 1.06 years.

Gavino (2018) developed an onion harvester with a field efficiency of 80.52 per cent and a field capacity of 0.086 ha per hour. With this digger, the amount of work required for onion harvesting was lowered from 122 to 69 man-hours per ha. The custom rate of digging and windrowing onions per hectare using the machine was calculated to be ₹1245.60 per hectare and the total cost from harvesting to bagging was approximately ₹10,257.85, resulting in a decrease of approximately ₹ 4835.85 per hectare for the completion of harvesting from uprooting to bagging operations than manual harvesting.

Ghule *et al.* (2018) designed and developed equipment to meet harvesting requirements while lowering the cost of onion harvesting. Power was transferred from one shaft to another by pulleys using flat belts, V-belts, and ropes. The angle of the v-belt was approximately 30°- 40°. The power was transmitted by the wedging movement of the belt and the V-groove in the pulley or sheaves which results in increased friction forces. Teeth on bevel gears with pitch angles of exactly 90 degrees point outward parallel with the axis and resemble crown points. A roller bearing's function was to minimize rotational friction and to provide radial support to axial loads. The developed harvester was very small size comparison to other available harvesters and affordable to all farmers. The smaller size of harvester helps in boosting the efficiency.

Omar *et al.* (2018) created a tractor-mounted onion harvester. The onion harvester design comprises of a frame, a lifting device (blade and collected roller), an elevator and a collecting mechanism. Experiments were conducted and performance was assessed using four harvest depths (40, 60, 80, and 100 mm) and four forward speeds (0.720, 0.837, 0.947, and 1.125 km h^{-1}). Field capacity and filed efficiency, lifting efficiency, total crop losses, power and energy consumed and overall cost needs for onion crop harvesting were recorded. The findings showed that the highest field capacity was 0.180 fed h^{-1} at speed of 1.125 km h^{-1} and the maximum field efficiency was 73.9 per cent at speed of 0.720 km h^{-1}. When compared to the manual harvesting at a depth of 40 mm, and the field capacity and field efficiency were 0.05 ha h^{-1} and 84.26 per cent, respectively. The developed onion harvester achieved 99.20 per cent lifting efficiency and 1.90 per cent total losses, compared to the manual harvesting which recorded 98.10 per cent and 2.50 per cent, respectively.

Shelar *et al.* (2019) constructed a self-propelled onion harvester that performed well in terms of productivity, crop damage, fuel economy and operator comfort. The roll cage consisted of a structural base and a 3-D shell surrounding the driver. It was also obtained that the roll cage design was optimized according to a set of specific guidelines established by the Society of Automotive Engineers (SAE). It was also acquired the optimal factor of safety which assures that the roll cage of the machine is safe in all situations. In compliance with the event's rigorous rules, the model was optimized using that project and on ANSYS. The roll cage was also evaluated using finite elements, and as a consequence we can infer that the roll cage fulfils the required factor of safety and is safe for a driver.

Gujar *et al.,* (2020) designed and developed a self- propelled onion harvester which has a hydraulic jack mechanism that can be adjusted the height of the digging system as per the type of crops harvested. The machine was tested for a worst case scenario as there are variety of soil available throughout India and so, black cotton soil which has a 0.7 kg/cm^2 soil resistance was chosen for testing of developed digger. The digging blade has a dimension of 810×100×5 and the material of construction was chosen as C45. The angle of conveyor system was 30° and the velocity was 0.52 m/s. the spacing between separating unit was 0.025m.

Joshi *et al.,* (2020) designed and developed a three point actuated conveying and digging system for self propelled onion harvester. The developed mechanized onion harvester can run on power supply from vehicle and does not require any external power source. The digging system consists of a trapezoidal scoop and v- shaped digging blades and while the conveying system designed for separation of soil mass from onion and collection of onion bulb at the end. The three point actuators were made for adjustment of entire harvester electrically. The front two actuators help in changing of conveyor angle while when all the three combined they control height of digging operation.

Goutam (2021) designed and developed a tractor operated onion digger. The working width of blade was kept at 600 mm that can wok up to 100mm depth from ground surface. Three different blade shapes was used *viz.* V- shape, serrated blade and flat blade and the best working blade was selected for the developed digger. ANSYS-R1-2021 was used to test the material of blade. Three different separator velocity (0.5, 1.0 and 1.5 m s^{-1}) and five inclination angle (10, 15, 20, 25 and 30°) was analyzed statistically with the help of factorial randomized block design. The overall dimension of the developed digger was found to be 1500× 85 × 800 mm which has a small size in comparison to other developed digger and was developed to affordable for small farmers. The best result was found in V-shaped blade with rake angle of 20°, at a separator velocity of 0.7 ms^{-1} . At the forward speed of operation 2.0 km h^{-1} the damage percentage was found to be minimum and digging efficiency was maximum. The cost of operation of developed onion digger and with manual method were found ₹ 3,346.72/- per hectare, and ₹ 17,121.74/- per hectare, respectively.

Erokhin *et al.*, (2022) modeled and developed an onion harvester which has a automated separation system. The digger has a adjustable blade angle inclination angle which provide an increase in production of quality onions at optimal values of parameters. Translational speed of movement of rod elevator at a speed of 1.0 m/s with an adjustable blade angle has a separation index of 98.5 per cent, damaged per cent of 1.1 per cent.

2.3 Performance Evaluation of Onion Digger and Cost Economics

It was critical to test the prototype in the field after the machine had been developed. Previous study work was examined step by step for machine and harvesting parameter testing which is described in this section.

Fujii *et al.* (2008) examined former welsh onion harvesters and compared performance evaluation. The farmer who acquired the Welsh onion harvester underwent a Customer Satisfaction (CS) Portfolio study. A conjoint analysis was also done based on likes and dislikes. They noticed that farmers had great expectations yet they just wanted to pay the bare minimum. The results also revealed that farmers were more interested in the operational efficiency of the harvester than its cost. It was concluded that farmers desired high-efficient machinery at a lower cost.

Hong *et al.* (2014) conducted an experiment to assess harvesting performance. The operating efficiency, harvest rate, and damage rate of a welsh onion harvester were compared at tractor running speeds of 50 mm s^{-1}, 114 mm s^{-1}, and 158 mm s^{-1}. The mechanization of the harvesting process which is now associated with the maximum labour hour was anticipated to increase labour productivity and the agricultural environment.

Budhale *et al.* (2019) examined blade angle and vehicle speeds to assess the performance of an onion harvester machine. Based on the damage of the harvested onions, a vehicle speed of 2.4 km h^{-1} and blade angle of 20° were chosen for the harvesting process. The harvester delivered less damaged onions than manual harvesting. Indian agriculture was experiencing labour shortages, rising input costs, and conventional harvesting was too difficult for labourers to do adequately in the field. Because mechanization decreased all issues in that sector, it was required to design and develop digging and conveying units to boost machine efficiency and minimize operating costs and labour fatigue.

Narendra *et al.* (2019) studied a tractor-operated root crop digger in Haryana's sandy loam soil for potato, carrot, and onion crops. Expose percentage, cut percentage, bruised percentage, and digging efficiency were assessed at three different forward speeds and blade angles. The root crop digger was driven at speeds of 2.3, 2.2, and 3.2 km h^{-1}, with blade angles of 23°, 20°, and 17° for potato, carrot, and onion crops, respectively, yielding digging efficiency of 98 per cent, 100 per cent, and 100 per cent, cut percentages of 1.71, 46, and 0.00 per cent, bruised percentages of 2.45, 2.28, and 3.39 per cent, and exposed percentages of 91, 92, and 97 per cent. Though the digging efficiency for carrots was 100 per cent the machine's cut percentage was 46% per cent, indicating that it has to be modified for carrot digging. The unit's operational costs for potato, carrot, and onion digging were ₹ 2241, ₹ 2641, and ₹ 1885 per ha, respectively. Mechanical diggers reduced digging expenses by 54% per cent, 46 per cent, and 51 per cent, respectively, as compared to manual harvesting of potato, carrot, and onion crops.

Nour *et al.* (2020) worked on the development and performance evaluation of a local harvesting machine for onion crop, and field tests were conducted in El-qureen city, Sharkia Governorate, Egypt to evaluate a single-row designed machine. To achieve entire mechanical onion harvesting a local peanut harvesting equipment has been designed. The designed harvesting machine's performance was evaluated using the following parameters: varied forward speeds of 1.7, 2.4, 3.1, and 3.8 km h^{-1} and soil moisture contents (db) of 9.4, 12.7, 15.8 and 18.8 per cent. Field capacity and field efficiency, lifting efficiency, machine productivity, necessary power, total harvesting losses, specific energy, operational and total expenses were all considered while evaluating the performance of the designed machine. At constant digging depth, the pulling chain speed and penetration angle were 10.0 cm, 66.13 m min^{-1} and 10 °, the correct forward speed and soil moisture content were 3.1 km h^{-1} and 15.8 per cent (d.b.) to operate the built machine with high field power, performance, and low specific energy and total cost.

2.4 Study of Some other Root Crop Digger/ Harvester

Many researchers worked on different diggers and harvesters for tuber crops which provide information on tuber crop planning, development and assessment. Digger and harvester similar to onion digger are reviewed and presented here.

Trivedi and Singh (1975) designed a two-row mechanical digger. Field tests were carried out at various operational speeds and blade shapes installed at a rack angle of 20°. In terms of recovery, convex blades performed better than concave blades with 87.60-93.44 per cent in convex and only 77.47-82.14 per cent in concave. They concluded that operating at a depth of roughly 200mm minimized potato damage. It was discovered that 20 hp tractors were running the digger safely, with the best results produced at an operational speed of 4 km h^{-1}.

Singh and Singh (1979) developed a two mechanical digger and tested its performance by altering the blade. The blade forms that were employed were convex, concave, and sweep. The convex type blade caused the least damage and recovered the most potatoes. The potato spinner and elevator digger were also compared to the convex blade of two row mechanized digger. The damage percentage of the potato spinner was determined to be around 10.33 per cent, whereas the damage percentage of the two row mechanical digger was approximately 0.11 per cent. The recovery rate with the elevator digger was 92 per cent whereas the recovery rate with the two-row mechanical digger was 73.4 per cent. The digger operated best at 4 km h^{-1} forward speed.

Jubouri *et al.* (1984) analyzed the performance of a vibratory potato digger using an orbital (circular) vibration theory in the vertical plane through the row. According to theory, the velocity ratio (ratio between vibrating blade tip and vibrating blade carrier) increases when the draft force decreased and required power increased. A field test was performed to confirm the prediction theory utilizing a vibratory digger at an operational speed of 3 km h^{-1} and a depth of operation of 200 mm, with vibration amplitudes of 10-25 mm at a frequency of 7518 Hz. Similar findings in terms of draught ratio were found in field tests, as expected by theory. However, the required power in the actual field test was greater than predicted. It was also discovered in field tests that as the needed draught dropped the potato damage and losses decreased when compared to traditional non vibratory potato diggers.

Awadhwal *et al.* (1995) designed and developed a groundnut harvester, which was constructed at the ICRLSAT Asia Center. It is made up of a single and two share units. To promote penetration, the digger's two share system was slanted at 120° and created chisel point. A single bottom digger was made up of a draw pole that was pulled by a pair of bullocks, whereas two or more bottom diggers were driven by tractor. Because of its 600 mm working width the bullock drawn chisel digger was able to harvest two rows with spacing of around 300 mm and field capacity was reported to be about 0.088 ha/h with less than 5 per cent loss. It undercuts groundnut tap roots, letting plants to stand erect without difficulty. The chisel digger performed well even in soil conditions where the blade digger's performance was poor and not suitable for operation at the specified depth.

Singh (2006) developed and tested a tractor-mounted two-row multipurpose potato digger (MPD). On the blade two replaceable ridge opening devices were installed. To keep the digger steady, two furrow guides were installed on the sides of the columns. The prototype proved effective in digging in early days (60-65 days, without removing haulms) and main crop in optimal moisture conditions, as well as in dry condition at 610 and 686 mm row-to-row spacing. When compared to manual harvesting with *khurpa,* the labour needs for digging early crop were reduced by 37% and damage was reduced by 72%. When MPD was compared to a digger elevator (ED) MPD exposed 3.5 per cent fewer tubers than ED at optimal moisture conditions and field capacity was 0.36 ha h-1 more than ED. In the case of MPD, exposure was increased by 15.9 per cent in dry field conditions. At a row spacing of 686 mm the prototype was likewise effective at collecting potatoes. This required a little modification to the ridge opening mechanisms on the blade. There was no significant breakdown of MPD in a long-term assessment.

Younis *et al.* (2006) improved the cutting of soil and reduced drawbar bull potato tuber bruising by using a vibrating device on the potato digger blade. The vibrating device of digger consists of beam holder, follower, cam, and transmission system. To evaluate the machine's performance many parameters were checked. The digger was tested at four different speeds (0.9, 1.5, 1.9, and 3.2 km h^{-1}) and four distinct vibrating amplitudes (3, 5, 6, and 10 mm), and five different vibrating frequencies (400, 600, 800, 1000 and 1200 rpm). The drawbar pull of the manufactured digger was lowered by 25.17, 25.91, 28.43, and 30.47 per cent at forward speeds of 0.9, 1.5, 1.9 and 3.2 km h^{-1}, respectively when compared to the original digger records at amplitude of 10 mm with a frequency of 1200 rpm. The appropriate amplitude was 6 mm with a frequency of 800 rpm which gave the lowest drawbar pull with lowest bruising ratio. The developed digger may be operated with a 110 hp tractor instead of a 140 hp tractor or higher by lowering harvesting expenses by 28.5 per cent. Their adjustment was successful which increases the machine field capacity by 8.3 per cent.

Ibrahim *et al.* (2008) developed a multi-purpose digger for harvesting potato and peanut using a vibrating separation mechanism that successfully separated the crops while causing minimal damage. Harvester was put through its paces at three distinct forward speeds and three different tilt degrees. Speed of operation for potato crop was 1.8, 2 and 2.6 kmh^{-1} whereas for peanut crop 1.4, 1.8 and 2.3 km h^{-1} respectively. Both crops had identical tilt angles (12°, 18°, and 24°). The studies were conducted during two good agricultural seasons in 2007 for potatoes and peanuts in El Assasin country, El Sharkia Governorate and 2008 in Manzala city, El Dekahlia Governorate. The harvesting depth of 22 cm, forward speed of 2.6 km h^{-1} and a tilt angle of 18° was ideal operating conditions for the potato crop and harvesting depth of 15 cm, forward speed of 2.3 km h^{-1} and a tilt angle of 12° was ideal operating conditions for the peanut crop according to the obtained data.

Khurana *et al,.* (2013) designed and developed a root crop harvester for onion, garlic, carrot and potato crops. The root crop harvester was a modification of a previously existing potato digger and was used to evaluate the mechanized digging of crops like onion, carrot and potato. The digger blade has width and thickness of 1144 and 16 mm. The blade of digger made an angle of 20° with the horizontal. The elevator conveyor made an angle of 18° with horizontal and was attached behind the blade. Two oval agitators were attached to the conveying system for separation of soil particles from the tubers. Power was supplied to the digger via gearbox and two coulter discs were attached at the front of blade for easy slicing and lifting of soil. The exposed percentage was found to be 99.00, 96.80, 98.60 and 96.40 per cent for onion, carrot, garlic and potato, respectively. The damaged percentage was found to be less than 1.00 percent for onion, less than 2.8 per cent for carrot, 1.16 per cent for garlic and 1.92 percent for potato crop.

Akhir *et al.* (2014) designed and tested a sweet potato tuber digging device on bris soil. The soil texture was sandy (94.53 per cent fine sand), with an average moisture content of 9.16 per cent and a mean bulk density of 1.44 g cm^{-3}. The digging tools were tested in a soil bin filled with bris soil to determine the appropriate draught power and area of soil disturbance. Three different types of soil digging tools were constructed and installed i.e. flat or plane, V-shaped, and hoe-shaped blades were used. Hoe blades are made up of three 25 mm diameter rods that are 300 mm in length and 65 cm in width and have a sharp cutting edge, whereas the flat and V-shaped blades were 300 mm in length and 130 cm in width. The findings were examined using statistical analysis of variance (ANOVA). The machine was tested in two fields for two distinct sweet potato types and harvesting efficiency was found to be around 93.64 per cent in telong (in plot-A) and 90.49 per cent in vitato (in plot-B). In plot-A, the operational speed was about 0.56 km h^{-1} and the turning loss was 102.7s whereas in plot-B, the operational speed was approximately 0.99km h^{-1} and the turning loss was 81.22 s. Field capacity was discovered to be around 0.068 ha h^{-1} in plot-A and 0.12 ha h^{-1} in plot-B, with no significant variation in field efficiency detected in either field. The average working hour in both fields was 11.47 h ha^{-1}.

Shirwal *et al.* (2015) investigated the design characteristics that influence mechanical carrot harvesters. An experiment was carried out to assess the different design factors. That factors included three soil separator lengths (40, 60, and 80 cm), three rake angles (15°, 25°, and 35°) and three soil separator angles (0, 10°, and 20°). The combination of these all characteristics resulted in an ideal soil moisture content of 12 per cent. The dependent parameters were harvesting efficiency, damaged carrot and soil separation index. Harvesting efficiency was highest (97.40 per cent) when the separator length was 600 mm and the separator angle was 20° and the blade rake angle was 25°. By utilizing a separator 40 cm long and at an angle of 20° from horizontal the damage was reduced to roughly 4.87 per cent. Carrots with a rake angle of 25° to 35° suffered damage ranging from 4.63 to 4.97 per cent. The length and angle of the separator had the largest influence on the soil separation index. The soil separation index (0.23) was lowest at separator length 800 mm with inclination angle 20°.

Shirwal *et al.* (2015) developed and evaluated performance of a carrot harvester. The major components of the harvester were a V-type digging blade (350 mm width and 15 mm thick) and a separating unit (of length 700 mm with space between rods of 5 cm). To analyze the performance various degrees of rake angles, soil separator lengths and soil separator angles were employed. Harvesting efficiency of approximately 97.80 per cent, damage loss of around 4.6 per cent and average soil separation Index of around 0.21 with field capacity of 0.21 ha h^{-1} was found after operating carrot harvester in the field. At a speed of 3.8 km h^{-1} the machine required 5.18 kW of power to function.

Singla *et al.* (2016) designed and developed the tractor operated carrot digger. The carrot digger was made up of a digging unit, a transportation unit, a de-topping unit, a collecting unit, a main frame, and a power transmission system. Power was delivered from the tractor PTO to the conveying and de-topping unit using a chain sprocket system, universal shafts, a gear box, and bevel gears. Overall, the transmission ratio was 3.6 and the transmission ratios of the gearbox and bevel gears were 1.8 and 2, respectively. A sweep type blade was used to dig the carrots, and two triple pitch roller chains rotated in opposing directions to hold the leaves of the carrots excavated by the digging blade. Under the conveying unit, a de-topping mechanism with two serrated discs rotating in opposing directions was fitted to cut carrot leaves. The digging, cutting and picking, efficiency of the de-topping unit were all 100 per cent, 100 per cent and 61.56 per cent, respectively. The digger's effective field capacity was 0.11 ha h^{-1} with a field efficiency of 61.70 per cent. In comparison to the manual method of harvesting, the designed carrot digger saved 94 per cent of the time and 63.36 per cent of the money.

Kumar, D. and Tripathi, A. (2017) developed a potato digger cum elevator capable of excavating potatoes with little damage. It reduces labour by 75 per cent and operating time by 50 per cent when compared to manual digging with spades, *kudali*, and *khurpi*. When the crop was harvested using traditional methods such as spade and *khurpa*, it took roughly 210 man-days per hectare. Farmers with 10 ha or more of land usually utilise tractor-mounted potato digger cum elevators. In elevator diggers, potato damages such as bruise, cut, split, and so on are on the order of 10-12 per cent. Damage is caused by two pairs of elliptical sprockets that separate potatoes from the soil, soil clods and foreign substances. The potato digger cum elevator exposed 95-98 per cent of the potatoes in a single pass. When compared to manual digging with spades or cultivators, overall operating time and diesel consumption per unit area are reduced by at least 75 per cent and operational costs are lowered by 50 per cent. The potato damage caused by digger cum elevator is around 2-2.5 per cent which is less than the damage caused by *deshi* plough (5.2 per cent) and hand digging with spade and *khurpi* (4.5- 7 per cent). It also minimizes harvesting losses by around 4-5 per cent.

Nagendra *et al.* (2018) designed the tractor-drawn ginger harvester cum elevator with the purpose of having mechanical methods for harvesting ginger crop. The experiment was conducted on red clay soil with moisture content (db) of 13.50 per cent at the time of harvesting. The experiment plot had a size of 0.2 hectares and was utilized for observations. The ginger harvester cum elevator was tested at a forward speed of 2.5 km h-1. The required draught and power for harvesting ginger crop using a harvester cum elevator were determined to be 2625.82 N and 1.82 kW, respectively. The operating fuel consumption was found to be 5.03 l h^{-1}. The effective field capacity, theoretical field capacity, and field efficiency of the ginger harvester cum elevator were calculated to be 0.18 ha h^{-1}, 0.22 ha h^{-1},and 81.80 per cent , respectively and the digging efficiency, rhizome damage, separation index, and conveying efficiency were recorded to be 99.18 ha h^{-1}, 1.06 per cent, 85.38 per cent, and 99.72 per cent, respectively.

Sun *et al.* (2018) developed the self-propelled garlic harvester. It consists of a chain style clamping and conveying unit which was designed on the basis of physical characteristics of garlic stem. Field testing and simulation analyses were carried out by varying different factors such as chain speed and knife rotational speed. The garlic digging efficiency, transported garlic, dust exposer, stem cutting and garlic harvesting results were used to evaluate the test. The clamping and conveying unit was developed with a tension of 12000 N at a 42° angle from horizontal and a spacing of 15 mm between conveying chains. The cutter's rotation speed was kept constant at 150 rpm. They obtained a field capacity of roughly 0.045 ha h^{-1} at an operational speed of 2.8 km h^{-1}, with damage percentage, leakage rate, and drain cut rate were observed about was about 0.43, 0.96 and 1.441 per cent.

Deshvena *et al.* (2019) carried out an experiment to assess the performance of a tractor-drawn turmeric digger. A test setup was employed with the option of varying design factors, which included a digging unit and a soil separation unit. To improve performance three distinct shapes of blades were compared strip shape, inverted V shape and crescent shape. Soil moisture, digging unit, rack angle, and operating speed were all examined as design criteria. Performance criteria such as harvesting efficiency, damaged percentage of turmeric rhizomes, soil separation index, power demand, and design values for various components were determined at various levels of design parameters. Maximum digging efficiency was recorded in the strip form which was approximately 97.35 per cent at an operational speed of 3.0 km h^{-1} and a rack angle of 20° and soil moisture content was 14.23±0.35%. The capacity of the field was also measured. The turmeric digger cum separator was tested with three distinct digging blade shapes and three different forward speeds namely 1.5, 3.0, and 4.5 km h^{-1}.

Narendra *et al.* (2019) investigated the root crop digger for potato crop digging in a field trial. Field tests were conducted by varying two factors namely forward speed (2.3, 2.8, and 3.3 km h^{-1}) and rake angles (17, 20, and 23) at three levels of both parameters with three replications. In terms of potato exposed after potato after digging, undug, cut, bruised percentage, and digging efficiency, the digger performed well at operational speed 2.3 km h^{-1} and 23° blade angle, with values of 90.62, 2.10, 1.71, 2.48, and 97.90 per cent, respectively. When compared to manual digging including labour, utilizing a digger might save around 5 per cent on digging costs. The percentage of exposed potatoes, un dug potatoes, and chopped potatoes decreased with increase in blade angle of root crop digger but the digging efficiency increased with increase in blade angle. It was discovered that the forward speed of 2.3 km h^{-1} and blade angle of 23° are the ideal for digger operation for potato crop.

Nath *et al.* (2019) investigated the effect of soil depths and moisture content affected the effectiveness of a carrot combine harvester mechanism. The performance was examined and the average bulk density was reported to be 1.40, 1.48 and 1.59 g cm-3 for 5, 10 and 15 cm depths, respectively. The average moisture content of the soil was 9.30, 11.93, and 12.03 per cent at 5, 10 and 15 cm depths, respectively. The coefficients of internal friction, soil metal friction and cohesion were 30.74°, 26.02°, and 0.07kg cm^{-2} , respectively. The maximum draught (212 kg) was measured at a depth of operation of 15 cm and a rake angle of 30 degrees. While, at 5 m depth of operation and 20 degree rake angle, the least draught (65.5kgf) was recorded. The draught of the carrot combine harvester rose as the rake angle and moisture content increased. The results show that lifting efficiency has a significant influence on moisture count.

Sharma *et al.* (2019) designed and simulated of low cost root crop harvester. All measurements, dimensions, and material selections were taken using the design hand data book and ASTM-A36. The root crop harvester was created analytically and then validated using CAD software. CATIA V5 software was used to model the optimal geometry of the plough, wheel assembly link, and plough Link. When two times the parameters were applied, the components design was verified to be safe during operation. Based on the cost of parts used in the proposed machine, it was inferred that the cost of the suggested machine was 20 per cent cheaper than the cost of a similar machine on the market.

Issa *et al.* (2020) conducted a field experiment on the design, ANSYS analysis, and performance evaluation of a potato digger harvester and the model for this project was created using Solid Works software to overcome design challenges. The trials were conducted using tractor forward speeds of 2.5, 4.5, and 6.5 km h^{-1}, digger angles of 12°, 17°, and 22°, and conveyor speeds of 2.8 and 4 km h^{-1} as parameters. The field capacity and efficiency were measured as well as the results of fuel consumption, power required, energy required, lifting potatoes, scuffed damage tubers, peeler damage tubers and overall damage. The maximum field efficiency was 91per cent at forward speeds of 2.5 km h^{-1} and conveyor speeds of 4 km h^{-1}. At 2.5 km h^{-1} forward speed and 22° digger angle, the machine required a maximum power of 16.13 kW. The lifting of potatoes frequently improved as the digger angle increased from 87.63% to 95.14 % at 12° and 22°, respectively. Furthermore, when the digger angle, forward speed, and conveyor speed increased so did the total damage. As a result, with a forward speed of 2.5 km h^{-1}, digger angle of 22° and a conveyor speed of 2.8 km h^{-1} the overall damage percentage was 2.67 per cent.

2.5 Economic Evaluation of the Developed Harvesters

Nagendra *et al.* (2018) conducted on doubling farmers revenue from ginger crop harvesting using a tractor-drawn ginger digger-cum-elevator. In the study field, a tractor-mounted ginger digger cum elevator prototype was examined in black and red soil and was compared to manual harvesting under similar conditions. The field capacity was 0.085 hectare per hour and the harvesting efficiency was 77.27 per cent with less than 3.29 per cent rhizome damage. Harvesting capacity was 85.90 per cent when harvested manually with 4.26 per cent rhizome damage and 98.76 per cent rhizome lift but it was 99.01 per cent when harvested using a ginger harvester-cum-elevator. The harvester cost ₹80,000 and the cost of harvesting per hectare was ₹35,738. However, manual harvesting was expensive and operating cost was around ₹70,000 per hectare. The payback period was 2.0 years and the breakeven point was 16 hectares per year annum. The saving in cost of operation over manual ginger harvesting with the harvester was 48.94 per cent.

2.6 Inference of Review

It was discovered that timely harvesting was critical in onion crop. Harvesting onions in India is mostly done manually; it is a time-consuming job and some areas of Chhattisgarh encounter labour shortages at the time of harvesting. The previously constructed mechanical harvester plays an important role in lowering the cost and time of operation compared to manual harvesting. The following conclusions were withdrawn from the review of literatures:

i. Physical and Engineering properties of onion bulb plays significant role for selection of onion digger for harvesting of onion. The behavior of soil parameters also used selection of digger.

ii. Onion agronomical data varies by area and variety optimal spacing was seen to be 150 x 100 mm and onion bulb depth was discovered to be up to 80 mm from the ground surface. These agronomical characteristics aid in determining machine operating breadth and digging depth.

iii. Various factors, such as blade angle and forward speed, influence machine performance. As a result, it was critical to evaluate the various onion diggers while taking into account all of these criteria.

iv. Most researchers employed blade rake angles of 15°, 20° and 25° with the best results obtained between 15° and 20°. Also the forward speed of the onion digger was chosen between 1.8 and 4.0 km h^{-1} and at lower forward speed the best result was obtained.

CHAPTER-III
MATERIALS AND METHODS

This chapter describes the materials and methods used for measuring physical and engineering properties of onion bulbs at the time of harvesting, performance evaluation of onion diggers, cost economics of manual, tractor drawn onion digger, tractor drawn vibro onion digger and tractor drawn duck foot type onion digger during the year 2021-22. The farmers of Chhattisgarh due to shortage of labourers opting for mechanized harvesting of onion. Therefore, it is felt necessary to test the available machines for its suitability in Chhattisgarh region. This machine was designed by different manufacture of India for digging of matured onion bulb on larger scale.

3.1 Climate and Weather Condition

The Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur research farm is located on NH-53 in the eastern part of Raipur city, between 22^{o} 06' North latitude and 81^{o} 57' East longitude, at an elevation of 286 m above mean sea level. The average annual temperature in Raipur is 26.5°C. The annual precipitation here is approximately 1401 mm. The difference in precipitation between the driest and wettest months is 387mm/15inch. The average temperatures vary during the year by 15.1°C. April is the month with the lowest relative humidity (28.72 %). August is the month with the greatest number of rainy days (25.13 days). The month with the fewest rainy days is December (1.30 days). The soil at the experimental site is a silt clay soil mixed with sand. It is known as '*Dorsa*' in the local dialect.

3.2 Physical and Engineering Properties of Onion Plant and Bulb

The physical and engineering properties are one of the major parameters for any type of digger. Hence a study was conducted to know all the physical and engineering parameters before the study. Onion bulb is present under the soil surface just below its leafy stem. The detail physiology of an onion plant is presented in Fig.3.1. Nasik Red (N-53) variety of onion (100 samples) was collected from the field and its details parameters were studied as below:

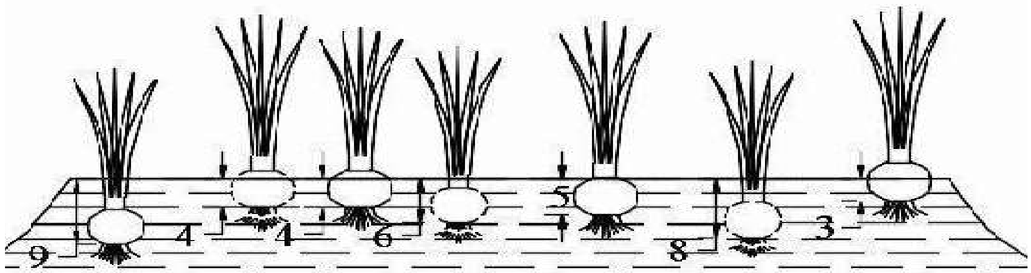


Fig. 3.1 Depth of placement of onion bulb

3.2.1 Polar diameter (D_p)

Polar diameter is the distance between the onion bulb crown and the point of root attachment to the bulb (Singhal and Samuel, 2003) as shown in Fig. 3.1. The polar diameter was measured for 100 randomly selected onion bulbs using a digital vernier caliper with a minimum least count of 0.01 mm, and the mean value was calculated. (Sahay and Singh, 1994).

3.2.2 Equatorial diameter (D_e)

The equatorial diameter was the maximum width of the onion in a plane perpendicular to the polar diameter, as shown in Fig. 3.2. The equatorial diameter was measured with the help of a digital vernier caliper. The mean value of equatorial diameter was determined using 100 randomly selected onion bulbs.

3.2.3 Thickness (T)

The thickness was the smallest dimension among all the dimensions. It was measured with the help of vernier caliper with a least count of 0.01 mm Fig. 3.3 represent the thickness of onion bulb.

3.2.4 Geometric mean diameter (D_g)

The geometric mean diameter (D_g) and arithmetic mean diameter (D_a) was calculated by using the following relationship (Mohsenin, 1986) given in Equation 3.1.

$$D_g = (D_p D_e T)^{\frac{1}{3}} \qquad --- (3.1)$$

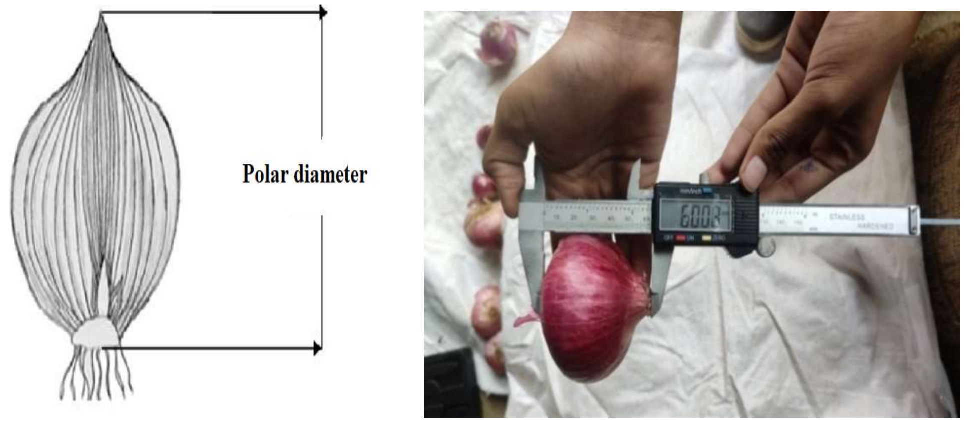


Fig. 3.2 Polar diameter (D_p) of onion bulb

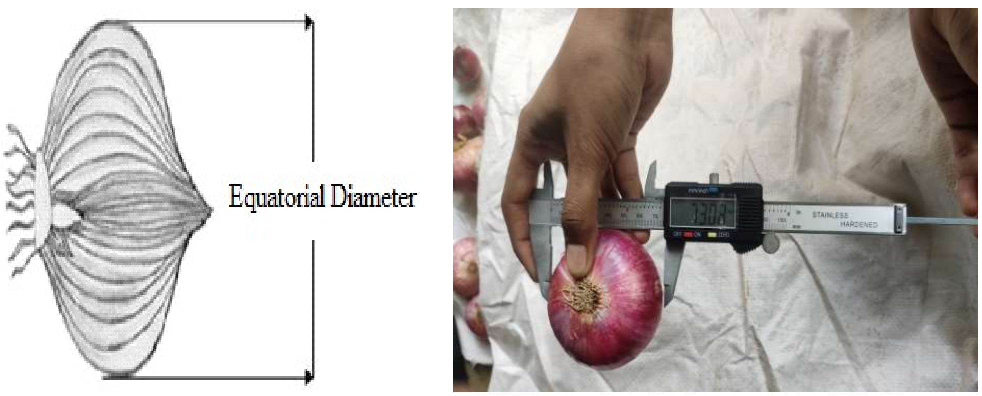


Fig. 3.3 Equatorial diameter (D_e) of onion bulb

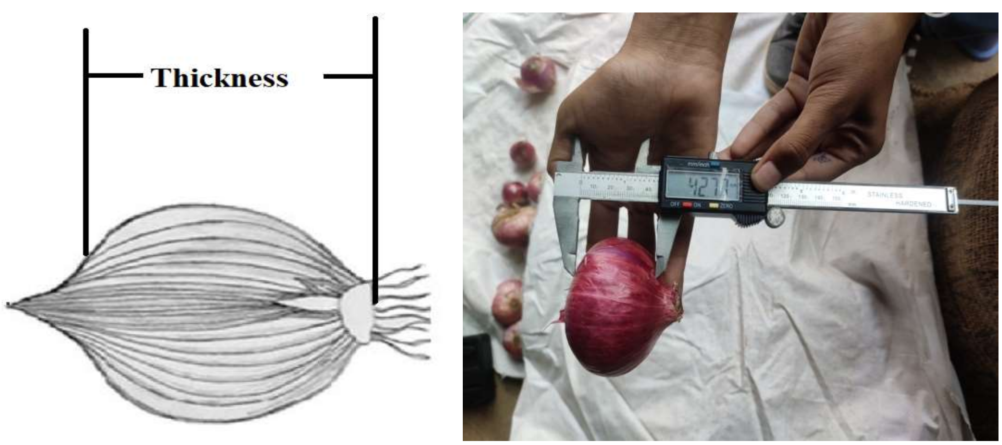


Fig. 3.4 Thickness (T) of onion bulb

Where,

D_p = Polar diameter (largest intercept length), mm;

D_e = Equatorial diameter (width), mm; and

T = Thickness, mm.

3.2.5 Arithmetic mean diameter (D_a)

Arithmetic mean diameter is the sum of all the three linear dimensions namely equatorial diameter, polar diameter and thickness of the sample divided by the total number of linear dimensions. The linear dimensions were measured using digital vernier calipers of 0.01 mm least count (Bahnasawy *et al.*, 2004).

$$D_a = \left(\frac{D_p D_e T}{3}\right) \qquad --- (3.2)$$

Where,

D_p = Polar diameter (largest intercept length), mm;

D_e = Equatorial diameter (width), mm; and

T = Thickness, mm.

3.2.6 Sphericity (ϕ)

Sphericity defines the ratio of the diameter of a sphere of the same volume as that of the particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle (Sahay and Singh, 1994 and Kaveri and Tirupathi, 2015). This parameter shows the shape character of onion relative tothe sphere having the same volume given in Equation 3.3.

$$\text{Sphericity} = \sqrt{\frac{\text{volume of particle}}{\text{volume of circumscribed sphere}}} = \frac{(D_p D_e T)^{\frac{1}{3}}}{D_e} \qquad --- (3.3)$$

Where,

D_p = Polar diameter (largest intercept length), mm;

D_e = Equatorial diameter (width), mm; and

T = Thickness, mm.

3.2.7 Shape index

It is the ratio of the equatorial diameter and root of the product of polar diameter and thickness of onion and it was used to evaluate the shape of onion bulbs and it wascalculated using the following equation (Abdalla, 1993).

$$\text{Shape index} = \frac{D_p}{\sqrt{D_e T}} \qquad ---(3.4)$$

Where,

D_p = Polar diameter (largest intercept length), mm;

D_e = Equatorial diameter (width), mm; and

T = Thickness, mm.

3.2.8 Aspect ratio (R_a)

The aspect ratio is defined by the ratio of width of the bulb to the length of bulb into 100. R_a of the onion bulb was determined as recommended by using Equation 3.5. (Abdalla, 1993).

$$R_a = \frac{D_p}{D_e} \times 100 \qquad ---(3.5)$$

Where,

R_a = Aspect ratio, %;

D_p = Polar diameter, mm; and

D_e = Equatorial diameter, mm.

3.2.9 Surface area (S_a)

Surface area is defined as the total area over the outside of the onion bulb. Surface area (S_a) of the onion bulb theoretically calculated using the Equation 3.6. (Bhansaway *et al.*, 2004).

$$S_a = \pi \times D_g^2 \qquad ---(3.6)$$

Where,

S_a = Surface area, mm^2; and

D_g= Geometric mean diameter, mm.

Fig. 3.5 Frontal surface area of onion bulb

Fig. 3.6 Cross sectional surface area of onion bulb

3.2.10 Frontal surface area (A_{fs})

It is the representation of solid object when it cut by an intersecting plane. The frontal surface area of onion bulb was determined by following Equation 3.7 (Bhansaway *et al*., 2004).

$$A_{f.s} = \frac{\pi}{4} D_p D_e \qquad --- (3.7)$$

Where,

D_p = Polar diameter, mm; and

D_e = Equatorial diameter, mm.

3.2.11 Cross sectional areas (A_{cs})

Cross sectional area refers to the area of section made by a plane cutting an object transversely at right angles to the longest axis. The cross sectional area of sample was determinedby given Equation.3.8 (Bhansaway *et al*., 2004).

$$A_{c.s} = \frac{\pi}{4} \frac{(D_e + D_p + T)^2}{9} \qquad --- (3.8)$$

Where,

$A_{c.s}$= Cross sectional area, cm^2;

D_e - Equatorial diameter of onion, cm;

D_p - Polar diameter of onion, cm; and

T - Thickness of onion, cm.

3.2.12 Mass of onion bulb (kg)

The mass of an onion bulb was measured by using an electronic balance. Mean value of mass was determined using 100 randomly selected onion bulbs from a lot and was represented in Fig.3.7.

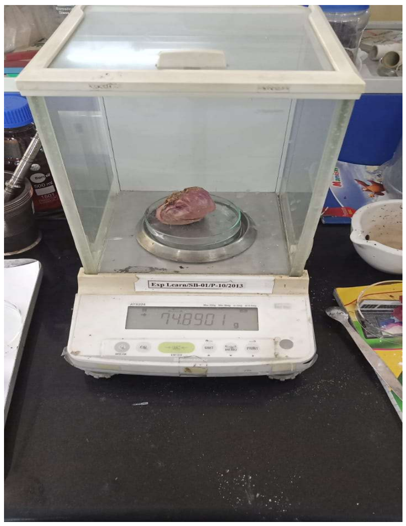


Fig. 3.7 Mass of onion bulb using electrical weighing balance

Fig. 3.8 Measurement of bulk density of onion bulb

3.2.13 Bulk density (bd)

Bulk density of onion was calculated by placing the sample of onion bulbs in a square box of 200×200×200 mm (Ghaffari *et al*., 2013 and Pavani, 2017). The onion sample was filled in the box and then weighed by using electronic balance with least count of 0.001g. Bulk density was calculated by using the relationship givenin Equation 3.9 and shown in Fig. 3.8.

$$\text{Bulk density (bd)} = \frac{\text{Weight of bulb(kg)}}{\text{Volume of box(m}^3\text{)}} \qquad --- (3.9)$$

3.2.14 Moisture content of onion (m_c)

Oven dry method which is a direct method was used to measure the moisture content of onion bulb. The bulb was weighed and dried, then weighed again according to standard procedures and it was expressed as a percentage of moisture based on dry matter. The sample's moisture content was determined using the standard air oven method shown in Fig. 3.9. The test sample was first weighted and then placed in a hot air electric oven set at 105ºC for 24 hours. The sample was taken out of the oven and placed in a desiccator to cool to room temperature.

The weight of the sample was precisely measured after cooling. The weight loss was calculated, and the moisture content was calculated, using the Equation 3.10: (Mohsenin, 1986).

Fig. 3.9 Onion sample kept in electric oven for 24 hours

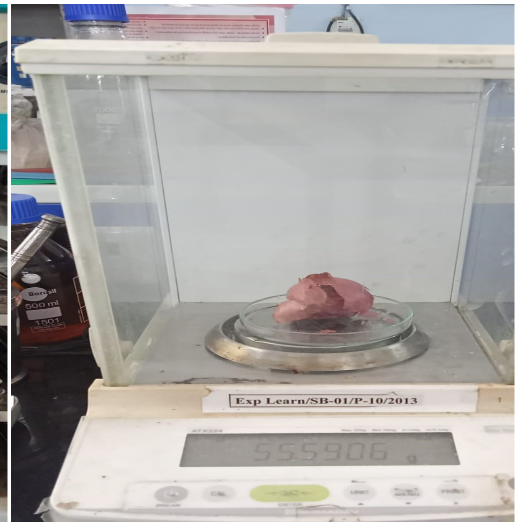


Fig. 3.10 Sample weight after drying by electronic weighing balance

$$m_c(d_b) = \frac{w_2 - w_3}{w_3 - w_1} \qquad ---(3.10)$$

Where,

m_c = Moisture content on dry basis, %;

w_1 = Weight container, g;

w_2= Sample weight before drying + container weight, g; and

w_3= Sample weight after drying + container weight, g.

3.3 Experimental Details

The experiment plan was laid in Factorial Randomized Complete Block Design (Gomez and Gomez, 1984) with three main treatments (Type of digger) along with three sub treatment (speed) replicated four times. The details of the digging treatments and plot layout plan are presented in Tables 3.1 and Fig. 3.17.

Table: 3.1 Factor taken into consideration in factorial RBD design

Main factor (Type of digger)	Sub factor 2 (Speed, km h^{-1})
Onion Digger(M1)	2.5 (S1)
Vibro Onion digger(M2)	3.0 (S2)
Onion digger (Duck foot Type) (M3)	3.5 (S3)

Table 3.2 Independent and dependent parameters for factorial RBD design

Independent parameters	Dependent parameters
Types of digger	Damage percentage (%)
	Exposure percentage (%)
Speed of operation (km h^{-1})	Separation index (%)
	Digging efficiency (%)

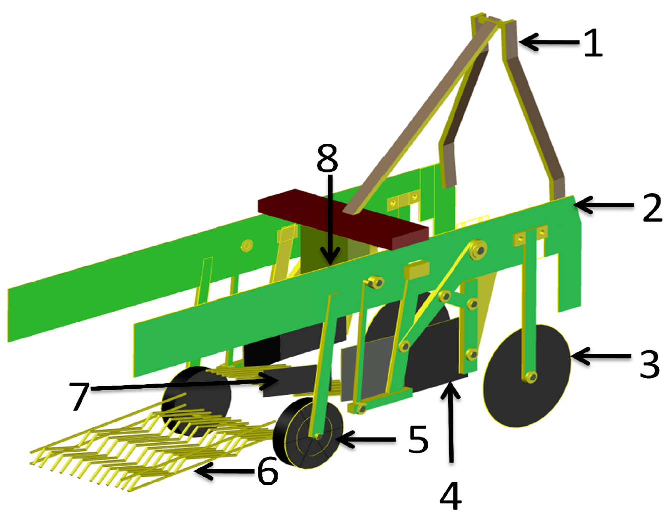
3.3.1 Working of tractor operated onion digger

The machine comprises of two digging blade which help in uprooting onion from the soil and each blade has 13 nos. of digging rod on them which helps in separation of onion from soil after digging. Power was transferred from PTO shaft to the digger which oscillates the shaking mechanism to and fro and separate onion from soil which were collected manually afterwards. It reduces the time required for digging and labour also. The specification and CAD diagram were represented in Table 3.3 and Fig.3.12.

Table 3.3 Specification of onion digger (M1)

S. No.	Particulars	Specifications
1	Length (mm) × Width (mm) × Height (mm)	1510 ×1100×1200
2	Weight (kg)	250 approx
3	Working width (mm)	1000
4	No of blades	2
5	No of digging rods in each blade	13
6	Guiding wheel diameter (mm)	400
7	Power transmission	PTO
8	Power source	40 hp and above
9	Field capacity	3.5 – 4.5 ha day^{-1}
10	Suitable travelling speed of tractor	2.0 – 4 km h^{-1}

Fig. 3.11 Onion digger (M1)



1- Hitch point
2- Frame
3- Guiding Wheel
4-Guiding Plate (1)
5- Ground wheel
6- Digging rod
7- Guiding plate (2)
8- Gear box

Fig. 3.12 Isometric view of onion digger (M1)

3.3.2 Working of vibro onion digger

Power was transferred from the PTO shaft to the vibratory sub-soiler which helps in loosening of soil and uproot the onion bulb from the ground. Digger attachment has five v shaped blade which helps in lifting the onion from the soil then it will be separated from the soil on the digging rod due to vibratory mechanism. The uprooted onion fall behind the digger which was collected manually which in terms saves time and labour compared to traditional harvesting method.

Table 3.4 Specification of vibro onion digger (M2)

S. No.	Particulars	Specifications
1	Length (mm) × Width (mm) × Height (mm)	1100 ×1000×1500
2	Weight (kg)	250 approx
3	Width of operation(mm)	1000
4	No. of V blade	5
6	No. of digging rod	35
5	Power transmission	PTO
6	Power source	40 hp and above
7	Field capacity	3.5 – 4.5 ha day^{-1}
8	Suitable travelling speed of tractor	2.0 – 4.0 km h^{-}

3.3.3 Working of duck foot onion digger

It was attached to tractor through a three point linkage and has five duck foot tines. It dig the soil by the help of tines. Each tyne has ten digging rods which helps in separation of soil from onion which were collected afterwards manually by help of labours. The specification and CAD diagram were represented in Table 3.5 and Fig.3.16.

Table 3.5 Specification of duck foot type digger (M3)

S. No.	Particulars	Specifications
1	Length (mm) × Width (mm) × Height (mm)	2000 ×800×1000
2	Weight (kg)	150 approx
3	Width of operation(mm)	2000
4	Working width (mm)	1950
5	No. of tines	5
6	No of digging rod on each tyne	10
7	Power source	35 hp and above
8	Field capacity	3.5 – 4.5 ha day^{-1}
9	Suitable travelling speed of tractor	2.0 – 4.0 km h^{-1}

Fig. 3.13 Vibro onion digger (M2)

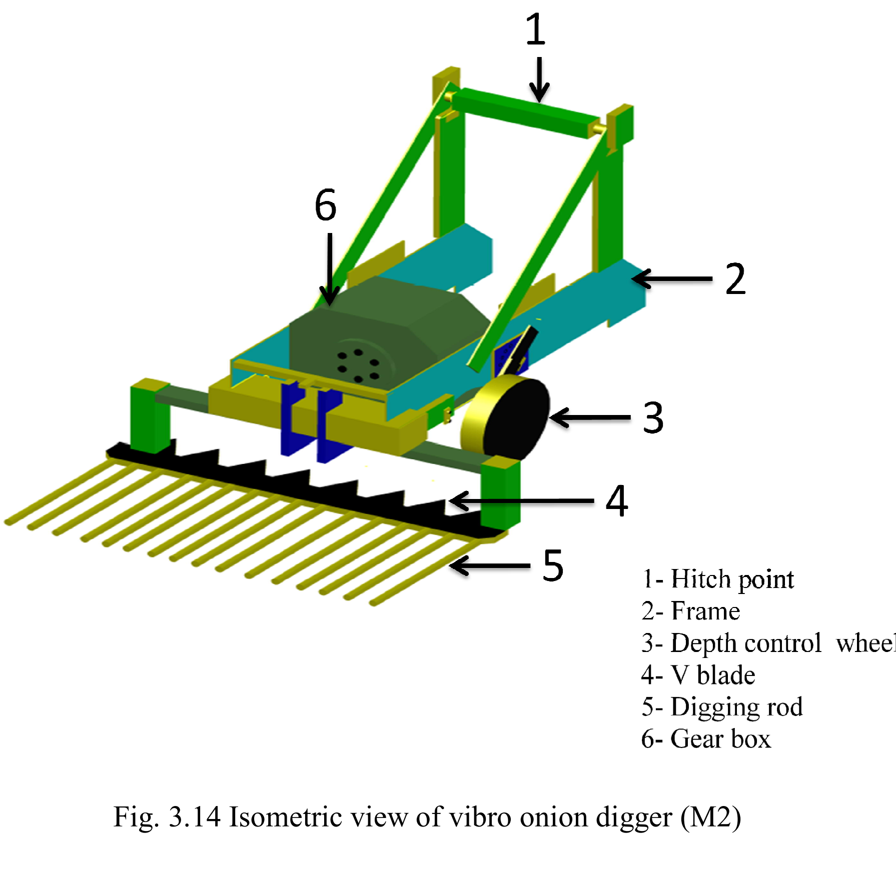


Fig. 3.14 Isometric view of vibro onion digger (M2)

Fig. 3.15 Duck foot type onion digger (M3)

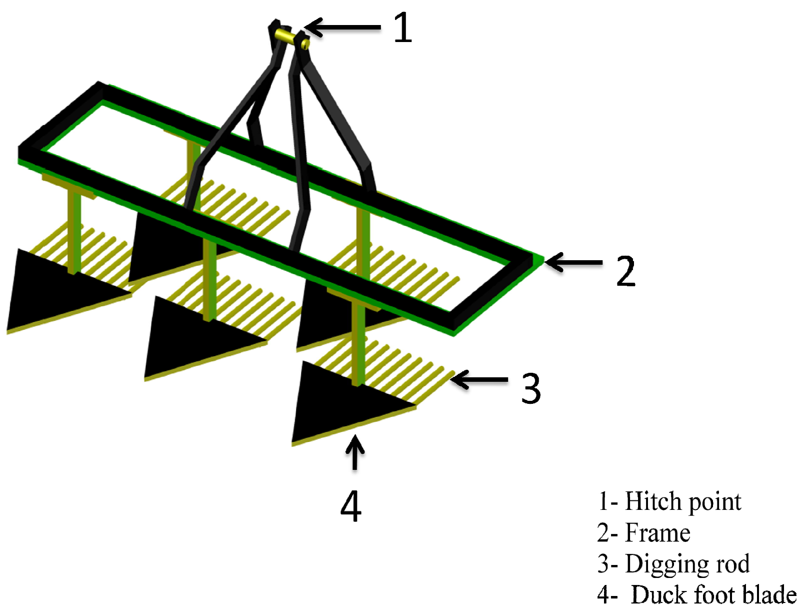


Fig. 3.16 Isometric view of duck foot type onion digger (M3)

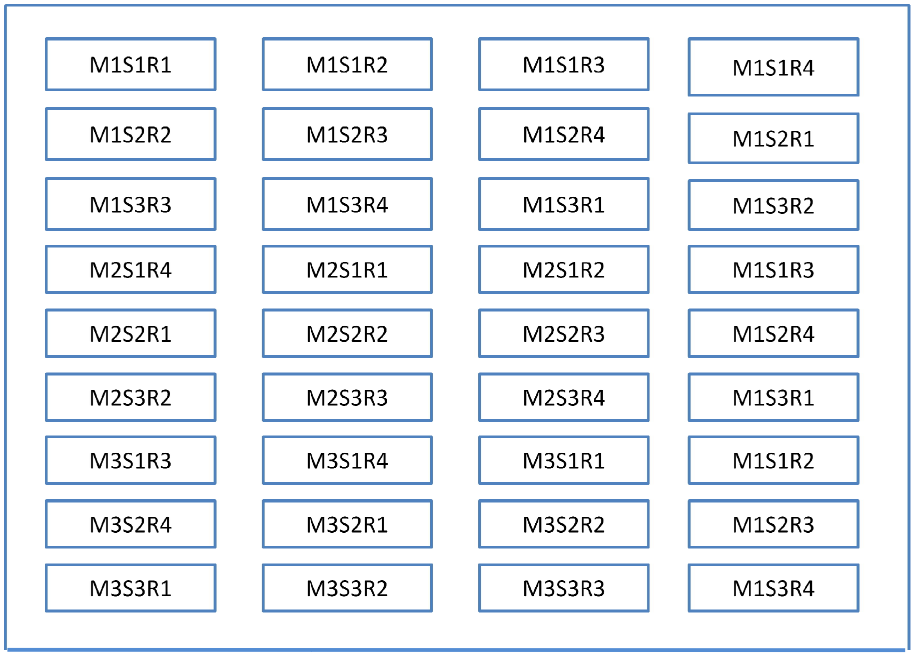


Fig. 3.17 Field layout of factorial RBD design

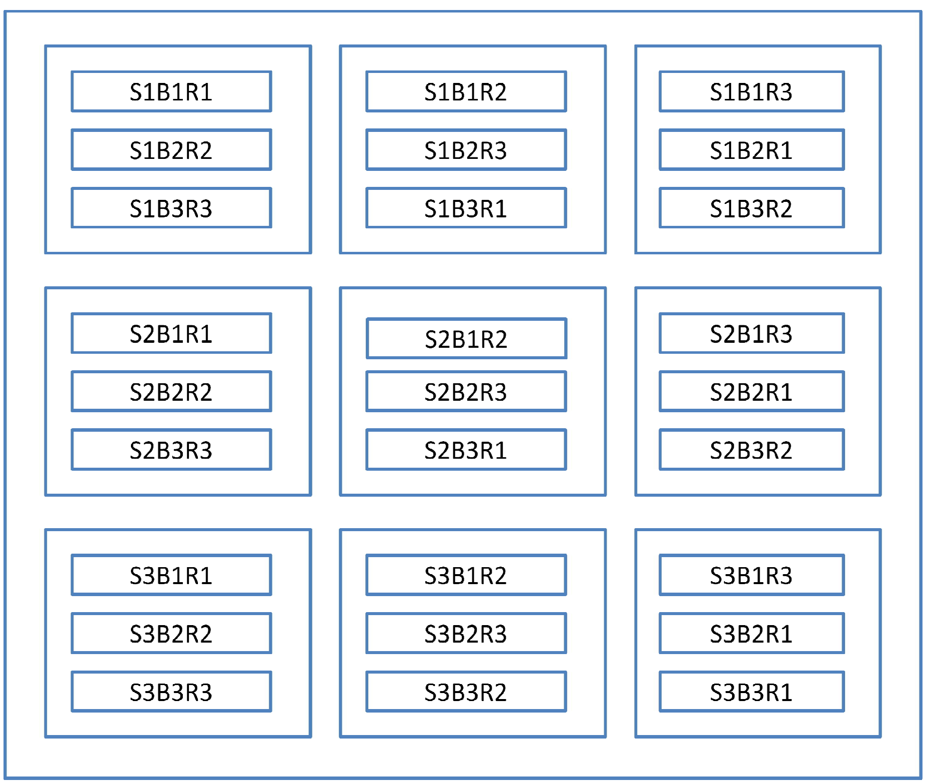


Fig. 3.18 Layout of Split plot design

3.4 Onion Digger

Three treatments were replicated 3 times. The result of the treatments which have better output than the others were again tested by using Split Plot design by taking three main plot (S1,S2 and S3) , three sub plot (B1,B2 and B3) and were replicated by three times. The experimental layout is given in Table 3.7 and Figure 3.18.

Table 3.6 Factor taken into consideration in split plot design

Type of digger	Main plot (Speed of operation) (km h^{-1})	Sub plot (Blade Angle) (°)
The best selected from preliminary trial	2.5(S1)	15 (B1)
	3.0(S2)	20 (B2)
	3.5(S3)	25 (B3)

Table 3.7 Independent and dependent parameters for split plot design

Independent parameters	Dependent parameters
Speed of operation (S), km h^{-1}	Damage percentage (%)
	Exposure percentage (%)
Blade angle (B), °	Separation index (%)
	Digging efficiency (%)

3.5 Performance Evaluation of Onion Digger

Performance evaluation of onion digger has been carried out by using standard IS 13818.1993 and the following tests are carried out for measurement of different parameters of onion digger.

3.5.1 Laboratory test

Following test was carried out during laboratory testing and checking of specification and material of the onion digger and it is given in appendix A.

- Checking of specification
- Visual observation and provision for adjustments.

3.5.2 Field test

The field test was carried out to gather actual data on overall machine performance, operational accuracy, work capacity, and field efficiency. The tractor drawn onion digger, vibro onion digger, and duck foot type digger were tested in field for study of the machine performance in accordance with BIS standards IS 13818.1993.

However, manual harvesting was also considered due to the area's customary prevailing traditions.

a) Soil moisture content
b) Bulk density
c) Percent damaged onion by mass
d) Percent exposed onion by mass
e) Filed efficiency
f) Labour requirement

3.5.2.1 Soil moisture content

The oven drying method was used to determine the moisture content of the soil (Khura, 2011). Soil samples were obtained at random from a field. A weighing balance was used to determine the weight of the moist soil sample. The soil sample was placed in a hot air oven at 105°C for 24 hours and weight of the dried sample was recorded moisture content was measured by using Equation 3.11:

$$m_c(db) = \frac{w_2 - w_3}{w_3 - w_1} \quad --- (3.11)$$

Where,

m_c = Moisture content on dry basis, %;

w_1 = Weight of container, g;

w_2= Sample weight before drying + container weight, g; and

w_3= Sample weight after drying + container weight, g.

3.5.2.2 Bulk density

Bulk density of soil is the ratio of mass and volume of soil. The bulk density was determined after the collection of soil sample by using core cutter and hammer as shown in Fig.3.7. The diameter and length of the core cutter was 100 mm and 130 mm respectively. Soil samples were collected from each experimental plot and weighted. The samples for drying were placed in an oven at 105° C for 24 hours. The dried samples re-weighted in an electrical balance meter having maximum capacity to weight 5 kg and the difference was recorded.

Measurement of bulk density with core cutter and hammer was shown in Fig 3.8. Bulk density was calculated by using Equation 3.12:

$$\rho_b = \frac{M}{\pi D^2 L} \qquad ---(3.12)$$

Where,

ρ_b = Bulk density, kg cm^{-3};

M = Mass contained in soil sample of oven dry soil, kg;

V = Volume of cylinder sampler, m^3;

D = Diameter of cylinder sampler, m; and

L = Height of cylinder sampler, m.

Fig. 3.19 Collection of soil sample by core cutter

Fig. 3.20 Determination of moisture content of soil sample by oven dry method

3.5.2.3 Theoretical field capacity

Theoretical field capacity was measured as per following formula (kepner, *et.al* 1982). It depends only upon the average travel speed and maximum working width. It represents the maximum achievable field capacity that can be obtained at a given field speed when full operating width was used.

$$\text{Theoretical field capacity}\left(\frac{ha}{h}\right) = \frac{W \times S}{10} \qquad ---(3.13)$$

Where,

W = Effective width of implement, m; and

S = Speed of operation, km/h.

3.5.2.4 Actual field capacity

The implement was continuously operated in the field to assess its actual coverage. The time required for complete harvesting was recorded and effective field capacity was calculated. It includes turning loss and break down time also.

$$\text{Actual field capacity,} \left(\frac{\text{ha}}{\text{h}}\right) = \frac{\text{A}}{\text{T}} \qquad --- (3.14)$$

Where,

A = Actual area covered, ha; and

T = Time required to cover the area, h.

3.5.2.5 Field efficiency

The field efficiency is the ratio of actual and the theoretical field capacity (Kepner *et al.*, 1982).

$$\text{Field efficiency (\%)} = \frac{\text{AFC}}{\text{TFC}} \times 100 \qquad --- (3.15)$$

Where,

AFC = Actual field capacity (ha/h); and

TFC = Theoretical field-capacity (ha/h).

3.5.2.6 Onion damage percentage

The plants dug were collected and all the mature onion should be detached manually and analyzed for the damaged onion. The ratio of number of damaged bulbs during harvesting to the total number of onion harvested from the area is calculated using Equation 3.16. (Khura *et al.*, 2011, Mehta, T. D. and Yadav, R.2015 and Pavani, 2017)

$$\text{Damage Percentage(\%)} = \frac{\text{Number of bulbs damaaged during harvesting}}{\text{Total number of bulbs harvested from the area}} \times 100 \; -- (3.16)$$

3.5.2.7 Onion exposure percentage

The dug plants were collected, and all mature onions were manually detached and analyzed for exposed onion. The percentage of onion exposure was calculated by comparing the amount of detached onion lying on the surface to the total amount of onion collected from the plants in the sample area. (IS:11033-1984).

$$\text{Exposure Percentage (\%)} = \frac{\text{Number of bulbs exposed during harvesting}}{\text{Total number of bulbs harvested from the area}} \times 100 \quad --- (3.17)$$

3.5.2.8 Soil separation index

It is the ratio of weight of soil with onion collected behind the separator of onion digger to the theoretical weight of soil and onion from unit area (Mehta, T. D. and Yadav, R. 2015 and Pavani, 2017). The theoretical weight of soil that was cut by the blade with onion plant mass at recommended depth of operation. It was measured by using Equation 3.18.

$$\text{Separatin index (\%)} = \left(\frac{W_a}{W_t} - 1\right) \times 100 \quad --- (3.18)$$

Where,

Wa = Actual weight of soil and onion bulb collected at rear end of soil separator, kg; and

Wt = Theoretical weight of soil cut by blade along with onion bulb at a working depth of operation, kg.

3.5.2.9 Digging efficiency

It is the ratio of the number of onion plants successfully harvested to the total number of onion plants present in a given area before harvesting (Mehta, T. D. and Yadav, R. 2015, Khura *et al.*, 2011, and Pavani, 2017) which was given in Equation 3.19.

$$\text{Digging efficiency (\%)} = \frac{\text{Number of onionplants succesfully harvested}}{\text{total number of onion plants present in the are}} \times 100 \quad --- (3.19)$$

3.6 Manual Onion Digging

The onion crop was harvested manually with the help of spade and collected side by side. The operation required a group of labour to cover the field and this process was extremely slow. (Singh. *et al.,* 2004).

A field area of 5×5 m^2 is harvested by 2 nos of labour by use of spade. The damage percentage, exposure percentage, separation index and digging efficiency calculated for manual onion digging.

3.6.1 Damage percentage for manual digging:

The damage percentage of onion was calculated by using Equation 3.16. The samples were collected from an area of 1×1 m^2 with three replication.

3.6.2 Exposure percentage for manual digging:

The exposure percentage of onion was calculated by using Equation 3.17. The samples were collected from an area of 1×1 m^2 with three replication.

Fig. 3.21 Undamaged onion from the field after digging operation

Fig. 3.22 Damaged onion after digging operation

`Fig. 3.23 Inspection for damaged and exposed onion

Fig. 3.24 Manual harvesting of onion

3.6.3 Separation index for manual digging:

The separation index of manual digging was calculated by using Equation 3.18. The samples were collected from an area of 1×1 m^2 with three replication.

3.6.4 Digging efficiency for manual harvesting:

The digging efficiency of manual digging was calculated by using Equation 3.19. The samples were collected from an area of 1×1 m^2 with three replication.

3.7 Cost Economics

Cost of operation depends on all the treatments basis of fabrication cost of implements, maintenance and labour cost, which were measured by using Equation 3.61 to 3.63 as presented in Appnedix-G. The IS: 9164 was used to calculate the cost of machine assistance. The developed onion harvester operational cost was divided into fixed and variable cost. Fixed cost was independent of operational use and cost of operation was increase/decreases with the variable cost (Kamboj, 2012). The depreciation, interest on the capital cost, shelter, insurance and taxes were taken under fixed cost and variable cost include fuel, lubricants, repair-maintenance cost and wages of labour. For calculation of variable and fixed cost procedure is giving below, which was used for cost analysis (Sabaji *et al.,* 2012):

3.7.1 Fixed cost of machine

i. Deprecation (D)
ii. Interest on investment (I)
iii. Shelter/housing cost (S)

3.7.1.1 Depreciation

It is the measure of the amount by which the value of the machine decreases over the time. The annual depreciation is calculated as follows (IS: 9164-1979):

$$D = \frac{P - S}{L \times H} \qquad --- (3.20)$$

Where,

P = Capital cost, ₹;

D = Depreciation, ₹ h^{-1};

S = Salvage value, 10 per cent of capital cost;

H = Number of working hours per year. ₹, and

L = Life of machine, year.

3.7.1.2 Interest on investment (I)

Interest is calculated based on the average investment of the machine, taking into account the machine value of the first year and last year. These are actually calculated on an annual basis. The annual interest on the investment can be calculated by using below formula (IS: 9164-1979).

$$I = \frac{P + S}{2} \times \frac{i}{H} \qquad --- (3.21)$$

Where,

I = interest per year, ₹ $year^{-1}$;

P= Capital cost of machine, ₹;

S= Salvage value of machine, ₹;

H=Number of working hours per year, and

i = interest rate per year, (usually it is assumed as 12 %).

3.7.1.3 Shelter cost

Shelter costs are based on local prevailing rates, but in general shelter costs account for 2 per cent of the initial machine cost per year. (IS: 9164-1979)

$$SC = \frac{P}{H} \times \frac{2}{100} \qquad --- (3.23)$$

3.7.1.4 Total fixed cost

Total fixed cost of the machine was calculated by adding all *viz.* depreciation, interest, shelter cost. As no insurance was done for the onion harvester it was not taken into consideration, whereas, in calculating tractor cost it was taken into consideration.

$$\text{Total fixed cost} = \mathrm{D} + \mathrm{I} + \mathrm{SC} \qquad ---(3.24)$$

3.7.2 Variable cost of farm machine

i. Fuel cost (F)
ii. Lubrication oil cost (L)
iii. Repair and maintenance cost (R)
iv. Labour wages (W)

3.7.2.1 Fuel cost (F)

Actual fuel consumption of tractor was used to determine fuel cost.

3.7.2.2 Lubrication oil cost (L)

Total fixed cost of the machine was calculated by adding all *viz.* depreciation, interest, shelter cost. As no insurance was done for the onion harvester it was not taken into consideration, whereas, in calculating tractor cost it was taken into consideration.

$$\text{Total fixed cost} = \mathrm{D} + \mathrm{I} + \mathrm{SC} \qquad ---(3.24)$$

3.7.2.3 Repair and maintenance cost (R)

Cost of repair and maintenance taken as 5 per cent of the principle cost of the machine per year.

$$\text{Repair and maintenance cost} \left(\frac{\mathrm{Rs}}{\mathrm{h}}\right) = \frac{\mathrm{C} \times \mathrm{m}}{\mathrm{H}} \qquad ---(3.25)$$

Where,

m = repair and maintenance rate 5%.

3.7.2.4 Labour wages (W)

Actual wages of the worker were used to calculate labour wages.

3.7.2.5 Total variable cost

Total cost was calculated by adding fuel cost, lubrication cost, repair and maintenance and labour wages.

$$\text{Total variable cost} = \mathrm{F} + \mathrm{L} + \mathrm{R} + \mathrm{W} \qquad ---(3.26)$$

3.7.3 Total cost

Total cost was calculated by adding total fixed cost and total variable cost.

$$\text{Total cost} = \text{Total fixed cost} + \text{total variable cost} \qquad --- (3.27)$$

3.7.4 Breakeven point

The breakeven point is where the business's total revenue is equal to its total expenses. This means at the breakeven point there's no profit; it's simply net zero. The breakeven point was calculated by following formula (Sharma and Mukesh, 2008).

$$\text{BEP} = \frac{\text{FC}}{\text{CH} - \text{C}} \qquad --- (3.28)$$

Where,

BEP = Breakeven point, h y^{-1};

FC = Annual fixed cost, ₹ y^{-1};

C = Operating cost, ₹ h^{-1}, and

CH = Custom hiring charges, ₹ h^{-1}.

= (C + 20 per cent over head) + 20 per cent profit over new cost

3.7.5 Payback period

Payback period was determined for developed onion digger by using Equation 3.29 to know the time required to get back the investing, (Reddy *et al.*, 2003).

$$\text{PBP} = \frac{\text{IC}}{\text{ANP}} \qquad --- (3.29)$$

Where,

PBP= Payback period, year;

IC = Initial cost of machine, ₹; and

ANP = Average net annual profit, ₹ y^{-1}.

$$\text{ANP} = (\text{CH} - \text{C}) \times \text{AU} \qquad --- (3.30)$$

$$\text{AU} = \text{AA} \times \text{EC} \qquad --- (3.31)$$

Where,

CH = Custom hiring charges, ₹ h^{-1};

AA = Average annual use, h y^{-1}, and

EC = Effective capacity of machine, ha h^{-1}.

CHAPTER-IV
RESULT AND DISCUSSION

This section summarizes the results and discussion of the experiment carried out to achieve the objective of study. This chapter describes the results of engineering properties of onion bulbs, field performance of digger for onion harvesting and cost economics of onion harvesting.

Onion is an essential condiments in our nation and both manual and tractor drawn diggers are utilized in India for digging onions in the fields. In Chhattisgarh, manual method was widely used as a method of harvesting for onion bulbs. However, many farmers opt for mechanized harvesting. The Raipur district is the highest producer of onion bulb in Chhattisgarh. Previously, onions were harvested manually. Given the importance of onion harvesting, four kinds of digging were employed: manual digging with a spade, onion digger, vibro onion digger, and duck tooth type digger.

The onion crops were cultivated in accordance with usual procedure on precise plot sizes as specified in the Chapter-III. Prior to the field testing of onion digger the plot of onion was chosen for field testing. Tractor-drawn seed and fertilizer drill was used for planting. The specifications for all of the diggers were recorded and are shown in Tables 3.3, 3.4, and 3.5. Before digging operation the bulk density and moisture content of the soil for each plot were tested and determined to be in the range of 1.41 - 1.47 per cent and 9 - 14 per cent, respectively. Four digging methods were employed for the onion crop: manual digging with a shovel, onion digger, vibro onion digger, and digger (duck foot type). The collection of onion was done by manual method after every digging operation.

4.1 Physical and Engineering Properties of Onion Bulb at the time of Harvesting

Physical and engineering features were critical in understanding material behavior. Several parameters were determined at the the crop harvesting stage in order to identify the best digger for harvesting. The physical and mechanical parameters of an onion bulb were measured using the N-53 variety. The data's after following all the steps of previous chapter were obtained and results were discussed in this chapter.

Table 4.1 Polar diameter, equatorial diameter and thickness of onion bulb

Particulars	Polar Diameter (mm)	Equatorial Diameter (mm)	Thickness(mm)
Mean ($\bar{x}$)	41.25	46.60	33.26
Range (R)	28.19 -7.33	26.21 -86.04	13.23-49.66
SD (σ)	8.10	10.06	5.79
CV	19.63	21.60	17.40

4.1.1 Polar diameter (D_p)

Polar diameter of the onion bulb was measured by taking 100 samples. It varied as per shape and size of the onion and average polar diameter was observed to be 41.25±0.81mm with SD and CV (per cent) about 8.10 and 19.63, respectively given in Table 4.2 and its range varies from 28.19 to 7.33 mm. This data was used select the appropriate onion digger for harvesting. Similar results were also reported by Pavani (2017) for *bhimasuper* variety. In another study on *red*, *white* and *yellow* onion bulbs also reported similar results. (Ghaffari *et al.*, 2013)

4.1.2 Equatorial diameter (D_e)

The average equatorial diameter of the onion bulb was obtained to be 46.60±1.01 mm with SD and CV (per cent) about 10.06 and 21.60, respectively given in Table 4.1 and its range varies from 26.21 to 86.04 mm. This data was used to select the appropriate onion digger for harvesting.. Similar results were also reported by Khura *et al.*, 2011 and Ghaffari *et al.*, 2013.

4.1.3 Thickness (T)

Thickness of the selected onion samples were also measured and average thickness of the onion bulb was found to be 33.26±0.58 mm with SD and CV (per cent) about 5.79 and 17.40, respectively given in Table 4.2 and its range varies from 13.23 to 49.66 mm.

4.1.4 Geometric mean diameter (D_g)

Geometric mean diameter was used to determine the spacing between separator rods. Obtained data of polar diameter, equatorial diameter and thickness were used to determine geometric mean diameter of the onion bulb. It defines the overall diameter of the onion bulb. Geometric mean diameter of the onion bulb was measured to be 39.80±0.67 mm with SD and CV (per cent) about 6.74 and 16.93, respectively as given in Table 4.2 and its range varies from 26.28 to 63.63 mm.

Table 4.2 Arithmetic mean and geometric mean diameter of freshly harvested onion bulb

Particulars	GMD	AMD
Mean ($\bar{x}$)	39.80	40.37
Range (R)	26.28-63.63	26.53-65.33
SD (σ)	6.74	6.94
CV	16.93	17.20

4.1.5 Arithmetic mean diameter (D_a)

Arithmetic mean diameter of the onion bulb was observed to be 40.37±0.69 mm with SD and CV (per cent) about 6.94 and 17.20 respectively and its range varies from 26.53 to 65.33 mm. Similar results were obtained for red onion bulb (Ghaffari *et al*., 2013) and for *bhimasuper* variety by Pavani, 2017.

Table 4.3 Sphericity, shape index, aspect ratio of onion bulb

Particulars	Sphericity	Shape Index	Aspect Ratio
Mean ($\bar{x}$)	0.87	1.06	0.90
Range (R)	0.66-1.11	0.74 -1.73	0.65 – 1.50
SD (σ)	0.09	0.15	0.16
CV	10.57	14.32	17.74

4.1.6 Sphericity (ϕ) and shape index

Sphericity and shape index were determined to find out the shape of the onion bulb. The sphericity was 0.87 ±0.01 with SD and CV (per cent) about 0.09

and 10.57, respectively and its range varies from 0.66 to 1.11. The shape index was obtained was 1.06±0.02 with SD and CV (per cent) about 0.15 and 14.32, respectively and its range varies from 0.74 to 1.73 which is given in Table 4.3. Based on obtained data onion bulb was considered spherical because its shape index was <1.5 (Bahnasawy *et al.*, 2004). Pavani, 2017 was reported sphericity of 1.0±0.01 for *bhima super* variety. Similar results were also reported for shape index about 1.22 (Khura *et al.*, 2011) and 1.27 (Kaveri and Thirupathi, 2015).

4.1.7 Aspect ratio (R_a)

Aspect ratio of the onion bulb was measured by taking 100 samples. It was varies with the different shape and size of the onion and average aspect ratio was observed to be 0.90±0.02 mm with SD and CV(per cent) about 0.16 and 17.74, respectively and its range varies from 0.65 to 1.50 which is given in Table 4.3.

Table 4.4 Surface area, frontal surface area and cross sectional area of onion bulb

Particulars	Surface Area	Frontal Surface Area	Cross Sectional Area
MEAN ($\bar{x}$)	5114.90	1550.26	1316.74
Range (R)	2169.24 -12712.51	629.18 – 4070.07	552.65 – 3350.39
SD (σ)	1828.82	621.47	480.99
CV	35.75	40.09	36.53

4.1.8 Surface area (S_a)

Surface area of the onion bulb was evaluated to know the exposed area of the onion bulb. Surface area of the onion bulb was measured to be 5114.90±182.88 m^2 with SD and CV (per cent) about 1828.82 and 35.75, respectively and its range varies from 2169.24 to 12712.51 mm^2 which is given in Table 4.4.

4.1.9 Frontal surface area (A_{fs})

Frontal surface area of the onion bulb was measured to be 1550.26±62.15 mm^2 with SD and CV (per cent) about 621.47 and 40.09, respectively and its range varies from 629.18 to 4070.07 mm^2 which is given in given in Table 4.4.

4.1.10 Cross sectional area (A_{cs})

Cross sectional area of the onion bulb was measured to be 1316.74±48.10 mm^2 with SD and CV (per cent) about 480.99 and 36.53 per cent, respectively and its range varies from 552.65 to 3350.39 mm^2 which is given in Table 4.4.

4.1.11 Mass of onion bulb

Mass of the onion bulb is important to calculate bulk density of onion bulb. Average mass of onion bulb was measured to be 46.22±3.14g with SD and CV (per cent) about 31.39 and 67.92 per cent, respectively given in Table 4.4.

4.1.12 Bulk density (bd)

Bulk density was calculated by placing the sample in a square box and weighing the sample using electronic balance. Bulk density was obtained 547.92± 5.83 kgm^{-3} with SD and CV (per cent) about 58.27 and 10.63, respectively and its range varies from 490.00 to 625.25 kgm^{-3} which is given in Table 4.5.

4.1.13 Moisture content

Oven drying method was used to determine the moisture content of the onion bulb on wet basis. Moisture content of the onion bulb was obtained 33.81±0.87 per cent with SD and CV (per cent) about 8.67 and 25.64, respectively and its range varies from 24.32 to 45.95 per cent which is `given in Table 4.5.

Table 4.5 Bulk density and moisture content of onion bulb.

Particulars	Onion bulb	
	Bulk density (kg m^{-3})	Moisture content (%)
Mean ($\bar{x}$)	547.92	33.81
Range (R)	490.00 - 626.25	24.32 - 45.95
SD (σ)	58.27	8.67
CV	10.63	25.64

4.2 Soil Parameter

Soil parameters play very important role in designing of a blade for digging of soil. The main component of the developed digger is the cutting blade, which is involved in the soil to excavate up the onion bulb and convey it to the separator. Various soil parameters related to onion digger is determined and presented at the time of digging. The samples were taken randomly from the test field area. Soil tool interaction behavior is predicted by different measurement.

4.2.1 Moisture content

Moisture content of the soil was determined by oven drying method. Core cutter was used to take sample of soil from different place of the field. Moisture content of the soil during harvesting was obtained about 11.999±0.197 per cent with SD and CV (per cent) about 1.966 and 16.380 by using 10 samples of soil, respectively given in Table 4.6.

Table 4.6 Bulk density and moisture content of soil sample.

Particulars	Soil sample	
	Bulk density(kg m^{-3})	Moisture content (%)
Mean ($\bar{x}$)	1.447	11.999
Range (R)	1.418 - 1.477	9.360 - 14.205
SD (σ)	0.026	1.966
CV	1.822	16.380

4.2.2 Bulk density

Bulk density of onion field was determined by using core cutter. Bulk density of the soil during harvesting was obtained about 1.447±0.003 g cm^{-3} with SD and CV (per cent) about 0.026 and 1.822 per cent by using 10 samples of soil, respectively given in Table 4.6. With the help of bulk density the capacity of the separator of onion digger was determined.

4.2.3 Theoretical field capacity (TFC)

Theoretical field capacity was calculated by using equation 3.13. The theoretical capacity of onion digger for 2.5, 3.0, 3.5 km h^{-1} was found to be 0.25, 0.30 and 0.35 ha h^{-1}, respectively. For vibro onion digger it was found 0.25, 0.30 and 0.35 ha h^{-1} for forward speed of 2.5, 3.0, 3.5 km h^{-1}, respectively. Theoretical field capacity for duck foot type onion digger was found to be 0.50, 0.60 and 0.70 ha h^{-1} for 2.5, 3.0, 3.5 km h^{-1}, respectively.

Table 4.7 Theoretical field capacity, effective field capacity and field efficiency of diggers

Speed (km h^{-1})	Type of digger	Theoretical field capacity (TFC) (ha h^{-1})	Effective field capacity (EFC) (ha h^{-1})	Field Efficiency (%)
2.5	Onion digger	0.25	0.20	78
	Vibro onion digger	0.25	0.20	80
	Duck foot type onion digger	0.50	0.38	76
3.0	Onion digger	0.30	0.24	81
	Vibro onion digger	0.30	0.26	86
	Duck foot type onion digger	0.60	0.38	78
3.5	Onion digger	0.35	0.29	83
	Vibro onion digger	0.35	0.47	84
	Duck foot type onion digger	0.70	0.57	82

4.2.4 Effective field capacity (EFC)

It represents the actual area covered per hour. The effective capacity of onion digger for 2.5, 3.0, 3.5 km h^{-1} was found to be 0.20, 0.24, and 0.29 ha h^{-1}, respectively. For vibro onion digger it was found 0.20, 0.26 and 0.29 ha h^{-1} for forward speed of 2.5, 3.0, 3.5 km h^{-1}, respectively. Effective field capacity for duck foot type onion digger was found to be 0.38, 0.47, and 0.57 ha h^{-1} for 2.5, 3.0, 3.5 km h^{-1}, respectively.

4.2.5 Field efficiency:

It represents the ratio of EFC and TFC and expressed in percentage. The Field efficiency of onion digger for 2.5, 3.0, 3.5 km h^{-1} was found to be 78, 81 and 83 per cent, respectively. For vibro onion digger it was found 80, 86, 84per cent for forward speed of 2.5, 3.0, 3.5 km h^{-1}, respectively. Effective field capacity for duck foot type onion digger was found to be 76, 78 and 82 per cent for 2.5, 3.0, 3.5 km h^{-1}, respectively.

4.3 Performance Evaluation of Onion Digger

Three onion diggers which were available in the market has been tested at field of IGKV, Raipur (CG). Randomized block design (RBD) was followed as described in table 4.1 for evaluation of parameters. The harvesting parameters *viz,* damage percentage, exposure percentage, separation index and digging efficiency, machine parameters *viz,* field capacity, field efficiency were measured.

4.3.1 Effect of types of digger and speed of operation on damage percentage of onion bulb

The effect of different type of digger and speed of operation on damage percentage was observed. The ANOVA and mean table were presented in the Appendix- C and Table 4.8, respectively. It was observed from the data that there was significance difference between damage percentages of onion bulb for the different types of digger. The maximum average damage was observed to be 18.32 per cent for duck foot onion digger while the minimum average was observed to be 2.42 per cent for vibro onion digger.

It was found that there is significance difference between damage percentages of onion bulb at different speed of operation at 5 per cent level of significance. The damage percentage was observed to increase with the increase in speed of operation. However, the maximum average damage percentage was observed to be 9.65 per cent at 3.5 km h^{-1} speed while the minimum average damage percentage was observed 6.91 per cent at 2.5 km h^{-1}.

Table 4.8 Mean table of effect of types of digger and operating speed on damage percentage

Diggers	Speed of operation (km h^{-1})			Mean (M)
	2.5	3.0	3.5	
Onion digger (M1)	3.17	3.25	4.84	3.75
Vibro onion digger (M2)	2.04	2.16	3.06	2.42*
Duck foot type onion digger (M3)	15.52	18.39	21.06	18.32
Mean (S)	6.91*	7.93	9.65	
Factors		C.D.	SE(d)	SE(m)
Factor (Digger, M)		0.478	0.230	0.163
Factor (Operating speed, S)		0.478	0.230	0.163
Interaction (Digger, M× Operating speed, S)		0.828	0.399	0.282

The interaction effect between type of digger (M) and speed of operation (S) was also observed and found to be significant at 5 per cent level and was presented in Table 4.8 and the maximum damage per cent was found to be 21.06 per cent for duck foot type onion digger (M3) at speed of operation of 3.5 km h^{-1} (S3). The lowest damage per cent was found to be 2.04 per cent for vibro onion digger (M2) at operating speed of (S2) 2.5 km h^{-1}. The damage percentage increases with increase in speed of operation. Similar results were found by Narendra *et al.* (2019), Goutam (2021) and Khura *et al.,* (2011).

The damage percentage (D) of different types of digger (M) follows a quadratic relation with the speed (S) of operation and it was represented in Table.4.9.

Table 4.9 Regression equation of damage percentage for different types of digger

S.No	Parameters	Regression equation
1	Onion digger (M1)	$D = 4.591- 2.173S\ 0.752S^2$
2	Vibro onion digger (M2)	$D = 2.713- 1.067S+0.394S^2$
3	Duck foot type onion digger (M3)	$D = 12.46+ 3.150S -0.094S^2$

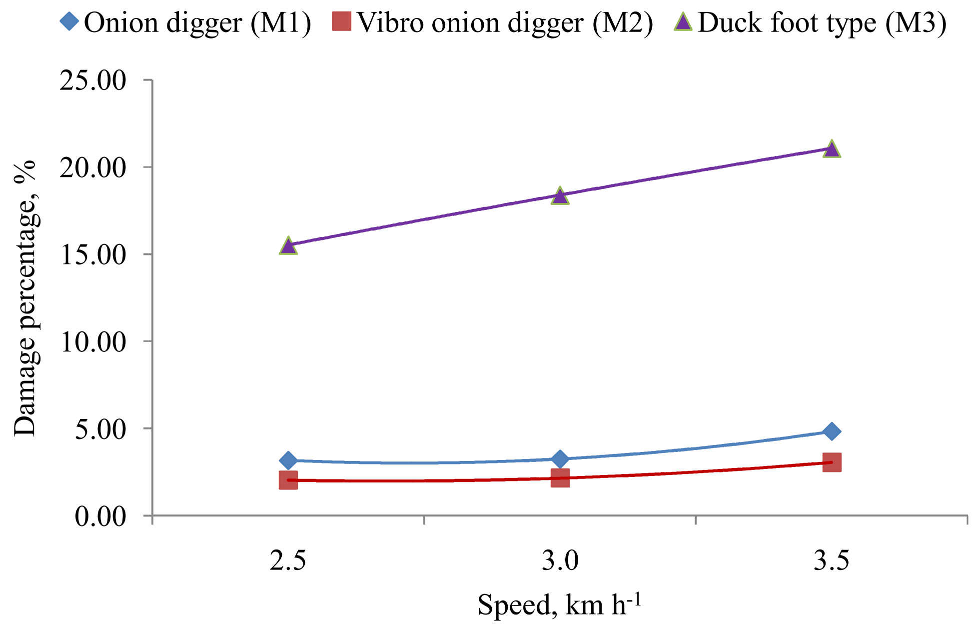


Fig. 4.1 Effect types of digger and operating speed on damage percentage

4.3.2 Effect of types of digger and speed of operation on bulb on exposure percentage of onion

The effect of different type of digger and speed of operation on exposure percent was observed. The ANOVA and mean table were presented in the Appendix- C and Table 4.10, respectively. It was observed from the data that there is significance difference between exposure percents of onion bulb for the different types of digger. The maximum average exposure was observed to be 74.24 per cent for vibro onion digger (M2) while the minimum average was observed to be 63.09 per cent for onion digger (M1).

It was found that there is significance difference between exposure percentages of onion bulb at different speed of operation at 5 per cent level of significance. The maximum average exposure percentage was observed to increase with the increase in speed of operation. However, the maximum exposure percentage was observed to be 69.44 per cent at 3.5 km h^{-1} (S3) speed while the minimum average was observed to be 66.07 per cent at 2.5 km h^{-1} (S2).

The interaction effect between type of digger (M) and speed of operation (S) was also observed and found to be significant at 5 per cent level and was presented in Table 4.8 and the highest exposure per cent was found to be 76.32 per cent for vibro onion digger (M2) at speed of operation of 3.0 km h^{-1} (S2). The lowest exposure per cent was found to be 61.45 per cent for tractor operated onion digger (M1) at speed of operation of 2.5 km h^{-1} (S1). Similar results were found by Goutam (2021) and Khura *et al.,* (2011).

Table 4.10 Mean table of effect of types of digger and operating speed on exposure percentage

Diggers	Average speed of operation (km h^{-1})			Mean (M)
	2.5	3.0	3.5	
Onion digger (M1)	61.45	62.92	64.90	63.09
Vibro onion digger (M2)	72.08	74.31	76.32	74.24*
Duck foot type onion digger (M3)	64.67	65.86	67.09	65.87
Mean (S)	66.07*	67.69	69.44	
Factors		C.D.	SE(d)	SE(m)
Factor (Digger, M)		0.408	0.196	0.139
Factor (Operating speed, S)		0.408	0.196	0.139
Interaction (Digger, M× Operating speed, S)		0.706	0.340	0.240

The exposure percentage (E) of different types of digger (M) follows a polynomial equation of order 2 with the speed of operation (S) and it was represented in Table.4.11.

Table 4.11Regression equation of exposure percentage for different types of digger

S .No	Parameters	Regression equation
1	Onion digger (M1)	$E = 60.51+ 0.673S+0.263S^2$
2	Vibro onion digger (M2)	$E= 69.65+2.532S - 0.103S^2$
3	Duck foot type onion digger (M3)	$E = 63.51+1.142S +0.016S^2$

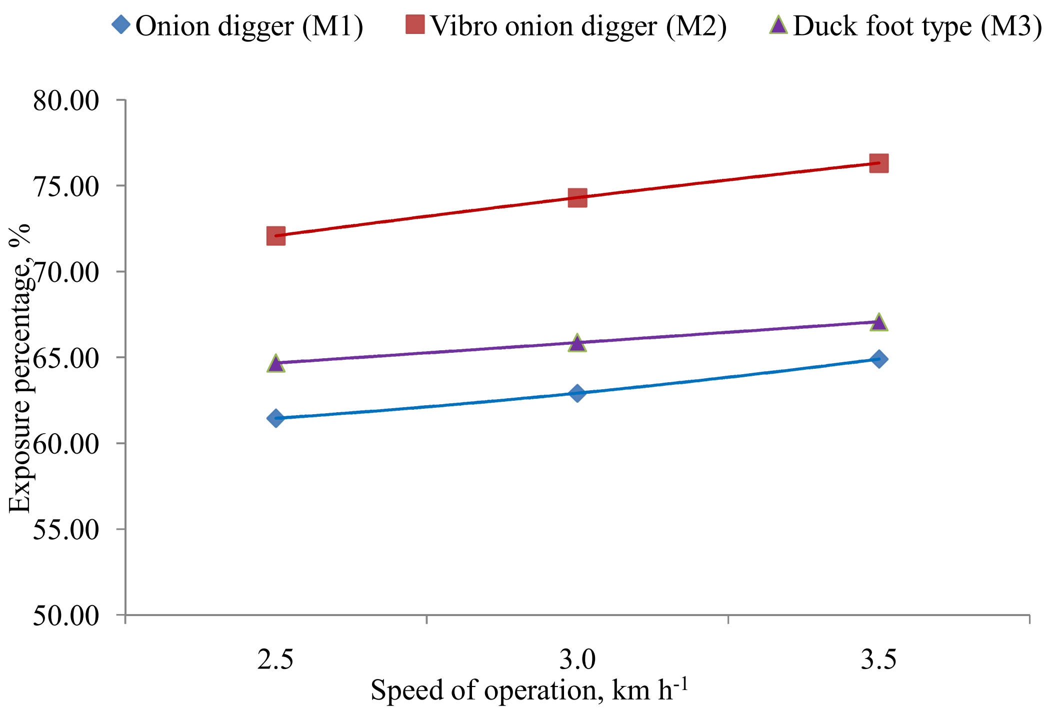


Fig. 4.2 Effect of types of digger and operating speed on exposure percentage

4.3.3 Effect of types of digger and speed of operation on bulb on separation index

The effect of different type of digger and speed of operation on separation index was observed. The ANOVA and mean table were presented in the Appendix- C and Table 4.12, respectively. It was observed from the data that there is significance difference between separation indexes of onion bulb for the different types of digger. The maximum average separation index was observed to be 75.81 per cent for vibro onion digger (M2) while the minimum average was observed to be 56.23 per cent for duck foot type onion digger (M3).

It was found that there is significance difference between separation indexes of onion bulb at different speed of operation at 5 per cent level of significance. The separation index was observed to decrease with the increase in speed of operation. However, the maximum average separation index was observed to be 69.03 per cent at 2.5 kmh^{-1} (S1) operating speed while the minimum average was observed to be 65.81 per cent at 3.5 km h^{-1} (S3).

The interaction effect between type of digger (M) and speed of operation (S) was also observed and found to be significant at 5 per cent level and was presented in Table 4.12 and Fig.4.3. The highest separation index was found to be 77.10 per cent for vibro onion digger (M2) at speed of operation of 2.5 km h^{-1}. The lowest separation index was found to be 54.16 per cent for duck foot type onion digger (M3) at speed of operation of 3.5 km h^{-1} (S3). Similar results were found by Goutam (2021) and Khura *et al.,* (2011).

Table 4.12 Mean table of effect of types of digger and operating speed on separation index

Diggers	Average speed of operation (km h^{-1})			Mean (M)
	2.5	3.0	3.5	
Onion digger (M1)	71.96	74.55	68.92	71.81
Vibro onion digger (M2)	77.10	75.97	74.35	75.81*
Duck foot type onion digger (M3)	58.04	56.49	54.16	56.23
Mean (S)	69.03*	69.00	65.81	
Factors		C.D.	SE(d)	SE(m)
Factor (Digger, M)		0.726	0.35	0.247
Factor (Operating speed, S)		0.726	0.35	0.247
Interaction (Digger, M× Operating speed, S)		1.257	0.605	0.428

The separation index (SI) of different diggers follows a quadratic relation with speed of operation (S) and it was represented in Table.4.13.

Table 4.13 Regression equation of separation index for different types of digger

S .No	Parameters	Regression equation
1	Onion digger (M1)	$SI = 61.14 + 14.92S - 4.111S^2$
2	Vibro onion digger (M2)	$SI = 77.73 - 0.392S - 0.246S^2$
3	Duck foot type onion digger (M3)	$SI = 58.80 - 0.377S - 0.391S^2$

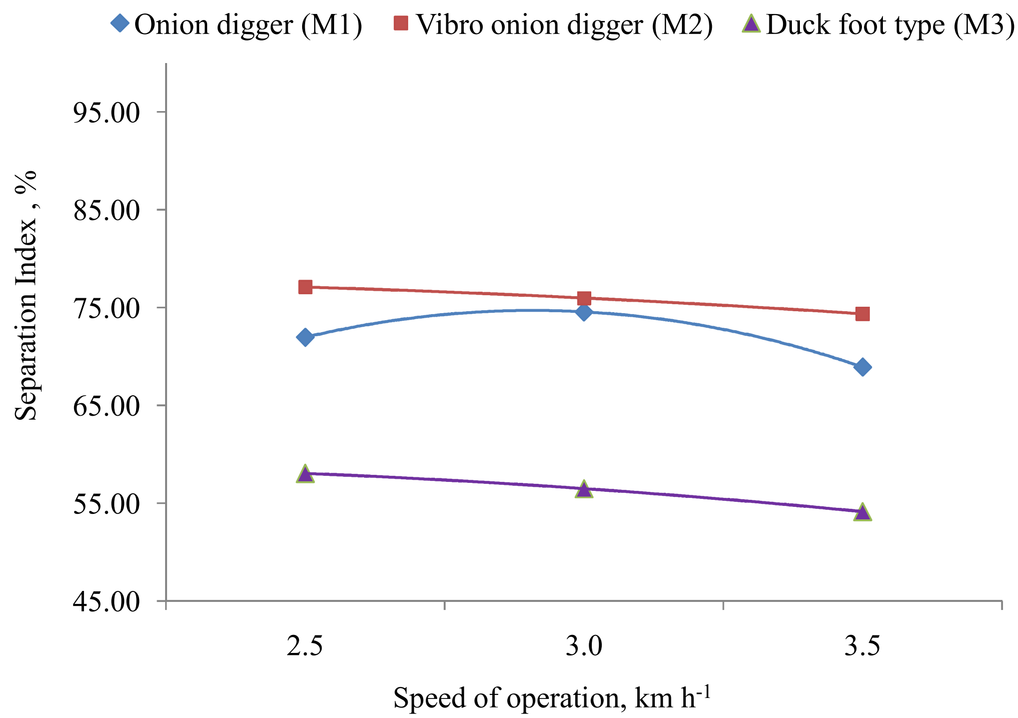


Fig. 4.3 Effect of types of digger and speed on separation index

4.3.4 Effect of types of digger and speed of operation on digging efficiency

The effect of different type of digger and speed of operation on digging efficiency was observed. The ANOVA and mean table were presented in the Appendix- C and Table 4.11, respectively. It was observed from the data that there is significance difference between digging efficiency of onion bulb for the different types of digger. The maximum average digging efficiency was observed to be 93.22 per cent for vibro onion digger (M2), while the minimum average was observed to be 90.80 per cent for onion digger (M1).

It was found that there is significance difference between digging efficiency of onion bulb at different speed of operation at 5 per cent level of significance. The digging efficiency was observed to decrease with the increase in speed of operation. However, the maximum average separation index was observed to be 88.34 per cent at 2.5 km h^{-1} (S1) operating speed while the minimum average was observed to be 85.05 per cent at 3.5 km h^{-1} (S3).

The interaction effect between type of digger (M) and speed of operation (S) was also observed and found to be significant at 5 per cent level. The maximum digging efficiency was observed for 93.62 per cent for vibro onion digger (M2) at speed of operation of 2.5 km h^{-1} (S2). The minimum digging efficiency was observed to be 72.57 per cent for duck tooth type of onion digger (M3) at operating speed of 3.5 km h^{-1} (S3). The interaction of types of onion digger and speed of operation was represented in Table 4.14.

Table 4.14 Mean table of effect of types of digger and operating speed on digging efficiency

Diggers	Average speed of operation(km h^{-1})			Mean
	2.5	3.0	3.5	(M)
Onion digger (M1)	91.43	90.97	90.00	90.80
Vibro onion digger (M2)	93.62	93.46	92.60	93.22*
Duck foot type onion digger (M3)	79.99	76.88	72.57	76.48
Mean (S)	88.34*	87.10	85.05	
Factors		C.D.	SE(d)	SE(m)
Factor (Digger, M)		0.544	0.262	0.185
Factor (Operating speed, S)		0.544	0.262	0.185
Interaction (Digger, M× Operating speed, S)		0.943	0.454	0.321

The digging efficiency (De) of different types of digger follows a quadratic relation with speed of operation (S) and it was represented in Table.4.15.

Table 4.15 Regression equation of digging efficiency for different types of digger

S .No	Parameters	Regression equation
1	Onion digger (M1)	$De = 91.37 + 0.312S - 0.257S^2$
2	Vibro onion digger (M2)	$De = 93.08 + 0.875S - 0.346S^2$
3	Duck foot type onion digger (M3)	$De = 81.88 - 1.294S - 0.603S^2$

It was observed from the above data that vibro onion digger (M2) have maximum digging efficiency, separation index, exposure percentage, and minimum damage percentage in comparison to the other onion diggers. So, a detailed study of vibro onion digger at three different speeds with three blade angle was carried out.

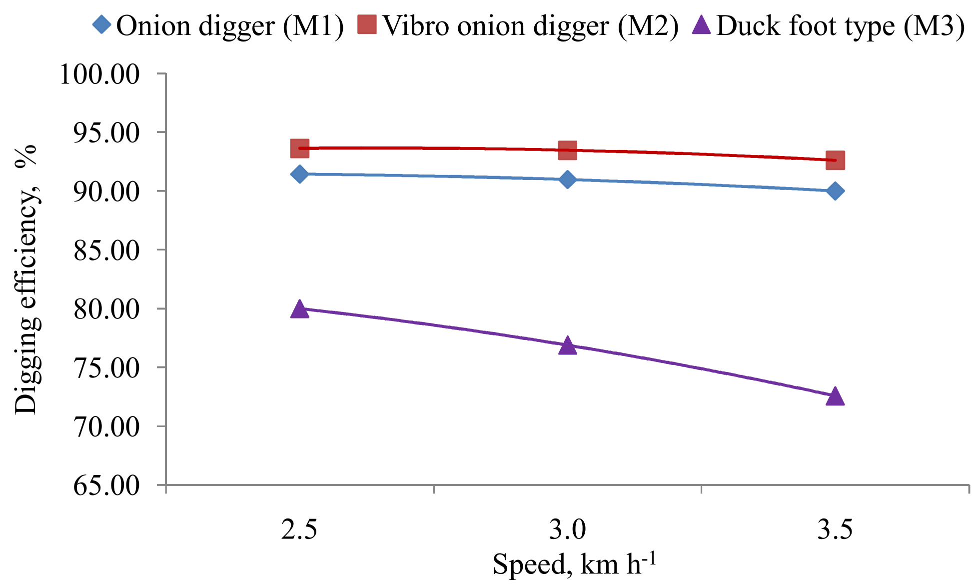


Fig. 4.4 Effect of types of digger and operating speed on digging efficiency

Split plot experimental design was used for statistical analysis to analyze the effect of the variables on vibro onion digger. Main plot taken as different speed of operation (S1, S2 and S3) and sub plot as different blade angle (B1, B2 and B3). Result obtained from test and their ANOVA is presented in Table 4.16, Table 4.18, Table 4.20 and Table 4.21, respectively and Appendix-D.

4.4 Performance Evaluation of Vibro Onion Digger

4.4.1 Effect of speed of operation and blade angle on damage percentage

The effect of different speed of operation and with varying blade angle on damage percentage was observed. The ANOVA and mean table were presented in the Appendix-D and Table 4.16, respectively. It was observed from the data that there is significance difference between damage percentages of onion bulb for with increase of speed of operation. The maximum average damage was observed to be 4.10 per cent for speed of operation of 3.5 km h^{-1} (S3) while the minimum average was observed to be 3.03 per cent for operating speed 3.0 km h^{-1} (S2).

It was found that there is significant difference between damage percentages of onion bulb at different blade angle at 5 per cent level of significance. The damage percentage was observed to increase with the increase in blade angle. However, the highest damage (4.37 per cent) was observed to be at blade angle of 25° (B3) while the lowest (2.51 per cent) was observed at 20° (B2) blade angle.

Table 4.16 Mean table of effect of different speed of operation and blade angle on damage percentage

Operating Speed (km h^{-1})	Blade angle (°)			Mean
	15	20	25	
2.5	4.22	2.58	3.98	3.59
3.0	3.46	1.98	3.65	3.03*
3.5	3.96	2.98	5.49	4.10
Mean	3.88	2.51*	4.37	
Factors		C.D.	SE(d)	SE(m)
Factor (Operating speed)		0.15	0.05	0.03
Factor (Blade angle)		0.27	0.12	0.08
Factor (Blade angle) at same level of (Operating speed)		0.48	0.21	0.06
Factor (Operating speed at same level of Blade angle)		0.41	0.18	0.13

The effect of blade angle at same level of operating speed on damage per cent was significantly different at 5 per cent and was presented in Table 4.16. The effect of operating speed at same level of blade angle was significantly different at 5 per cent. The maximum damage percentage was observed to be 5.49 per cent at speed of operation (S3)3.5 km h^{-1} with blade angle 25° (B3) and minimum damage percentage was found to be 1.98 per cent for blade angle (B2) 20° with a operating speed of (S2) 3.0 km h^{-1}. Similar results were found by Goutam (2021) and Khura *et al.,* (2011).

The damage percentage (D) of different blade angles (B) follows a polynomial equation with order 2 relation with speed of operation (S) and the regression equation was represented in Table.4.17.

Table 4.17 Regression equation of damage percentage for different blade angles

S .No	Parameters	Regression equation
1	B1, 15°	$D= 6.24-2.65S +0.63S^2$
2	B2, 20°	$D= 4.78 -3.0S + 0.8S^2$
3	B3, 25°	$D = 6.48-3.585S+1.085S^2$

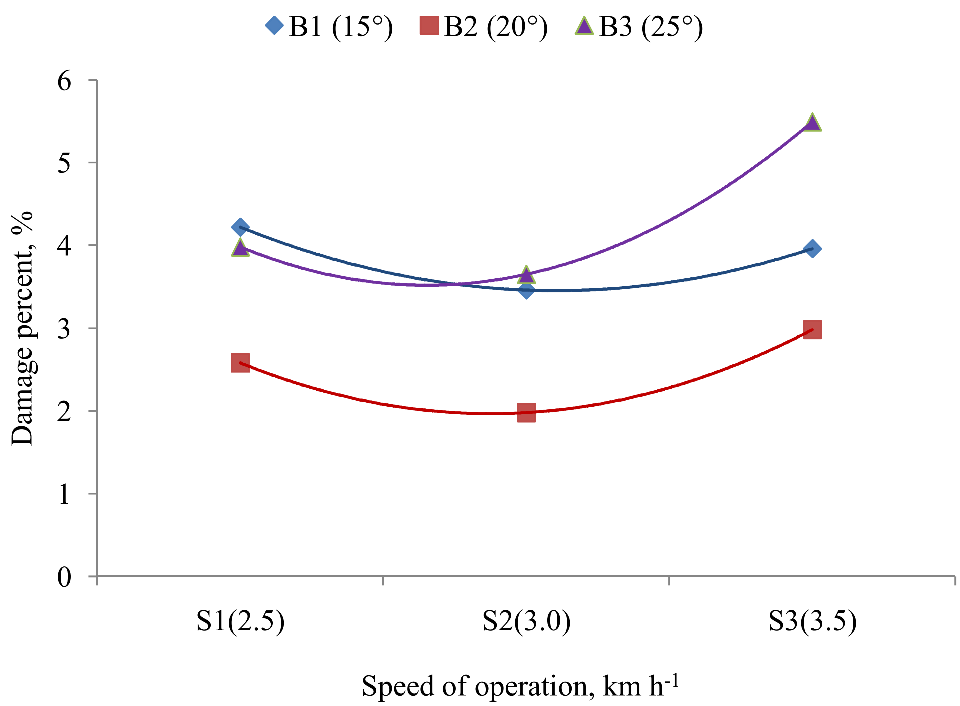


Fig.4.5 Effect of speed of operation and blade angle on damage percentage

4.4.2 Effect of speed of operation and blade angle on exposure percentage

The effect of different digger speed of operation and with varying blade angle on exposure percentage was observed. The ANOVA and mean table were presented in the Appendix-D and Table 4.18, respectively. It was observed from the data that there is significance difference between exposure percentages of onion bulb with increase of speed of operation. The maximum average exposure was observed to be 96.58 per cent for speed of operation of 3 km h^{-1} (S3) while the minimum average was observed to be 94.55 per cent at speed of operation of 2.5 km h^{-1} (S2) for vibro onion digger.

Table 4.18 Mean table of effect of different speed of operation and blade angle on exposure percentage

Operating Speed (km h^{-1})	Blade angle (°)			Mean (S)
	15	20	25	
2.5	93.85	94.35	95.44	94.55
3.0	95.83	96.68	97.22	96.58*
3.5	95.12	95.92	96.20	95.75
Mean (B)	94.93	95.65	96.29*	

Factors	C.D.	SE(d)	SE(m)
Factor (Operating speed)	0.39	0.13	0.99
Factor (Blade angle)	0.37	0.16	0.11
Factor (Blade angle) at same level of (Operating speed)	0.61	0.29	0.17
Factor (Operating speed) at same level of (Blade angle)	0.57	0.27	0.19

It was found that there is significance difference between damage percentages of onion bulb at different blade angle at 5 per cent level of significance. The damage percentage was observed to increase with the increase in blade angle. However, the maximum average exposure percentage was observed to be 96.29 per cent at blade angle of 25° (B3) while the minimum average exposure percentage was observed to be 94.93 per cent at 15° (B1) blade angle. Similar results were found by Goutam (2021) and Khura *et al.,* (2011).

The effect of blade angle at same level of operating speed on exposure per cent was significantly different at 5 per cent. The effect of operating speed at same level of blade angle was significantly different at 5 per cent. The highest and lowest exposure percentage was observed 97.22 and 93.58 per cent respectively. The blade angle and speed of operation for maximum and minimum exposure was observed at (25° , (B3) 3.0 km h^{-1}, (S2)) and (15°(B1), 2.5 km h^{-1}(S1)) respectively.

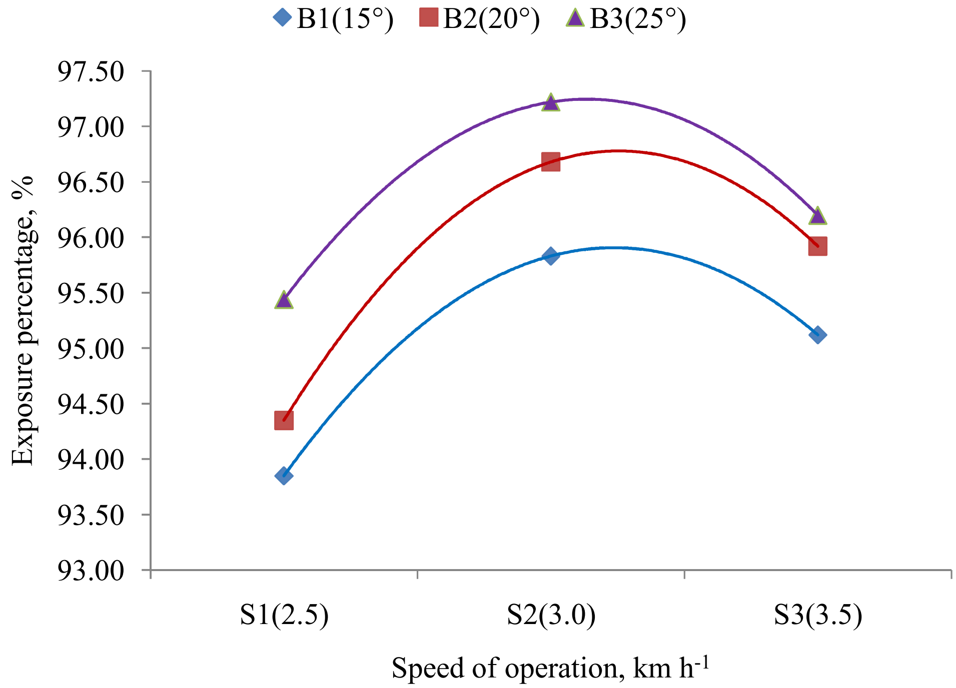


Fig. 4.6 Effect of speed of operation and blade angle on exposure percentage

The effect of blade angle at same level of operating speed on exposure per cent was significantly different at 5 per cent. The effect of operating speed at same level of blade angle was significantly different at 5 per cent. The highest and lowest exposure percentage was observed 97.22 and 93.58 per cent respectively. The blade angle and speed of operation for maximum and minimum exposure was observed at (25° ,(B3) 3.0 km h^{-1}, (S2)) and (15°(B1), 2.5 km h^{-1}(S1)) respectively.

The exposure percentage (D) of different blade angles (B) follows a quadratic relation with speed of operation (S) and the regression equation was represented in Table.4.20.

Table 4.19 Regression equation table of exposure percentage for different blade angles

S .No	Parameters	Regression equation
1	B1, 15°	$E = 89.18 + 6.015\ S - 1.345\ S^2$
2	B2, 20°	$E = 88.93 + 6.965\ S - 1.545\ S^2$
3	B3, 25°	$E = 90.86 + 5.98\ S - 1.4\ S^2$

4.4.3 Effect of speed of operation and blade angle on separation index

The effect of different digger speed of operation and with varying blade angle on separation index was observed. The ANOVA and mean table were presented in the Appendix-D and Table 4.20, respectively. It was observed from the data that there is significance difference between separation index of onion bulb with increase of speed of operation. The maximum average exposure was observed to be 57.09 per cent for speed of operation of 3 km h^{-1} (S2) while the minimum average was observed to be 53.11 per cent at speed of operation of 3.5 km h^{-1} (S3)or vibro onion digger.

It was found that there is significance difference between separation index of onion bulb at different blade angle at 5 per cent level of significance. The damage percentage was observed to increase with the increase in blade angle. However, the maximum average damage was observed to be 55.87 per cent at blade angle of 15° (B1) while the minimum average was observed to be 55.00 per cent at 20° (B2) blade angle.

Table 4.20 Mean table of effect of different speed of operation and blade angle on separation index

Operating Speed (km h^{-1})	Blade angle (°)			Mean
	15	20	25	(S)
2.5	55.39	54.44	53.63	54.48
3.0	57.87	57.71	55.69	57.09*
3.5	54.36	52.85	52.13	53.11
Mean (B)	55.87*	55.00	53.81	
Factors		C.D.	SE(d)	SE(m)
Factor (Operating speed)		0.37	0.13	0.09
Factor (Blade angle)		0.28	0.12	0.09
Factor (Blade angle) at same level of (Operating speed)		0.54	0.22	0.15
Factor (Operating speed) at same level of (Blade angle)		0.54	0.22	0.15

The effect of blade angle at same level of operating speed on separation index was significantly different at 5 per cent. The effect of operating speed at same level of blade angle was significantly different at 5 per cent. The minimum separation index was found to be 52.13 per cent was observed to be operating speed 3.5 km h^{-1} (S3) with a blade angle 25° (B3). The highest separation index was observed to be 57.87 per cent for blade angle 15° (B1) and operating speed 3.0 km h^{-1} (S2). Similar results were found by Goutam (2021) and Khura *et al.,* (2011).

The separation index (SI) of different blade angles (B) follows a quadratic relation with speed of operation (S) and the regression equation was represented in able.4.21.

Table 4.21 Regression equation of separation index for different blade angles

S .No	Parameters	Regression equation
1	B1, 15°	$SI= 46.92 + 11.46S+ 2.995S^2$
2	B2, 20°	$SI= 43.04+ 15.46S -4.065S^2$
3	B3, 25°	$SI= 45.95+10.49S -2.81S^2$

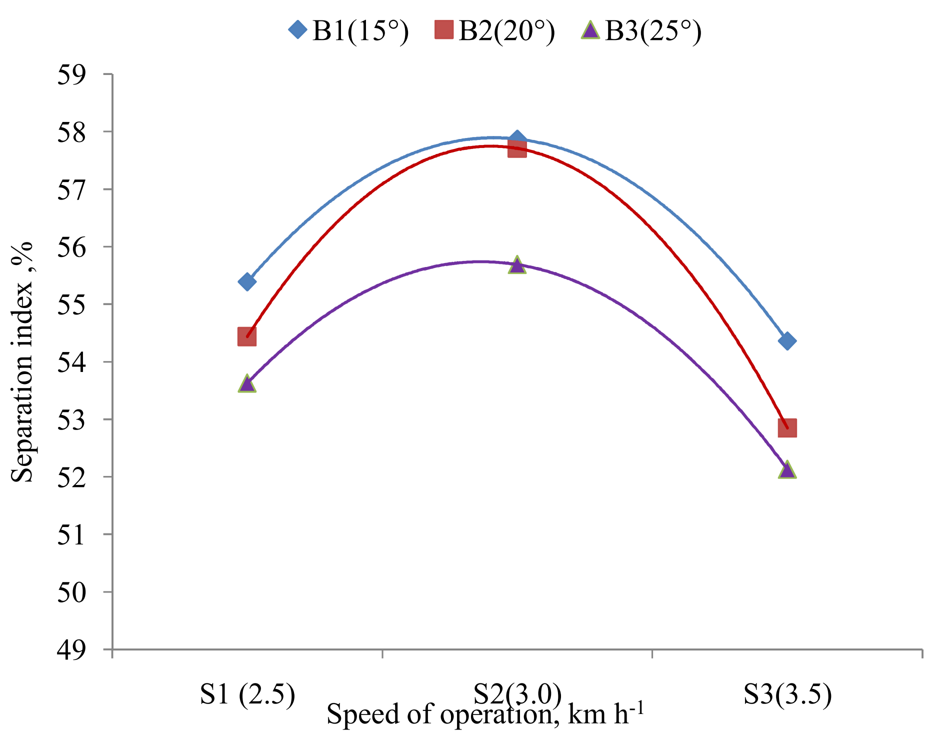


Fig.4.7 Effect of speed of operation and blade angle on separation index

4.4.4 Effect of speed of operation and blade angle on digging efficiency

The effect of different digger speed of operation and with varying blade angle on digging efficiency was observed. The ANOVA and mean table were presented in the Appendix-D and Table 4.22, respectively. It was observed from the data that there is significance difference between digging efficiency of onion bulb with increase of speed of operation. The maximum average exposure was observed to be 93.54 per cent for speed of operation of 3 km h^{-1} (S2) while the minimum average was observed 92.27 per cent at speed of operation of 2.5 km h^{-1} (S1) for vibro onion digger.

It was found that there is significance difference between digging efficiency of onion bulb at different blade angle at 5 per cent level of significance. The digging efficiency was observed to increase with the increase in blade angle. However, the maximum average digging efficiency was observed to be 93.85 per cent at blade angle of 20° (B2) while the minimum average was observed to be 91.75 per cent at 15° (B1) blade angle.

Table 4.22 Mean table of effect of different speed of operation and blade angle on digging efficiency

Operating Speed (km h^{-1})	Blade angle (°)			Mean
	15	20	25	(S)
2.5	90.76	93.23	92.80	92.27
3.0	92.33	94.81	93.47	93.54*
3.5	92.14	93.50	91.56	92.40
Mean (B)	91.75	93.85*	92.61	
Factors		C.D.	SE(d)	SE(m)
Factor (Operating speed)		0.556	0.195	0.138
Factor (Blade angle)		0.406	0.184	0.130
Factor (Blade angle) at same level of (Operating speed)		0.778	0.319	0.239
Factor (Operating speed) at same level of (Blade angle)		0.793	0.326	0.230

The effect of blade angle at same level of operating speed on digging efficiency was significantly different at 5 per cent. The effect of operating speed at same level of blade angle was significantly different at 5 per cent. The lowest digging efficiency was observed to be 90.76 per cent for blade angle 15° (B1) with an operating speed of 2.5 km h^{-1} (S1) and the maximum digging efficiency observed to be 94.81 per cent for operating speed 3.0 km h^{-1} (S2) with a blade angle 20° (B2). Similar results were found by Goutam (2021) and Khura *et al.,* (2011).

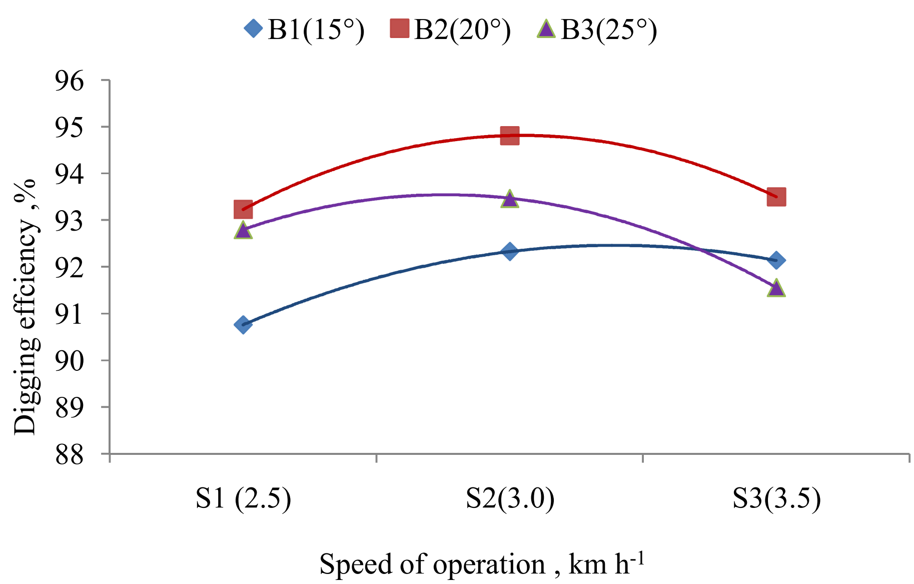


Fig. 4.8 Effect of speed of operation and blade angle on digging efficiency

The digging efficiency (De) of different blade angles (B) follows a quadratic relation with speed of operation (S) and the regression equation was represented in Table.4.23.

Table 4.23 Regression equation table of digging efficiency for different blade angles

S .No	Parameters	Regression equation
1	B1, 15°	$De = 87.43+4.21S -0.88S^2$
2	B2, 20°	$De = 88.76+5.915S -1.445S^2$
3	B3, 25°	$De = 89.55+4.54S -1.29S^2$

4.5 Manual Digging of Onion Bulbs

The manual harvesting operation of onion bulb was carried out by with the help of spade, *khurpa*. The results of respective dependent parameters were discussed below.

4.5.1 Damage percentage

The total number of damage onion found to be 5 for a plot of $1 \times 1 m^2$ and for the same plot total onion was found to be 61. So, the damage percentage was calculated by using Equation 3.16 and found to be 8.19 per cent.

4.5.2 Exposure percentage

The total number of exposed onion found to be for a plot of $1 \times 1\ m^2$ 55 and for the same plot total onion was found to be 61. So, the exposure percentage was calculated by using Equation 3.17 and found to be 90.16 per cent.

4.5.3 Separation index

The mass of soil and onion mixture found to be for a plot of $1 \times 1\ m^2$ and for the same plot total the theoretical weight of dirt and soil from unit area was found to be 15.24 kg. So, the separation index found to be 90.41 per cent.

4.5.4 Digging efficiency

The total number of onion plants harvested successfully found to be 51 and the total number of plants present for an area of $1 \times 1\ m^2$ 61. So, the digging efficiency found to be 83.60 per cent.

4.6 Cost Economics

The cost of operation of several onion diggers was computed by taking the unit cost of an onion digger, a vibro onion digger and a duck foot type onion digger, which were , ₹ 98000, ₹ 92000, and ₹42000/-, respectively. The cost of operation was calculated using some assumptions. Onion diggers are expected to last 6 years with 250 hours of operation each year. Salvage value, interest rate, and labor required were calculated at 10 per cent of the principle cost, 10 per cent per year, and 2 nos., respectively. Repair and maintenance cost, Diesel cost, fuel consumption, lubrication cost, and shelter cost were calculated as 12 per cent of principle cost, 95.84 l^{-1}, 5 l hour^{-1}, 20 per cent of fuel cost and 2 per cent of principle cost respectively.

Table 4.24 Cost economics of different onion diggers

S. No	Particulars	Amount			
		Tractor	Onion digger	Vibro onion digger	Duck foot type onion digger
1	Capital cost, ₹	650000	98000	92000	42000
2	Life, year	10	6	6	6
3	Annual use, h year^{-1}	1000	250	250	250
4	Fixed cost				
	a. Depreciation @ 10% salvage value, ₹ h^{-1}	58.50	58.80	55.20	25.20
	b. Interest @ 10 % per year,₹h^{-1}	35.75	21.56	20.24	9.24
	c. Shelter and tax @ 2% of initial cost , ₹ h^{-1}	13.00	7.84	7.36	3.36
A. Total fixed cost, ₹ h^{-1}		107.25	88.20	82.80	37.80
5	Variable cost				
	a. Fuel cost, l^{-1}	95.84			
	b. Fuel consumption, l h^{-1}	5			
	c. Fuel cost, ₹ h^{-1}	479.2			
	d. Lubrication cost	95.84			
	e. Repair and maintenance @ 12 % of initial cost, ₹ h^{-1}	78.00	47.04	44.16	20.16
	f. Labour required	1	1	1	1
	g. Working hour, h day^{-1}	8	8	8	8
	h. Labour cost, ₹ day^{-1}	350.00	350.00	350.00	350.00
	i. Labour cost, ₹ h^{-1}	43.75	43.75	43.75	43.75
B. Total variable cost, ₹ h^{-1}		696.79	90.79	87.91	63.91
Total cost of operation, ₹ h^{-1} (A+B)		804.04	178.99	170.71	101.71
Cost of operation, Rs/kg			0.026	0.023	0.009
Breakeven point, h year^{-1}		349.81	551.97	535.15	336.05
Payback period, year		8.48	9.81	9.51	5.97

The cost of operation is detailed in Table 4.19 and Appendix E. The average operation cost for onion digger, vibro onion digger and duck foot onion digger found to be ₹ 983.03 h^{-1}, ₹ 974.75 h^{-1} and ₹ 905.75 h^{-1}, respectively. The breakeven point for onion digger, vibro onion digger and duck foot type onion digger were found to be ₹551.97 h $year^{-1}$, ₹535.15 h $year^{-1}$ and ₹ 336.05 h $year^{-1}$, respectively. The payback period for onion digger, vibro onion digger and duck foot type onion digger was found to be 9.81 year, 9.51 year and 5.97 year, respectively.

4.7 Comparison between Manual Harvesting with different Onion Diggers Available in Chhattisgarh.

The manual harvesting operation was compared with different types of digger available in Chhattisgarh region and was represented in Table 4.25. The output capacity (kg/h) for manual harvesting, tractor drawn onion digger, vibro onion digger and duck foot type onion digger was found to be 65.32, 3728, 4996, and 4313 kg h^{-1} respectively.

Table 4.25 Comparison between manual harvesting with different onion diggers available in Chhattisgarh.

S No.	Manual Harvesting	Tractor operated onion digger	Vibro onion digger	Duck foot type onion digger
Method of operation	Manual method for collection	Mechanized digging+ Manual collection	Mechanized digging+ Manual collection	Mechanized digging+ Manual collection
No of rows at one pass	One	One	One	Two
Width of operation (m)	0.7	1	1	2
Damage percentage (%)	8.19	3.25	2.16	21.06
Exposure percentage(%)	90.16	62.92	74.31	65.86
Separation index (%)	90.41	74.55	75.97	74.35
Digging efficiency (%)	93.60	90.97	93.46	76.88
Field capacity (ha h^{-1})	0.0023	0.24	0.26	0.38
Output capacity (kg h^{-1})	65.32	3728	4996	4313
Cost of operation (₹ h^{-1})	43.75	178.99	170.71	101.71
Cost of operation (₹ kg^{-1})	0.669	0.048	0.034	0.023

The cost of operation (₹ kg^{-1}) was found to be 0.669, 0.048, 0.034 and 0.023 respectively for manual harvesting, tractor drawn onion digger, vibro onion digger and duck foot type onion digger respectively. The duck foot onion digger has minimum cost of operation i.e. ₹ 0.023 kg^{-1} but has high damage percentage and low digging, separation and exposure percentage. So, for Chhattisgarh region vibro onion digger was considered as the best digger and its cost operation per kg was found to be ₹ 0.034 kg^{-1}.

CHAPTER-V
SUMMARY AND CONCLUSION

India has bestowed with several agro-ecological areas that give sufficient opportunity for growing a wide range of horticulture crops, which account for a substantial portion of overall agricultural output in the country. For the crop year 2022-23, the overall horticulture production of the country is predicted to reach 333.25 million tones, which is down 0.4 per cent from the previous crop year 2021-22's total of 334.60 million tonnes. Horticultural crops cover 0.792 million hectares in Chhattisgarh and produce 9.162 million tonnes per year. The total area under onion cultivation in Chhattisgarh is 23310 ha with a production of 365740 MT (2021-22) with a productivity of 15.69 tonnes per hectare.

Harvesting of onion is a time consuming, expensive and labour intensive process. Timely harvesting of onion is essential to reduce post harvest loss and for a better yield of bulbs. A partial economical harvester for marginal farmers should be a mechanized harvester that can dig the onion for onion growers, separating soil mass from the onions and finally can be picked up hand by laborers. Mechanization of onion harvesting is of utmost importance to the onion farmers. To improve the mechanization status of onion in Chhattisgarh as well as India a study was conducted to select a suitable onion digger from the available diggers. Test was conducted in a research farm of Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur during the year 2021-22. The study was carried out with the following objectives.

i. To study the physical and engineering properties of onion crop at the time of harvesting.
ii. To test and evaluate the performance of onion diggers in actual field conditions
iii. To select suitable tractor drawn onion digger for Chhattisgarh.

A study was conducted for selection of a suitable onion digger for harvesting. Various crop and soil parameters at the time of harvesting were studied. Physical and engineering properties of onion bulb were also studied for selection of appropriate digger. The data's were observed from a factorial Randomized Block Design plots by taking two independent parameters viz. type of digger (onion vibro digger (M1), vibro onion digger (M2), duck foot type onion digger (M3)) and operational speed (2.5 km h^{-1} (S1), 3.0 km h^{-1} (S2), 3.5 km h^{-1} (S3)). A detailed study was also conducted on another field on the selection of optimized speed and blade angle for the selected digger in previous experiment. Different output parameters like effective field capacity, damage percentage, exposure percentage, separation index and digging efficiency were also recorded. The salient findings are as given below:

1. The average polar diameter, average thickness, equatorial diameter, geometric mean diameter and arithmetic diameter of onion bulb was observed to be 41.25±0.81mm, 46.60±1.01 mm, 33.26±0.58 mm 39.80±0.67 mm and 40.37±0.69 mm respectively. These parameters play an important role in the performance of the machine.

2. The sphericity, shape index and aspect ratio of the onion bulbs were determined to be 0.87 ± 0.01, 1.23±0.02 and 1.06±0.02 respectively. Surface area, frontal surface area and cross sectional area of the onion bulbs were measured to be 5114.90±182.88mm^2, 1550.26±62.15mm^2 and 1316.74±48.10 mm^2 respectively.

3. The average mass, Bulk density and moisture content of onion bulb were recorded as 46.22±3.14g, 547.92±5.83 kg m^{-3} and 83.09±0.55% respectively.

4. The moisture content and bulk density of soil at the time of harvesting was found to be 14.28±0.83 per cent and 1.65±0.024 g cm^{-3} respectively.

5. Effective field capacity and filed efficiency was found maximum for duck foot type onion digger (M3) and followed by vibro onion digger (M2) and tractor drawn onion digger (M1).

6. The minimum damage per cent was found to be 2.16 per cent for vibro onion digger (M2). The highest exposure per cent was found to be 76.32 per cent for vibro onion digger (M2).

7. The maximum separation index was found to be 77.10 per cent for vibro onion digger (M2). The maximum digging efficiency was observed to be 93.62 per cent for vibro onion digger (M2).

8. The minimum damage percentage was found to be 1.98 per cent for blade angle 20° (B2) with an operating speed of 3.0 km h^{-1} (S2). The highest 97.22 per cent for blade angle for 25° (B3) at speed of operation were 3.0 km h^{-1} (S2).

9. The highest separation index was observed to be 57.71 per cent for blade angle 20° (B2) and operating speed 3.0 km h^{-1}(S2). The maximum digging efficiency observed to be 94.81 per cent for operating speed with a blade angle 20° (B2).

10. The average operation cost for onion digger, vibro onion digger and duck foot onion digger were found to be be ₹ 983.03 h^{-1}, ₹ 974.75 h^{-1} and ₹ 905.75 h^{-1}, respectively. The breakeven points were found to be 551.97 h $year^{-1}$, 535.15 h $year^{-1}$ and 336.05 h $year^{-1}$ respectively. The payback period were found to be 9.81 year, 9.51 year and 5.97 year respectively.

11. The vibro onion digger was tested and it was observed that the lowest damage, highest expose, highest separation index and highest digging efficiency were found to be at speed of operation of 3.0 km h^{-1}(S2) and blade angle of 20° (B2).

Conclusions

i. Physical and engineering properties of onion bulb have significant effect on digging of onion bulbs.
ii. Vibro onion digger found to be having highest exposure, separation index and digging efficiency and lowest damage and was found to be effective than two digger available for testing. The speed of operation of 3.0 km h^{-1} and blade angle 20° found to best suitable for vibro onion digger.
iii. For Chhattisgarh region vibro onion digger was found to more effective in terms of damage percentage, exposure percentage, separation index and digging efficiency.

Future suggestions

i. The available diggers can be tested for root crops like potato, carrot, ginger and garlic.

ii. A detail study can be conducted by taking different blade angle and speed of operation for the three type of digger available in Chhattisgarh region.

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APPENDIX-A

Table A-1: Physical properties of onion bulb

S.N	Polar Diameter (mm)	Equatorial Diameter (mm)	Thickness (mm)	Arithmetic mean diameter	Geometric mean diameter	Sphericity	Shape Index
1	60.50	70.81	40.73	57.35	55.88	0.79	1.13
2	34.80	42.97	33.69	37.15	36.93	0.86	0.91
3	48.68	59.25	36.31	48.08	47.14	0.80	1.05
4	44.08	45.85	36.31	42.08	41.87	0.91	1.08
5	38.65	43.45	31.69	37.93	37.61	0.87	1.04
6	45.98	51.25	37.60	44.94	44.58	0.87	1.05
7	60.12	73.46	46.09	59.89	58.82	0.80	1.03
8	60.97	72.23	48.98	60.73	59.97	0.83	1.03
9	45.31	53.48	38.85	45.88	45.49	0.85	0.99
10	39.74	52.94	39.74	44.14	43.73	0.83	0.87
11	44.60	56.37	38.84	46.60	46.05	0.82	0.95
12	41.84	54.30	37.42	44.52	43.97	0.81	0.93
13	38.65	36.08	29.39	34.71	34.48	0.96	1.19
14	36.97	35.70	28.35	33.67	33.45	0.94	1.16
15	45.64	52.00	34.74	44.13	43.52	0.84	1.07
16	60.29	86.04	49.66	65.33	63.63	0.74	0.92
17	46.37	60.51	43.92	50.27	49.76	0.82	0.90
18	46.37	47.77	34.81	42.98	42.56	0.89	1.14
19	31.32	38.81	23.63	31.25	30.63	0.79	1.03
20	37.16	49.98	28.80	38.65	37.68	0.75	0.98
21	40.56	39.40	27.11	35.69	35.12	0.89	1.24
22	44.21	37.15	35.79	39.05	38.88	1.05	1.21
23	43.85	43.73	38.34	41.97	41.89	0.96	1.07
24	49.93	44.62	38.31	44.29	44.03	0.99	1.21
25	39.65	39.12	27.18	35.32	34.80	0.89	1.22
26	37.70	32.12	33.42	34.41	34.33	1.07	1.15
27	31.22	43.40	27.98	34.20	33.59	0.77	0.90

S.N	Polar Diameter (mm)	Equatorial Diameter (mm)	Thickness (mm)	Arithmetic mean diameter	Geometric mean diameter	Sphericity	Shape Index
28	41.38	48.62	37.89	42.63	42.40	0.87	0.96
29	37.48	55.20	32.15	41.61	40.52	0.73	0.89
30	33.94	51.10	41.05	42.03	41.45	0.81	0.74
31	50.40	63.39	33.18	48.99	47.33	0.75	1.10
32	40.34	45.90	30.30	38.85	38.28	0.83	1.08
33	39.34	42.62	32.28	38.08	37.83	0.89	1.06
34	40.13	49.32	36.48	41.98	41.64	0.84	0.95
35	46.81	46.82	34.30	42.64	42.20	0.90	1.17
36	45.49	49.44	29.92	41.62	40.67	0.82	1.18
37	40.39	43.43	27.91	37.24	36.58	0.84	1.16
38	31.61	34.51	44.76	36.96	36.55	1.06	0.80
39	36.25	41.91	31.05	36.40	36.13	0.86	1.00
40	46.01	52.73	35.55	44.76	44.18	0.84	1.06
41	41.54	48.88	37.19	42.54	42.27	0.86	0.97
42	39.84	45.18	29.81	38.28	37.72	0.83	1.09
43	37.61	43.25	32.80	37.89	37.65	0.87	1.00
44	44.05	50.33	35.52	43.30	42.86	0.85	1.04
45	48.28	47.43	35.30	43.67	43.24	0.91	1.18
46	42.13	55.24	36.09	44.49	43.79	0.79	0.94
47	43.96	42.73	34.29	40.33	40.09	0.94	1.15
48	63.92	54.73	43.65	54.10	53.45	0.98	1.31
49	44.67	68.25	36.65	49.86	48.16	0.71	0.89
50	43.97	49.51	37.77	43.75	43.48	0.88	1.02
51	44.13	47.51	32.63	41.42	40.90	0.86	1.12
52	48.27	60.05	31.38	46.57	44.97	0.75	1.11
53	35.34	45.44	28.20	36.33	35.64	0.78	0.99
54	31.80	39.45	26.20	32.48	32.03	0.81	0.99
55	42.44	54.95	36.73	44.71	44.08	0.80	0.94
56	43.94	38.33	29.70	37.32	36.85	0.96	1.30
57	32.48	32.09	43.91	36.16	35.77	1.11	0.87

S.N	Polar Diameter (mm)	Equatorial Diameter (mm)	Thickness (mm)	Arithmetic mean diameter	Geometric mean diameter	Sphericity	Shape Index
58	42.60	47.39	33.09	41.03	40.58	0.86	1.08
59	42.53	40.66	33.61	38.93	38.74	0.95	1.15
60	42.88	37.80	30.33	37.00	36.63	0.97	1.27
61	47.26	51.06	34.33	44.22	43.59	0.85	1.13
62	34.00	35.23	26.36	31.86	31.61	0.90	1.12
63	32.65	28.75	28.06	29.82	29.75	1.03	1.15
64	28.64	39.40	26.06	31.37	30.87	0.78	0.89
65	34.41	35.01	26.45	31.96	31.70	0.91	1.13
66	34.65	47.60	31.81	38.02	37.44	0.79	0.89
67	36.92	43.67	33.49	38.03	37.80	0.87	0.97
68	46.70	31.13	28.58	35.47	34.64	1.11	1.57
69	37.41	33.72	28.24	33.12	32.90	0.98	1.21
70	30.87	42.33	26.69	33.30	32.67	0.77	0.92
71	39.45	44.36	38.85	40.89	40.81	0.92	0.95
72	42.72	38.12	29.01	36.62	36.15	0.95	1.28
73	77.33	55.65	35.72	56.23	53.57	0.96	1.73
74	43.11	45.46	32.47	40.35	39.92	0.88	1.12
75	35.76	55.29	34.67	41.91	40.93	0.74	0.82
76	44.23	54.08	37.54	45.28	44.78	0.83	0.98
77	32.83	39.06	24.91	32.27	31.73	0.81	1.05
78	29.27	32.26	19.23	26.92	26.28	0.81	1.18
79	31.92	47.56	28.51	36.00	35.11	0.74	0.87
80	37.92	49.80	31.41	39.71	39.00	0.78	0.96
81	36.19	52.70	21.92	36.94	34.71	0.66	1.06
82	30.66	41.36	28.07	33.36	32.90	0.80	0.90
83	36.63	30.32	28.83	31.93	31.75	1.05	1.24
84	34.32	47.64	31.19	37.72	37.08	0.78	0.89
85	37.84	45.50	34.32	39.22	38.95	0.86	0.96
86	29.84	41.03	25.75	32.21	31.59	0.77	0.92
87	30.58	26.21	22.81	26.53	26.34	1.01	1.25

S.N	Polar Diameter (mm)	Equatorial Diameter (mm)	Thickness (mm)	Arithmetic mean diameter	Geometric mean diameter	Sphericity	Shape Index
88	41.73	36.58	29.53	35.95	35.59	0.97	1.27
89	30.51	35.75	24.76	30.34	30.00	0.84	1.03
90	38.69	43.93	28.54	37.05	36.47	0.83	1.09
91	49.30	58.63	38.53	48.82	48.11	0.82	1.04
92	28.19	39.68	28.83	32.23	31.83	0.80	0.83
93	40.90	49.01	36.14	42.02	41.69	0.85	0.97
94	40.93	47.49	38.83	42.42	42.26	0.89	0.95
95	40.40	40.43	30.05	36.96	36.61	0.91	1.16
96	49.65	47.76	33.41	43.61	42.95	0.90	1.24
97	44.05	48.02	32.53	41.53	40.98	0.85	1.11
98	38.45	35.04	43.37	38.95	38.80	1.11	0.99
99	39.66	53.84	33.64	42.38	41.57	0.77	0.93
100	47.59	52.09	33.12	44.27	43.46	0.83	1.15
Mean	41.25	46.60	33.26	40.37	39.80	0.87	1.06
Std Error	0.81	1.01	0.58	0.69	0.67	0.01	0.02
SD	8.10	10.06	5.79	6.94	6.74	0.09	0.15
CV	19.63	21.60	17.40	17.20	16.93	10.57	14.32
Variance	65.57	101.27	33.51	48.19	45.38	0.01	0.02

Table A-2: Physical properties of onion bulb

S.No.	Weight, g	Aspect ratio	Surface area, mm^2	Frontal surface area, mm^2	Cross sectional area, mm^2
1	140.00	0.85	9804.81	3362.94	2581.58
2	26.00	0.81	4283.12	1173.85	1083.59
3	76.00	0.82	6976.53	2264.17	1814.67
4	42.00	0.96	5503.86	1586.54	1390.02
5	34.00	0.89	4442.60	1318.28	1129.37
6	54.00	0.90	6240.65	1849.83	1585.62
7	151.00	0.82	10865.44	3466.89	2815.65
8	141.00	0.84	11293.57	3457.03	2894.87
9	56.00	0.85	6498.01	1902.20	1652.40
10	54.00	0.75	6003.75	1651.51	1529.45
11	69.00	0.79	6658.42	1973.57	1704.92
12	63.00	0.77	6070.99	1783.45	1555.89
13	22.00	1.07	3732.56	1094.68	945.57
14	20.00	1.04	3512.72	1036.07	890.11
15	63.00	0.88	5948.15	1863.02	1528.52
16	217.00	0.70	12712.51	4072.07	3350.39
17	94.00	0.77	7775.84	2202.59	1983.49
18	48.00	0.97	5688.45	1738.85	1450.34
19	19.00	0.81	2944.98	954.19	766.77
20	50.00	0.74	4457.65	1457.95	1172.45
21	27.00	1.03	3873.28	1254.48	999.91
22	24.00	1.19	4747.05	1289.29	1197.05
23	38.00	1.00	5510.58	1505.28	1382.98
24	42.00	1.12	6086.93	1748.88	1539.63
25	17.00	1.01	3803.56	1217.62	979.10
26	34.00	1.17	3701.22	950.58	929.66
27	40.00	0.72	3543.59	1063.63	918.17
28	71.00	0.85	5645.25	1579.34	1426.59

S.No.	Weight, g	Aspect ratio	Surface area, mm^2	Frontal surface area, mm^2	Cross sectional area, mm^2
29	54.00	0.68	5154.77	1624.08	1359.14
30	101.00	0.66	5393.78	1361.45	1386.72
31	32.00	0.80	7033.12	2507.96	1884.02
32	33.00	0.88	4601.76	1453.51	1184.61
33	40.00	0.92	4492.80	1316.19	1138.32
34	45.00	0.81	5444.54	1553.68	1383.20
35	51.00	1.00	5592.93	1720.44	1427.49
36	47.00	0.92	5194.78	1765.49	1359.58
37	31.00	0.93	4202.22	1377.00	1088.85
38	31.00	0.92	4194.72	856.33	1072.34
39	26.00	0.86	4099.41	1192.60	1040.28
40	54.00	0.87	6129.56	1904.49	1572.95
41	49.00	0.85	5609.78	1593.92	1420.35
42	39.00	0.88	4466.99	1412.98	1150.11
43	34.00	0.87	4450.12	1276.91	1126.79
44	48.00	0.88	5768.91	1740.37	1471.79
45	45.00	1.02	5870.29	1797.59	1497.05
46	66.00	0.76	6022.14	1826.90	1553.56
47	36.00	1.03	5045.47	1474.55	1276.60
48	73.00	1.17	8970.72	2746.20	2297.55
49	99.00	0.65	7284.36	2393.25	1951.26
50	50.00	0.89	5937.37	1708.91	1502.54
51	42.00	0.93	5252.35	1645.84	1346.98
52	73.00	0.80	6350.75	2275.41	1702.24
53	34.00	0.78	3989.32	1260.59	1035.91
54	23.00	0.81	3221.91	984.79	828.31
55	65.00	0.77	6101.53	1830.68	1568.97
56	28.00	1.15	4262.85	1322.11	1093.53
57	13.00	1.01	4017.56	818.19	1026.42

S.No.	Weight, g	Aspect ratio	Surface area, mm^2	Frontal surface area, mm^2	Cross sectional area, mm^2
58	49.00	0.90	5169.62	1584.77	1321.30
59	31.00	1.05	4711.41	1357.48	1189.91
60	23.00	1.13	4213.82	1272.38	1074.86
61	57.00	0.93	5967.08	1894.28	1534.76
62	17.00	0.97	3136.81	940.29	796.99
63	12.00	1.14	2779.73	736.87	698.05
64	23.00	0.73	2991.52	885.81	772.34
65	19.00	0.98	3155.96	945.68	801.66
66	42.00	0.73	4400.60	1294.73	1134.73
67	30.00	0.85	4485.76	1265.65	1135.13
68	14.00	1.50	3766.76	1141.21	987.62
69	18.00	1.11	3399.56	990.25	861.27
70	26.00	0.73	3351.86	1025.78	870.30
71	36.00	0.89	5230.57	1373.75	1312.30
72	18.00	1.12	4103.47	1278.36	1052.51
73	61.00	1.39	9010.44	3378.18	2482.32
74	39.00	0.95	5004.83	1538.43	1277.87
75	54.00	0.65	5259.30	1552.08	1378.59
76	67.00	0.82	6296.44	1877.69	1609.71
77	23.00	0.84	3161.17	1006.64	817.29
78	12.00	0.91	2169.24	741.24	568.88
79	35.00	0.67	3870.77	1191.72	1017.17
80	48.00	0.76	4775.73	1482.41	1237.85
81	46.00	0.69	3782.30	1497.16	1070.99
82	27.00	0.74	3397.76	995.46	873.79
83	17.00	1.21	3166.19	871.84	800.16
84	38.00	0.72	4318.03	1283.48	1116.70
85	25.00	0.83	4763.61	1351.55	1207.49

S.No.	Weight, g	Aspect ratio	Surface area, mm^2	Frontal surface area, mm^2	Cross sectional area, mm^2
86	8.00	0.73	3133.63	961.10	814.26
87	24.00	1.17	2179.13	629.18	552.65
88	19.00	1.14	3977.10	1198.29	1014.35
89	34.00	0.85	2826.46	856.23	722.60
90	73.00	0.88	4176.43	1334.23	1077.77
91	73.00	0.84	7268.42	2269.01	1870.96
92	15.00	0.71	3181.29	878.08	815.61
93	51.00	0.83	5456.66	1573.54	1385.84
94	50.00	0.86	5607.95	1525.86	1412.35
95	33.00	1.00	4209.36	1282.20	1072.34
96	51.00	1.04	5792.10	1861.46	1492.71
97	45.00	0.92	5272.68	1660.50	1354.14
98	28.00	1.10	4728.20	1057.62	1191.13
99	59.00	0.74	5425.90	1676.21	1409.91
100	58.00	0.91	5931.57	1945.99	1538.24
Mean	46.22	0.90	5114.90	1550.26	1316.74
Std. Error	3.14	0.02	182.88	62.15	48.10
SD	31.39	0.16	1828.82	621.47	480.99
CV	67.92	17.74	35.75	40.09	36.53
Variance	985.55	0.03	3344592.50	386221.56	231348.15

APPENDIX-B

Table B-1: Moisture content of soil

Observations	Weight of container, g	Weight of container + sample, g	Weight of container + dried soil, g	Moisture Content, % (db)
1	26.4	220.43	199.58	12.04
2	26.6	219.66	200.74	10.86
3	26.3	225.62	201.87	13.53
4	27	227.70	202.74	14.20
5	26.8	214.72	198.64	9.36
Mean	26.62	221.62	200.71	11.999
Std. Error				0.197
SD				1.966
CV				16.380
Variance				3.863

Table B-2: Bulk density of soil

Observations	Weight of sample before drying, g	Weight of sample after drying, g	Volume of core cutter, cm^3	Bulk Density, $g\ cm^{-3}$
1	1651	1448	1021	1.42
2	1710	1504	1021	1.47
3	1680	1468	1021	1.44
4	1704	1508	1021	1.48
5	1680	1460	1021	1.43
Mean	1685	1477	1021	1.447
Std. Error				0.003
SD				0.026
CV				1.822
Variance				0.001

APPENDIX-C

Table C-1: Effect of speed and type of digger on damage percentage

Machine	Speed of operation (km h^{-1})	Treatment	R1	R2	R3	R4	Damage percentage (Mean)
1	2.5	M1S1	7.84	7.36	6.54	6.96	7.18
	3.0	M1S2	8.06	8.46	7.68	8.98	8.30
	3.5	M1S3	9.34	9.48	9.72	8.86	9.35
2	2.5	M2S1	1.82	1.92	2.02	2.40	2.04
	3.0	M2S2	2.04	1.98	1.92	2.68	2.16
	3.5	M2S3	3.10	2.98	2.95	3.20	3.06
3	2.5	M3S1	15.54	16.27	14.28	15.98	15.52
	3.0	M3S2	17.56	18.78	17.94	19.26	18.39
	3.5	M3S3	20.24	19.78	21.56	22.67	21.06

Table C-2: ANOVA table for effect of type of digger and operating speed on damage percentage

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	2.446		
Factor (Digger)	2	1,867.77	933.882	2,933.55
Factor (Operating speed)	2	46.165	23.082	72.507
Interaction (Digger× Operating speed)	4	24.925	6.231	19.574
Error	24	7.64	0.318	
Total	35	1,948.94		

Table C-3: Effect of speed and type of digger on exposure percentage

Machine	Speed of operation (km h^{-1})	Treatment	R1	R2	R3	R4	Exposure Percentage (Mean)
1	2.5	M1S1	60.78	61.05	62.24	61.74	61.45
	3.0	M1S2	62.48	62.56	63.47	63.15	62.92
	3.5	M1S3	64.87	64.54	65.24	64.96	64.90
2	2.5	M2S1	72.48	71.08	72.15	72.62	72.08
	3.0	M2S2	74.88	73.24	74.16	74.94	74.31
	3.5	M2S3	76.82	75.48	76.14	76.84	76.32
3	2.5	M3S1	63.74	65.21	64.80	64.94	64.67
	3.0	M3S2	65.48	65.74	65.76	66.47	65.86
	3.5	M3S3	66.84	66.86	67.42	67.22	67.09

Table C-4: ANOVA table for effect of type of digger and operating speed on exposure percentage

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	3.329		
Factor (Digger)	2	807.606	403.803	1,745.65
Factor (Operating speed)	2	68.017	34.009	147.02
Interaction(Digger × Operating speed)	4	3.561	0.89	3.848
Error	24	5.552	0.231	
Total	35	888.065		

Table C-5: Effect of speed and type of digger on separation index

Machine	Speed of operation (km h^{-1})	Treatment	R1	R2	R3	R4	Separation index (Mean)
	2.5	M1S1	72.46	71.94	71.89	71.54	71.96
1	3.0	M1S2	75.50	74.60	74.60	73.50	74.55
	3.5	M1S3	67.92	70.25	68.45	69.06	68.92
	2.5	M2S1	76.24	77.36	77.82	76.98	77.10
2	3.0	M2S2	75.97	76.25	76.98	74.68	75.97
	3.5	M2S3	73.98	74.87	74.08	74.46	74.35
	2.5	M3S1	58.44	58.94	57.14	57.64	58.04
3	3.0	M3S2	56.00	58.50	54.74	56.72	56.49
	3.5	M3S3	53.16	54.65	53.40	55.42	54.16

Table C-6: ANOVA table for effect of type of digger and operating speed on separation index

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	5.193		
Factor (Digger)	2	2,567.95	1,283.97	1,751.83
Factor (Operating speed)	2	82.533	41.266	56.303
Interaction (Digger× Operating speed)	4	26.857	6.714	9.161
Error	24	17.59	0.733	
Total	35	2,700.12		

Table C-7: Effect of speed and type of digger on digging efficiency

Machine	Speed of operation ($km\ h^{-1}$)	Treatment	R1	R2	R3	R4	Digging efficiency (Mean)
1	2.5	M1S1	92.12	91.26	91.56	90.78	91.43
	3.0	M1S2	91.24	90.24	91.86	90.54	90.97
	3.5	M1S3	90.58	89.82	89.44	90.14	90.00
2	2.5	M2S1	93.74	94.48	93.6	92.65	93.62
	3.0	M2S2	93.44	93.24	93.82	93.32	93.46
	3.5	M2S3	92.92	92.48	92.84	92.16	92.60
3	2.5	M3S1	80.24	79.28	79.86	80.56	79.99
	3.0	M3S2	75.96	78.24	76.34	76.98	76.88
	3.5	M3S3	73.24	72.92	71.65	72.46	72.57

Table C-8: ANOVA table for effect of type of digger and operating speed on digging efficiency

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	0.938		
Factor (Digger)	2	1,965.73	982.865	2,384.69
Factor (Operating speed)	2	66.283	33.141	80.41
Interaction (Digger× Operating speed)	4	51.408	12.852	31.182
Error	24	9.892	0.412	
Total	35	2,094.25		

APPENDIX-D

Table D-1: Effect of speed and blade angle of vibro onion digger on damage percentage

Speed of operation (km h^{-1})	Blade Angle (°)	R1	R2	R3	Damage percentage (Mean)
2.5	15	4.22	3.97	4.47	4.22
	20	2.37	2.79	2.58	2.58
	25	4.26	3.70	3.98	3.98
3.0	15	3.18	3.46	3.74	3.46
	20	2.12	1.98	1.84	1.98
	25	3.87	3.65	3.43	3.65
3.5	15	3.96	4.16	3.76	3.96
	20	3.16	2.98	2.80	2.98
	25	5.49	5.27	5.71	5.49

Table D-2: ANOVA table for effect of different speed of operation and blade angle on damage percentage

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F tab at 5%
Replication	2	0.02			
Factor (Operating speed)	2	5.57	2.78	201.28	19.25
Error (Operating speed)	4	0.05	0.01		
Factor (Blade angle)	2	16.71	8.35	121.68	19.41
Interaction (Operating speed × Blade angle)	4	2.61	0.65	9.50	5.91
Error (Blade angle)	12	0.82	0.06		
Total	26	25.80			

Table D-3: Effect of speed and blade angle of vibro onion digger on exposure percentage

Speed of operation (km h^{-1})	Blade Angle (°)	R1	R2	R3	Damage percentage (Mean)
	15	94.23	93.48	93.86	93.86
2.5	20	93.84	94.54	94.68	94.35
	25	95.78	95.47	95.08	95.44
	15	95.78	95.46	96.26	95.83
3.0	20	96.46	96.78	96.8	96.68
	25	97.04	97.16	97.48	97.23
	15	94.78	95.24	95.36	95.13
3.5	20	96.02	95.78	95.96	95.92
	25	96.08	96.66	95.88	96.21

Table D-4: ANOVA table for effect of different speed of operation and blade angle on exposure percentage

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F tab at 5%
Replication	2	0.11			
Factor (Operating speed)	2	18.70	9.35	106.90	19.25
Error (Operating speed)	4	0.35	0.08		
Factor (Blade angle)	2	8.24	4.12	32.43	19.41
Interaction (Operating speed × Blade angle)	4	0.55	0.13	1.08	5.91
Error (Blade angle)	12	1.52	0.12		
Total	26	29.49			

Table D-5: Effect of speed and blade angle of vibro onion digger on separation index

Speed of operation (km h^{-1})	Blade Angle (°)	R1	R2	R3	Damage percentage (Mean)
2.5	15	55.47	55.74	54.96	55.39
	20	54.56	54.68	54.08	54.44
	25	53.25	53.78	53.86	53.63
3.0	15	57.48	58.26	57.88	57.87
	20	57.44	57.89	57.82	57.72
	25	55.48	55.78	55.82	55.69
3.5	15	53.78	54.84	54.46	54.36
	20	52.88	52.74	52.94	52.85
	25	51.78	52.24	52.38	52.13

Table D-6: ANOVA table for effect of different speed of operation and blade angle on separation index

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Tab. F at 5%
Replication	2	0.82			
Factor (Operating speed)	2	73.54	36.77	481.85	19.25
Error (Operating speed)	4	0.31	0.08		
Factor (Blade angle)	2	19.17	9.59	128.79	19.41
Interaction (Operating speed × Blade angle)	4	2.11	0.53	7.07	5.91
Error (Blade angle)	12	0.89	0.07		
Total	26	96.84			

Table D-7: Effect of speed and blade angle of vibro onion digger on digging efficiency

Speed of operation (km h^{-1})	Blade Angle (°)	R1	R2	R3	Damage percentage (Mean)
2.5	15	90.63	90.78	90.88	90.76
	20	92.48	93.46	93.76	93.23
	25	92.74	92.82	92.84	92.80
3.0	15	92.16	92.36	92.48	92.33
	20	94.86	94.8	94.78	94.81
	25	93.42	93.44	93.56	93.47
3.5	15	92.08	92.46	91.88	92.14
	20	93.84	93.68	92.98	93.50
	25	91.87	90.78	92.02	91.56

Table 4.19. ANOVA table for effect of different speed of operation and blade angle on digging efficiency

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Tab. F at 5%
Replication	2	0.07			
Factor (Operating speed)	2	8.776	4.388	25.649	19.25
Error (Operating speed)	4	0.684	0.171		
Factor (Blade angle)	2	20.062	10.031	65.548	19.41
Interaction (Operating speed × Blade angle)	4	5.581	1.395	9.118	5.91
Error (Blade angle)	12	1.836	0.153		
Total	26	36.928			

APPENDIX-E

Economic Analysis

Following assumption was made for economic analysis of onion digger:

a. Capital cost of Tractor = ₹ 650000/-
b. Capital cost of onion digger (M1) = ₹ 98000/-
c. Capital cost of vibro onion digger(M2) =₹ 92000/-
d. Capital cost of duck foot type onion digger(M3) =₹ 42000/-
e. Expected life of tractor = 10 years
f. Expected life of onion digger = 6 years
g. Working hour (h) = 1000 h y-1, when working hour is 8 h/day
h. Working hour (h) = 250 h y-1, when working hour is 8 h/day
i. Salvage value (S) = 10% of initial cost
j. Rate of interest = 10% per annum
k. Labour required =01 (Tractor operator) , 01 (Manual collection)
l. Diesel cost = ₹ 102 l^{-1}
m. Repair and maintenance = 12% of initial cost
n. Shelter, insurance and tax cost = 2% of initial cost

Cost analysis of onion digger:

Fixed cost

Depreciation

$$D = \frac{C - S}{L \times H}$$

Where,

D = Depreciation per hour

C = Purchase price, Rs = 98000

S = Salvage value, Rs. (Which is 10% of purchase price)

L = Life of machine, year

H = no of operating hours per year

$$D = \frac{98000 - 9800}{6 \times 250}$$

$$D = ₹\,58.80\ h^{-1}$$

Interest on investment

$$I = \frac{C + S}{2} \times \frac{i}{H}$$

Where,

i = % rate of interest per year = 10% per year

$$I = \frac{98000 + 9800}{2} \times \frac{0.10}{250}$$

$$I = ₹\,21.56\ h^{-1}$$

Shelter Taxes and Housing

Assume 2% of purchase price of machine

$$SC = \frac{98000 \times 0.02}{250} = ₹\,7.84\ h^{-1}$$

Total fixed cost,

FC = Depreciation + Interest + Shelter, Taxes and Housings

$$FC = 58.80 + 25.87 + 7.84 = ₹\,88.20\ h^{-1}$$

Variable cost

Repair and maintenance

The repair and maintenance cost is taken 12 % of initial purchase price.

Repair and maintenance cost (Rs/h) = $\frac{C \times m}{H}$

= repair and maintenance rate 12 % of initial cost

$$= \frac{98000 \times 0.12}{250} = ₹\,47.04\ h^{-1}$$

Wages and labour charge

Wages are calculated using the worker's real wages.

Labour charges = 350 Rs/day

For 8 h = 43.75 Rs/h

Labour required = 1

$= ₹\,43.75\ \mathrm{h}^{-1}$

Total variable cost,

VC = Repairs and maintenance + Wages and labour charges

$= 47.04 + 43.75\ = ₹\,90.79\ \mathrm{h}^{-1}$

Total cost of operation

The total cost of operation of the planter is the sum of its total fixed and variable costs.

Total cost of operation, TC = Fixed cost + Variable cost

$$= 88.20 + 90.79 = ₹\,164.29\ \mathrm{h}^{-1}$$

Breakeven point:

The breakeven point was calculated by following formula (Sharma and Mukesh 2008).

$$\mathrm{BEP} = \frac{\mathrm{FC}}{\mathrm{CH} - \mathrm{C}}$$

Where,

BEP = Breakeven point, h y^{-1};

FC = Annual fixed cost, ₹ y^{-1};

C = Operating cost, ₹ h^{-1}, and

CH = Custom hiring charges, ₹ h^{-1}.

= (C + 20 per cent over head) + 20 per cent profit over new cost

$$\mathrm{BEP} = \frac{22050.00}{130.73 - 90.79} = \ 551.97\ \mathrm{h\ year}^{-1}$$

Payback period

Payback period was determined for developed onion digger by using Equation 3.71 to know the time required to get back the investing, (Reddy *et al.*, 2003).

$$\mathrm{PBP} = \frac{\mathrm{IC}}{\mathrm{ANP}}$$

Where,

PBP= Payback period, year;

IC = Initial cost of machine, ₹; and

ANP = Average net annual profit, ₹ y^{-1}.

$$\mathrm{PBP} = \frac{98000}{9986.9} = 9.81 \text{ year}$$

$$\mathrm{ANP} = (\mathrm{CH} - \mathrm{C}) \times \mathrm{AU} = 39.95 \times 250 = ₹\, 9986.9 \text{ year}^{-1}$$

Cost analysis of vibro onion Digger:

Fixed cost

Depreciation

$$\mathrm{D} = \frac{\mathrm{C} - \mathrm{S}}{\mathrm{L} \times \mathrm{H}}$$

Where,

D = Depreciation per hour

C = Purchase price, Rs = 92000

S = Salvage value, Rs. (Which is 10% of purchase price)

L = Life of machine, year

H = no of operating hours per year

$$\mathrm{D} = \frac{92000 - 9200}{6 \times 250}$$

$$\mathrm{D} = ₹\, 55.20\ \mathrm{h}^{-1}$$

Interest on investment

$$I = \frac{C+S}{2} \times \frac{i}{H}$$

Where,

i = % rate of interest per year = 10 % per year

$$I = \frac{92000 + 9200}{2} \times \frac{0.10}{250}$$

$$I = ₹\,20.24\ \ h^{-1}$$

Shelter Taxes and Housing

Assume 2% of purchase price of machine

$$SC = \frac{92000 \times 0.02}{250} = ₹\,7.36\ h^{-1}$$

Total fixed cost,

FC = Depreciation + Interest + Insurance + Shelter,Taxes and Housings

$FC = 55.20 + 20.24 + 7.36 = ₹\,82.80\ \ h^{-1}$

Variable cost

Repair and maintenance

The repair and maintenance cost is taken 12 % of initial purchase price.

$$\text{Repair and maintenance cost}\ \left(\frac{Rs}{h}\right) = \frac{C \times m}{H}$$

= repair and maintenance rate 10 % of initial cost

$= \frac{92000 \times 0.12}{250}$

= $₹\,44.16\ \ h^{-1}$

Wages and labour charge

Wages are calculated using the worker's real wages.

Labour charges = 350 Rs/day

For 8 h = 43.75 Rs/h

Labour required = 1

= ₹ 43.75 h^{-1}

Total variable cost

VC = Repairs and maintenance + Wages and labour charges

= 44.14+87.5

= ₹ 87.91 h^{-1}

Total cost of operation

The total cost of operation of the planter is the sum of its total fixed and variable costs.

Total cost of operation, TC = Fixed cost + Variable cost

$= 82.80 + 87.91 =$ ₹ 170.71 h^{-1}

Breakeven point:

The breakeven point was calculated by following formula (Sharma and Mukesh 2008).

$$BEP = \frac{FC}{CH - C}$$

Where,

BEP = Breakeven point, h y^{-1};

FC = Annual fixed cost, ₹ y^{-1};

C = Operating cost, ₹ h^{-1}, and

CH = Custom hiring charges, ₹ h^{-1}.

= (C + 20 per cent over head) + 20 per cent profit over new cost

$$BEP = \frac{20700}{126.59 - 87.91} = 535.15 \text{ h year}^{-1}$$

Payback period

Payback period was determined for developed onion digger by using Equation 3.71 to know the time required to get back the investing, (Reddy *et al.*, 2003).

$$\mathrm{PBP} = \frac{\mathrm{IC}}{\mathrm{ANP}}$$

Where,

PBP= Payback period, year;

IC = Initial cost of machine, ₹; and

ANP = Average net annual profit, ₹ y^{-1}.

$$\mathrm{PBP} = \frac{92000}{9670.1} = 9.51 \text{ year}$$

$ANP = (CH - C) \times AU$

ANP =38.68× 250 = ₹ 9671.1 year^{-1}

Cost analysis of duck foot type onion digger:

Fixed cost

Depreciation

$$\mathrm{D} = \frac{\mathrm{C} - \mathrm{S}}{\mathrm{L} \times \mathrm{H}}$$

Where,

D = Depreciation per hour

C = Purchase price, Rs = 42000.00

S = Salvage value, Rs. (Which is 10% of purchase price)

L = Life of machine, year

H = no of operating hours per year

$$\mathrm{D} = \frac{42000 - 4200}{6 \times 250}$$

$$\mathrm{D} = ₹\ 25.20\ \mathrm{h}^{-1}$$

Interest on investment

$$I = \frac{C + S}{2} \times \frac{i}{H}$$

Where,

i = % rate of interest per year = 10 % per year

$$I = \frac{42000 + 4200}{2} \times \frac{0.10}{250} = ₹\, 9.24\ h^{-1}$$

Shelter Taxes and Housing

Assume 2% of purchase price of machine

$= \frac{42000 \times 0.02}{250} = ₹\, 3.36\ h^{-1}$

Total fixed cost

FC = Depreciation + Interest + Shelter, Taxes and Housings

= 18.90+9.24+3.36

= ₹ 37.80 h^{-1}

Variable cost

Repair and maintenance

The repair and maintenance cost is taken 12 % of initial purchase price.

Repair and maintenance cost (Rs/h) = $\frac{C \times m}{H}$

= repair and maintenance rate 10 % of initial cost

$= \frac{42000 \times 0.12}{250} = ₹\, 20.16\ h^{-1}$

Wages and labour charge

Wages are calculated using the worker's real wages.

Labour charges = 350 Rs/day

For 8 h = 43.75 Rs/h

Labour required = 1

= ₹ 43.75 h^{-1}

Total variable cost,

VC = Repairs and maintenance + Wages and labour charges

= 20.16 +87.5= ₹ 63.91 h^{-1}

Total cost of operation

The total cost of operation of the planter is the sum of its total fixed and variable costs.

Total cost of operation, TC = Fixed cost + Variable cost

= 31.50+63.91=₹ 101.71 h^{-1}

Breakeven point:

The breakeven point was calculated by following formula (Sharma and Mukesh 2008).

$$\mathrm{BEP} = \frac{\mathrm{FC}}{\mathrm{CH} - \mathrm{C}}$$

Where,

BEP = Breakeven point, h y^{-1};

FC = Annual fixed cost, ₹ y^{-1};

C = Operating cost, ₹ h^{-1}, and

CH = Custom hiring charges, ₹ h^{-1}.

= (C + 20 per cent over head) + 20 per cent profit over new cost

$$\mathrm{BEP} = \frac{9450}{92.03 - 63.91} = 336.05 \text{ h year}^{-1}$$

Payback period

Payback period was determined for developed onion digger by using Equation 3.71 to know the time required to get back the investing, (Reddy *et al.*, 2003).

$$\mathrm{PBP} = \frac{\mathrm{IC}}{\mathrm{ANP}}$$

Where,

PBP= Payback period, year;

IC = Initial cost of machine, ₹; and

ANP = Average net annual profit, ₹ y^{-1}.

$$\text{PBP} = \frac{42000}{7030.1} = 5.97 \text{ year}$$

ANP =28.12 × 250 = ₹ 7030.1 year^{-1}

RESUME

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