DESIGN AND DEVELOPMENT OF A TRACTOR OPERATED RAISED BED ONION BULB PLANTER

Ph.D. (Agril. Engg.) Thesis

By

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DESIGN AND DEVELOPMENT OF A TRACTOR OPERATED RAISED BED ONION BULB PLANTER

Thesis

Submitted to the
Indira Gandhi Krishi Vishwavidyalaya, Raipur

By

BHOOKYA DEVOJEE

IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
Doctor of Philosophy

In

Agricultural Engineering

(Farm Machinery and Power Engineering)

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CERTIFICATE- I

This is to certify that the thesis entitled **"Design and development of a tractor operated raised bed onion bulb planter"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agricultural Engineering** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Bhookya Devojee** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or has been published/published part has been fully acknowledged. All the assistance and help received during the course of investigations have been duly acknowledged by him/her.

Co-Chairman — Date: 7/11/2020

Chairman — Date: 7/11/2020

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Member	(Dr. R. R. Saxena)	07.11.2020

CERTIFICATE- II

This is to certify that the thesis entitled **"Design and development of a tractor operated raised bed onion bulb planter"** submitted by **Bhookya Devojee** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agricultural Engineering** in the Department of **Farm Machinery and Power Engineering** has been approved by the external examiner and Student's Advisory Committee after oral examination, under the chairmanship of Head of the Department/Dean (in case of out campii).

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Approved/ Not Approved

Director of Instructions __________

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Place: IGKV, Raipur

B. Devoji

(Bhookya Devojee)

Date: 7/11/2020

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Symbol	Abbreviation
AOAC	Association of Official Agricultural Chemists
ANOVA	Analysis of Variance
APMC	Agricultural Producing Market Company
B.C.	Before Christ
BIS	Bureau of Indian Standard
Cor	Correlation
CIAE	Central Institute of Agricultural Engineering
CV	Coefficient of Variance
CD	Critical Difference
CRD	Completely Randomized Design
CO	Coimbatore
cm	Centimeter
˚C	Degree Celsius
DAP	Days after Planting
DGCIS	Directorate General of Commercial Intelligence and Statistics
df	Degree of freedom
d.b.	Dry basis
FAO	Food and Agriculture organization
et al.	and others
e.g.	For example
g/cm^3	gram per cubic centimeter
GDP	Gross domestic product
g	Grams
ha	Hectare
h/yr	Hour per year
hp	Horse power
ha/day	Hectare per day
ha/man/day	Hectare per man per day
ha/h	Hectare per hour
i.e.	That is to say; in other words
ICAR	Indian Council of Agricultural Research
IGKV	Indira Gandhi Krishi Vishwavidyalaya
IIHR	Indian Institute of Horticultural Research
IS	Indian Standards
ISO	International Standard Organization
INR	Indian rupees
km/h	kilometer per hour
$kg\ h^{-1}$	kilogram per hour
$kg\ ha^{-1}$	kilogram per hectare
kg/m^3	kilogram per cubic meter

Symbol	Abbreviation
kW	kilowatt
kN	kilonewton
l/h	Liter per hour
MT	Million tons
man-hr/ha	Man hour per hectare
m/min	Meter per minute
m/s	Meter per second
m. c	Moisture content
Mg	Million gram
MJ	Mega Joule
MPa	Mega Pascal
MS	Mild steel
MS	Mean squares
mm	Millimeter
N	Newton
N/mm^2	Newton per square millimeter
ON 5	Onion 5
PROB	Probability
q/ha	Quintal per hectare
rpm	revolution per minute
RBD	Randomized block design
RH	Relative humidity
□ h^{-1}	Rupees per hour
RNAM	Regional Network of Agricultural Machinery
SD	Standard deviation
SS	Stainless steel
SS	Sum of squares
$SE_{(m)}$	Mean standard error
t hr^{-1}	Tonne per hour
t/ha	tonne per hectare
USA	United States of America
WHO	World health organization
w.b	Wet basis
viz.,	Namely
yr.	year
%	Per cent
**	Significant at 1 % level
*	Significant at 5 % level
<	Less than
>	Greater than
Ø	Diameter

THESIS ABSTRACT

a)	Title of the Thesis	Design and development of a tractor operated raised bed onion bulb planter
b)	Full Name of the Student	Bhookya Devojee
c)	Major Subject	Farm Machinery and Power Engineering
d)	Name and Address of the Major Advisor/	Dr. A. Carolin Rathinakumari Principal Scientist (FMPE) Division of Post-Harvest Technology and Agricultural Engineering, ICAR-Indian Institute of Horticultural Research, Bangalore
	Co Major Advisor	Dr. A. K. Dave Professor and Head Department of Farm Machinery and Power Engineering IGKV, Raipur
e)	Degree to be Awarded	Doctor of Philosophy (Agricultural Engineering)

B.Devojee

Signature of the student

Signature of Major/Co Major Advisor

Signature of Head of the Department

Date: 28/12/2020

ABSTRACT

India has witnessed increase in horticulture production over the last few years. Horticulture has been considered as one of the potential agriculture-based enterprise in accelerating the growth of countries economy. One of the most important variables that decides the successful operations of a farming system is the availability of farm labour and its use. As the labour availability in rural area is diminishing, sustaining as well as increasing the productivity

requires the use of suitable machinery. Compared to any other vegetable crop, onion is planted with very close spacing. Due to this, the labour requirement for planting is high, also labourers demand higher wages for onion planting. This leads to higher cost of cultivation. Hence it was felt necessary to design and develop a suitable raised bed onion planter. To complete the task studies were conducted. The onion bulbs were divided into nine categories and the physical and mechanical properties of onion bulbs required for designing onion planter were determined by using standard procedure. Experiments were conducted to observe the effect of different planting orientations of onion bulbs on growth parameters. Experiments were conducted with four sizes of onion (grade I (2-3 g weight), grade II (3-4 g weight), grade III (4-5 g weight) and grade IV (5-6 g weight)); four cup sizes (C1-35 mm, C2-31 mm, C3-29 mm and C4-25 mm); three levels of angle of inclination (60º, 75º and 90º) and four levels peripheral speed of metering unit (0.5, 1.0, 1.5 and 2 kmph.) on the developed experimental setup of laboratory to optimize the design parameters. The observations on per cent singles; per cent doubles; per cent multiples; per cent missings and per cent bulb damage were recorded. All observations were statistically analyzed and a prototype based on optimized parameters were design, developed and evaluated.

Effect of size of onion was significant in all the selected physical and mechanical properties except true density and moisture content. The length, width and thickness ranged from 21.21±2.60 to 32.31±3.30, 13.54±1.77 to 30.95±2.91 and 10.91±1.40 to 22.63±2.15 mm. The geometric mean diameter of onion bulb ranged from 14.54±0.96 to 28.22±2.04 mm. The sphericity of onion bulb ranged from 0.69±0.08 to 0.87±0.06. The shape index for grades <2 g, 2-3 g and 3-4 g were found to be 1.78±0.32, 1.711±0.25, 1.59±0.25 respectively, > 1.5 and for the remaining grades i.e. 4-5 g to > 9 g the shape index values were found to be < 1.5. The projected area of onion bulb ranged from 1.55±0.30 to 5.5±0.51 cm^2. The one hundred weight of onion bulb ranged from 121.6±6.30 to 1185±19.59 g. The bulk density of onion bulb ranged from 480.19±13.13 (< 2 g) to 1086±205.22 (> 9 g) kg m^{-3}. The maximum true density of onion bulb was 1086±205.22 kg m^{-3} obtained in > 9 g, while minimum true density of onion bulb was 950.70±257.92 kg m^{-3} in < 2-3 g. The average moisture content of onion bulb was found to be 80.02 ±0.43 %. The angle of repose ranged from 20.71±1.92 to 40.61±3.68º. The coefficient of friction was determined for onion bulbs on different surfaces such as, mild steel, ply wood and galvanized iron. The coefficient of friction for mild steel, ply wood, and galvanized iron ranged 0.628±0.03 to 0.456±0.016, 0.236±0.03 to 0.174±0.016 and 0.344±0.01 to 0.310±0.017

respectively. The individual observations of kharif, rabi and pooled data analysis of effect of planting orientation suggests that root portion down planting gave highest germination, plant height and yield of onion followed by root portion inclined and horizontal.

In the laboratory with (2-3 g) of onion size with four cups, the maximum per cent singles (79.09 %) were recorded whereas the minimum values of per cent doubles (4.90 %), per cent multiples (2.26 %), per cent missings (1.76 %) and per cent bulb damage (0.00 %) were found. Similar trends were also observed for (3-4g), (4-5) and (5-6g) onion size. However, amongst the four cup, the values of per cent singles were maximum (81.03 %) with cup 4 at 1 kmph speed and 90 degree angle of inclination and values of per cent doubles (8.67 %), multiples (5.36 %), missings (4.94 %) and bulb damage (2 %) were minimum. So, the cup size 25 mm, speed of travel 1 kmph and angle of inclination as 90 degree was optimized for metering mechanism. On the basis of optimized parameters, the bulb planter was designed and fabricated successfully.

Under the field trials, the performance parameters were found to 71.84 ± 1.14 per cent singles, 8.94 ± 0.63 per cent doubles, 11.48 ± 0.42 per cent multiples 7.70 ± 0.24 per cent missings and 1 ± 0.138 per cent bulb damage. Performance indices in terms of miss index, multiple index, quality feed index, precision, mean and standard deviation were found to be 0.076±0.002, 0.114±0.004,0.808±0.002, 0.14±0.005, 10.63±0.144 and 0.49±0.05, respectively. The raised bed onion bulb planter performance parameters in terms of theoretical field capacity, effective field capacity, field efficiency, fuel consumption, depth of planting, row to row spacing and plant to plant spacing 0.15 ha/h, 0.122 ±0.002 ha h^{-1}, 81.7±0.146 %, 3.17±0.035 l h^{-1}, 4.112 ±0.134 cm, 15.00±0.053 cm and 10.44±0.084 cm. The cost of prototype and cost of operation was Rs.49, 300/- and Rs. 4, 211.91/ ha, respectively. The cost saved over manual planting was about 58 per cent. The precision value of developed planter was observed 14 per cent, hence the machine falls under the category of good performance.

शोध सारांश

अ) शोध शीर्षक	–	"ट्रेक्टर चलित रेजड बेड प्याज बल्ब प्लांटर का डिजाइन और विकास"
ब) छात्र का नाम	–	भूक्या देवोजी
स) मुख्य विषय	–	कृषि यंत्र एवं शक्ति अभियांत्रिकी
द) प्रमुख सलाहकार का नाम और पता	–	डॉ ए कैरोलिन रथिनकुमारी प्रधान वैज्ञानिक, कृषि यंत्र एवं शक्ति पोस्ट हार्वेस्ट प्रौद्योगिकी और कृषि इंजीनियरिंग विभाग, आईसीएआर–इंडियन इंस्टीट्यूट ऑफ हॉर्टिकल्चर रिसर्च, बैंगलोर
सह प्रमुख सलाहकार		डॉ. ए. के. दवे, प्राध्यापक एवं विभागाध्यक्ष, फार्म मशीनरी एवं शक्ति अभियांत्रिकी विभाग, इंदिरा गांधी कृषि विश्वविद्यालय, रायपुर
इ) सम्मानित उपाधि		कृषि अभियांत्रिकीय में डॉक्टर ऑफ फिलॉसफी

B Devoji

छात्र का हस्ताक्षर

प्रमुख/सह प्रमुख सलाहकार के हस्ताक्षर

दिनांक : 28/12/2020

विभागाध्यक्ष के हस्ताक्षर

सारांश

भारत ने पिछले कुछ वर्षों में बागवानी उत्पादन में वृद्धि देखी है। बागवानी को देश की अर्थव्यवस्था के विकास में तेजी लाने वाले संभावित कृषि आधारित उद्यम के रूप में माना जाता है। कृषि प्रणाली के सफल संचालन का निर्णय लेने वाले सबसे महत्वपूर्ण कारकों में कृषि प्रक्षेत्र में उपलब्ध मानव श्रम एवं उनके उपयोग को माना जाता है। जैसे–जैसे ग्रामीण क्षेत्र में

श्रम की उपलब्धता कम हो रही है, वैसे–वैसे उत्पादकता बढ़ाने के लिए उपयुक्त म ीनरी के उपयोग की आव यकता है। किसी भी अन्य सब्जी की फसल की तुलना में, प्याज को बहुत पास–पास में लगाया जाता है। जिसके कारण अधिक श्रम की आव यकता होती है, साथ ही साथ मजदूर प्याज रोपण के लिए उच्च मजदूरी की मांग करते है। इससे खेती की लागत अधिक होती है। इसलिए एक उपयुक्त रेजड़ बेड प्याज प्लांटर को डिजाइन एवं विकसित करना को आव यक समझ कर कार्य पूरा करने के लिए अध्ययन किया गया। प्याज के बल्बों को नौ श्रेणियों में विभाजित किया गया था और प्याज के बोने की विधि के यंत्र के लिए आव यक प्याज के बल्बों के भौतिक और यांत्रिक गुणों को मानक प्रक्रिया का उपयोग करके प्राप्त किया गया था। विकास मापदंडों पर प्याज बल्बों के विभिन्न रोपण झुकाव के प्रभाव का निरिक्षण करने के लिए प्याज के चार आकर (ग्रेड I (2–3 ग्राम वजन), ग्रेड II (3–4 ग्राम वजन), ग्रेड III (4–5 ग्राम वजन) और ग्रेड IV (5–6 ग्राम वजन) के साथ प्रयोग किए गए। चार कप आकार सी 1 (34 मिमी), सी 2 (31 मिमी), सी 3 (29 मिमी), सी 4 (25 मिमी), झुकाव के कोण के तीन स्तर A1 (60°), A2 (75°) और A3 (90°) और चार चालन गति S1 (0.5), S2 (1.0), S3 (1.5) और S4 (2 किमी प्रति घंटे) के साथ मीटरिंग इकाई के डिजाईन मापदंडों को अनुकूलित करने के लिए प्रयोग ाला में विकसित प्रयोगात्मक सेटअप पर अध्ययन किया गया। अध्ययन के परिणाम एकल, दोगुना, मिसिंग, बहुसंख्य एवं बल्ब क्षति प्रति ात पर दर्ज किए गए। सभी परिणामों का सांख्यिकीय वि लेशण किया गया था और अनुकूलित मापदंडों के आधार पर एक प्रोटोटाइप को डिजाइन और विकसित कर मूल्यांकन किया गया।

प्याज का आकार सही घनत्व और नमी को छोड़कर सभी चयनित भौतिक और यांत्रिक गुणों में महत्वपूर्ण थी। लंबाई, चौड़ाई और मोटाई 21.21±2.60 से 32.31±3.30, 13.54±1.77 से 30.95±2.91 और 10.91±1.40 से 22.63±2.15 मिमी तक थी। प्याज के बल्ब का ज्यामितीय

माध्य व्यास 14.54±0.96 से 28.22±2.04 मिमी तक था। प्याज के बल्ब की गोलाकारता 0.69±0.08 से 0.87±0.06 तक थी। ग्रेड <2 g, 2-3 g और 3-4 g के लिए आकार सूचकांक क्रम ाः 1.78±0.32, 1.711±0.25, 1.59±0.25 पाया गया, > 1.5 और भोश ग्रेड 4-5 g से > 9 g के लिए आकृति सूचकांक मान < 1.5 पाए गए। प्याज के बल्ब का अनुमानित क्षेत्र 1.55±0.30 से 5.5±0.51 वर्ग सेमी तक था। 100 प्याज के बल्ब का वजन 121.6±6.30 से 1185±19.59 ग्राम तक था, प्याज के बल्ब का थोक घनत्व 480.19±13.13 (< 2 g) से 1086±205.22 (> 9 g) kg m^{-3} तक था। प्याज के बल्ब का अधिकमत वास्तविक घनत्व > 9 g में 1086±205.22 kg m^{-3} प्राप्त हुआ, जबकि प्याज के बल्ब का न्यूनतम वास्तविक घन्तव < 2-3 में 950.70±257.92 kg m^{-3} था। प्याज के बल्ब की औसत नमी 80.02 ±0.43 %. पाई गई। रेपो का कोण 20.71±1.92 से 40.61±3.68° तक थी। घर्शण गुणांक को विभिन्न सतहों जैसे कि हल्के स्टील, प्लाई लकड़ी और जस्टी लोहा पर प्याज के बल्बों के लिए निर्धारण किया गया था। हल्का स्टील, प्लाई लकड़ी और जस्ती लोहा के लिए घर्शण गुणांक क्रम ाः 0.628±0.03 से 0.456±0.016, 0.236±0.03 से 0.174±0.016 और 0.344±0.01 से 0.310±0.017 तक रहा। रोपण अभिविन्यास के प्रभाव का खरीफ, रबी और संपूर्ण डेटा के वि लेशण से पता चलता है कि उच्चतम अंकुरण, पौधे की अधिकतम ऊंचाई एवं उपज नीचे जड़ वाले प्याज रोपण से प्राप्त हुई। इसके प चात क्षैतिज जड़ वाले भाग और झुकाव वाले रोपण का क्रम प्राप्त हुआ।

चार कप के साथ प्याज (2–3 ग्राम) के आकार के साथ प्रयोग ााला में, अधिकतम एकल (79.09 %) दर्ज किया, जबकि न्यूनतम दोगुना (4.90 %), गुणक (2.26 %), मिसिंग (1.76%) और बल्ब क्षति (0.00%) पाए गए। इसी तरह के रूझान (3-4g), (4-5) and (5-6g) प्याज के आकार के लिए भी देखे गए। हालांकि चार कपों में से कप क्रमांक सी 4(25 mm) के तहत 1 किमी प्रति घंटे की गति पर 90° झुकाव पर मीटरींग इकाई के द्वारा एकल का मान

(81.03%), एवं न्यूनतम मान दोगुना (8.67%), बहु गुणक (5.36%), मिसिंग (4.94%) और बल्ब क्षति (2%) थे। इस आधार पर कप चार आकार 25 मिमी, गति 1 किमी प्रति घंटे और झुकाव का कोण 90 डिग्री के रूप में मीटरिंग इकाई हेतु अनुकूलित पाया गया। अनुकूलित मापदंडों के आधार पर, बल्ब प्लान्टर को सफलतापूर्वक डिजाइन और निर्मित किया गया।

प्रक्षेत्र में प्राप्त परीक्षण के आंकड़े 71.84 ± 1.14 प्रति ात एकल, 8.94 ± 0.63 प्रति ात दोगुना, 11.48 ± 0.42 प्रति ात बहु गुणक, 7.70 ± 0.24 प्रति ात मिसिंग और 1 ± 0.138 प्रति ात बल्ब क्षति के तहत पाए गए। मिस इंडेक्स, मल्टीपल इंडेक्स, क्वालिटी फीड इंडेक्स, सटीक, माध्य और मानक विचलन के संदर्भ में प्रद र्नि सूचकांक क्रम ाः 0.076±0.002, 0.114±0.004,0.808±0.002, 0.14±0.005, 10.63±0.144 और 0.49±0.05 पाया गया। प्याज बल्ब प्लांटर का प्रद र्न सैद्धांतिक क्षेत्र क्षमता, प्रभावी क्षेत्र क्षमता, क्षेत्र की दक्षता, ईंधन की खपत, रोपण की गहराई, पंक्ति दूरी और पौधे से पौधे की दूरी के मापदंडों के आधार पर क्रम ाः 0.15 हे/घंटा, 0.122 ±0.002 हे/घंटा, 81.7±0.146 %, 3.17±0.035 लीटर/घंटा, 4.112 ±0.134 सेमी, 15.00±0.053 सेमी और 10.44±0.084 सेमी पाया गया। प्रोटोटाईप की लागत और ऑपरे ान की लागत रू. 49, 300 /- और रू. 4, 211.91/- प्रति हेक्टेयर आंकी गयी। मैनुअल प्लांटिंग पर होने वाली लागत से लगभग 58 फीसदी की बचत प्राप्त हुई। विकसित प्लांटर का सटीक मान 14 फीसदी देखा गया, इसलिए म ीन अच्छे प्रद र्न की श्रेणी में आती है।

CHAPTER – I
INTRODUCTION

Agriculture sector is the backbone and its contribution in overall economic growth of country is very significant. It also determines the standard of living for more than 60 per cent of Indian people. Apart from this, Indian Agriculture still has its own constraints reflecting the low yields per hectare of crops compared to International standards. According to the agricultural census 2015-16, shrinkage in the average size of the agricultural lands is continuously increasing with the dropping of operational holding to 1.08 ha from 1.15 ha in 2010-11 (Business standard, 2018). With the farmland shrinkage, the contribution of small and marginal lands in agriculture has risen to 86.21 per cent of total operational holding in 2015-16 compared to 84.97 per cent in 2010-11(Anonymous, 2018).

In the world, India is the second largest producer of fruits and vegetables. In view of greater returns, horticultural crops offers better choice for the diversification of Indian agriculture. In the last few years, India has witnessed a rise in horticulture production. Important progress has been made in expanding the region, contributing to higher production. The horticulture sector has grown by 2.6 per cent annum over the last decade and annual output has risen by 4.8 per cent. The production of horticultural crops during 2017-18 amounted to 311.71 Million Tonne out of an area of 25.43 Million Hectares. Vegetable production grew from 101.2 Million Tonnes to 184.40 Million Tonne between 2004-05 and 2017-18, and fruit production improved from 50.9 Million Tonnes to 97.35 Million Tonnes between 2004-05 and 2017-18 (Horticultural Statistics at A Glance 2018) Ministry of Agriculture & Farmers' Welfare as depicted in below Figure 1.1.

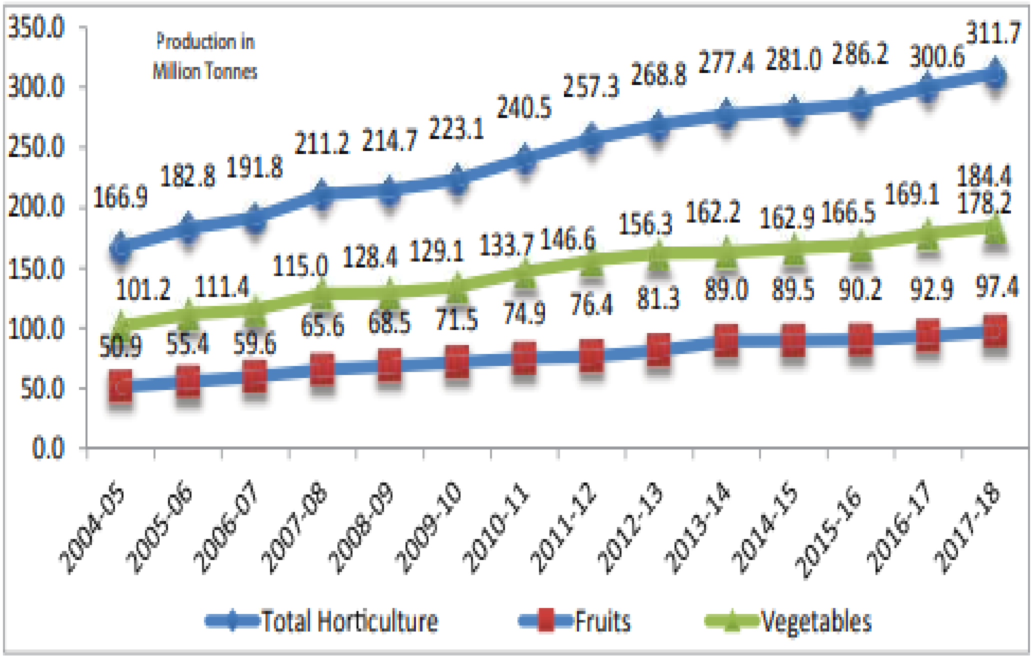


Fig 1.1 Production of total horticulture, fruits and vegetables in India over different years

In accelerating the development of the nation's economy, horticulture has been seen as one of the future agricultural-based enterprises. It leads to the country's programmes for nutritional security, poverty alleviation and employment generation. In addition to farmer's choices crop diversification, it offers sufficient space for mandating large numbers of agro-industries that create enormous job opportunities. Horticulture actually contributes 24.5 % of GDP out of 8 % of the land area. During the previous two planning phases, focus was paid to horticultural research and development. Its result is encouraging. We have now emerged as the largest producer of coconut and tea in the world and the second largest producer and exporter of tea, cashew, coffee, spices exporter of fresh and processed fruits, vegetables, and cut flowers have also been picking up (Anonymous, 2001).

As per Agricultural census 2011, 263 million people (54.6 per cent) are engaged in the agricultural sector which is likely to decline to 90 million (33 per cent) by 2020 (Anonymous, 2017 b). It implies decrease in workforce in agriculture especially during important seasons and operations which directly affect the production. Thus, modern engineering interventions are required in farm operations to fulfill need of the population. Here, mechanization in agriculture plays an important role. The mechanization is marked by wide variations in the availability of power in the region. There is a clear linear association between the usable farm power and the agricultural output per ha. The country's total farm power available during 2012-13 was around 1.84 kW ha^{-1}, which accounted for approximately 90 % of mechanical and electrical sources and only about 10 % of animal power and human labour (Mehta and Pajnoo, 2013). The needed power density is calculated to be 3.75 kW/ha to achieve the timeliness of operations. (Khandetod, 2019). Studies suggest that it is high time to improve the power availability on farm. Tractor population is increasing every year in India, it means the machinery utilizing to tractor are to be developed and its adoption is to be popularized. This highlights the focus in Indian agriculture on the growth and production of power machinery systems. The mechanization means that drudgery associated with different farm activities is minimized, as well as the use of inputs is economized and the capacity of available capital is therefore harnessed.

1.1 Onion Crop

Onion is one of the main commercially grown vegetable crops by all types of farmers and often eaten worldwide. The world production of onion has been recorded at 93.2 million tons. China accounts for 26 % and India accounts for 21 % (FAOSTAT, 2019). India exports its onions to many countries including the United Arab Emirates, Bangladesh, Malaysia, Sri Lanka, and Nepal.

India produces all varieties of onion *viz.*, common onion (red, yellow and white), rose onion, multiplier onion. Globally India stands first in total area under onion cultivation (13.15 lakh ha) and recorded second in production (220.71 lakh tons). According to second advanced estimate of 2019-20, it was reported that, in India the area, production and productivity of onion was 14.34 lakh ha, 267.38 lakh tons and 18.60 MT/ha, respectively. ppgha, 26.45 lakh tons and 13.89 MT/ha, respectively (www.indiastat.com). Area under onion cultivation and production increased from 39.53 % to 48.74 % from 2006-07 to 2017-18 (Anonymous, 2017 a). The major states producing onion along with total Indian production in the year 2017-18 are given in the table 1.1. (http://nhrdf.org/pdf/Annual-Report17-18.pdf)

Table 1.1. Major onion producing states in India in the year 2017-18

State	Area ('000 ha)	Production (in '000 MT)	Productivity in MT/ha
Maharashtra	507.96	8854.09	17.43
Karnataka	195.28	2986.59	15.29
Madhya Pradesh	150.87	3701.01	24.53
Rajasthan	64.76	996.73	15.39
Bihar	53.77	1240.59	23.07
Andhra Pradesh	42.00	915.73	21.80
West Bengal	35.20	633.60	18.00
Odisha	33.47	379.34	11.33
Tamil Nadu	28.36	301.14	10.62
Chhattisgarh	25.54	421.21	16.49
Others	0.88	16.77	19.15
India	1284.99	23262.33	18.10

Source: Horticulture Statistics Division, Department of Agri. & Cooperation.

1.2 Classification of Onion

Jones and Mann (1963) classify *Allium cepa* into four group for the use of horticulturists as under

a) **Common group of onions** (*Allium cepa* L.Var. Cepa*; Allium cepa* L. ssp. Cepa*,* and ssp. Australe Trofim): Large, usually single, bulbs. Plants derive from seeds or from sets of seeds produced. The majority of dry bulb-grown cultivars fall under this category. This is the world's most significant onion-grown trade group.

b) **Aggregatum group or shallots** (*Allium ascalonicum auct*. Non strand; *Allium cepa* L. ssp orientale kazak): The Bulbs are smaller and clustered with 3-4 bulbs than typical onions. Reproduction, via daughter bulbs, is almost entirely vegetative. Scapes are sometimes established and seed development is possible in some ways.

c) **Ever- Ready onion** (*Allium cepa* L.Var. Perutile strearn): With shorter flower stalks and smaller umbels, bulbs are narrow. It is possible to collect bulbs or leaves year round. It's primarily used as an onion salad. Again, this category is subdivided into onions and shallots of potato or multiplier.

(i) **Potato or multiplier onion**: The bulbs were split between 3 and 20 sets of bulbs that are wider than long. They are generally covered by dry skin on the outside.

(ii) **Shallot:** Shallots form cultures of narrow bulbs when separated. The flowers and leaves are normally smaller than ordinary onions. Shallots are ideal for regions with high latitudes and short seasons.

1.3 Aggregatum or Multiplier onion

The present study is about Aggregatum group or multiplier onion. In India multiplier onion is cultivated in area of 7.56 lakh ha with production of 12.16 Mt and productivity of 16.10 t/ha, respectively (Joslin, *et al.,* 2020). Multiplier onion is also known as small onion, potato onion, underground onion, shallots, nesting onions, ever-ready onion and Egyptian ground onion, which is noted for its hardiness and early maturity than the common onion. All the varieties of small onion do not produce seeds, but Co-5 onion variety was propagated through seeds as well as bulbs (Saraswathi *et al.,* 2017). It is a hot and subtropical area crop that is tolerant to hot and humid tropical climates, greater pest and disease resistance, and has longer storage life than common onion (Ashok, 2003). In the southern states of India, Tamil Nadu, Andhra Pradesh and South Karnataka as well as small parts of Orissa and Kerala, this form of onion is widely grown. Tamil Nadu accounted for 5 % of the area under onion cultivation in the country, of which 70 % of the area is cultivated with small onions (*A. cepa* var. *aggregatum*). More than 90 per cent of country's small onion is produced from Tamil Nadu and 10 per cent from Karnataka. In Tamil Nadu multiplier onion is cultivated in an area of 30,255 ha with a production of 2, 86,000 tons and productivity of 9.45 t/ha, respectively (Joslin, *et al.,* 2020). In India multiplier onion is largely cultivated in Tamil Nadu particularly in Erode, Coimbatore, Dindigul and Theni districts for its underground bulb (Sundharaiya *et al.,* 2016).

Small onion bulb is used as food, spice and seasoning of curries (Dabhi *et al.,* 2011), it stimulates the appetite. It is often used as raw, sliced, mixed with soy sauce and eaten with roasted meat. The Aggregatum onion is well known for its pungency and widely used in sambar, an important dish in South Indian kitchen preparation. It contributes significant nutritional value to the human diet and has medicinal properties. It is primarily consumed for their unique flavour or for their ability to enhance the flavour of other foods because of the presence of volatile compound known as allyl-propyl disulphide (Umesh *et al.,* 2015).

Multiplier onion is commercially propagated through bulbs. The production of small onion is 12-16 t/ha with a duration of 70 to 90 days. It is comprised of 3-4 bulbs of onion joined together, red in color and spherical in shape (Kaveri *et al.*, 2015). Small onions which are firm and marble size but have not sprouted are used as seed onion sets for sowing. Big sets were split into two bulbs, otherwise bulbs may produce a flower stalk very early. Farmers sometimes store the current season harvested onions to use as sets for the next season. Sets are available from onion traders as well as in markets. The bulbs are planted 2-3 cm deep and 5-10 cm apart and they are covered but not compressed by soil. Water is supplied to the plants's base until the soil is moist to a depth of 5-10 cm. In almost all kinds of soils, from sandy loam to thick clay, onion grows well. Soils that retain ample moisture, allow proper bulb expansion and are well supplied with humus are best suited for the cultivation of onions. The pH required for small onion cultivation varied (6.5-7.8) (Saraswathi *et al.,* 2017). But, small onion pre mature well in sandy soils compared to heavy compact ones.

1.4 Methods of Planting

The method of planting of onion is carried out depending upon soil conditions, topography, climatic conditions and economic aspects as well. The different methods employed for planting of onion are broadcasting of seeds, planting of onion bulbs on raised bed cultivation and transplanting of seedlings. There are three methods of planting of onion which are usually followed and are discussed below:

1.4.1 Broadcasting or drilling of seeds directly in the field

Onion seeds are broadcasted manually in flatbed cultivation or bed cultivation.

1.4.2 Planting bulbs directly in the field

Onion bulbs (cluster onion**)** are dibbled in the ridges which are spaced 15 cm row to row and 8-10 cm plant to plant. Some seed planters are available and being used for sowing also.

1.4.3 Raising seedlings and transplanting

Onion seedlings are grown in nursery and are transplanted in the field with the spacing of 10-15 cm row to row and 8-10 cm plant to plant.

1.5 Raised bed System

On ridges and furrows and a paired row system, aggregatum onion has historically been cultivated. Farmers have recently moved to raised beds in order to implement micro-irrigation systems. Irrigation water can be saved (18 percent to 30-50 percent) with the use of raised bed technology (Hossain *et al*., 2001; Naresh *et al*., 2010; and Singh *et al*., 2010). It not only saves water from irrigation, but also prevents surface of the wet soil around the roots from lodging, especially under high wind conditions. Several advantages of growing wheat on beds have been recorded, including increased yields, mechanical weeding opportunities and improved placement of fertilizers, saving in irrigation water, reduces lodging, water logging, seed rate and intercropping opportunities (Sarker *et al,* 2014). Farmers choose to take up raised bed cultivation, as the government is also supporting the micro irrigation method through subsidy schemes. Harvesting on raised bed system can be done easily by using machinery.

1.6 Justification of Onion Bulb Planter

There are two methods of seed production. Seed to seed and bulbs to seed approaches, and both techniques are in practice for processing of onion seeds. For seed production, the bulb to seed method is often followed because it makes true-to-type" and healthy bulbs for seed production and seed yields are comparatively very high. However, seed to seed method of planting may be adopted for varieties, which are having poor keeping quality. After preparation of soil, the grower will plant the bulbs in the saturated soil. Bulbs are planted vertically with the basal root plate down, pressed below the soil surface up to the neck portion was exposed above the soil. When compared to any other vegetable crops, onion is planted with very close spacing. In general, planting one ha of onion requires about 80-100 man-day by maintaining row to row spacing of 15 cm and plant to plant spacing of 10 cm (Madan, 2013). The cost of planting onion bulbs is very high, nearly □ 7,200/ha. As 6.7 lakhs hills per ha are to be planted, the labour requirement for planting is high, also labourers demand higher wages for onion bulb planting. This leads to higher cost of cultivation. The capacity of man power is very low about 0.05 ha/man/day and payment for planting is 11.90 % of total cost of cultivation.

Considering above facts, it was concluded that there is a need for onion bulb planting equipment. In the recent years, labour availability in rural areas is diminishing. Excessive drudgery and certain social influences are some of the reasons for the present generation for leaving farming activities. The cultivation of onions is discouraged day by day by farmers due to high labour intensive work and higher wage rates. In addition, the mechanization of onion bulb planting on the raised bed system (RBS) would lead to precision planting coupled with end-to-end mechanization of onion type aggregate planting. Mechanization not only increase efficiency and output, but also, relative to the current package of practices, decrease labour costs and drudgery. It should maintain low seed rate, uniform seed placement with less soil disturbance and poses less drudgery and maintain timeliness of operation and require minimum labour. Thus, a study was planned and conducted on **"**Design and development of a tractor operated raised bed onion bulb planter" with following objectives.

1. To study the physical and mechanical properties of onion bulbs.

2. To optimize the design and operational parameters of metering system.

3. To design and development of raised bed onion bulb planter.

4. To evaluate the performance of raised bed onion bulb planter.

CHAPTER - II
REVIEW OF LITERATURE

Planting is one of the most important unit operation of a crop production system and suitable machinery for the same is the foremost need. In planting, it is essential to achieve uniform placement with sound crop stand. The past work done by various researchers in India and abroad relating to design and performance evaluation of planters are reviewed and presented in this chapter. Major emphasis has been given to work related to objective of this study and those are presented below under following sections.

1. Physical and mechanical properties of different types of onion bulbs.
2. Raised bed system of cultivation
3. Studies on design and development aspect of different types of onion and other planters.
4. Evaluation of different types of planters and seed drills.

2.1 Physical and Mechanical Properties of Different Types of Onion Bulbs

2.1.1 Physical properties of multiplier onion

Kumari and Das (2015 a) studied the physical and mechanical properties of onion sets (aggregatum type onion) and those were graded into four grades based on weight (grade I: 2-3 g, grade II: 3-4 g, grade III: 4-5 g and grade IV: 5-6 g). The planter related physical properties of onion sets (namely sambar onion) were determined to design and develop a tractor operated onion set planter. The onion length, thickness, width, geometric mean diameter, sphericity, shape index, projected area, thousand seed onion weight, bulk density and true density and mechanical properties *viz.*, angle of repose and co-efficient of friction were determined for all the four grades. The length, width and thickness were 28.85 ± 0.57, 17.15 ± 0.35 and 12.95 ± 0.28 mm for grade - I onion sets (2-3 g weight), 27.55 ± 0.70, 19.65 ± 0.50, 16.05 ± 0.49 mm for grade - II onion sets (3-4 g weight), 28.10 ± 0.68, 21.75 ± 0.42, 17.40 ± 0.39 mm for grade - III onion sets (4-5 g weight), 30.10 ± 0.64, 29.05 ± 0.47, and 23.15 ± 0.36 mm for grade - IV onion sets (5-6 g weight), respectively, The geometric mean diameter of onion sets were 18.03 ± 0.17, 20.28 ± 0.18, 21.74 ± 0.26 and 23.66 ± 0.20 mm for the grades I, II, III and IV, respectively. The sphericity of onion sets was 0.70 ± 0.01, 0.74 ± 0.01, 0.78 ± 0.01 and 0.78 ± 0.01 for the grades I, II, III and IV, respectively. The shape index for onion sets were 1.71 ± 0.04, 1.57 ± 0.04, 1.46 ± 0.04 and 1.44 ± 0.03 for the grades I, II, III and IV, respectively. The smaller size of onion sets (I and II grade onion sets) had oval shape and the bigger size onion sets (III and IV grade onion sets) had spherical shape. The projected area for onion sets were 2.62 ± 0.13, 3.34 ± 0.26, 4.46 ± 0.21 and 5.05 ± 0.23 cm^2 for the grades I, II, III and IV, respectively. The big size onion sets *i.e* grade IV (5-6 g weight) had the highest one thousand onion set weight (5.48 ± 0.41 kg) followed by grade II (4-5 g weight: 4.39 ± 0.064 kg), grade III (3-4 g weight: 3.41 ± 0.22 kg) and grade I (2-3 g weight: 2.47 ± 0.170 kg). The bulk density of onion sets were 524 ± 12.77 kg/m^3, 476 ± 13.78 kg/m^3, 429 ± 20.08 kg/m^3 and 387 ± 6.91 kg/m^3 for the grades I, II, III and IV, respectively. The true density was highest for the grade-I onion sets (958.83 ± 64.93 kg/m^3) followed by grade-II (942.04 ± 20.90 kg/m^3), grade- III (939.88 ± 14.98 kg/m^3) and grade IV (933.80 ± 39.09 kg/m^3). The grade I (2-3 g weight) and grade II (3-4 g weight) onion sets had same angle of repose of 37.78 ± 0.70 degree and the grades III (4-5 g weight) and IV (5-6 g weight) had the same angle of repose of 36.92 ± 1.391 degree. The coefficient of friction had a higher value on wooden surface (0.46 ± 0.01) followed by mild steel surface (0.45 ± 0.03), galvanized iron surface (0.42 ± 0.02), aluminum surface (0.40 ± 0.01) and stainless-steel surface (0.31 ± 0.01) for grade I (2-3 g weight) onion set. The same trend was observed for all the other three grades *i.e.*, grade II, grade III and grade IV onion sets.

Kaveri *et al.* (2015) studied physical properties of multiplier Co-4 onion bulb (*Allium cepa* L.var. *aggregatum.* Don.). The multiplier onion bulb properties were studied for design of equipment for processing, sorting, transportation and heat transfer processes (heating and cooling). For fresh onion and 3 months of stored onion, the properties were analysed. The surface area ranged from 14.04 ±

6.93 cm^2 for fresh onions to 11.18 ± 2.40 cm^2 for onions stored for three months. For fresh and stored samples, the roundness values were 0.87 ± 0.04 and 0.84 ± 0.08. The properties like mass, length, true density, bulk density and porosity were also determined. The friction coefficient was high on the surface of the rubber and lower on the surface of polished wooden card board.

Gomathy *et al.* (2017) studied on moisture dependent physical properties of multiplier onion (*Allium cepa* L. var. *aggregatum*). In the range of 80.87 percent to 88.84 percent (w.b.), the physical properties of multiplier onions (Co-4) were analysed as a function of moisture content. With an improvement in the moisture content, the geometric, physical and frictional properties, including size, true density, bulk density and coefficient of friction improved. The mean equatorial diameter, polar diameter and onion thickness ranged from 30.80 to 34.00 mm, 24.20 to 25.90 mm 18.60 to 21.00 mm, respectively. The true density and bulk density ranged from 887.0 to 933.0 kg/m^3 and 397.54 to 462.63 kg/m^3.”The highest friction was offered by rubber, followed by cardboard, mild steel, galvanised iron and stainless steel. The porosity of onion decreased from 55.13 % to 50.39 % with increase in moisture content.

2.1.2 Physical properties of common onion

Maw *et al.* (1996) physical and mechanical properties of ‘Granex-Grano’ onion variety have been studied. They reported that, the mean mass, surface area, volume, density and overall mean equatorial and polar diameter were 98 g, 111 cm^2, 95 cm^3, 1.10 g/cm^3, 6.20 and 4.20 cm, respectively. They also observed that, 26.4 N and 25.0 N were the crushing and puncturing forces.

Bahnasawy *et al.* (2004) studied on physical and mechanical properties of some Egyptian onion cultivars. Three of the most common onions were selected (Giza 6 (white), Beheri (red) and Giza 20 (yellow). The polar and equatorial diameters ranged 5.12 ± 0.33 to 6.20 ± 1.5. The onion bulbs of beheri and Giza 20 were all circular in form and the onion of Giza 6 was an oval. The geometric mean diameter (D_{gm}) ranged from 5.48 to 5.98 cm, arithmetic mean dimeter (D_{am}) ranged from 5.50 to 6.01 cm, the frontal surface area ($A_{f.s}$) ranged from 23.30 to 28.81 cm^2 and cross-sectional area (A_{sc}) ranged from 23.96 to 29.52 cm^2 and all onion cultivars ranged in mass from 78.70 to 115.30 g. They ranged in volume from 77.2 or all onion cultivars. The volume ranged from 77.2 ± 25 to 108.8 ± 75 cm^3. The density differed between 1.04 ± 0.09 to 1.11± 0.15 g/cm^3. The rolling angle in the stable position differed from 20º to 31º and in the non-stable position from 14º to 23º. On the rubber floor, accompanied by the plywood and the galvanized steel surfaces, the maximum values for rolling angles were obtained. With the onion bulb size (bs), the rolling angle improved. The coefficient of friction (*f*) for all three cultivars differed from 0.67 to 1.34. On the plywood surface, followed by the rubber and galvanized steel surfaces, the maximum (f) was obtained. With the size of onion bulb, the crushing load improved and ranged from 443.30 to 819.70 N for Giza 6 (white onion), 341.40 – 980.70 N for Beheri (red onion) and from 400 to 780 N for Giza 20 (yellow onion). With the onion bulb size, the penetration force also improved and ranged from 26.90 to 35.90, 26.10 to 43.00 and 27.60 to 45.50 N with the same previous order.

Vijaya and Srivastava (2006) studied on physical and mechanical properties of three onion varieties namely Agri found Dark Red, Pusa Red and NP-53 significant to mechanical de-topping. The linear relationship was between polar diameter and equatorial diameter and also (with leaf) bulb weight was observed. The shape of onion crop may be known as oblate to spherical. The required average shear force was 16.23, 17.67 and 18 kgf, respectively. For all the three types, the cutting force increased with neck diameter. The mean length and number of leaves varied from 30.85 to 36.68 mm and from 8 to 10. It was observed that the Pusa red variety was found to be denser (270 kg/m^3) than the other two varieties. The mean coefficient of static friction was inversely proportional to the equatorial diameter, and the measurements were 0.43, 0.41 and 0.41, respectively.

Khura *et al*. (2010) determined engineering properties of onion crop relevant to design of onion digger. For small onion, the average equatorial diameter was 34.50 mm and polar diameter was 33.8 mm. However, these values for medium and large size onion were 49.82, 41.41, 64.68, and 53.20 mm, respectively. The plant height varied from 11.00 to 32.00 cm, for 14 cm row spacing. For small, medium and large sizes, the”average weight of onion bulbs with leaves were 21, 52, and 112 g, and the bulk density was 180, 260 and 290 kg/m^3, in same order, which helped in estimating the amount of material handled by the elevator”of onion digger.

Ghaffari *et al*. (2013 a) studied on physical properties of three Iranian onion varieties. The polar diameter (a) was between 46.93 mm and 59.82 mm and the equatorial diameter (c) was between 46.63 mm and 59.82 mm. The shape index of red Azarshahr, white Kashan and yellow, respectively, was 1.00 ± 0.02, 1.00 ± 0.02 and 1.09 ± 0.11. The cultivars of the 3-onion were spherical shaped. The coefficient of static friction was approximately 0.24 to 0.82, 0.19 to 0.91, 0.85 to 1.18 and 0.90 to 1.25 respectively on plywood, galvanized, rubber and PVC surfaces. A rolling angle of 11.13 to 15.87º was obtained. The findings results showed that, the rolling angle had no impact on frictional surface.

Ghaffari *et al.* (2013 b) carried out the mechanical properties of onion. To evaluate the mechanical properties, three different varieties of Iranian onion cultivars were used (Red Azarshahr, yellow Isfahan and white Kashan). Crushing load and energy, puncture load and energy was included was included those characteristics. The crushing force for all varieties was from 175 to 916.67 N and the crushing energy was from 1.3 to 17.58 MJ. The average puncture load were 19.40, 14.91 and 12.52 N, for the red, white and yellow cultivars, respectively. For red, yellow and white cultivars, puncture energy values were 2.91, 2.65, and 2.47 MJ, respectively.

Patel *et al.* (2016) studied on development and selection of spoons for metering of onion bulblets planter. Engineering properties of onion bulblets of variety Agrifound Dark Red were calculated. The raw sample of onion bulblets was categorised according to their diameters as a small, medium and large sample in three categories (Polar and equatorial). The engineering properties of the onion bulblets of each sample dimensions, such as polar diameter, equatorial diameter, geometric mean diameter, sphericity, shape factor, unit weight, and bulk density, were estimated at 74.00 % m. c. (w. b.), which were observed to be 23.62 mm, 13.20 mm, 1.87 mm, 15.58 mm, 0.66, 0.56 g, 607.82 kg/m^3, for small size samples, 27.90 mm, 19.54 mm, 3.91 mm, 21.30 mm, 0.70, 0.70 g, 664.47 kg/m^3 for medium size and 31.58 mm, 28.71 mm, 5.70 mm, 28.64 mm, 0.91, 0.91 g, 685.60 kg/m^3, respectively for large size samples. The angle of repose for small, medium and large samples were 36.20^0, 34.21^0 and 33.51^0 respectively and rolling angle values were 10.21º, 10.25^0 and 10.45^0 respectively for small, medium and large size samples. The shape factor values were 0.56 (oblate in shape), 0.70 (oblate in shape) and 0.91 (spherical in shape).

Mukesh and Patel (2017) studied on physical and mechanical properties of Talaja red onion Cultivar. The linear relation between the polar dimeter and the equatorial diameter and the bulbs weight was observed. Oval to spherical shape was considered onion crop. The mean bulk density of onions was observed as 548 kg/m^3. The coefficient of friction was observed to be 0.42, 0.39, 0.45 and 0.32 respectively for galvanised iron, mild steel, aluminium and plywood. The angle of repose for galvanised iron, mild steel, aluminium and plywood were all noticed to be 23º, 21º, 24º and 17 º, respectively.

Shoba *et al.* (2017) studied the physico-mechanical properties of onion varieties i.e., Ballari red, Arka kalyan, Satara (local verity) and Kalasa (local variety). The equatorial dimeter of the Bellari red onion variety of all sizes ranged from 4.01 to 8.35 cm, the polar dimeter from 3.82 to 6.62 cm and the thickness of the Ballari red onion variety from 1.25 to 2.51 cm, while lowest equatorial dimeter values were found in Kalasa variety (local variety), i.e. 3.2 to 7.12 cm, the polar diameter from 2.89 to 5.12 cm and the thickness from 1.22 to 2.01 cm, respectively. The shape index of three of the four was oval in shape. The geometric mean diameter (D_{gm}) and athimatic mean diameter (D_{am}) ranged from 2.65 to 5.09, 2.50 to 4.58, 2.35 to 4.43 and 2.23 to 4.13 cm respectively for large, medium and small size varieties such as Ballari red, Arka kalyan, Satara, Kalasa. In Ballari red onion, the maximum bulk density was observed from 678.9 to 390.42 kg/cm^3 followed by Arka kalyan from 662.70 to 390.42 kg/cm^3, Satara from 628.40 to 390.23 kg/cm^3, Kalasa 618.59 to 385.24 kg/cm^3 and the highest mean angle of repose was observed in Ballari red, i.e. 37° (large size) and the lowest was observed Kalasa (small size) 20.90 $^\circ$.

2.1.3 Physical properties of garlic

As the Aggregatum group onion has the similar morphological character of garlic, the work done to determine physical and mechanical properties of garlic were reviewed and reported in this Section.

Haydar *et al.* (2005) determined properties such as whole garlic diameter, mass, whole garlic segment number, length of whole garlic, width, thickness, geometric mean diameter, sphericity, projected area, volume, bulk density, density of segment, porosity, terminal velocity and hardness. 32.81 g, 2383.80 g, 27.24 mm, 46.51 mm, 15.15 mm, 0.559, 4.54 cm^2, 2245.64 mm^3, 478.75 kg/m^3, 54.16 % and 13.78, N was calculated as mean mass, mass weight of 1000 garlic segment, length of segment, diameter of whole garlic, geometric mean diameter, sphericity, projected area, volume, bulk density, porosity and hardness of segment. On a galvanized sheet, an iron sheet and plywood, a static and dynamic coefficient of friction was established for garlic segments. These static and dynamic coefficient friction values have been found to be 0.41-0.35, 0.47-0.40 and 0.54-0.48 respectively.

Manjunatha *et al.* (2008) determined engineering properties of garlic (*Allium Sativum* L.*).* The shape, average diameter, weight, bulk density, entire garlic segment number, average length, width, thickness, geometric mean diameter, sphericcity and 100 garlic segment mass weight were determined as round, 5.12 cm, 28.64 g, 144.44 g, 40.50 percent moisture content on weight basis. The terminal velocity, angle of repose, specific gravity, compressive and shear force of garlic segment increased from 7.18 to 12.24 m/s, 25.53 to 37.50 degrees, 0.90 to 0.97, 2.25 to 10.70 kgf and 1.75 to 2.83 kgf respectively in the moisture content range of 23.05 to 40.50 percent (w.b.), while the bulk density declined from 483.10 to 449.76 kg/m^3. The static coefficient of friction increased for increase in moisture content from 23.05 to 40.50 percent (w.b.) on three surfaces, including teak wood (0.46 to 0.53), aluminum (0.38 to 0.48) and mild steel (0.34 to 0.41), with an improvement in moisture content.

Bakhtiari and Ahmad (2015) designed and developed a pneumatic garlic clove metering system, physical and aerodynamic properties were studied. 32.00, 21.80, 20.90, 24.40 and 24.90 mm, respectively was the average length, width, thickness, geometric mean diameter and arithmetic mean diameter of garlic cloves. The average surface area, projected area, one thousand kernel mass, volume and bulk density of garlic cloves increased from 1718.30 to 2029.10 mm^2, 546.60 to 644.30 mm^2, 6783.00 to 8159.30 g, 5916.50 to 7356.00 mm^3 and 476.30 to 567.40 kg/m^3, respectively, with the moisture content range from 35.8 % to 60.5 % (w.b). In this study the true density declined from 1146.4 to 1109.3 kg/m^3 as the moisture content improved. The terminal velocity of garlic rose from15.60 to 16.70 m/s linearly within the same moisture range.

2.2 Raised Bed System of Cultivation

2.2.1 Effect of raised bed technology

Ahmad and Mahmood (2005) studied the impact of raised bed technology on water productivity and lodging of wheat. In order to determine the impact of sowing techniques on yield and lodging of wheat raised bed planting cultivation. Field study was carried out to evaluate the conventional sowing of wheat by drill and broadcast method. Four-row wheat bed planting was used on 90 cm bed – furrow system to plant wheat. The results showed the minimum impact of lodging in raised bed technology (20.50 percent) compared to flat-sow wheat (34.60 per cent). In addition, raised bed planting registered an 11.20 per cent increase in grain yield over flat-sowing methods. Drainage of excessive rain water from the fields and stronger plant anchorage on the beds resulted in reduced lodging in raised beds. Whereas, in comparison to flood irrigation of controlled plots, 40 to 50 percent savings that the technology of raised bed planting had a lot of potential to increase wheat water productivity.

Naresh *et al*. (2012) developed furrow irrigated raised bed (FRRB) planting technique for diversification of rice-wheat system for western IGP region. A field experiment was tested to assess furrow-irrigated raised beds and flat beds under irrigated conations. Crops were cultivated in bed planting systems on the raised beds in ridge furrow method. For growing high-value crops that were more susceptible to temporary water lodging tension, this method often considered more suitable. Farmers also grow crops on the raised beds, such as cabbage, carrot, radish, okra, onion, brinjal, cauliflower, colocasia, turmeric, cotton, maize and wheat. The findings revealed that, in areas where ground water levels are declining, the method of raised bed planting of crops can be especially beneficial. This option for tillage and crop establishment also facilities the diversification of crops and intercropping of multiple vegetables.

Vinayak (2016) designed and developed a power tiller operated raised bed seed cum fertilizer drill for dry paddy. The total width of the top, width of the bottom and depth of the bed is 58 cm. 78 cm and 11 cm, respectively, and the width of the furrow was 22 cm. For the raised bed and flatbed system, 185 and 143 plants per square meter area were observed. The theoretical field capacity, actual field capacity and field efficiency were observed as 0.16 ha/h, 0.12 ha/h and 78.37 percent respectively in the application of the raised bed system at 2 km/h level, while 0.12 ha/h, 0.09 ha/h and 77.29 per cent respectively in flat bed system. The energy required for operation of raised bed and flat bed system was found to be 0.29 and 0.36 hp, respectively. Rs. 16871 and 9871/-.is the total cost of raised bed and flatbed seed cum fertilizer drill. The cost of sowing paddy seed in the raised bed and flatbed system by the developed power tiller operated raised bed seed cum fertilizer drill was Rs. 1482 and 2072 /ha. The raised bed seed cum fertilizer drill output for dry paddy was adequate for working in the well-prepared seed bed for dry paddy sowing.

Joshi and Shrivastava (2017) modified and evaluated the tractor drawn raised bed seed drill under vertisol. The machine was evaluated and compared with the performance of a three-bed furrow raised bed drill, zero till drill, and traditional chickpea sowing activities. It was noticed that the overall time and expenses required by raising bed drills for making raised beds and sowing operations was 1.42 h/ha and Rs.439.77/ha, which is 17.44 % and 20.22 % less time needed than traditional sowing practices and tractor drawn zero till drill respectively. The average yield by raising bed drill was 1211.3 kg/ha. Whereas, by conventional practices and tractor drawn zero till drill was 1127.83 kg/ha and 1137.80 kg/ha, respectively. In the case of tractor-drawn raised bed seed drill machine, the soil conditions were also considered stronger.

Dnyaneshwar (2018) a tractor operated raised bed planter cum sprayer with a covering system and weeder was designed and developed. Farmers normally cultivate potatoes and other vegetables in beds. In Mexico's Yaqui Valley, where more than 90 % of farmers have adopted the method, the bed planting system for wheat was originally created. A prototype consisting of the main frame, transport wheel, planting unit, broad bed former device, power transmission unit and hitching unit, sprayer unit, seed cover, inter-cultivators was built to accomplish this purpose. It checked the system for its efficiency. The test result showed that, it performs the expected purpose of raised bed preparation and simultaneously seed planting on beds with an average field efficiency of 0.49 ha/h. The quality was sufficient for the inclined plate seed metering system. The unit was then considered appropriate for planting on the raised bed and simultaneously planting and spraying the seed on this bed.

2.3 Studies on Design and Development aspect of Different types of Onion and other Planters

2.3.1 Effect of orientation of planting to optimize the design and operational parameters of metering system

Orlowski and Rekowska (1992) the results of various strategies of clove sowing on garlic yield have been investigated. The treatments included (1) bud pointing upward (conventional); (2) bud pointing downward; (3) bud pointing each side; (4) bud at some random location (similar on machine sowing). The number of plants produced, plant height, garlic yield and quality were the dependent variables calculated. The findings revealed that treatments 1 and 2 have the highest and lowest yield, while treatments 3 and 4 displayed no substantial gap in yield respectively, and treatment 4 had a lower cost of production about 13.7-19.4 per cent lower than that of treatment 1, with no substantial change in efficiency.

2.3.2 Design of onion seed planter

Mohanlal (2012**)** developed a manually operated onion seed planter. The main frame, seed metering system and power transmission device part of the seed planter. The equidistant cells on its periphery were in the seed rotor. By varying the location of furrow openers, the row to row spacing was changed. The findings found that the weight of the system being built was 20.5 kg. Its field efficiency and capacity 83.33 percent and 0.09 ha/h. Rs.368 per hectare cost of operation. The machinery was sufficient for small and marginal framers.

Pawar (2013) evaluated pneumatic onion seeder and it was compared with manual transplanting method. The developed seeders were tested at 3 separate speeds (1.56, 2.47 and 4.20 km/h) for suitability of direct onion seed sowing. The physical properties of the onion seed of the GWO-I variety were observed as 0.19 cm, 0.69, 0.46 g/cc, 31.36° and 4.20 g, respectively, in terms of equivalent diameter, sphericity, bulk density, angle of repose and thousand seed weight. The output parameters, power requirements, energy requirements, wheel slip, fuel consumption and field efficiency of the seeder were checked and economically compared with the, manual transplant process. The best overall results were achieved at a speed of 4.20 km/h. The seed miss index (16.18 %), seed multiple index (5.59 %) quality of feed index (78.22 %) and spacing variability (10.09 %) were obtained. The population of plant per sq. m 51.50 and germination percentage 85.44 percent were observed. The wheel slip, fuel consumption, power requirement, energy requirement and field efficiency of the seeder were observed at the speed of 4.20 km/h at 10.47 %, 5.04 1/h 18.81 kW, 50.11 MJ/ha and 66.75 %, respectively. The overall expense of the machines direct seed sowing was Rs. 4, 322/ha and Rs. 21,956/ha was the total cost of manual transplantation.

Grewal *et al.* (2015) a six-row tractor operated inclined plate metering system for direct onion seed sowing was designed and evaluated. In the laboratory, inclined plates having 18, 24 and 30 grooves were evaluated. Based on the missing index, multiple index and quality feed index, output was assessed. For 18 groove plates at a speed of 2 km/h, the missing index was the highest. At a speed of 1 km/h, the minimum missing index was 30 groove plate was observed. For 30 groove plates, the multiple index was highest at 2 km/h speed. For 18 groove plates, the minimum multiple index values was 13.67 percent at speed of 2 km/h. At a forward speed of 1.5 km/h, the quality of feed index was best for 30 groove plates. For the field evaluation, 30 groove seed metering plates and a forward speed of 1.5 km/h were selected based on the results of the laboratory evaluation.

The average field capacity, fuel consumption, germination count after 28 DAS, bulb size, bulb weight and yield of the machine was found to be 0.11 ha/h. 3.2 l/h, 14.66 plants/m, 4.94 cm, 56.68 g and 334 q/ha was comparable with that of transplanted onion.

Gautam (2016) developed, tested and evaluated an inclined plate planter for pelleted vegetable seed. Onion (*Allium cepa* L.*)*, Carrot (*Daucus carota* L.) and Radish (*Raphanus sativus*) are important vegetable crop grown throughout the country. Seed pelleting was carried out at a ratio of 1:1 to 1:3. In the laboratory for the treated seeds (S1, S2 and S3), preliminary evaluation of the developed planter was performed using various developed seed plates having 18, 24 and 30 grooves at forward speeds of 1.0, 2.0, 3.0 km/h. Based on average spacing, missing index, multiple index and quality of feed index, performance was assessed. For S3 seed with 24 groove plate at 2.0 km/h forward speed and 45^o angle of inclination of plate. The optimal combination of direct sowing of onion, carrot and radish was found based on average seed spacing and index value. The machine for planting onion, carrot and radish S3 seeds on 100 cm wide beds was evaluated in the region. The yields observed for onion, carrot and radish were 478.80 q/ha, 252.00 q/ha and 322.60 q/ha respectively. The field capacity of the machine was found to be 0.164 ha/h and the fuel consumption was 4.5 l/h during the sowing process.

Kumar *et al.* (2016) designed, developed and evaluated a raised bed inclined plate planter for direct sowing of onion (*Allium cepa* l.) seed on beds. In the field of direct sowing of the onion seed variety Punjan Naroya on beds, the developed prototype was assessed. Three speeds of 1.5, 2.0 and 2.5 km/h and three plate angles of 26º, 36º and 46º and two row spacing of 15 and 18 cm were tested to the planter. The average seed spacing varied between 6.09-11.68 cm at forward speed of 2 km/h and a plate angle of 36º was 7.6 cm, closer to theoretical spacing of 7.5 cm required. The average expense and time saves of raised bed onion planters is 57.89 per cent and 98.75 percent relative to the manual process.

2.3.3 Onion bulb planter design

Sadhu (1982) designed and developed a tractor operated two row onion set planter. The metering mechanism used was horizontal plate type. The onion set hopper was a vertical, cylindrical shell mounted coaxially above the metering mechanism. The hopper consisted of an outer shell fitted around the outside at the bottom. This left an annular space between the two cylinders. The annular space was utilized as a passage to guide the onion-sets into the drop chute during operation. There were two guide plates in the annular space, fixed to the inner cylinder, adjacent to the outlet openings, so that the flow of onions was diverted into the drop chutes. The guide plates were located diametrically and tangentially to the inner cylinder at the bottom. Space was left between the guide plates and the horizontal plate to allow complete rotation. The metering mechanism was driven by a drive wheel while the planter was in motion, through the chain and sprockets.

Helmy *et al.* (2005) evaluated the available planters for planting onion sets. They stated that uniformity of onion set distribution within row depends to a great extent on the performance of the metering devices of the planting machine, where metering devices (Mechanical and pneumatic) were functioning according to seeds dimension and cell conditions.

Patel (2012) developed the metering device for onion bulblet planter having two types of cups: elliptical and round. It was also noted that round cup was best suited to large sized samples with minimum elevating error, 5 % and 3.5 % bulblet damage. The findings indicated that the yield was not impaired by bulblet orientation in soil and there was no need to include any additional arrangements for proper positioning of buds.

Madan (2013) developed a metering device for Onion (*Allium cepa* L.) bulblet planter. With the both hopper fills, elevating error were lower at the minimum travel speed of 0.78 km/h and at the minimum peripheral speed of 5.37 m/min. At the minimum travel speed of 0.78 km/h and minimum peripheral speed of 5.37 m/min, the elevating error was minimum (5 per cent and 3.63 per cent) for three fourth hopper fills. Damage of bulblets improved with changes in forward speed peripheral speed on all hopper fills. At forward speeds of 0.78 km/h and peripheral speed of 5.37 m/min, the risk of bulblets was lower for all hopper fillings. Damage of bulblets was smaller at all forward speeds and at all peripheral rotor speeds for half hopper fills. Bulblet damage was minimum (2 % and 1 %) at a minimum forward speed of 0.75 km/h and minimum peripheral speed of 5.37 m/min for half hopper fill. At three-fourth hopper fill, cell fills were almost 100 per cent for all forward speeds and for all peripheral rotor speeds. In laboratory and field experiments, actual and mean planting distances increased with an improvement in travel speed. The actual (11.45 cm and 11.56 cm) and mean (11.62 cm and 11.88 cm) planting distance were, for laboratory and field experiments, minimum travel speeds of 0.85 and 0.78 km/h, respectively. With the rise in travel speed, both in laboratory and field experiments, planting errors increased. Feed indices in laboratory and field experiments were optimum (95.58 percent and 90.32 percent) at minimum travel speed of 0.85 and 0.78 km/h, respectively. With a travel speed of 0.85 km/h and a peripheral speed of 5.37 m/min in the laboratory test and a travel speed of 0.78 km/h in the field test. The efficiency of metering device was highest for three fourth hopper fillings. In the laboratory and filed tests, the actual travel speed explains 10 per cent and 4 percent more variability in planting error than that of bulblet damage, respectively

Vasantrao (2013) developed and evaluated a tractor operated (18.5 hp) semi–automatic onion bulb planter. The measurement was completed at a forward speed of 1.3 km/h on average 206.61 kg with wheel slippage of 20.85 per cent was the necessary draft. The actual field efficiency was 0.042 ha/h with 53.85 per cent field efficiency. It was noticed that the missing number was 8.12 per cent. The obtained seed rate was 2833 kg/ha against recommended 3000 kg/ha. It was observed that the overall cost needed for the procedure was Rs.166.82 per hour. The running cost with developed machine was estimated as Rs.3971.90 per ha. Whereas with traditional system it was Rs.8880 per hectares.

Ranjan (2014) developed a vertical plate cup type metering device for onion bulblet planter. It was observed that, at the travel speed of 0.5 to 1 km/h, the elevating error, bulb damage cup fills were lower. The elevating error was 2.22 per cent minimal, bulb damage was 0.7 percent minimum, and cell fill was 107.79 percent maximum. For the three fourth seed box filling at the travel speed of 0.85 km/h and 90^{o} cup position, metering system output was highest.

Kumari and Das (2015 b) designed and developed a tractor operated onion set planter for planting onion sets of aggregatum group onions (*Allium cepa* L.) in close-spacing. For its efficiency, the onion set planter was assessed in the laboratory. The performance indices is 0.05,0.18, 0.77,0.27, 11.71 and 5.22 cm, respectively, for multiple index, miss index, quality feed index, precision, mean and standard deviation of onion set planter. In the acceptable region, the precision was 0.27 to show the encouraging performance of the planter in terms of single-set planting. The onion sets divided into four groups. The findings reported that plant to plant spacing for grades I (2-3 g weight), II (3-4 g weight), III (4-5 g weight) and IV (5-6 g weight) on 12 DAPs are 9.34 ± 1.530, 10.35 ± 2.162, 11.50 ± 2.305 and 12.64 ± 2.758 cm, respectively. The onion set planter field capacity was 0.15 ha/h. The operation cost was Rs. 4,150/ha. Saving of 30 percent cost was observed when onion planter was used compared to manual planting.

Singh (2015) developed an inclined plate metering device for manually operated onion bulb planter. The parameters chosen are three different angles of inclinations 50^0, 60^0 and 70^0 and different peripheral speeds tested for elevating error, filling of cell and damage to the bulb. The results shows that the minimum elevating error at the angle of inclination of 50^0 was 2.27 per cent at the peripheral speed of 7.60 m/min and 10.82 percent at the peripheral speed of 45.59 as compared to 60^0 and $70^{0,}$ i.e.2.28 to 11.63 and 4.95 to 13.77 per cent at various peripheral speed (7.6 to 45.59 m/min). It also claimed that the elevating error decreased as peripheral speed increased.

Bairwa (2016) developed an inclined plate metering device for manually operated onion bulb planter. During the stationary condition and travelling speed, the experimental set-up performed satisfactorily. At the inclination angle of 50^0, the maximum cell fill was 101.04 per cent, compared with 60^0 and 70^0 at the peripheral speed of 8.2 m/min. At all inclination angles, the cell fill decreased with changes in peripheral speed. The zero bulb damage was observed at an angle if inclination of 50^0 at a peripheral speed of 8.2 m/min. Bulb damage was rises with the increase in peripheral speed. The planting distance, mean planting distance, increased planting error and decreased feed index with increase in travel speed. Actual planting distance, mean planting distance, planting error was minimum of

10.3 cm, 10.95 cm, 1.56 cm and feed index was a maximum of 95.99 per cent at a minimum travel speed of 0.6 km/h.

. Ningthoujam *et al.* (2016) designed and developed a wooden plate metering device for onion bulb planter. The elevating error, the filling of the cells, the damage of bulbs, the actual planting distance, the mean planting distance, the planting error and the feed index were evaluated with respect to the three angular positions of the metering plate at different peripheral speeds of the rotor. The elevating error was observed to be minimum (1.51 per cent) at the 50° inclination of the metering plate relative to 60° and 70° at the 7.6 m/min the Cell fill was full (100.38 per cent), but the bulb damage was observed to be zero at the angle of inclination 50° at a peripheral speed of 7.6 m/min. With an increase in rotor peripheral speed and actual planting distance, the bulb damage increased, mean planting distance, planting error was minimum 10.79 cm, 11.08 cm, 1.92 cm, with a maximum feed index of (93.17 percent) at minimum travel speed of 0.6 km/h, respectively. However, with the increase in travel speed, the actual planting distance, mean planting distance, planting error increased and feed index decreased, but the cell fill decreased at all the inclination positions with the increase in peripheral speed.

Rathore and Chaturvedi (2018) developed and evaluated an onion bulblet planter for vertisol. Onion bulblet planter performance in terms of planting depth and width, missing index percentage, multiple percentage, seed damage, actual field capacity and field efficiency. The result indicated that, the field efficiency was maximum 83.33 per cent with minimum seed damage 10.20 per cent. The multiple index was 5.10 percent, missing index was 2.2 percent and the bulb spacing in the chisel type furrow opener was 10.66 cm at 1.8 km/h speed with 17.2 per cent moisture content.

2.3.4 Onion seedling planter design

The manual transplanting of onion seedlings is one of the major operations carried out by onion cultivars. The transplanting operation represents a significant portion of the transplant seedling cost and requires high manpower. Therefore, it is very important to minimize the time and labor involved in this process.

Ghadge *et al.* (2008) designed and developed an eight-row onion transplanter. The machine worked on the principle of dropped bulbs of onion to the ground. The machine consisted of main frame, four rotary trays of 330 mm diameter, feeding chute, eight L-type furrow openers, ground wheel, seating assembly and power transmission system. The machine was operated at a speed of 0.80 km/h. The field capacity of the transplanter was 0.076 ha/h.

More (2008) developed a tractor operated semi-automatic onion transplanter. The seedlings of 50 days old were delivered manually along with fertilizer. The working width of the equipment was 1200 mm with 8 furrow openers. The 35 hp tractor operated machine moves forward and the metering mechanism of star wheel type gets the drive to release fertilizer into the tubes. The running speed of 1-1.5 km/h. The seedlings were manually delivered for planting in the delivery chutes.

2.3.5 Garlic planter design

Bartos and Holik (1985) compared planting garlic cloves, cv. Japo, using the pneumatic-mechanical unit Fahse-Accord type Monoair 80 with the most widely used tulip bulb planter (control). The pneumatic planter culminated in a markedly improved distribution and emergence spatial (aerial and depth) plants and finally a higher number of bulbs harvested. Yield, market value and quality were all dramatically increased, substantially raising the weight and amount of grade 1 bulbs.

Rocha *et al.* (1991) developed a manually operated planter for garlic bulbs placed on two bicycle wheels and fitted with a distribution system for the toothed belt. The 25 × 47 mm and 25 mm high sponge teeth were used to equip the toothed rubber belt. Bulbs were spaced at 5 bulbs per m in the field tests using the prototype equipment.

Garg *et al.* (1998) developed a manually-operated, single-row garlic planter. This was simple in design and weighed only 12.0 kg. The machine was operated by 2 persons with a hopper capacity of 3.0 kg. One person steers the machine by holding it from handle, other pulled the machine from front through a rope attached to hook on the machine. For maintaining row to row spacing machine was provided with markers. Plant-to plant spacing on the periphery of the vertical plate may be changed by differing number of spoons. With the help of 3 people, it could plant 0.3-0.4 ha per day. The estimated cost of machine Rs. 1,000, which could be recovered from 0.4 hectares. In comparison to 520 man-h/ha by the conventional system, the labour demand for sowing garlic with a machine was just 83.00 man-h/ha. Compared to Rs. 5,200/ha with the conventional methodology, the expense of machine sowing was still Rs. 858/ha.

Park *et al.* (2000) developed a garlic clove planter, which planted garlic with its blunt root portion directed towards the ground in an upright position. Garlic planting equipment was supplied to plant garlic cloves while upright state, consisting of at least one guiding hopper for guiding garlic clove with downward position and a garlic clove planting plant supplied from each of the guiding hoppers.

Jarudchai *et al.* (2002) designed and developed a garlic planter in Thailand. Initially they compared the three types (inclined, vertical plate and spring plate) of metering mechanism to meter garlic cloves. The most impressive results regarding uniformity of the metering system and low damage of garlic (0.23 per cent) were presented by the bucket type metering device. The result indicated that 0.8 meters or 8 rows was the optimum width of the garlic planter. A 5 hp power tiller was mounted to the planter and was evaluated under actual field condition. The suitable soil condition was dry soil and after planting, irrigation should be done. The highest forward speed was 2.63 km/h and the planter wheel skid was high at about 23 per cent. The turning time at the headland was 37 seconds. The planter field capacity was 0.31 ha/h and the planter capacity was 0.53 ha/man-day with three operations.

Jagtap (2005) studied on performance evaluation of manually operated single row garlic planter. The machine consisted of a planting mechanism and a wheel hand hoe mounted over a hopper. A vertical disc with spoons on its face consisted of the planting mechanism. The 12 kg was the weight of the machine. Two persons were required to operate the machine and another person was needed to supply seeds. The machine capacity ranged from 0.0115 to 0.0192 ha/h. The design of the machine was quite simple, costing Rs. 1200 in contrast to about 593 man-h/ha, it was extremely labor-saving equipment as it only needed about 136.44 man-h/ha. The cost of planting using this machine was just 36 % of the cost of the conventional manual method of planting. It was noticed that the working of single-row garlic planter was satisfactory.

Bakhtiari and Loghavi (2009) worked on innovatively designed tractor-mounted, ground-wheel driven, triple unit, row crop precision planter capable of planting three rows of garlic (*Allium sativum* L.) clove on each raised bed. Seeding mass rate, seeding depth, seed spacing, miss index, multiple index and seed damage were among the performance parameters measured/calculated during the field tests. The findings revealed that the new machine was able to plant 220,000 plants/ha at 12.30 and 22.70 cm of seeding depth and spacing, respectively. Miss index, multiple index, seed damage were also assessed as, respectively, 12.23, 2.43 and 1.41 per cent.

Jiraporn *et al.* (2010) designed and developed a tractor operated 10-row garlic planter. The metering mechanism was buckets mounted on disc. The results showed that the buckets had a maximum scoop efficiency for one clove as 90.42 % at a disk revolution of 40 r/min and at a forward speed 1.67 km/h. The seed distribution tube above ground level was 30 cm, which cam lowest variation. The field capacity was 0.13 ha/man-h and the distance between the plants (plant spacing) was 11.73 cm. The slip was 10.36 percent. The furrow openers was a shoe type, placed in two lines with spacing of 250 mm between the lines. A constant draft force of 1.05 kgf/row was given. The germination percentage was 74.57 per cent. The yield of average was 26,929 kg/ha, while planting farmers yield was 30,419 kg/ha. The manual planting, the precision value was 20.93 per cent, while the 10-row garlic planter averaged 21.0 per cent.

Anon (2010) developed a tractor-operated garlic planter at MPUAT, Udaipur center. The metering mechanism provided with star wheel type seed and fertilizer. The main features of 12-row units with a minimum row spacing of 150 mm are the two-row paired hopper and the adjustable seed rate. During testing, the observed seed rate ranged from 500 to 700 kg/ha manually, depending on the size of the garlic cloves. The distance between garlic cloves varied from 50 to 100 mm. The field efficiency, field capacity and cost of planting were 70 percent, 0.35 ha/h and Rs.1,300/ha respectively

Nare (2010) designed and developed a self-propelled triple row ground wheel driven garlic clove precision planter. The buds pointed downwards and germinated faster with a missing index of 1.04 percent and multiple index 3.23 percent, the elliptical spoon of 180º considered better. The overall difference was calculated between the actual and theoretical seed spacing along a randomly selected 2 m length of 5 rows and found that the seeds were places at an average distance of 10.12 cm, which was very close to designed spacing with SD 1.56 and a coefficient of variation of 15.36 percent

Barik (2014) designed and developed a self-propelled garlic planter. The performance parameters were 9.42 cm, 6.80 percent, 12.72 percent, 80.48 percent, 22.67 percent and 8.26 percent, respectively, such as average seed spacing, miss index, multiple index, quality of feed index, precision and seed damage. In the field assessment, the draft requirement of 0.4 kgf per row was observed. A 2.65 kW petrol engine was used as the power unit and the consumption of fuel was 0.86 l/h. When the machine operated at 1.5 km/h, the field capacity and field efficiency was 0.09 ha/h and 77.70 %. The depth of planting average was 2.6 cm and average plant population was 73.40 percent. The machine estimated cost was 50,550/- with an hourly cost of operation of Rs.213/-. Compared to manual hand planting with a cost of Rs.22, 500/- per hectare, the running cost per hectare was Rs.2370/-. This saves 87.10 per cent per hectare in turn.

Nare *et al.* (2014) designed a self-propelled garlic *(Allium Sativum* L.) clove planter. A 3 hp diesel engine was used as prime mover of the garlic planter. The theoretical field capacity (TFC) was calculated as 0.081 ha/h, at a speed of 1.8 km/h, whereas, the actual field capacity (AFC) was found to be 0.065 ha/h with field efficiency of 79.84 %. It was observed that, the placement of garlic cloves were at uniform depth under a range from 4.20 cm to 5.20 cm with a minimum SD and CV of 0.33 cm and 6.92 % respectively. The miss index, multiple index and seed damage was found to be only 2.67, 8.0 and 1.46 per cent respectively, which was within acceptable limit. Operating cost per hour of the machine was calculated as Rs.151.00/h. For sowing one ha of land the planter required Rs. 2,321.50 which was much more less as compared to manual dibbling method which required 65 man days and required additional of Rs. 2,878.00. Thus, the developed machine saves 55.35 % of money over traditional methods.

2.3.6 Potato planter design

Buitnewerf *et al.* *(*2006) studied the functioning of potato planters which were based on transport and placement of the seed potatoes by a cup belt. The capacity of this process was rather low when planting accuracy has to stay at acceptable levels. The model calculate the time interval between each successive potato touching the ground. Just before they reach the soil surface, a high-speed camera was used to calculate the time interval for each successive potato and to visualize the potato behavior. The findings revealed that (a) the higher the speed of the cup belt, the more uniform the potato depositions and (b) the higher the planting accuracy was not result by a regular potato shape. By that the opening time at the bottom of the duct and by improving the design of cups and their position relevant to duct, major improvements can be made. Although keeping while a high planting accuracy, this will create more space for changes in the cup-belt speeds.

Hossain (2009) designed and developed a power tiller operated cup type potato planter. Potato planter maintained a single row of spacing 600 mm and seed to seed distance 250 mm. The developed planter was evaluated at four speeds and three seed sizes. In terms of uniformity of spacing and missed seeds, the forward speed of 2.4 km/h was considered to be the highest. In terms of uniformity spacing, seed size of 35 mm was found better at a speed of 2.4 km/h. The actual field capacity was 0.10 ha/hr for cup type planters. Potato planting cost and labour requirement by cup type planter and conventional method were Rs.1890.0, and Rs.5600.0/ha, and 4, and 70 man-days/ha, respectively. The cup type planter saved 61 % cost and 93 % labour requirement compare to conventional method.

Gaadi and Moray (2011) conducted to evaluate the performance of auto-feed cup belt potato planter three sizes (35-45, 45-55, 55-65 mm) and operated at three forward speeds (1.8, 2.25, 3 km/h). In terms of mean tuber spacing, (m), coefficient of variation (CV), multiple index (MULTI), miss index (MISI) and quality of feed index, the efficiency of planter was assessed. The findings showed that the rise in forward speed caused significant increase in the forward spacing of tuber and a significant decrease in the uniformity of the spacing of the tuber as shown by the CV, MULTI, MISI, index values. Tuber size was also found to cause negligible effects on the mean spacing of the tuber. But it was observed that the effect of tuber size on the uniformity of tuber spacing was important. 35-45 mm tuber sizes caused greater uniformity of tube spacing than other tuber sizes tested. On the other side, the tuber shape (variety) had major effects on both the overall uniformity and tuber spacing.

Jaideep (2017) designed, developed and evaluated a potato cum sugarcane bud planter. At various combinations of forward speed and seed hopper level, the planter was assessed. In the sugarcane crop at a forward speed of 3.2 km/h and in the potato crop at 3.0 km/h combined with more than half the hopper level, the planter gave desired performance. The planter effective field capacities were 0.47 and 0.49 ha/h for potato and sugarcane crops with a 75 percent field efficiency. The results (findings) obtained from the experiment revealed that the missing and multiple index was greatly affected by the forward speed and seed hopper level. The missing index also increased as the forward speed of the planter increased, although the multiple index decreased significantly. The planter draft requirement was 450 kgf for sugarcane planting and 435 kgf for potato planting. In compared to manual planting, the planting of sugarcane buds and potato tubers by developed planter resulted in net savings of Rs. 6433 and Rs. 5141 per hectare in sugarcane and potato crops. For both sugarcane and potato planting, the labour requirement for the developed planter was three man-hours per hectare.

Malik *et al*. (2017) designed and developed an automatic potato planter for mini tractor. Agronomic results obtained during the field assessment revealed that 2 km/h forward speed, the highest effective field capacity value was reported to be 0.09 ha/h, whereas at maximum depth of 15 cm, the lowest effective field capacity value was reported to be 0.07 ha/h at 1.25 km/h. The field efficiency obtained at three different speeds and depths of sowing. It was evident, effective field capacity increased as speed decreased and maximum field efficiency recorded at 1.25 km/h. At higher speeds and higher depths, the highest missing seed percentage has been recorded. At 2 km/h and 12 cm planting depth the maximum value of missing seed percent was 8.9 percent. At higher speeds, the value of missing seed percent larger value at faster speeds to higher chain velocity that allowed the seeds lees time to fill in the cups. The missing of seed percentage at 1.25 km/h and 1.5 km/h was similar as the speeds did not vary much. At 1.25 km/h and at a depth of 12 cm, the minimum value of the lost seed per cent was stated to be 5.5 percent.

Pooja (2018) developed a power tiller operated auto feed potato planter. Three different ground wheels were taken to get different belt speed with respect to the forward speed. Optimum result with respect to average spacing, seed uniformity, miss index, multiple index, quality of feed index was achieved at forward speed of 1.2 km/h and the seed conveyer belt speed corresponding to 420 mm diameter ground wheel. Average spacing was found to be 23.96 cm. Seed uniformity was found to be 91.51 per cent .Quality of feed index was found to be 91.90 percent. Miss index was found to be 3.60. Multiple index was found to be 4.50 percent. Field evaluation of the potato planter was conducted by taking 420 mm diameter ground wheel at a forward speed of 1.23 km/h. The actual field capacity was found to be 0.051 ha/h with a field efficiency of 67.6 percent. The payback period of the potato planter was calculated to be 67 hours considering the cost of the planter unit only. The cost of the prototype potato planter was calculated as Rs. 15,100. The cost of operation of power tiller operated potato planter was found to be Rs. 285/- per hour. Comparison was made with traditional manual method of planting. There is a saving of Rs. 4,412/ha by planting with power tiller operated planter as compared to traditional practice.

2.4 Evaluation of Different Types of Planters and Seed Drills

2.4.1 Evaluation of existing seed drills and planters

Kachman and Smith (1995) the mean spacing and standard deviation of seed spacing are helpful, but the distribution of plant spacing for single seed planters is not fully characterized. In addition to the mean and standard deviation of the seed spacing, the multiple index, the miss index, the quality of feed index and the precision should be taken in to consideration since the gap between plants within row is determined by a variety of variances, including multiple seed dropped at the same time, failure to drop a seed, failure to emerge seeds and variability around the drum.

Mari *et al*. (2002) to test the efficiency of potato planters, an experiment was carried out. At low third gear rpm, the potato planter was driven by a Flat-480 diesel tractor. At a moisture content of 15.73 percent, the parameters were determined, the fuel consumption was 24.04 l/ha. The travel reduction was 5.04 per cent, field efficiency was 67.47 percent and field efficiency were 0.80 ha/h. Farmers were interested in using potato planters to grow more potatoes, since in less time it covered more area. The machine saves the labour.

Celik *et al.* (2007) seed spacing, depth uniformity and plant emergence at three forward speeds (3.6, 5.4 and 7.2 km/h), four different types of seeders were studied and evaluated. The types of planter included no-till planter, vacuum precision planters, uniform planters and semi-automatic potato planters. In addition to the means and standard deviations of the sample methods, the sowing uniformity of the horizontal distribution of seeds was describe by using the multiple index, the miss index, the quality of feed index and the accuracy. Emergence percentage, emergence rate indexes, plant emergence ratio, uniformity of planting depth were found. The best uniformity of seed spacing and seed emergence ratio was obtained with the no-till planter and the best uniformity of seed depth was obtained with the precision vacuum planter. Only the mean emergence time ($P < 0.05$) was significantly impacted by forward speed. As forward speed increase, there was a decrease in mean emergence time.

Singh *et al.* (2012) in order to evaluate their suitability, the commercial bed planter and CIAE inclined plate planter were studied and assessed for chickpea and pigeon pea planting. For *Kabuli* chickpea, the commercial and CIAE inclined plate planter resulted in a mean plant spacing of 115 mm and 136 mm compared to the set spacing of 100 mm. As compared to 27.20 per cent and 9.10 per cent in CIAE inclined plate planters, the missing and multiple seed percentage was 15.30 per cent and 7.70 percent to commercial bed planters. For both the planters that were within the permissible range of 50-60 mm for chickpea and pigeon pea, uniform seed placement depth was obtained.

Rahman (2014) performance evaluation of an inclined plate seed metering system for planting maize under a zero till drill was studied. The seed intensity, planting depth, field productivity, fuel consumption and the operational cost were calculated. The efficiency of the inclined plate seed metering device was compared with the seed metering device of flute type. The maximum number of seeds falling at 1 meter distance using an inclined plate seed metering device was 7 and the minimum number of seed falling at 1 meter distance was 5. The average seed depth was 7 cm. The uniformity index varied from 90.35 per cent to 93.87 per cent for inclined plate seed metering devices. The flute type seed metering device uniformity index ranged from 77.28 per cent to 85.16 per cent.

2.5 Concluding Remarks

The review has indicated that good amount of work on physical and mechanical properties of onion and similar crops, importance of raised bed system, effect of orientation, design aspects of different types of onion and other planters and their evaluation criteria. But it has been observed that very little work has been done on physical and mechanical properties of multiplier onion. Similarly, negligible work on effect of orientation of multiplier onion on raised beds and suitable metering system for design and development of raised bed onion bulb planter has been reported. Hence, a need was felt to design and development of a tractor operated raised bed onion bulb planter with the following work: physical and mechanical properties of onion bulbs, optimization of design and operational parameters for metering system, design, development and evaluation of raised bed onion bulb planter.

CHAPTER – III
MATERIALS AND METHODS

Planting of crop is one of the most important operations associated with crop production. Increase in crop yield and returns as well as frequency and relatively depends on the even and timely establishment of desired plant population. In this chapter the methodology adopted for fulfilling the objectives of the study entitle on "Design and Development of a Tractor Operated Raised Bed Onion Bulb Planter" has been described on following heads.

3.1 Experimental Site and Raw Material

3.2 Physical and Mechanical Properties of Onion Bulbs

3.3 To Optimize the Design and Operational Parameters of Metering System

3.4 Experimental Set Up to Optimize the Parameters of Metering Mechanism for Onion Bulb Planter

3.5 Design Considerations

3.6 Design and Development of Test Rig of Onion Bulb Planter

3.7 Experimental Procedure

3.8 Performance Evaluation of Seed Metering Mechanism in the Laboratory

3.9 Determination of Performance Parameters

3.10 Statistical Analysis for Optimizing Design and Operational Parameters

3.11 Development of Raised Bed Onion Bulb Planter

3.12 Performance Evaluation of Tractor Operated Raised Bed Onion Bulb Planter

3.13 Cost Economics

3.1 Experimental Site and Raw Material

The design and development of tractor operated raised bed onion bulb planter was carried out in the Division of Post-Harvest Technology and Agricultural Engineering, ICAR-Indian Institute of Horticultural Research, Bengaluru. The field experiment was conducted at Block No-8 of Division of Vegetable crops at ICAR-IIHR, Bengaluru, Karnataka. It is located at a latitude of 13° 58' N, longitude of 78' E and 890 m elevated above the sea level.

The onion planter to be developed under this study was considered to plant multiplier category of onion under raised bed system. The planting material are small size onion bulbs which are also called as “multiplier onion”. The freshly harvested onion bulbs are generally stored for seed purpose for next season. In general, they are stored up to a period of four months (Sumanarathe *et al*., 2002). During the planting season, the onions are cleaned and made into single bulbs from the multiplier onion. At this stage, the bunch of multiplier onion bulb weighs up to maximum 36 g.

In this study 10 kg of onion bulbs were procured from commercial onion traders/local market. The onions bulbs were cleaned, separated into single bulbs and divided into 9 categories manually based on their individual weight *viz.* <2 g, 2-3 g, 3-4 g, 4-5 g, 5-6 g, 6-7 g, 7-8 g, 8-9 g, >9 g, respectively. The majority of onions weight belongs to less than six gram (Kumari and Das, 2015). Hence, the graded onion bulbs categories of 2-3 g, 3-4 g, 4-5 g, 5-6 g were used for all the experimental purpose during this study.

3.1.1 Sample size

In this study 100 onion bulbs were randomly selected from each grade (Plate 3.1) to determine the physical properties (Maw *et al.*, 1996).

a) Procured onion from Market

b) Grading of onions on weight basis

c) Grade - I (2-3 g weight)

d) Grade- II (3-4 g weight)

e) Grade- III (4-5 g weight)

f) Grade- IV (5-6 g weight)

Plate 3.1 Graded onion bulbs

3.2 Physical and Mechanical Properties of Onion Bulbs

The knowledge of physical and mechanical properties of onion bulb is important not only for categorizing the onion bulbs into different subgroups but also for designing of different machine parts for handling bulbs. The physical properties which influence the performance of seed metering mechanism such as linear dimensions, geometric mean diameter, sphericity, shape index, projected area, one hundred onion bulb weight, bulk density, true density, moisture content, angle of repose and coefficient of friction was determined for designing of tractor operated raised bed onion bulb planter. Linear dimensions of onion was required for designing of cup length and depth. It was also required for cup width to maintain number of bulbs to be over cup area of bulb from the cup surface. Angle of repose and coefficient of friction properties were determined to decide the slope for free flow of onion bulb from hopper. Bulk density and true density values are important to decide thickness of material of construction of seed hopper as well as design of seed hopper volume. The one hundred onion bulb weight was required to determine the number of bulb per square meter area for a desired seed rate. The nine onion grades *viz.*, <2 g, 2-3 g, 3-4 g, 4-5 g, 5-6 g, 6-7 g, 7-8 g, 8-9 g, >9 g, were selected to determine physical and mechanical properties. The physical and mechanical properties were determined as per the procedure given below:

3.2.1 Physical properties of onion bulbs

The following physical properties of onion bulbs were measured.

i) Linear dimensions - Length, width, thickness,

ii) Geometric mean diameter (D_p)

iii) Sphericity (ϕ)

iv) Shape index

v) Projected area

vi) One hundred onion bulb weight

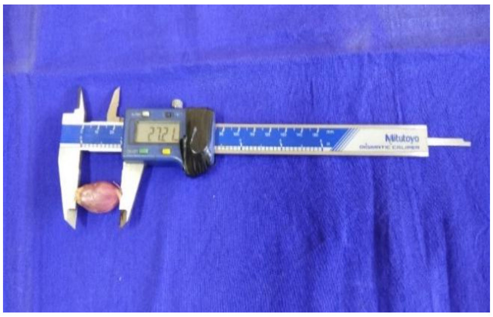
vii) Bulk density

viii) True density

ix) Moisture content.

3.2.2 Linear dimensions of onion bulbs - length, width and thickness

Size is necessary to describe any object defined with some dimensional parameters. The geometric dimensions of onion bulbs namely length, width and thickness were determined. One hundred onion bulbs were selected randomly and the geometric dimensions were measured by using digital Vernier caliper (Mitutoyo DIGIMATIC CALIPER 500-144CN-10) (Mitutoyo Corporation, Japan) having least count 0.01 mm (Plate 3.2).



a) Measurement the length

b) Measurement of width

c) Measurement of thickness

Plate 3.2 Measurement of linear dimensions of onion bulb

Average length (L), width (W) and thickness (T) were calculated as suggested by (Singhal and Samuel, 2003).

$$L = \frac{\sum_{i=1}^{n} L}{n} \qquad \text{- - - (3.1)}$$

$$W = \frac{\sum_{i=1}^{n} W}{n} \qquad \text{- - - (3.2)}$$

$$T = \frac{\sum_{i=1}^{n} T}{nn} \qquad \text{- - - (3.3)}$$

Where,

L = Length, mm,

W = Width, mm and

T = Thickness, mm.

3.2.3 Geometric mean diameter (D_p)

The geometric mean diameter (D_p) was calculated by using the following relationship (Mohsenin, 1986).

$$D_p = (LWT)^{1/3} \qquad \text{- - - (3.4)}$$

Where,

L = Length, mm,

W = Width, mm and

T = Thickness, mm

3.2.4 Sphericity (ϕ)

Sphericity defines the ratio of the diameter of a sphere of the same volume as that of particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle (Sahay and Singh, 1994). This parameter shows the shape character of onion bulb relative to the sphere having the same volume.

$$\text{Sphericity} = \sqrt{\frac{\text{Volume of the onion bulb}}{\text{Volume of circumsribed sphere}}} = \frac{(LWT)^{1/3}}{L} \qquad \text{- - - (3.5)}$$

Where,

L = Length, mm,

W = Width, mm and

T =Thickness, mm

3.2.5 Shape index

Shape index was used to evaluate the shape of onion bulbs for all the nine categories of onion bulbs and it was calculated using the following equation (Abd Alla, 1993).

$$\text{Shape index} = \frac{D_e}{\sqrt{D_p \times T}} \qquad \text{- - - (3.6)}$$

Where,

D_e = Length, mm,

D_p = Width, mm and

T =Thickness, mm

The onion bulbs would be considered an oval if the shape index >1.5., on the other hand, it would be considered spherical if the shape index <1.5.

3.2.6 Projected area

Twenty onion bulbs were randomly selected from each graded category. The bulbs were placed on a graph sheet and outer line was marked on the graph sheet. The projected area of onion bulb was determined by counting the number of squares inside the marked line. The onion bulbs were kept in an orientation that ensured maximum projected area. The procedure was replicated five times for each graded category of onion bulbs (Mohsenin, 1986).

3.2.7 One hundred onion bulbs weight

One hundred onion bulbs were randomly selected from each graded category and weight was measured (Plate 3.3) with an electronic balance (Model PS200/2000/C/2 - RADWAG, Poland) with an accuracy of ± 0.001 g. This procedure was replicated five times for each graded category of onion bulbs (Kumari and Das, 2015).

Plate 3.3 Measurement of 100 onion bulbs weight

3.2.8 Bulk density

The bulk density of onion bulb was determined by using container of cube shape 12.5×12.5× 13 cm (l×w×h). The onion bulbs were dropped into the containers from a height of approximately 15 cm. The excess bulbs were removed by sweeping the top surface of the container and care was taken that the bulbs were not compressed in any way while sweeping. Then the samples in the container were weighed by using an electronic balance (Plate 3.4). The bulk density was calculated using the equation (Mohsenin, 1986). This procedure was replicated for five times and the mean values were reported. The bulk density of onion bulbs was calculated by using the following formula.

$$\text{Bulk density} = \frac{\text{Weight of the seed onion (g)}}{\text{Volume of seed onion (cc)}} \qquad \text{- - - (3.7)}$$

a) Filling of onion in cube shape

b) Measurement of weight of onion

Plate 3.4 Measurement of bulk density

3.2.9. True density

The true density of onion bulb was determined by using the liquid displacement method. The solvent Toluene (C_7H_8) was used to determine the true density of onion bulbs (Sitkei, 1986; Singh and Goswami, 1996). The known volume of toluene was taken in a 100 ml measuring cylinder and twenty individual onion bulbs of nine grades were weighed and each grade onion was dropped into the measuring cylinder. The change in volume describe the true density of onion bulb (Plate 3.5). This procedure was replicated five times. The true density of the sample was calculated using the formula given below (Mohsenin, 1986).

[True volume of bulb] (cc) = [Final toluene level] - [Initial toluene level]"

$$\text{True density (kg/m}^3\text{)} = \frac{\text{Weight of bulbs (kg)}}{\text{True volume of bulbs (m}^3\text{)}} \quad \text{- - - (3.8)}$$

3.2.10. Moisture content

As change in moisture content can change in physical properties of seeds e.g. length, width, size *etc.* size of seeds plays a significant role in design of seed metering device (Plate 3.6). To determine the moisture content of sample, the onion bulbs were cut into thin slices of 1-2 mm. 10 g of slices was weighted in an electronic balance to a precision of 0.01 g, and kept in hot air oven at 60±2° c. The moisture content was determined by using standard procedure of (AOAC, 1970).

$$\text{M.C. (w. b.)} = \frac{W_w - W_d}{W_w} \times 100 \quad \text{- - - (3.9)}$$

Where,

M.C = Moisture content on wet basis, %

W_w = Initial mass of sample, g and

W_d = Final mass of sample, g.

a)Toluene solution

b) Filling of onion in cylinder

Plate 3.5 Measurement of true density

a) Onion bulbs before moisture content b) Onion bulbs after moisture content

Plate 3.6 Measurement of moisture content

3.2.11 Mechanical properties of onion bulbs.

The following mechanical properties of onion bulbs were determined as it was required to design the hopper of the onion bulb planter.

i) Angle of repose
ii) Coefficient of static friction.

3.2.11.1 Angle of repose

Angle of repose is one of the important mechanical property needed for the design of hopper system. A metal container having 125×125×200 mm (l × b × h) was used to measure angle of repose of onion bulbs. A removable front panel with 200 mm height and 125 mm width was used to release the material sideways. The container was filled with the onion bulbs, levelled and then the front panel was quickly slid upwards allowing the onion bulbs to flow down. The angle of repose was calculated by considering maximum depth of free fall surface of the sample and length of the box (Plate 3.7). The angle of repose of the sample was calculated using the formula given below (Mohsenin, 1986). The procedure was replicated five times with different samples and the mean was calculated.

$$\text{Angle of repose} = \tan^{-1}\frac{\text{Height of sample}}{\text{Length of sample}} \qquad \text{- - - (3.10)}$$

3.2.11.2 Coefficient of static friction

The coefficient of static friction (μ_s) is very important in the field of bulk storage, quality and handling of equipment in industry. The coefficient of static friction (μ_s) of onion bulbs was determined with respect to each of the following three structural materials such as plywood, galvanized iron sheet and mild steel sheet. The bulbs were placed on the test surface at the top edge. The inclined surface was tilted until the samples begin to move leaving the inclined surface. The angle of inclination to the horizontal was measured directly on the instrument scale and it was taken as angle of internal friction. The tangent of the above angle was taken as co-efficient of friction between the test surface and onion bulb sample (Plate 3.8). This procedure was repeated five times for each structural material with each grade of onion bulbs. The coefficient of friction was calculated as the tangent of the angle using the equation given below (Mohesenin, 1986)

$$\mu_s = \tan\theta \qquad \text{- - - (3.11)}$$

Where,

μ_s = Co-efficient of static friction

θ = Angle of inclination of material surface, degree

Plate 3.7 Measurement of angle of repose

Plate 3.8 Measurement of coefficient of friction

3.3 To Optimize the Design and Operational Parameters of Metering System

3.3.1 Studying the growth parameters of onion bulbs while planting at different orientations

It is a documented practice that during manual planting as the root portion of the onion bulb is pressed down in to the wet soil, the germination percentage will be as high as 100 % (assuming 100 % viability of onion bulb). However, when the onion bulb is dropped by any mechanical planting mechanism (Mechanical planter), there are chances the bulbs would be planted in any one of the following four orientations a) root portion down b) root portion up c) inclined and d) horizontal orientation (Plate 3.9). To understand the effect of orientation on growth of onion bulbs in terms of germination percentage, plant height and yield a field experiment was planned and conducted during both Rabi and Kharif season. The design of experiment was Randomized Block Design (RBD) having four treatments and five replications. The following crop growth parameters were observed

i) Germination percentage at 7 and 15 days after planting (DAP)

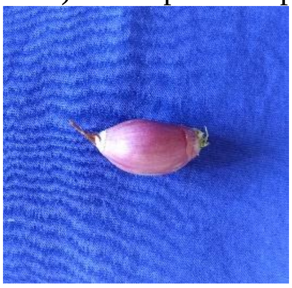
ii) Plant height at 15 and 30 days after planting (DAP)

iii) Yield at harvest

a) Root portion down

b) Root portion up

c) Root portion inclined



d) Root portion horizontal

Plate 3.9 Different orientation of onion bulbs

3.3.2 Rabi season

The field experiment was conducted at Block No-8 of Division of Vegetable crops at ICAR-IIHR, Bengaluru, Karnataka. A raised bed of 45 m length and 0.9 m width was prepared. The planting was done on 14. 01. 2019 with plant to plant spacing of 10 cm and row to row spacing of 15 cm as per recommended practice. The experiment had four treatments of planting positions *viz.*, T_1- Root portion up, T_2-Root portion down, T_3-Horizontal, T_4-Inclined and five replications. Each replication has a bed of 2 m length and 0.9 m width, a gap of 0.1 m was given in between two replications. In each replication 80 bulbs are planted as per recommended practice and its layout is shown in Fig. 3. 1. The crop was raised by following standard package of practices shown in (Plate 3.10). The observations were recorded *viz.*, percentage of germination on 7th and 15th days after planting (DAP)), height of plant 15th and 30th DAP and yield. The data was statistically analyzed. Plate 3.11 is showing how the germination was affected when root portion was in upward direction. Plate 3.12 is highlighting growing of onion under different orientations.

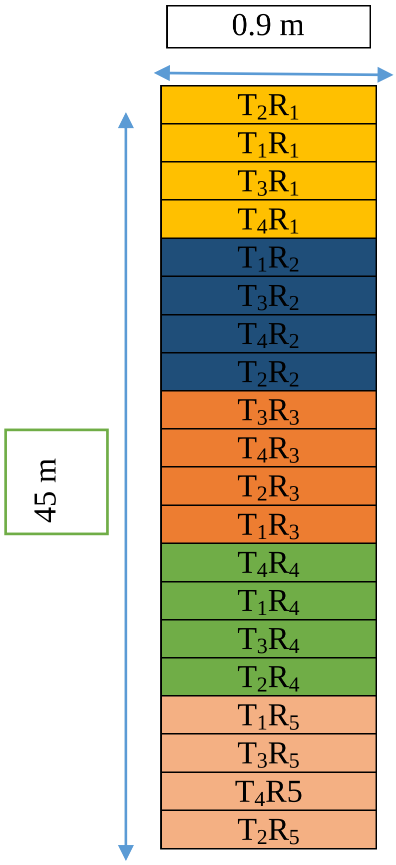


Fig 3.1 Field layout of crop in the rabi season

a) Planting of onion bulbs

b) Weeding

c) Spraying

d) Germination counting

e) Plant height measurement

f) Harvesting

g) De- topping

h) Grading

Plate 3.10 Different operations performed in cultivation of onion crop in the Rabi season

Plate 3.11 Germination of root portion up

a) Root portion up

b) Root portion down

c) Horizontal

d) Inclined

Plate 3.12 Growing of onion crop in different orientation

3.3.3 Kharif season

The experiment was carried out with a 47 m length and 0.9 m width on raised bed with plant to plant spacing of 10 cm and row to row spacing was 15 cm. Date of planting was 5. 06. 2019. The experiment had similar four treatments and five replications as of rabi for planting positions. Each treatment had 2.2 m length and 0.9 m width of bed, 88 bulbs were planted in each treatment (Totally 1760 bulbs) in the Block No-8, Division of Vegetable Crops at ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka. The design of experiment was Randomized Block Design (RBD). The field layout is shown in (Fig 3.2).

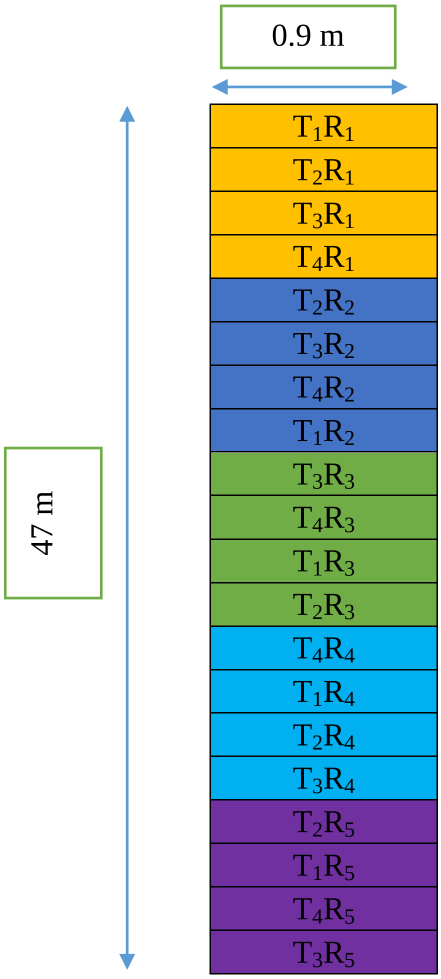


Fig 3.2 Field layout of crop in Kharif season

The crop was raised by following standard package of practices shown in (Plate 3.13). The following observations were recorded viz., germination efficiency on 7th and 15th days after planting (DAP)), height of plant 15th and 30th DAP and yield.

a) Planting of onion bulbs

b) Weeding

c) Spraying

d) No of plants counting

e) Height measurement

f) De topping of onion

i) Grading of onion bulbs

j) Final grading

k) Total field of onion

Plate 3.13 Different operations performed in cultivation of onion crop in the kharif season

3.4 Experimental Set Up to Optimize the Parameters of Metering Mechanism for Onion Bulb Planter

Amount of seeds in a row is an important factor in crop production, which can affect growth and yield and this to a great extent depending on the performance of the metering mechanism of the seed drill/planter. Therefore, proper design of a metering mechanism device is an essential element for satisfactory performance of seed drill/planter. Metering mechanism, is the heart of a sowing for any machine, which distributes seed uniformly at a desired application rate with minimum damage. In case of planters the metering mechanism precisely controls seed spacing in a row. Devices for metering the seed in case of planter usually have cells on a moving member to have positive seed metering. The commonly recommended metering system on planters are horizontal plate, inclined plate, vertical rolls with cells etc. (RNAM, 1991).

3.4.1 Onion bulb planter metering mechanism

Planting equipment's with inclined plate seed metering devices are used in India and many developing countries for planting of peanut (*Arachis hypogaea*), chickpea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*) and maize (*Zea manys*) crops. After reviewing and studying the different mechanism adopted for planting bold seeds, garlic and onion bulbs cup type metering mechanism was considered as metering mechanism for planting multiplier onion bulb.

3.4.2 Laboratory experimental set up to optimize the parameter of onion bulb planter

In order to achieve the uniformity in seed spacing and accuracy in seed rate, cup type metering mechanism was adopted, which result in maximum cell fill efficiency and minimum seed damage and adjust the forward speed of the planting equipment to obtain the recommended seed rate and spacing. The experimental set up/ arrangement according to different metering related parameters was developed.

3.5 Design Considerations

The crop and machine parameters were very important for the design of onion bulb planter. Following were crop and machine parameters.

3.5.1 Crop parameters

Under the crop parameters, the size of the onion bulb was considered as important for the design and development of raised bed onion bulb planter.

3.5.2 Machine parameters

Review suggests that forward speed, inclination of seed metering plate and cup size are important parameters which influences the performance of the planting machine. Hence under the category of machine parameters, for judging the performance onion bulb planting machine forward speed of operation, inclination of seed metering plate, cup size of different shape is selected as variable’s under study.

3.5.2.1 Forward speed of operation

The performance of a planter depends on the forward speed of operation which effects on the following performance parameter such as per cent singles, per cent doubles, per cent multiples, per cent missings and bulb damage. In this experiment four forward speeds *viz.*, S_1 (0.5 km h^{-1}), S_2 (1 km h^{-1}), S_3 (1.5 km h^{-1}), S_4 (2 km h^{-1}) were selected. Literature suggests that if the forward speed is high, the cup cannot hold the onion bulbs in the cup whereas if the forward speed is low the cup can hold multiple onion bulbs in the cups. The measurement of rpm of the machine is shown in (Plate 3.14).

Plate 3.14 Measurement of rpm of machine

3.5.2.2 Angle of inclination of seed metering mechanism

The cell fill is affected by angle of inclination of seed metering mechanism**.** Seed rate and spacing parameters are influenced by seed metering mechanism of angle of inclination. In this experiment three angle of inclinations *viz.*, A_1 (60°), A_2 (75°) and A_3 (90°) were chosen. Three different seed boxes were fabricated with each of mild steel sheet of 1 mm thickness to hold 1 kg of onion bulbs in the seed box. If one angle of inclination of seed box is used for other two angle of inclination, the cup cannot pick the onion bulb due to clearance between the box and cup. Due to this reason for three different angles, three different types of seed boxes were fabricated those boxes are shown below (Plate 3.15).

a) Angle of inclination at 60° | b) Angle of inclination at 75° | c) Angle of inclination at 90°

Plate 3.15 Different angle of inclination of seed box

3.5.2.3 Cup size

The cup size is very important parameter in the onion bulb planter, if wider cup were selected it may hold multiple bulbs, smaller if selected it may cause to bulb damage or cannot hold the onion bulb properly. Four different sizes of cups were selected and the length, width and depth are presented in the table 3.2 and size of cups are shown below (Plate 3.16, 3.17, 3.18, and 3.19).

Table 3.1 Specifications of different types of cup for laboratory investigations

Dimensions	Cell configuration			
	Cup type 1 C_1	Cup type 2 C_2	Cup type 3 C_3	Cup type 4 C_4
Length, mm	34	31	29	25
Width, mm	26.6	31	29	25
Depth, mm	14	18	8	13

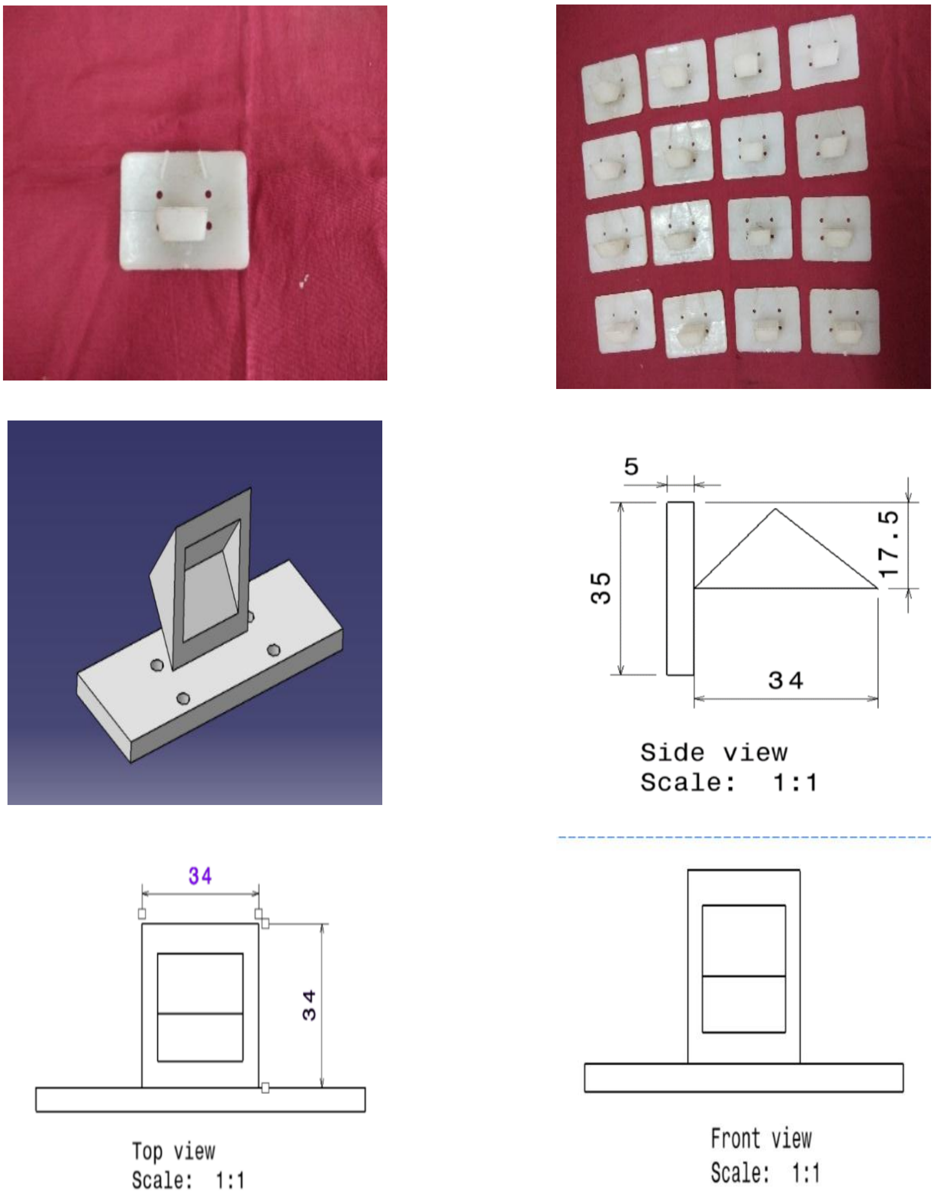


Plate 3.16 Cup 1 (34 mm)

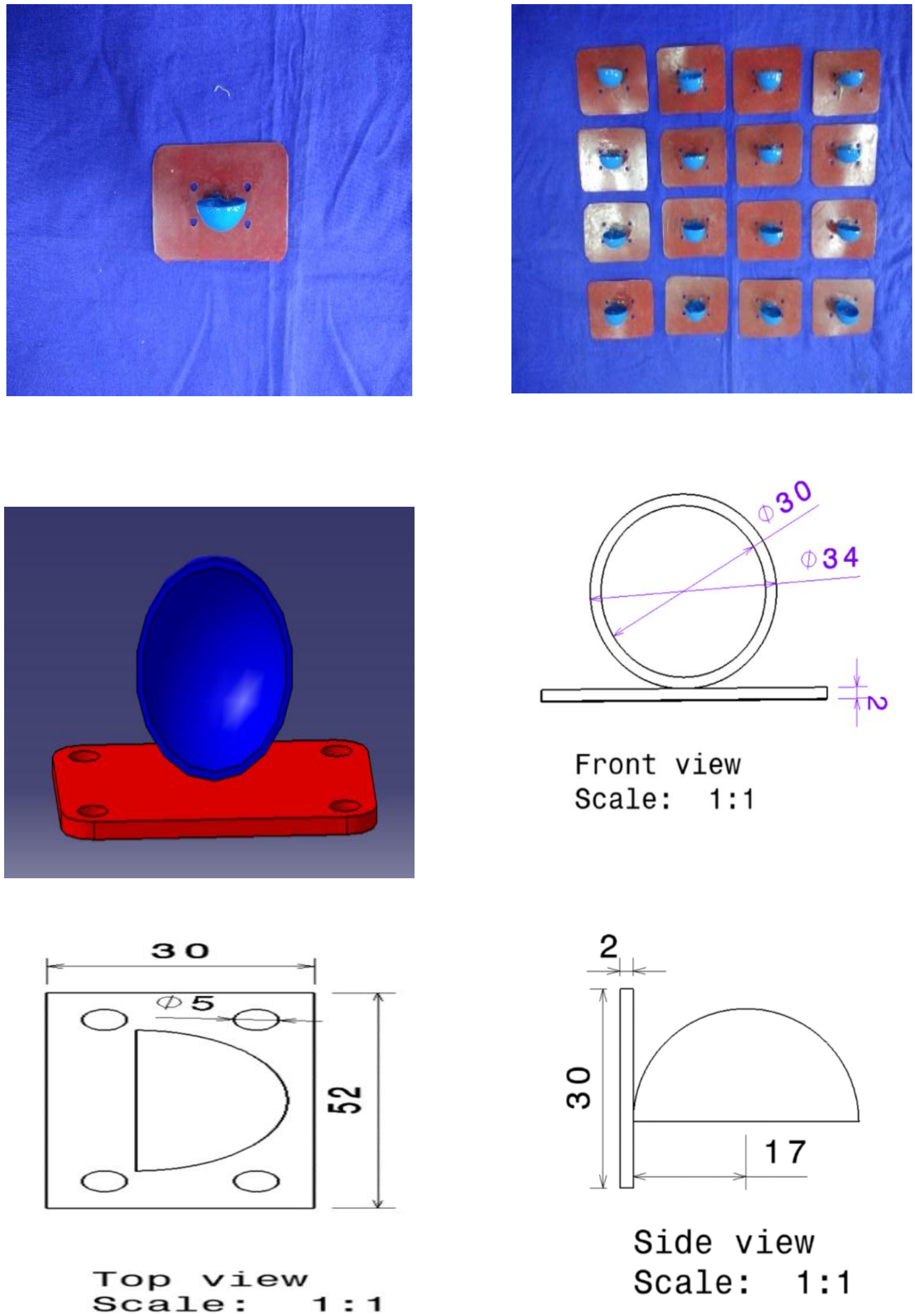


Plate 3.17 Cup 2 (31 mm)

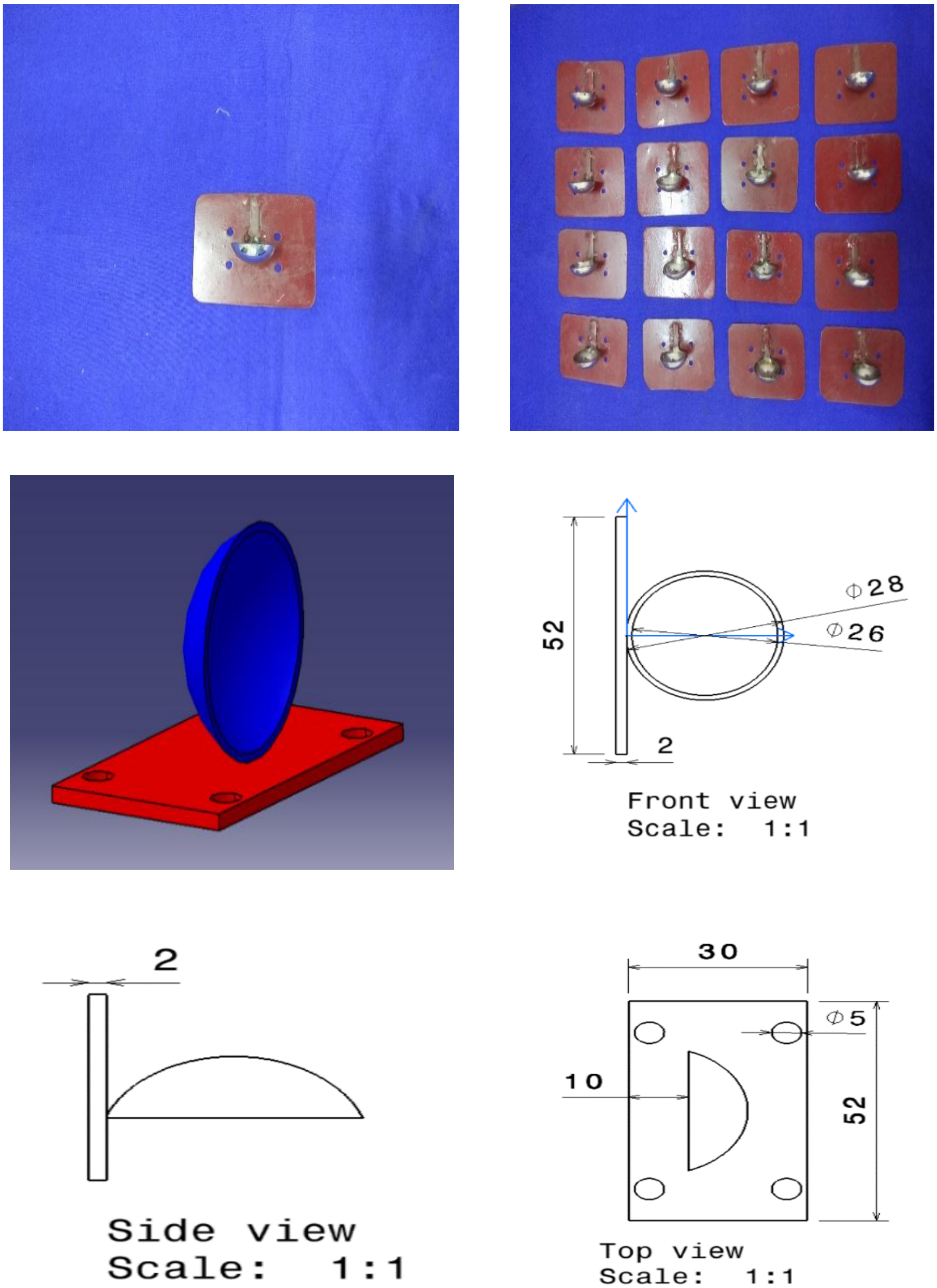


Plate 3.18 Cup 3 (29 mm)

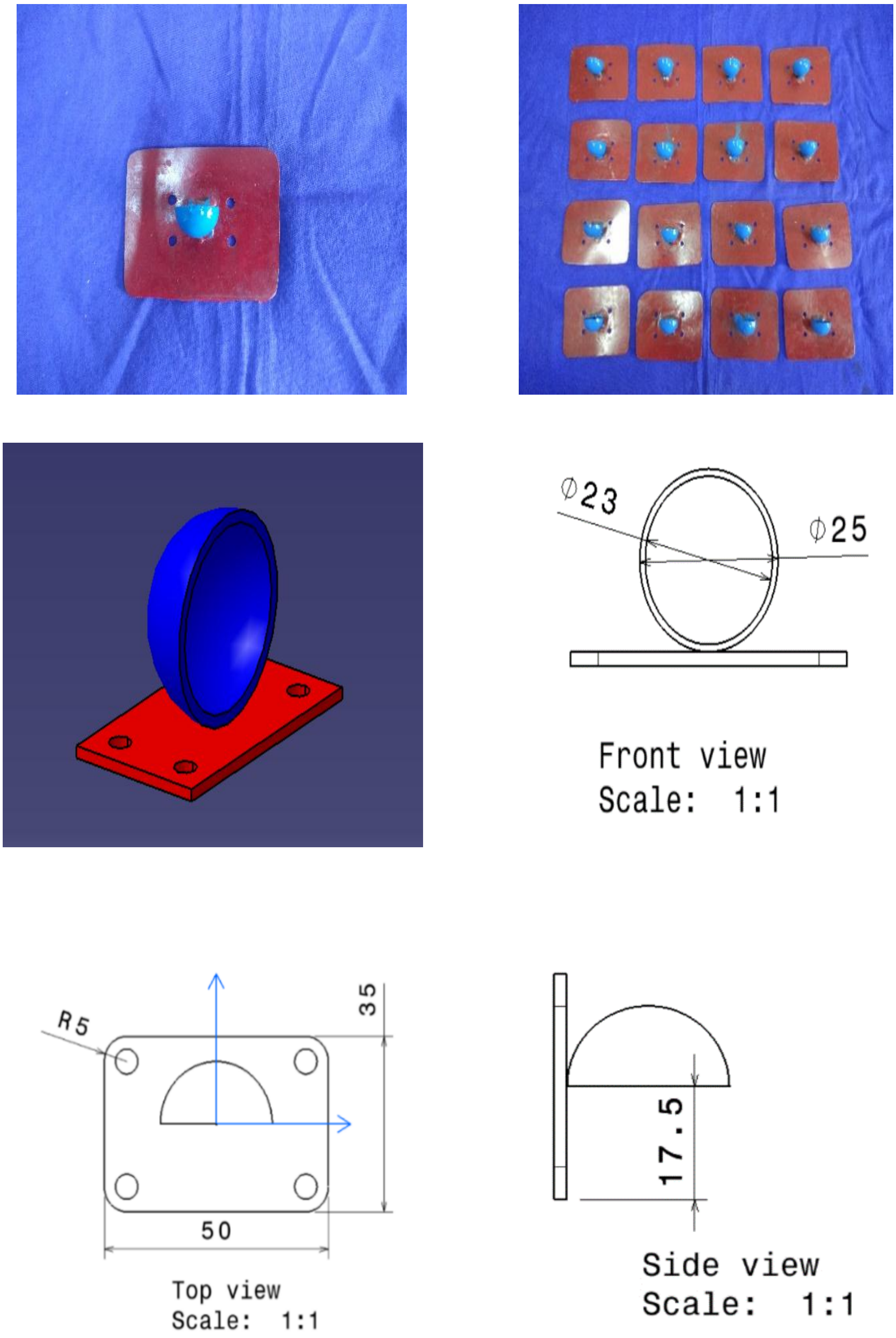


Plate 3.19 Cup 4 (25 mm)

3.5.2.4 Onion size

As stated in section 3.1.1 four sizes of onion bulbs i.e. 2-3 g, 3-4 g, 4-5 g and 5-6 g were selected for planting purpose. Hence, based on size of the onion bulbs from 2-3 g to 5-6 g, four cup sizes were chosen for optimizing the suitable cup size for the onion bulb metering mechanism.

Table 3.2 Mean dimension of onion bulb

Weight, g	Size, mm			
	Length	Width	Thickness	Geometric mean diameter
2-3	23.24	15.52	12.16	16.31
3-4	23.94	17.37	13.27	17.60
4-5	26.20	20.98	16.38	20.73
5-6	27.62	22.57	17.67	22.16
Mean	25.25	19.11	14.87	19.20

3.6 Design and Development of Test Rig of Onion Bulb Planter

3.6.1 Experimental setup

A test rig was fabricated for optimizing the design and operational parameters of onion bulb planter. The experimental set up consists of main frame, rollers, conveyor belt, power transmission system and seed metering unit. The description of the various components of the experimental setup is given below:

The main frame was rectangular in section of 10 × 0.2 × 0.5 m (L×W×H) fabricated out of 25 × 25 × 5 mm (L×W×T) Mild Steel "L" angle (Plate 3.20). Two Rollers, each having diameter of 116 mm (OD), Length of 150 mm was fabricated out of seamless pipe. The rollers were mounted on the main frame at both the ends with necessary bearings (P-205) and fasteners (Plate 3.21). The conveyor belt (canvas belt) having length 20 m, width 0.1 m and thickness 0.06 m. The belt was fitted between the two rollers and joined by comb (Plate 3.22). The belt was supported by necessary Idlers. The conveyor belt was powered by electric motor of 3 phase 2 HP, 75 Rpm (Model: 1PC 142/12.5/200-24, SR NO: 130604000024566) as shown in (Plate 3.23). Power transmission system consisted of pulleys and belt to transmit power from motor to conveyor belt.

Plate 3.20 Main frame

a) Roller

b) Tightening of belt

Plate 3.21 Roller with sticky belt

Plate 3.22 Joining of belt with comb

Plate 3.23 Electric motor

3.6.2 Calculation of diameter of pulley of sticky belt

On the basis of literature and review four forward speeds *viz.*, 0.5, 1, 1.5, 2 km h^{-1} were selected for optimizing the operational speed of onion bulb planter. The diameter of the pulley to be used to achieve the above forward speed of metering unit was calculated as explained below:

3.6.3 Calculation of speed of pulley of sticky belt

Plant to plant spacing of onion bulb = 10 cm

No. of onion bulb to be dropped per meter length of run = $\frac{1\text{ m}}{0.1\text{ m}}$= 10 Nos - - - (3.12)

In 1 m distance 10 onion bulbs will be dropped

Hence, in one-meter travelled distance, 10 onion bulbs need to be dropped.

When the forward speed is 0.5 km h^{-1}

Number of onion bulbs need to be dropped

$$= \frac{0.5 \times 1000\ (\text{m}) \times 10}{\text{m}} = 5000 \text{ bulbs h}^{-1} \quad \text{- - - (3.13)}$$

$$= \frac{5000}{60} = 83.3 = 83 \text{ onion bulbs min}^{-1} \quad \text{- - - (3.14)}$$

Total no. of cups on the metering unit was 17

Hence, the required rpm by the metering unit to drop 83 bulbs/min = $\frac{83}{17}$ = 4.88

$$= 4.90 \text{ rpm} \quad \text{- - - (3.15)}$$

Linear distance of metering mechanism was 1.2 m

Therefore, the linear speed of metering unit

$$= 4.90 \times 1.2 \text{ m} = 5.88 \text{ m min}^{-1} \quad \text{- - - (3.16)}$$

Assume diameter (D) of pulley was 3 inches = 0.076 m

Hence, the required rpm by the pulley to achieve 0.5 km h^{-1} forward speed by the metering unit $= \pi \times d \times N = 5.88 \text{ m min}^{-1}$ - - - (3.17)

$$= \pi \times 0.076 \text{ m} \times N = 5.88 \text{ m min}^{-1}$$

$$N = 24.62 \text{ rpm} = 25 \text{ rpm}$$

Similarly, for speed of 1, 1.5, 2 km h^{-1}, the rpm of pulley was calculated and arrived as 49, 73, 98 rpm.

3.6.4 Calculation of diameter of pulley at speed 0.5 km/h

Label on the rpm of electric motor was (N2) = 75 rpm,

Initially diameter of pulley on the motor assumed was (D2) = 0.0762 m (3"),

Diameter of pulley of sticky belt (D1) = x (assumed)

RPM of pulley of sticky belt (N1) = 25 rpm (speed was calculated above 3.17)

Then diameter of pulley of sticky belt was calculated by

$$N1D1 = N2D2 \quad \text{- - - (3.18)}$$

$$25 \times x = 75 \times 0.0762$$

$$x = 0.22 \text{ m } (9")$$

So, diameter of pulley of sticky belt will be 0.22 m (9”)

Similarly, for speed of 1, 1.5, 2 km h^{-1} diameter of pulley of sticky belt was 0.10 m (4”), 0.076 m (3”), 0.050 (2”).

3.6.5 Components of seed metering unit

The seed metering unit consists of (Plate 3.24) followings

i. Seed box
ii. Elevator with cup
iii. Sprocket and chain

Plate 3.24 Final seed metering unit

Seed hopper was fabricated out of mild steel sheet having thickness of 1 mm. Three types of hopper boxes were fabricated suitable for 3 inclinations *viz.*, A_1 (90°), A_2 (75°) and A_3 (60°) with each of the hopper to hold one kg of onion bulbs (Plate 3.27, 3.28 and 3.29). A chain (k-2 type) was used as elevator (Plate 3.26) for metering the onion bulbs. The length of chain was 135 cm, number of hubs on the chain was 17 to hold 17 cups having center to center distance between hub was 8 cm. Four sizes of cups were selected as presented in the table (3.3). A holder plate for fixing the cups was fabricated. The cups were fitted to holder plate and the plates were fitted to the chain with necessary fasteners. This system was fitted to a pair of sprockets (Plate 3.25) and mounted on the shaft with necessary bearings (FL-205) and fasteners. A seed tube was fitted at the delivery mouth of the elevator thus the metered seeds were guided to fall on the sticky belt. The seed tube had diameter of 60 mm (OD) and thickness 5mm of braided PVC material (Plate 3.30).

3.6.6 Theoretical volume of hopper

Hopper capacity was calculated on the basis of the quantity of material to be filled in the hopper with following relationship (Sharma and Mukesh, 2013).

$$V_b = 1.1V_s \qquad \text{- - - (3.19)}$$

$$\text{and } V_S = \frac{W_s}{\rho s} \qquad \text{- - - (3.20)}$$

Where,

V_b =Volume of hopper, cm^3

V_s = Volume of seeds, cm^3

ρ = Bulk density of seeds, kg m^{-3}

W_s= Weight of seeds in the box, g and

Ps= Density of seeds. g cm^{-3}

For light weight and easy operation let 1 kg of bulbs filled in the box then volume of seed box become

$$V_b = \frac{1.1 \times 1 \times 1000}{0.620} = 1774.19 \text{ cm}^3 \qquad \text{- - - (3.21)}$$

Capacity of seed box,

$$Q = V_b \times \rho \qquad \text{- - - (3.22)}$$

$$Q = 0.00177419 \times 620 \text{ kg/m}^3 \text{ So, } Q = 1.099 \text{ kg.}$$

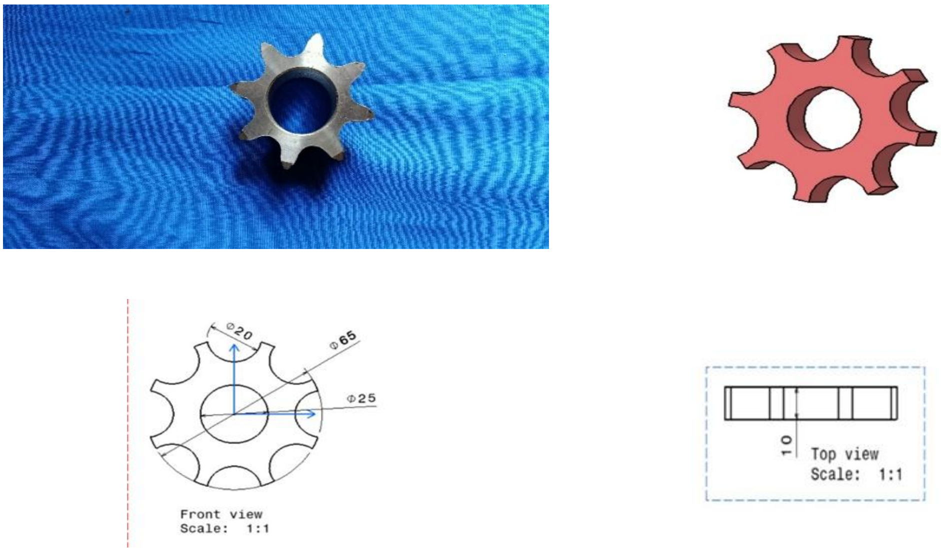


Plate 3.25 Sprocket

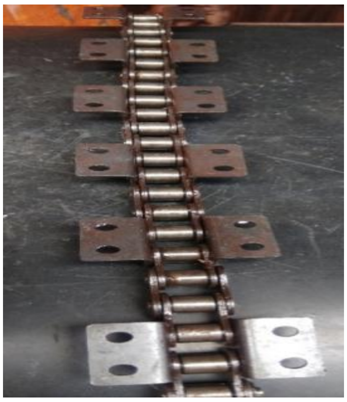


Plate 3.26 Chain

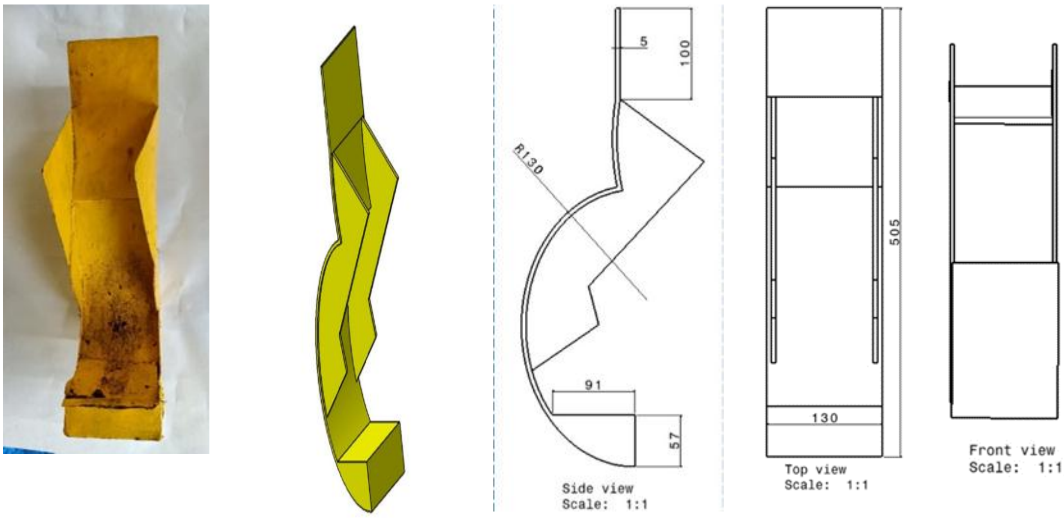


Plate 3.27 Hopper for 90^0

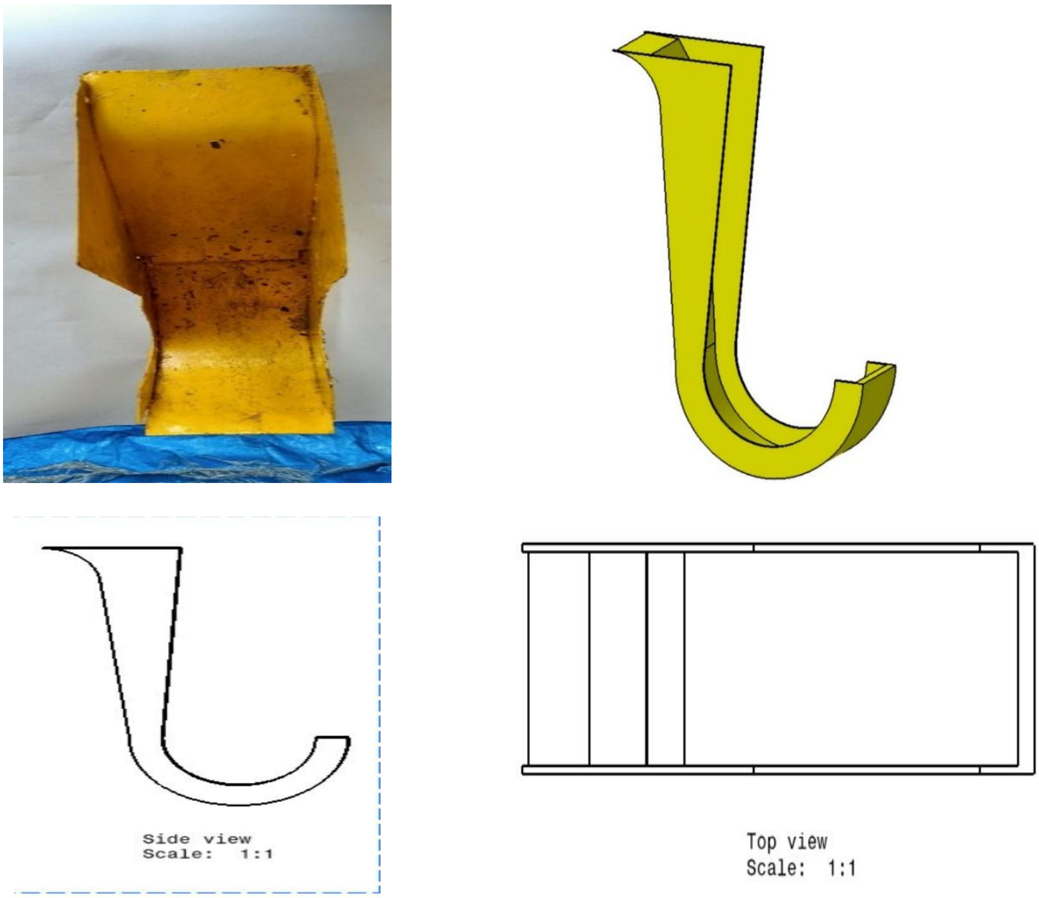


Plate 3.28 Hopper for 75°

Plate 3.29 Hopper for 60°

Plate 3.30 Seed tube

3.7 Experimental Procedure

The experiment was conducted on the sticky belt (Plate 3.31) as per the variables selected (Table 3.3). Initially one cup size was fixed on the chain by using screw system. Seed box was fixed at the bottom of seed metering unit at one angle. On the main frame mild steel flat of 500×25 ×3 mm (L×W× T) was welded and 10 mm diameter of hole was made on it and square tube with 1 inch was welded on flat plate of metering unit. Different angle of inclination (height) was adjusted by bolt with thread system between square tube and flat which was welded on main frame. The seed delivery tube was attached bottom back side of metering mechanism. The distance between the seed tube and sticky belt was kept minimum to avoid bouncing of seeds on the sticky belt. Grease with thickness of 3 mm was smeared on top surface of the sticky belt so that the delivered onion bulbs get stuck on the belt. The sticky belt was operated at desired speed by changing pulleys of different sizes. When the sticky belt with onion reached at end of the main frame, the belt was stopped. The distance between fallen onions were measured. The following performance parameters such as per cent singles, per cent doubles, per cent multiples, per cent missing and per cent bulb damage was determined. The experiment was carried out for different onion sizes, different angle of inclination (height) and forward speed of operation and observations were recorded. The experiment was repeated for three replications.

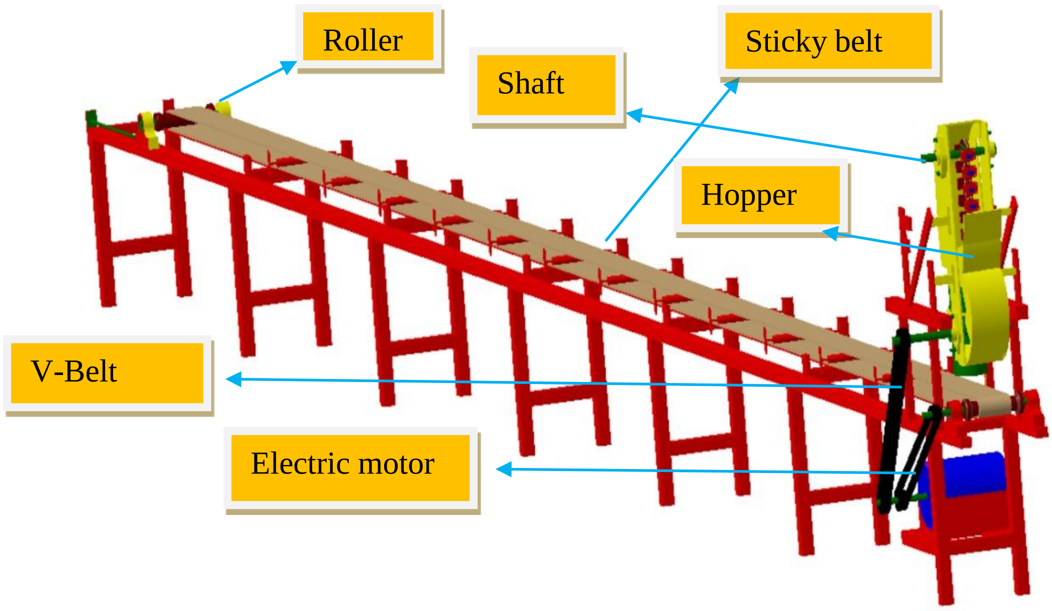


Plate 3.31 Experimental set up to optimize the parameters of metering mechanism for onion bulb planter

3.8 Performance Evaluation of Seed Metering Mechanism in the Laboratory

The laboratory test was carried out to optimize the cup size, forward speed and angle of inclination of metering unit suitable for all the four sizes of onion bulbs. The experimental plan describing the independent and dependent parameters is given in the table 3.3. The independent and dependent parameters were selected on the basis of review of literature to optimize the seed metering mechanism.

Table 3.3 Design of experimental Plan

S. No.	Independent variables	Levels	Observations
1.	Onion size	4 (2-3, 3-4, 4-5, 5-6 g)	1. Per cent singles
2.	Cup size	4 (C_1, C_2, C_3, C_4)	2. Per cent doubles
3.	Forward speed	4 (0.5, 1, 1.5, 2 kmph)	3. Per cent multiples
4.	Angle of inclination	3 (90°, 75°, 60°)	4. Per cent missing 5. Percent bulb damage
	Total no. of replications - 3		
	No. of experiments		= 4 ×4×4×3×3 = 576

3.9 Determination of Performance Parameters

The dependent performance parameters such as per cent singles, per cent doubles, per cent multiples, per cent missing, per cent bulb damage were evaluated (Plate 3.32) at each of the selected levels of forward speed, angle of inclination of seed metering mechanism, cup shape and onion size. The performance parameters were calculated in the following manner.

Plate 3.32 Testing of the onion bulbs on sticky belt

3.9.1 Multiple index

Multiple index (D) includes two or more seeds picked and dropped by the seed metering unit by a single hole in the metering plate. The multiple index is an indicator of more than one seed dropped within a desired spacing. It is the percentage of spacing that are less than or equal to half of the theoretical spacing. The objective is to minimize multiples to save cost of seeds and to subsequently reduce the labour required for thinning the extra plant population (Grewal *et al.*, 2015 and Singh *et al.*, 2012).

$$D = \frac{n_2}{N} \qquad \text{- - - (3.23)}$$

Where,

n_2 = Number of spacing that are less than or equal to half of the theoretical spacing in the given observations

N = Total number of observations.

3.9.2 Missing index

Missing index (M) indicates that the incapability of seed metering unit to drop even a single seed within the desired range of seed spacing. Missing index is the indicator of how often the seed skips the desired spacing. It is the percentage of spacing greater than 1.5 times the theoretical spacing. The seed metering unit should be designed for minimum missing index to achieve the desired plant population (Grewal *et al.*, 2015 and Singh *et al.*, 2012).

$$M = \frac{n_1}{N} \qquad \text{- - - (3.24)}$$

Where,

n_1 = Number of spacing greater than 1.5 times the theoretical spacing in the given observations

N = Total number of observations

3.9.3 Bulb damage

The average per cent of onion bulb damage were calculated by collecting bulb along the row for a span of 10 m randomly. The number of bulbs that were damaged mechanically including any significant bruising, skin removal or crushing was counted and their percentage was calculated as the seed damage percentage (Bakhtiari and Loghavi, 2009).

3.10 Statistical Analysis for Optimizing Design and Operational Parameters

The effects of selected variables on the performance were analyzed using statistical tool. The experiment is completely randomized block design (CRBD). The analysis was carried out to determine the mean and interaction of the selected variables i.e. forward speed, angle of inclination, cup size and onion size as well as dependent variables such as per cent singles, per cent doubles, per cent multiples, per cent missing and per cent bulb damage.

3.11 Development of Raised Bed Onion Bulb Planter

The raised bed onion bulb planter was designed and developed in the Division of Post-Harvest Technology and Agricultural Engineering, ICAR-Indian

Institute of Horticultural Research, Bengaluru, Karnataka. The construction details of the planter is presented below. The raised bed onion bulb planter consisted of i. Main frame, ii. Ridger, iii. Leveller, iv. Seed hopper, iv. Chute, vi. Seed metering unit, vii. Seed tube, viii. Furrow opener and ix. Ground wheel.

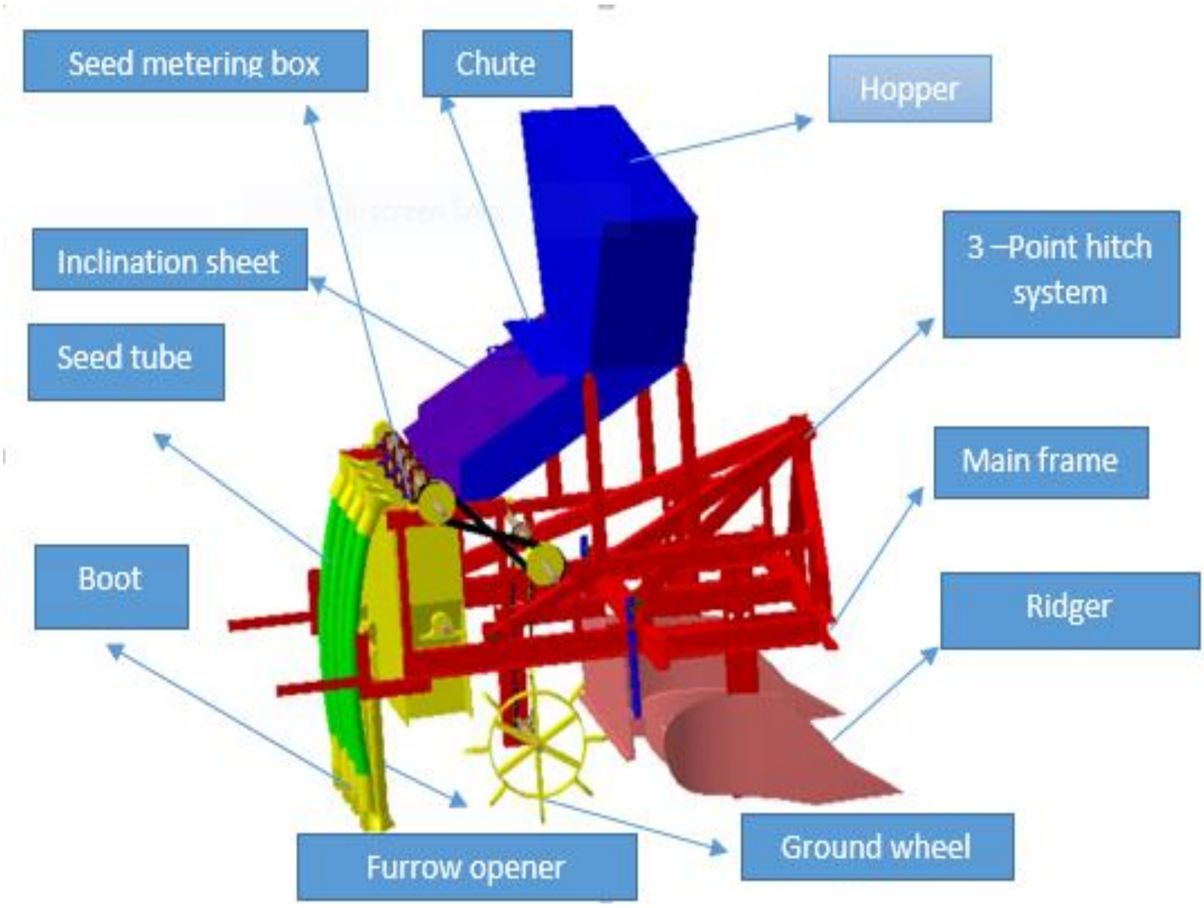


Plate 3.33 Tractor operated raised bed onion bulb planter

3.11.1 Main frame

The Main frame is the basic structure of the onion bulb planter to which all the components of the onion bulb planter were fitted. The material of the main frame was selected based on achieving a reasonable weight, required strength, reliability and readily available material. The machine is also connected to the rigid three-point hitch system for the tractor in front of the main frame. The Main frame of the unit was fabricated using a mild steel of ‘C’ channel section of 75×40×5 mm (W× L ×T), having dimension of 1480 ×580 mm (L×W) (Plate 3.34).

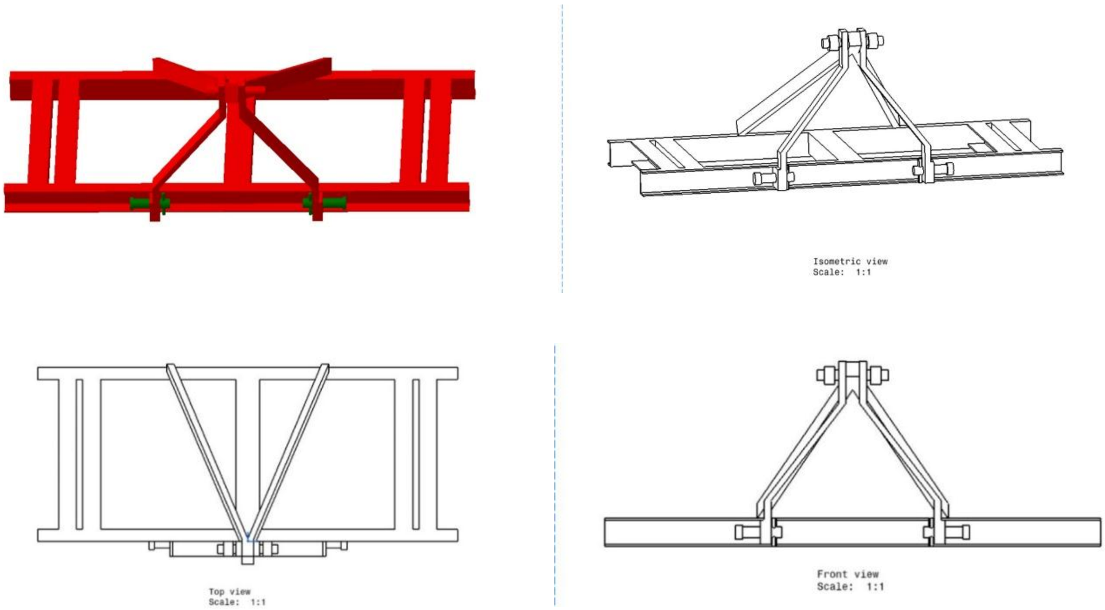


Plate 3.34 Main frame

3.11.2 Raised bed former

Ridgers are commercially used for making furrows and ridges. The ridger body was operated in fine tilled soil by a tractor. The share point penetrates in to the soil and the ridger body displaces the soil to both sides and furrow was created. Ridger (with adjustable wings) was procured from the market having recommended dimensions. Top width, bottom width and height of riger varied from 15 to 25 cm, 35 to 40 cm and 15 to 20 cm, respectively. The ridgers (Two numbers) were fixed on either side of the above-mentioned frame, as shown in (Plate 3.35). Leveler was used to level the bed formed by the ridger. The leveler was fabricated out of mild steel sheet of 1 mm thickness. Length and height of leveler was 900 mm and 300 mm. The construction details of leveller are shown in (Plate 3.36).

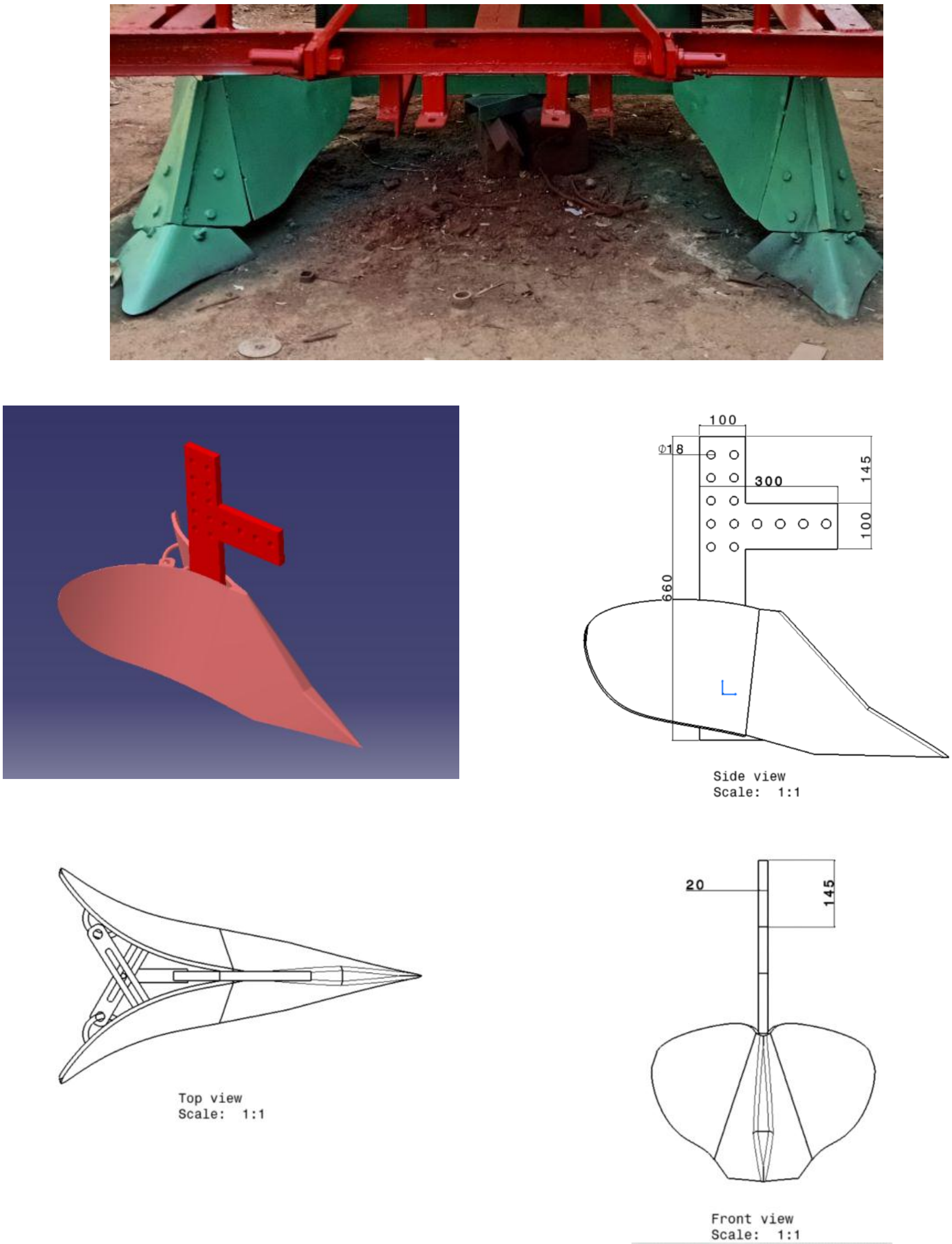


Plate 3.35 Ridger

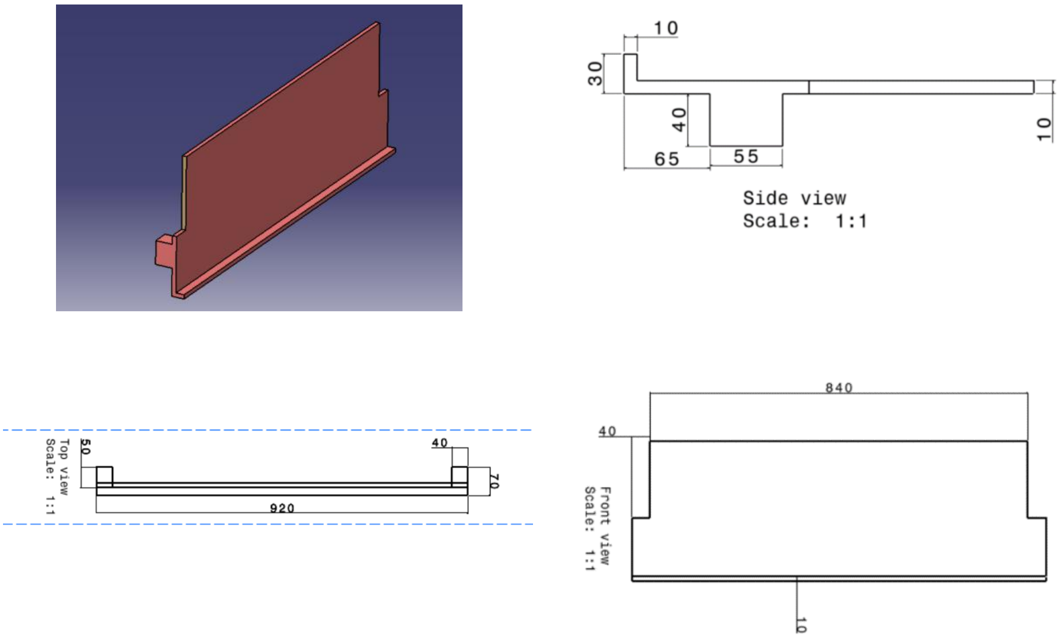


Plate 3.36 Leveler

3.11.3 Seed hopper

Seed box was used to store the onion bulbs for planting. Hopper was designed to cover full width of the machine and located above the main frame. The cross section of the seed box may be trapezoidal, rectangular, triangular or cylindrical. The inclination of front and rear walls of hopper must be greater than maximum angle of repose (for emptying) of seed or fertilizer material to be handled by the machine. On the basis of the reviews and studies of physical properties of onion bulbs, the average bulk density of onion bulb was 620 kg m^{-3} and the angle of repose equal or more than 40° was taken for designing of the seed hopper. Location of hopper in onion bulb planter vary from 40 to 90 cm above the ground level. Inclination of delivery tubes and ease of filling the hopper are the two major considerations while deciding the height. The hopper was made with MS (Mild steel) sheet. The capacity of the hopper was 115 kg. With volume of hopper as 0.1 cubic meter. Hopper designed was trapezoidal shape. Bottom width, top width, height and length of the hopper was 80, 160, 50 and 30 cm, respectively. Seed metering mechanism was placed at the bottom of the box. An adjustable chute was provided at bottom of the hopper which was used for controlling the onion flow. Inclination sheet was provided with 4 compartments for diverting the seed from hopper to the metering mechanism. A view of seed box or hopper is shown in (Plate 3.37).

The capacity of the box was calculated by using following equation:

$$\rho = \frac{Q}{V} \qquad \text{- - - (3.25)}$$

Let, V= Volume of box, m^3

ρ= Bulk density of onion bulbs, kg m^{-3}

On the basis of the studies of physical properties of onion bulbs, the average bulk density of onion bulb was 620 kg m^{-3}

Q = Box capacity, kg

The shape of the box is trapezoidal

Then Volume of box was calculated by using following formula

Volume of box = Area of the trapezoidal × Length of box - - - (3.26)

$$\text{Area of the trapezoidal} = \frac{(a+b)}{2} \times h \qquad \text{- - - (3.27)}$$

Where,

a = Bottom width of box = 0.8 m; b = Top width of box = 1.6 m and

h = Height of box = 0.5 m

Area of the trapezoidal = $\frac{(0.8+1.6)}{2} \times 0.5 = 0.6\ m^2$,

Length of box = 0.3 m

Volume of box = 0.6 m^2 × 0.3 m = 0.18 m^3,

Q = Box capacity, kg

$$\rho = \frac{Q}{V} = 620 = \frac{Q}{0.18}$$

Q = 111.6 kg

Therefore, Box capacity = 112 kg

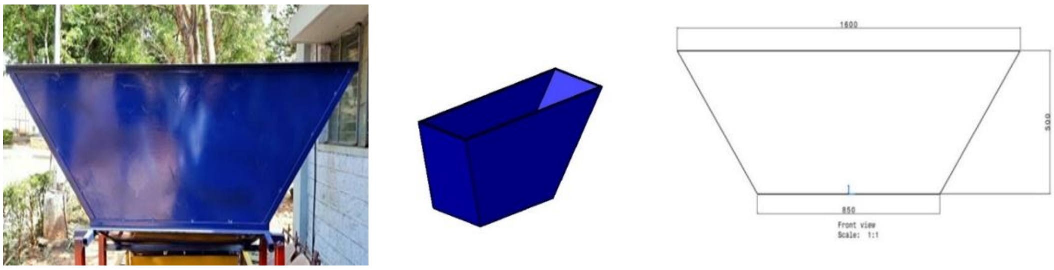


Plate 3.37 Seed box

3.11.4 Chute

Chute was used to control the flow of the onion from the hopper. It was attached at bottom back side of the hopper. Chute can be adjusted up to 30 cm. Chute was made up of mild steel sheet of 1 mm thickness. Length and width of chute was 78 and 44 cm. Handle was attached at center of the chute for pulling and pushing purpose during the control of onion from hopper. Handle was made up of mild steel of 8 mm rod. Length of handle was 16 cm; width was 10 cm in that 4 cm welded inside the chute. A view of chute is shown in (Plate 3.38).

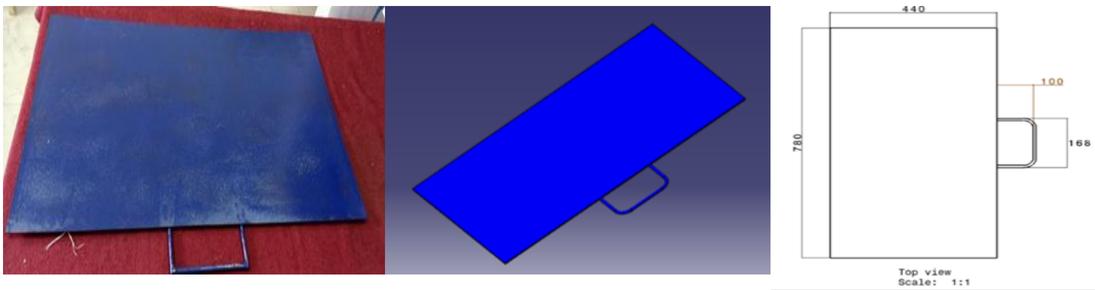


Plate 3.38 Chute

3.11.5 Inclination sheet

Inclination sheet was used to free flow the onion from hopper or seed box to metering mechanism. Inclination sheet was made up of 1 mm mild steel sheet. The inclination sheet was attached to back end of bottom of the hopper. The Length, width and height of inclination sheet was 860, 800 and 170 mm (L×W×H). Four partitions were made on the inclination sheet. The gap provided between first, second, third and fourth partitions was 230, 150,150 and 250 mm, respectively. A view of chute is shown in (Plate 3.39).

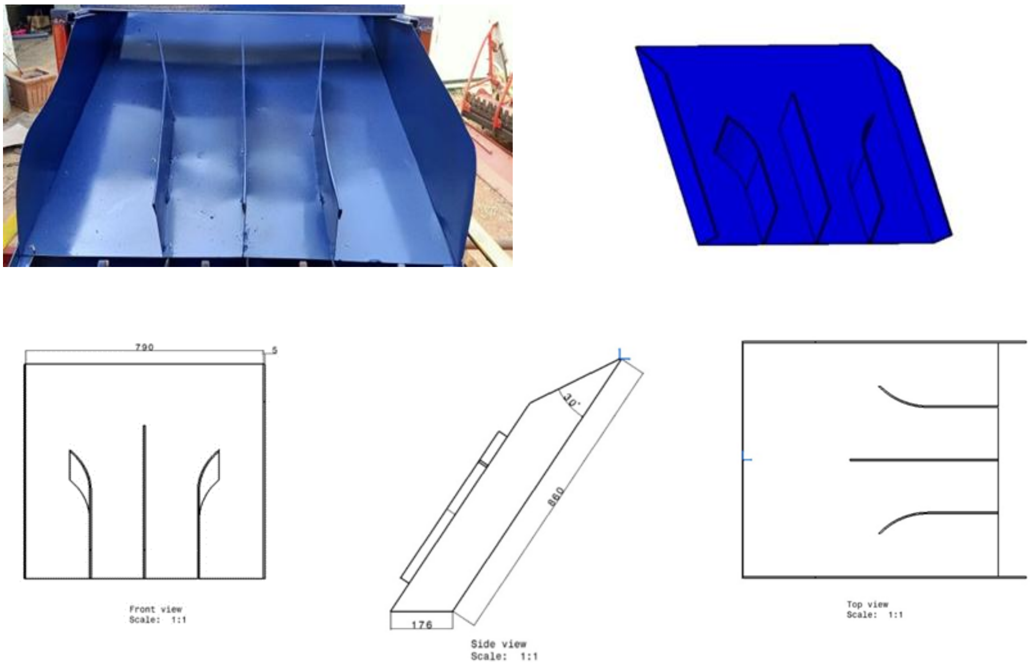


Plate 3.39 Inclination sheet

3.11.6 Seed metering unit

Metering mechanism is the heart of sowing of the onion bulb planter and its function is to meter the seeds or bulbs uniformly at the desired application rates. In planters it also controls seed spacing in a row. A seed planter was required to drop the seeds at rates varying across wide range. Proper design of the metering device is an essential element for satisfactory performance of the seed planter. In this design, the seed metering cups lifts the seeds from the hopper and drops the seeds into the funnel, which is conveyed to the furrow opener through the seed tube. For varying the seed rate and sowing different seeds, the size and number of cups on the seed metering device depends on the size of seed and desired seed spacing. Seed metering mechanism box was made up of mild steel sheet of 2 mm thickness. The seed box had dimensions of length 780 mm, width 200 mm and height 400 mm. The seed metering unit consists of hopper seed box, seed elevator and seed tube (Plate 3.40 to 3.43). The seed box was fabricated out of mild steel sheet of 1 mm thickness. There were four seed metering unit which would plant four rows.

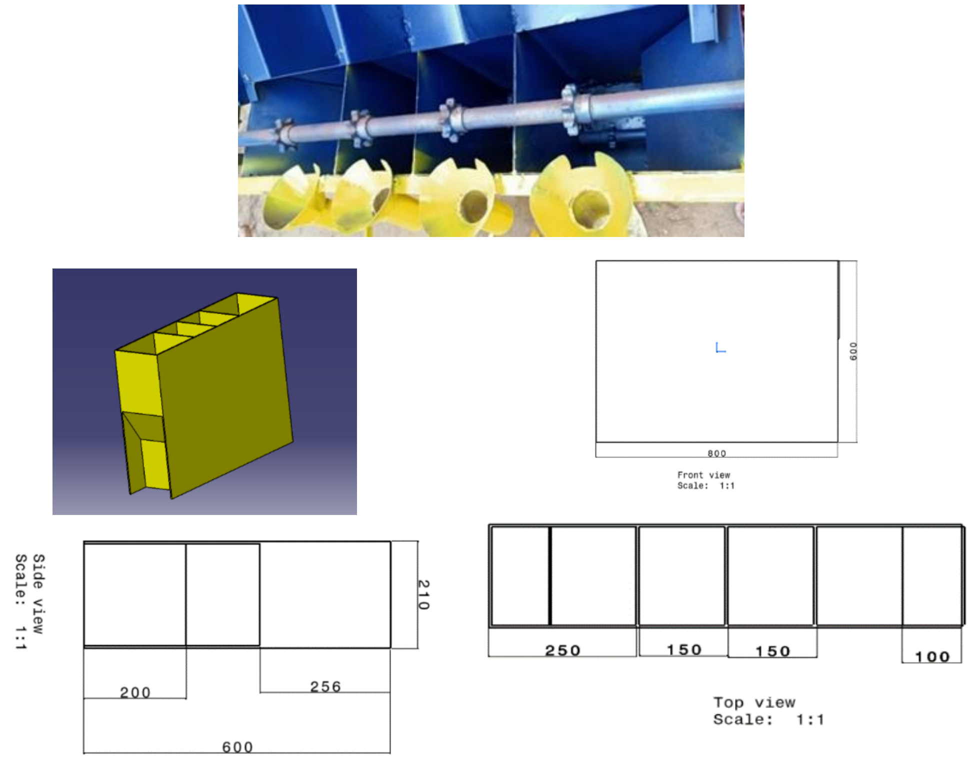


Plate 3.40 Metering mechanisam box

Plate 3.41 Shaft with sprockets

Plate 3.42 Sprocket

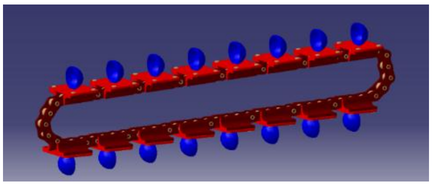
 

Plate 3.43 Chain with cups

3.11.6.1 Design of cup type metering mechanism

Calculation for number of cups on metering device

No. of cups on seed plate can be calculated by

$$i = \frac{(c \times t)}{a} \quad \text{(Ranjan, 2014)} \qquad \text{- - - (3.28)}$$

Where,

i= No. of cups; c = circumference of ground wheel, 120 cm

t = speed ratio (Drive wheel shaft to metering shaft); a = bulb to bulb spacing= 10 cm

Speed ratio of axle pegged ground wheel to metering shaft

$$= \frac{\text{No.of teeth on metering shaft } (T_M)}{\text{No.of teeth on drive wheel shaft } T_{D)}} \qquad \text{- - - (3.29)}$$

$$\frac{N_g}{N_m} = \frac{T_m}{T_g} \qquad \text{- - - (3.30)}$$

Where,

N_g= rpm of ground wheel,

N_m= rpm of metering shaft,

T_g= No. of teeth on sprocket of ground wheel and

T_m= No. of teeth on sprocket of metering shaft

$$\text{Speed ratio } S_r = \frac{N_g}{N_m} = \frac{8}{8} = 1$$

No. of teeth on sprocket of metering shaft T_m= T_g×1= 8×1

The no. of rev/min of ground wheel was 1 times that no. of rev/min instead metering unit

Therefore, no. of cups = $i = \frac{(c \times t)}{a}$

$$i = \frac{(120 \times 1)}{10}$$

$$= 12$$

Therefore, no. of cups was taken as 12

Circumference of ground wheel = $\pi \times d$ - - - (3.31)

$$= 3.14 \times 38$$

$$= 119.32 \text{ cm}$$

$$= 120 \text{ cm (Approx.)}$$

Peripheral distance between cups = $\frac{\text{Circumference of ground wheel}}{\text{No.of cups}}$ - - - (3.32)

$$= \frac{120}{12} = 10 \text{ cm}$$

Therefore, peripheral distance between cups was taken as 10 cm

3.11.6.2 Design of power transmission from ground wheel to metering device

Speed of operation assumed as 1 km h^{-1} = 16.66 m min^{-1}

Diameter of ground wheel (D_g) = 0.38 m

RPM of axle of pegged ground wheel is given by

$$V_g = \pi D_g N_g \quad \text{- - - (3.33)}$$

Where,

V_g = speed (m min^{-1}),

D_g= Ground wheel, dia, m,

N_g= Ground wheel revolution, rpm, and

$$V_g = \pi D_g N_g \quad \text{- - - (3.34)}$$

$$16.67 = 3.14 \times 0.38 \times N_g$$

$N_g = 13.97 = 14$ rpm

The detail of power transmission was explained as follows:

The power transmission from ground wheel to idler shaft, idler shaft to metering shaft through chain and sprocket

i) Ground wheel sprocket to idler shaft sprocket = 14 rpm (1:1)

Number of teeth on ground wheel sprocket (T1) = 8

Number of teeth on idler shaft sprocket (T2) = 8

ii) Idler shaft sprocket to up side of seed metering shaft = 14 rpm(1:1)

Number of teeth on up side of seed metering shaft (T3) = 8

Number of teeth on down side of seed metering shaft (T4) = 8

Therefore, speed of metering shaft = 14 rpm

Considered the speed of the metering mechanism was 14 rpm.

3.11.7 Pulley

Pulley was used for transmission of mechanical power from idler shaft to metering shaft with the help of belt drive. Two pulleys were used in the onion bulb planter with each of 3-inch diameter. One pulley on the idler shaft and another pulley at upper part of metering mechanism shaft. The pulley used was shown in (Plate3.44).

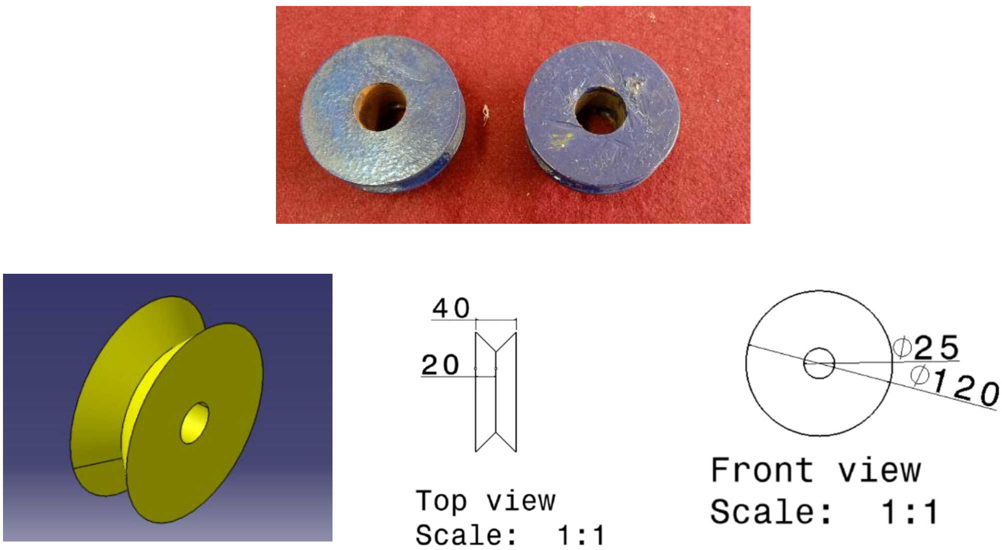


Plate 3.44 Pulley

3.11.8 Belt

In the onion bulb planter hopper was fixed on the main frame. The ridger was attached to the main frame for making the bunds. There is no space in front of onion bulb planter to fall onion bulbs on font side. To overcome that problem, metering mechanism was kept back side of the hopper. Power was transmitted from ground wheel to idler shaft forward direction with help of chain and sprocket system. From idler shaft to upper part of the metering mechanism power was required in reverse direction. Chain and sprocket system was not possible here for that purpose belt and pulley system was used. 42 inch B cross belt was arranged here. A view of belt is shown in (Plate 3.45).

Plate 3.45 Belt

3.11.9 Seed delivery system

The seed delivery system consists of funnel and seed tube. A funnel was fabricated out of MS sheet of 1 mm thickness. The funnel had 100 mm top diameter, bottom diameter of 50 mm and height of 60 mm. The neck portion of funnel was pipe having diameter of 45 mm and length 70 mm, fabricated out of mild steel sheet of 1 mm thickness (Plate. 3.46).

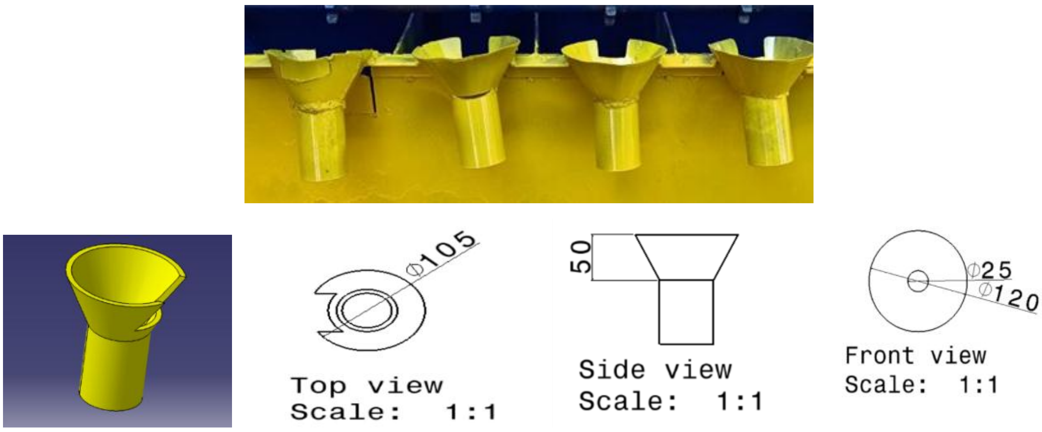


Plate 3.46 Funnel with tube

The seed tube was used to collect the seeds from funnel to the furrow lines through suitable boots and furrow openers. Uniform seed to seed spacing was achieved when all seeds are released by the metering device from the same height with the same velocity. Seed tube was braided PVC (Poly Vinyl Chloride) material, different diameters are reported in text and Plate 3.47, thickness 2.5 mm and length 710 mm (Plate 3.47). The seed tube was inserted into the funnel neck.

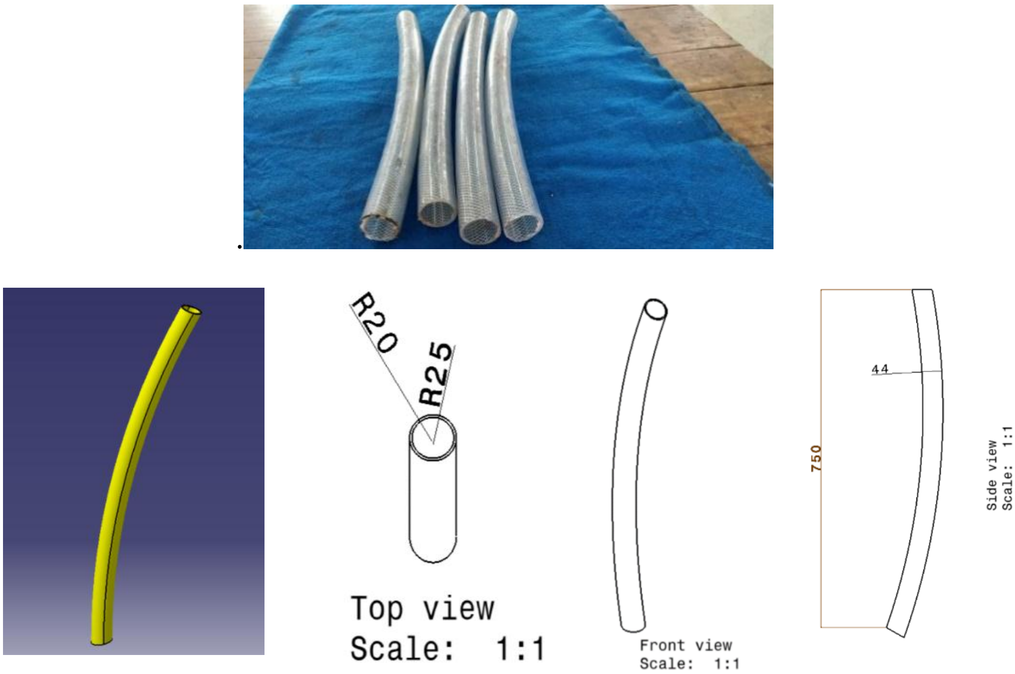


Plate 3.47 Seed tube

3.11.10 Furrow opener

Furrow openers of a sowing device is the final modifier of soil environment in a seedbed. Hence, it is one of the most important component of onion bulb planter. Furrow openers are used to place the seeds at a desired depth with minimum dispersion. The depth of placement at which bulb to be placed in the soil depends on the soil type, soil moisture level, crop variety and angle of attack should be considered in designing furrow openers. Row to row distance can be changed by adjusting holes drilled in the frame. Different types of furrow openers in use namely hoe type, shoe type, stub runner type, full or curved runner type, single disc type, double disc type etc. Furrow openers open the soil where seeds metered out and falling through the boot will be dropped and covered. A inverted

T- type furrow opener was found most suitable for this planter because the shovel has to work in the tilled soil to form a furrow of sufficient width to facilitate proper placement of onion bulbs. The material used for the furrow opener was Mild Steel Angle iron of 40 mm and length of furrow opener was 550 mm. Upper part of the furrow opener one flat with length of 250 mm, width 100 mm and thickness 5 mm was attached with 8 holes of 10 mm kept on both sides of the flat to adjust the height of furrow opener. At the upper end of standard, the clamping attachment was provided. The construction details of furrow opener is presented in (Plate 3.48).

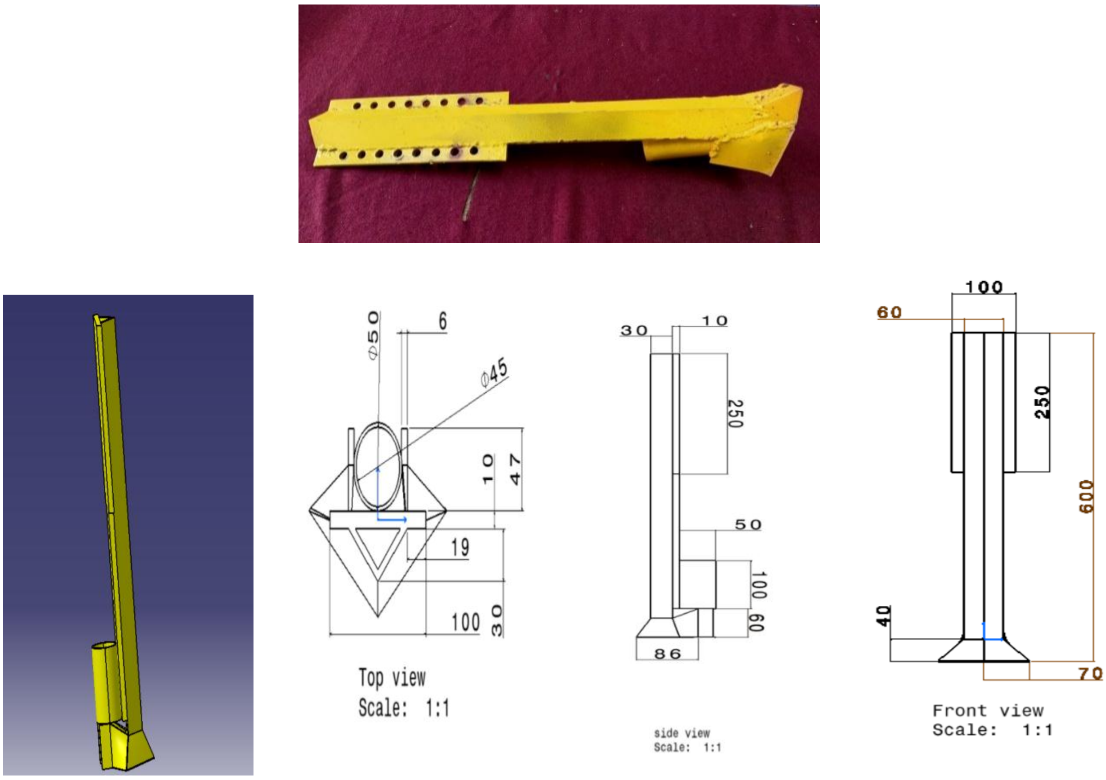


Plate 3.48 Furrow opener

3.11.11 Boot

Seed boot drops the seed into the slit and placed in the soil opened by the furrow opener. Boot was made up of MS pipe. The Length of boot was 100 mm and diameter of boot was 70 mm. A view of boot is shown in (Plate 3.49).

Plate 3.49 Boot

3.11.12 Ground wheel

The seed metering unit was driven by ground wheel. The rotation of the ground wheel is converted as the rotation of metering shafts through chain, sprockets and belt drive. The type of drive wheel used for planter depends on the ground conditions. The ground wheel diameter is selected on the basis of ground clearance that was available below the seed box. Since the ground wheel was more concerned for supporting the seed box and its movement along with the planter and for power transmission, main focus was given on the width of the wheel, so as to prevent its sinkage into the soil. The function of wheel is to provide a better traction or grip on the soil and supply power to metering mechanism, small lugs were provided on the periphery of the wheel. Ground wheel was fabricated out of 50 ×5 mm (W ×T) Mild steel flat and diameter of 380 mm was made and center of the ground wheel bush was kept with 60 mm of length and diameter of 25 mm. Six spokes were attached to ground wheel from center of the bush with each of 135 mm length and width of 50 mm and thickness of 5 mm. For gripping purpose on the periphery of ground wheel 8 lugs were attached with length of 75 mm and 25 mm bent to corner of the lugs to avoid slippage of ground wheel during operation. The ground wheel rotated a hub with 8 teeth sprocket attached on the ground wheel shaft axle. The metering shaft so that the transmission ratio of 1:1 was maintained. The construction details of ground wheel was shown in (Plate.3.50).

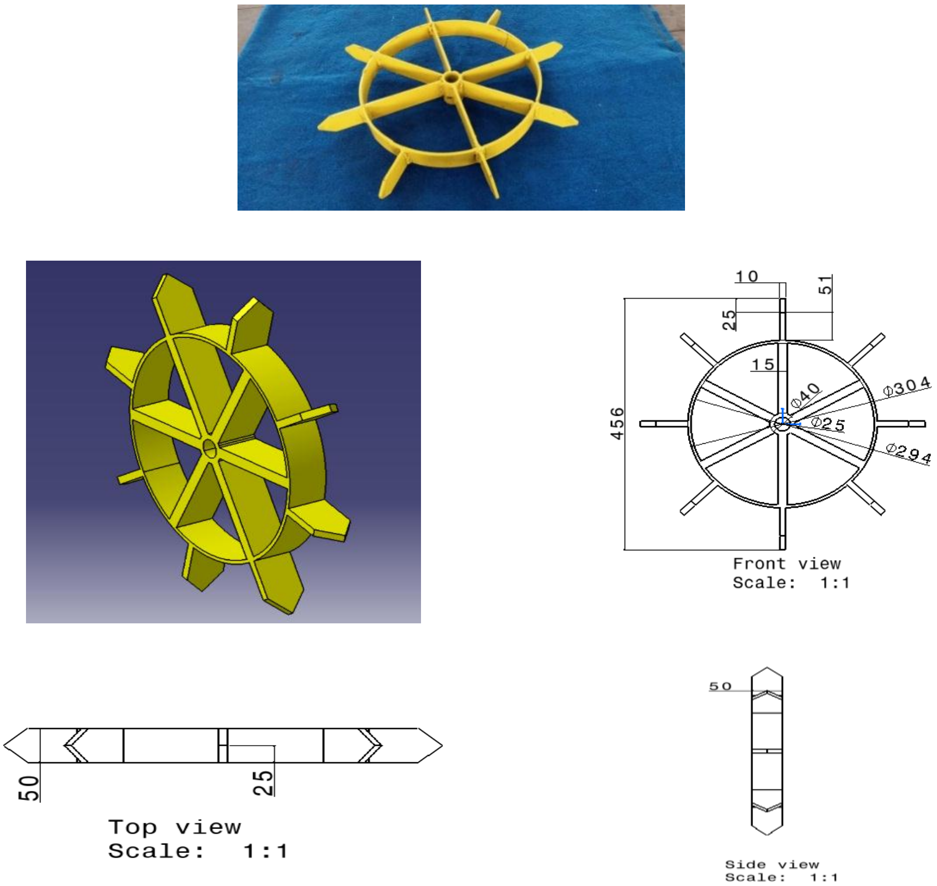


Plate 3.50 Ground wheel

3.12 Performance Evaluation of Tractor Operated Raised Bed Onion Bulb Planter

The performance evaluations of onion bulb planter were tested under the field conditions (RNAM, 1995). The field experiment was conducted at Block No-8 of Division of Vegetable crops at ICAR-Indian Institute of Horticultural Research. Bengaluru, Karnataka. Rectangular field was selected for the evaluation and planting was done lengthwise to reduce the turning losses of the bulb planter Plate (3.51 to 3.54). The field was prepared with two pass of cultivator and one pass of rotavator. The observations recorded during the performance evaluation were singles, doubles, multiples, missing index, quality feed index, bulb damage, theoretical field capacity, effective field capacity, field efficiency, speed of operation, fuel consumption, depth of planting, row to row spacing and plant to plant spacing.

Plate 3.51 Evaluation of machine in the field

Plate 3.52 Picking of cup with onion bulbs

Plate 3.53 Field before planting

Plate 3.54 Field after planting

3.12.1 Multiple index

Multiple index (D) includes two or more seeds picked and dropped by the seed metering unit by a single hole in the metering plate. The multiple index is an indicator of more than one seed dropped within a desired spacing. It is the percentage of spacing that are less than or equal to half of the theoretical spacing. The objective is to minimize multiples to save cost of seeds and to subsequently reduce the labour required for thinning the extra plant population (Grewal *et al.*, 2015 and Singh *et al.*, 2012).

$$D = \frac{n_2}{N} \qquad \text{- - - (3.35)}$$

Where,

n_2 = Number of spacing that are less than or equal to half of the theoretical spacing in the given observations

N = Total number of observations.

3.12.2 Missing index

Missing index (M) indicates the incapability of seed metering unit to drop even a single seed within the desired range of seed spacing. Missing index is the indicator of how often the seed skips the desired spacing. It is the percentage of spacing greater than 1.5 times the theoretical spacing. The seed metering unit should be designed for minimum missing index to achieve the desired plant population (Grewal *et al.*, 2015 and Singh *et al.*, 2012).

$$M = \frac{n_1}{N} \qquad \text{- - - (3.36)}$$

Where,

n_1= Number of spacing greater than 1.5 times the theoretical spacing in the given observations

N = Total number of observations

3.12.3 Quality of feed index

The quality of feed index (Q) is the measure of how often the spacing was close to the theoretical spacing. It is the percentage of spacing that are more than half but not more than 1.5 times the theoretical spacing. The quality of feed index is mathematically expressed as follows **(**Grewal *et al.*, 2015 and Singh *et al.*, 2012).

Quality of feed index (Q) = 100 – (miss index + multiple index) - - - (3.37)

3.12.4 Precision

Precision (C) is a measure of the variability in spacing after accounting for variability due to both multiples and skips. The precision is the coefficient of variation of the spacing that are classified as singles (Kumari and Das, 2015).

$$C = \frac{S_2}{X} \quad \text{- - - (3.38)}$$

Where,

S_2 –Sample standard deviation of the n_2 observations

X- Sample mean

3.12.5 Bulb damage

The average per cent of onion bulb damage were calculated by collecting bulbs along the row for a span of 10 m randomly. The number of bulblets that were damaged mechanically including any significant bruising, skin removal or crushing was counted and their percentage was calculated as the seed damage percentage (Bakhtiari and Loghavi, 2009).

3.12.6 Theoretical field capacity

Theoretical field capacity of the machine is the rate of field coverage that would be obtained if the machine was performing for its theoretical width of the time at the rated forward speed and always covered 100 per cent of its rated width. It is expressed as hectare per hour and determined as follows (Kepner *et al.,* 1978)

$$\text{Theoretical field capacity, ha/h} = \frac{\text{Width(m)} \times \text{Speed (km/ h)}}{10} \quad \text{- - - (3.39)}$$

3.12.7 Effective Field Capacity

The effective field capacity is the actual average rate of coverage by the machine, based upon the total field time. It is a function of the rated width of the machine, the percentage of rated width actually utilized, speed of the travel and the amount of field time lost during the operation. Effective field capacity is usually expressed as hectare per hour (Kepner *et al.*, 1978)

$$\text{EFC} = \frac{A}{T_p T_i} \qquad \text{- - - (3.40)}$$

Where,

EFC= Effective field capacity, ha/h,

A= Actual area covered, ha,

T_p =Productive time, h and T_i = Non-Productive time, h

3.12.8 Field efficiency

Field efficiency is the ratio of effective field capacity to the theoretical field capacity, expressed as percentage (Kepner *et al.*, 1978). It includes the effect of time lost in the field and time lost to utilize the full width area with overlapping. It is calculated by using the following formula.

$$\text{Field efficiency, per cent} = \frac{\text{Effective field capacity (ha h}^{-1})}{\text{Theoretical field capacity (ha h}^{-1})} \times 100 \qquad \text{- - - (3.41)}$$

3.12.9 Speed of operation

The speed of operation was calculated by observing the distance traveled and the time taken (RNAM, 1995).

$$S = \frac{L}{t} \qquad \text{- - - (3.42)}$$

Where,

S = Forward speed of operation, m/s

L = Distance traveled, m

t = Time taken, s

3.12.10 Fuel consumption

The fuel consumption has direct effect on economics of the developed machine. It was measured by top fill method (RNAM, 1995). The fuel tank was filled to full capacity before and after the test. After completion of test operation, amount of fuel required to top fill again is the fuel consumption for the test duration. It was expressed in litre per hour.

$$\text{Fuel consumption} = \frac{\text{Fuel consumption, L}}{\text{Time, hr}} \qquad \text{- - - (3.43)}$$

3.12.11 Depth of planting

Depth of planting affects proper establishment of plant and thus the performance of the planter. The depth of the planting was measured by measuring scale in different rows at different places. Average of five observations was taken as depth of planting and was expressed in cm. (Nare *et al.,* 2014).

3.12.12 Row to row spacing

The spacing between two consecutive rows of onion bulb planter was measured with the help of steel tape. The row to row spacing was measured in the field at five different locations randomly and average value of spacing was calculated. (Nare *et al.,* 2014).

3.12.13 Plant to plant spacing

The plant to plant spacing along the one meter row length was measured with the help of steel tape during the field operation. The plant to plant spacing was recorded in the field at five different locations randomly in each row and average plant to plant spacing was computed. (Nare *et al.,* 2014).

3.13 Cost Economics

The fixed and variable costs for operating onion bulb planter per hour was calculated as per the procedure described by IS: 9164-1979 (Anon, 1979) and (Mahajan *et al.,* 2007). From the field capacity of the planter, the cost of operation per hectare was calculated. This cost was compared with cost incurred by traditional sowing method. The cost saved by the planter over traditional sowing method was worked out.

CHAPTER - IV
RESULTS AND DISCUSSION

In this chapter the results of following experiments are presented and discussed: Engineering properties of onion bulbs; effect of orientation of onion bulb planting on germination and growth; effect of forward speed, angle of inclination, cup size and onion size on per cent singles, per cent doubles, per cent multiples, per cent missings and per cent bulb damage to optimize the design and operational parameters of metering system. These results were statistically analyzed and presented. Based on these results a tractor operated raised bed onion bulb planter was designed, fabricated and presented systematically. In addition to this the performance and field evaluation results of developed machine is also presented and discussed. The results are presented under following headings:

4.1 Physical Properties of Onion Bulbs

4.2 Mechanical Properties of Onion Bulbs

4.3 Effect of Different Planting Orientation on Growth Parameters of Onion Bulbs

4.4 Optimization of Design and Operation Parameters of Onion Bulb Planter

4.5 Prototype Tractor Operated Raised Bed Onion Bulb Planter

4.6 Performance Evaluation of Tractor Operated Raised Bed Onion Bulb Planter

4.7 Cost Economics

4.1 Physical Properties of Onion Bulbs

The size of the cup in the seed metering unit of onion bulb planter depends on the physical properties of onion bulb. The physical property also depends on the size of the onion bulbs. The aggregatum type onion is cluster in nature having up to 10 individual onion bulbs. Hence the individual onions were separated from the cluster and graded into 9 grades *viz.*, < 2 g, 2-3 g, 3-4 g, 4-5 g, 5- 6 g, 6-7 g, 7-8 g, 8-9 g, > 9 g based on individual weight. The physical properties such as i. Linear dimensions (length, width and thickness), ii. Geometric mean diameter, iii. Sphericity, iv. Shape index, v. Projected area, vi. One hundred onion bulb weight, vii. Bulk density, viii. True density and ix. Moisture content were determined.

4.1.1 Onion bulb length, width and thickness

The linear dimensions *viz.*, length, width and thickness of onion bulb were measured as explained in section 3.2.2 and the results are presented in the table 4.1. From Fig. 4.1 (a), it was observed that the linear dimensions increased with increase in size of onion bulb. The length, width and thickness ranged from 21.21±2.60 to 32.31±3.30, 13.54±1.77 to 30.95±2.91 and 10.91±1.40 to 22.63±2.15 mm. These results were similar to the findings of Patel *et al.*, (2016), Karthik *et al.*, (2016) and Kumari and Das (2015 a). It was also observed that the size of onion bulb had significant effect on linear dimensions (Table 4.1). (Appendix A1, A2, A3).

4.1.2 Onion bulb geometric mean diameter

The geometric mean diameter of onion bulb was computed as explained in section 3.2.3 and the results are presented in the table 4.1. From Fig. 4.1 (a), it was observed that the geometric mean diameter increased with increase in size of onion bulb. The geometric mean diameter of onion bulb ranged from 14.54±0.96 (< 2 g) to 28.22±2.04 (>9 g) mm. The results were similar to the findings of Patel *et al.*, (2016), Karthik *et al.*, (2016) and Kumari and Das (2015 a). From (Table 4.1) (Appendix, A4), it was also observed that the size of onion bulb had significant effect on geometric mean diameter.

4.1.3 Sphericity

The sphericity of onion bulb was determined as explained in section 3.2.4 and the results are presented in the table 4.1. From Fig. 4.1 (a), it was observed that the sphericity increased with increase in size of onion bulb. The sphericity of onion bulb ranged from 0.69±0.08 (< 2 g) to 0.87±0.06 (> 9 g). The results were similar to the findings of Patel *et al.*, (2016) and Kumari and Das (2015 a). From (Table 4.1) (Appendix, A5), it was also observed that the size of onion bulb had significant effect on sphericity.

4.1.4 Shape index

The shape index of onion bulb was determined as explained in section 3.2.5 and the results are presented in the table 4.1. The shape index for grades <2 g, 2-3 g and 3-4 g were found to be 1.78±0.32, 1.711±0.25, 1.59±0.25 respectively, (> 1.5) and the remaining grades i.e. 4-5 g to > 9 g the shape index values were found to be (< 1.5) Fig 4.1 (a). From the above observation, it was clear that, the onion bulbs having sizes < 2 g, 2-3 g and 3- 4 g were oval in shape, remaining grades i.e. 4-5 g to 9 g onion bulbs were spherical in shape. The results were similar to the findings of Kumari and Das (2015 a). From (Table 4.1) (Appendix, A6), it was also observed that the size of onion bulb had significant effect on shape index.

4.1.5 Projected area

The projected area of onion bulb was measured as explained in section 3.2.6 and the results are presented in the table 4.1. From Fig. 4.1 (b), it was observed that the projected area increased with increase in size of onion bulb. The projected area of onion bulb ranged from 1.55±0.30 (< 2 g) to 5.5±0.51 (> 9 g) cm^2. The results were similar to the findings of Kumari and Das (2015 a). From (Table 4.1) (Appendix, A7), it was also observed that the size of onion bulb had significant effect on projected area.

4.1.6 One hundred onion bulbs weight

The one hundred weight of onion bulb was measured as explained in section 3.2.7 and the results are presented in the table 4.1. From Fig. (4.2), it was observed that the one hundred onion bulb weight increased with increase in size of onion bulb. The one hundred weight of onion bulb ranged from 121.6±6.30 (< 2 g) to 1185±19.59 (> 9 g) g. Similar results were also reported by Karthik *et al.*, (2016) and Kumari and Das (2015 a). From (Table 4.1) (Appendix, A8), it was also observed that the size of onion bulb had significant effect on one hundred onion bulb weight.

4.1.7 Bulk density

The bulk density of onion bulb was measured as explained in section 3.2.8 and the results are presented in the table 4.1. From Fig. (4.2), it was observed that the bulk density increased with increase in size of onion bulb. The bulk density of onion bulb ranged from 480.19±13.13 (< 2 g) to 1086±205.22 (> 9 g) kg m^{-3}. The results were similar to the findings of and Patel *et al.*, (2016) and Shoba *et al.*, (2017). From (Table 4.1) (Appendix, A9), it was also observed that the size of onion bulb had significant effect on bulk density.

4.1.8 True density

The true density of onion bulb was measured as explained in section 3.2.9 and the results are presented in the table 4.1. From Fig (4.2), the maximum true density of onion bulb was 1086±205.22 kg m^{-3} obtained in > 9 g, while minimum true density of onion bulb was 950.70±257.92 kg m^{-3} in < 2-3 g. The results were similar to the findings of Karthik *et al.*, (2016). From the (Table 4.1) (Appendix, A10), it was clear that, the size of the onion did not have significant effect on true density of onion bulbs

4.1.9 Moisture content

The procedure followed to measure the moisture content of onion bulb for different grades explained under section 3.2.10 and the results are presented in the table 4.1. The moisture content of onion bulb ranged from 79.325±1.231 to 80.62±0.878 %. From the (Table 4.1) (Appendix, A11), it was clear that, the size of onion did not have significant effect on moisture content.

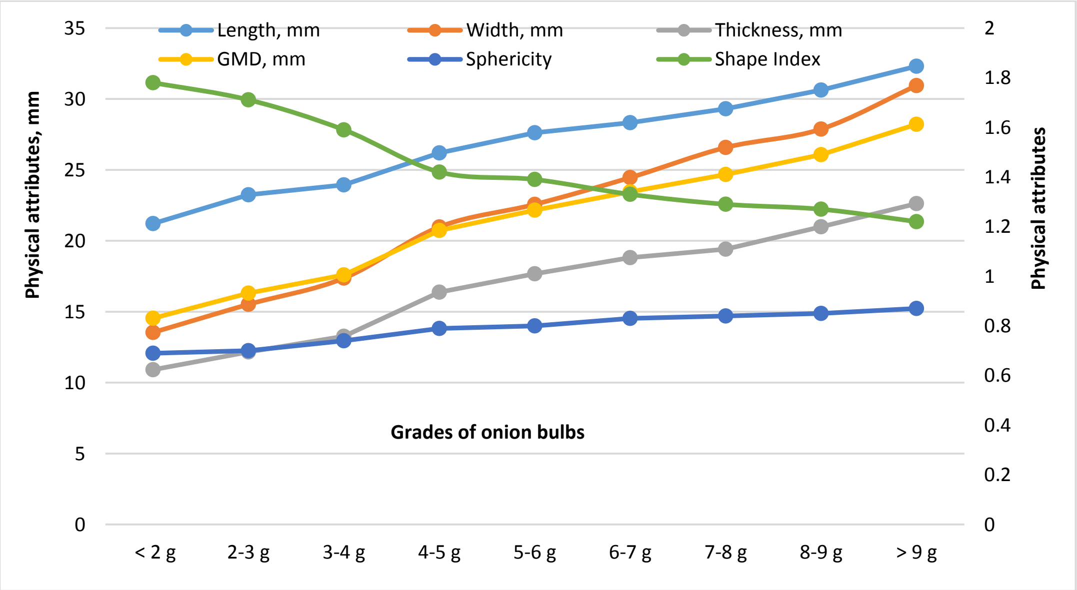


Fig. 4.1 (a). Physical property of onion bulb for different onion grades

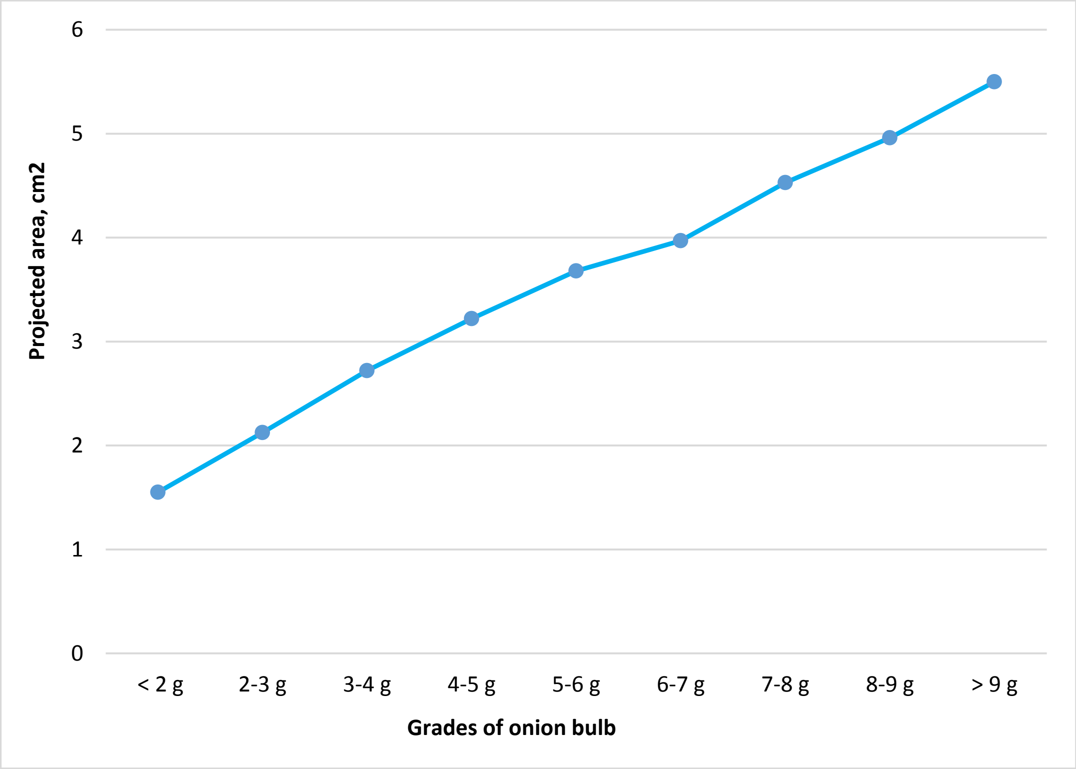


Fig. 4.1 (b). Projected area of onion bulb for different size of onion grades

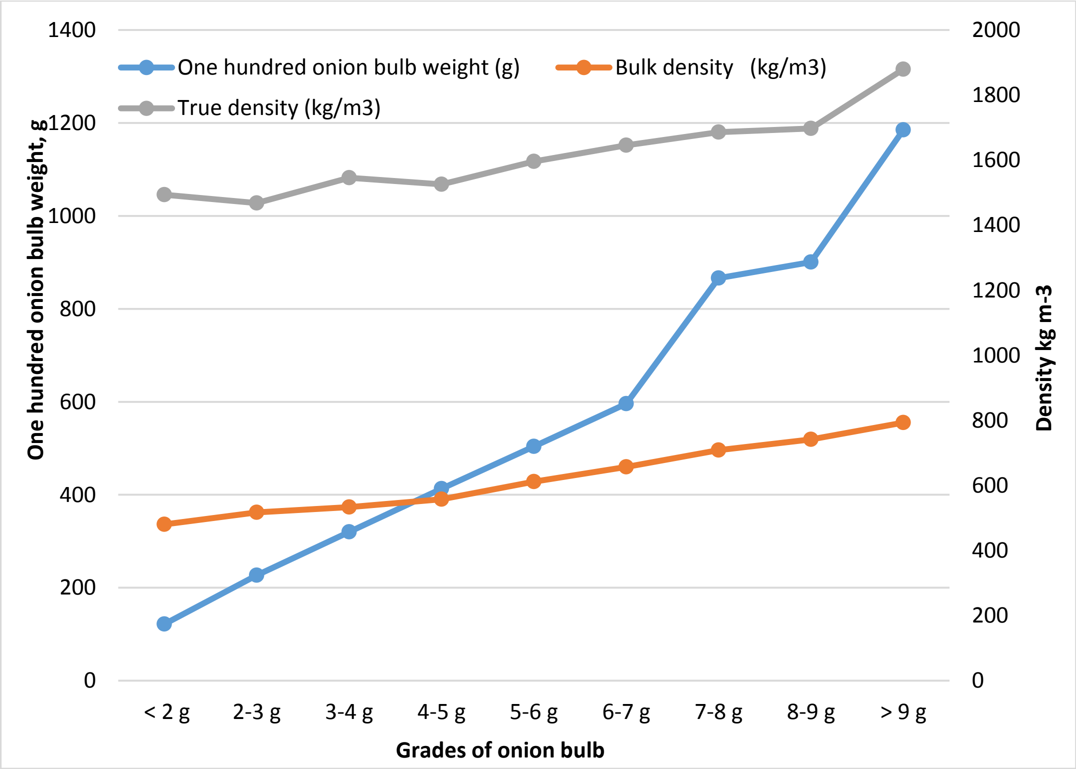


Fig. 4.2 One hundred onion bulb weight, bulk density and true density for different onion grades

4.2 Mechanical Properties of Onion Bulbs

The following mechanical properties of onion bulbs were also determined looking to its importance and requirement for designing the hopper of the onion bulb planter.

i) Angle of repose

ii) Coefficient of friction.

4.2.1 Angle of repose

The angle of repose of onion bulb was measured as explained in section 3.2.11.1 and the results are presented in the table 4.2. From Fig. (4.3), it was observed that the angle of repose decreased with increase in size of onion bulb. The angle of repose ranged from 20.71±1.92 (> 9 g) to 40.61±3.68 (< 2 g). Similar results were also reported by Patel *et al.*, (2016) and Kumari and Das (2015 a). From (Table 4.2) (Appendix, A12). It was also observed that the angle of repose of onion bulb had significant difference between the grades.

4.2.2 Coefficient of friction

The coefficient of friction of onion bulb was measured as explained in section 3.2.11.2 and the results are presented in the table 4.2. The coefficient of friction was determined for onion bulbs on different surfaces such as, mild steel, ply wood and galvanized iron. The coefficient of friction for mild steel, ply wood, and galvanized iron ranged 0.628±0.03 to 0.456±0.016, 0.236±0.03 to 0.174±0.016 and 0.344±0.01 to 0.310±0.017 respectively. The results were similar to the findings of Kumari and Das (2015 a). The type of material and size of onion had significant effect on co-efficient of friction (Table 4.2) (Appendix, A13). Onions bulbs had highest co-efficient of friction on mild steel followed by galvanized iron and ply wood, respectively. It was also observed that, smaller size onion had higher coefficient of friction than bigger size onions.

4.2.3 Interaction of sphericity, shape index and angle of repose of diifrent onion grades

This inference clearly indicated the interaction between the size and shape of the onions (Fig 4.3). In case of bigger size of onion, the shape was found to be spherical in shape (shape index < 1.5) which led to have less coefficient of friction, whereas the smaller size onions were oval in shape (shape index above 1.5) which led to have higher coefficient of friction. From the above inference, it was clear that as the sphericity increases and shape index decreases with the increase of onion size. The shape of onion bulb has spherical shape due to which the angle of repose decreased with increase in size of onion bulbs.

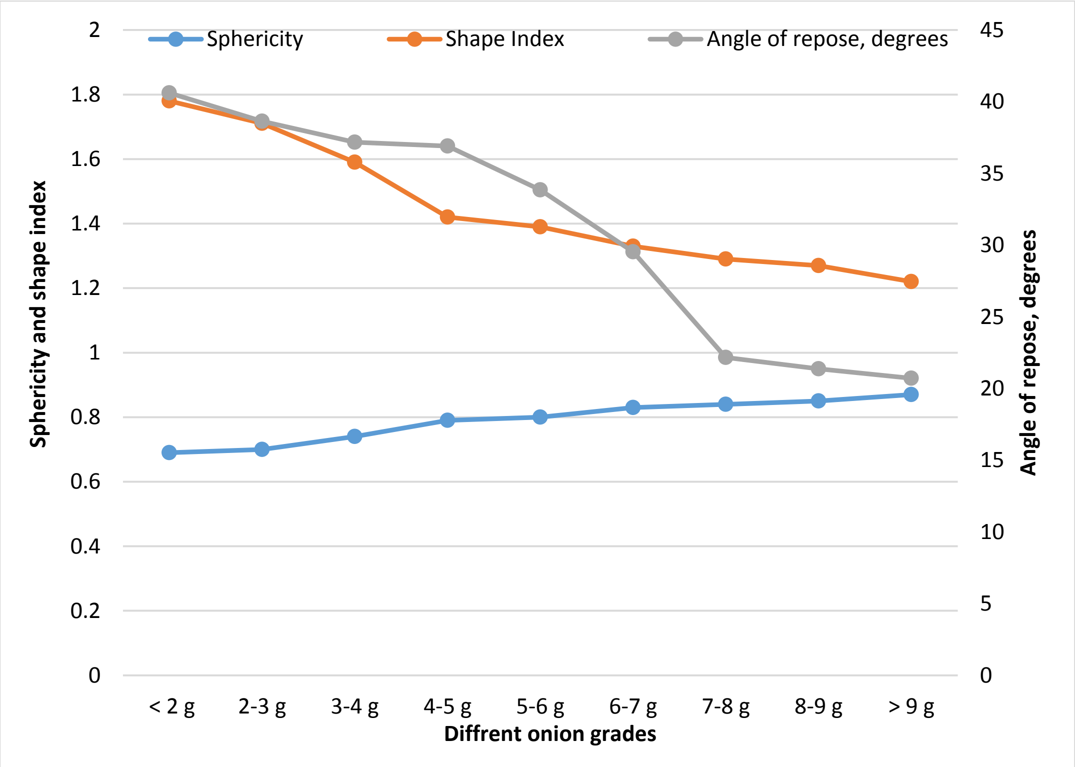


Fig. 4.3. Interaction of sphericity, shape index and angle of repose of diiferent onion grade

Table 4.1 Physical properties of multiplier onion

Physical Properties	Grades									CD (0.01)
	<2 g	**2-3 g**	**3-4 g**	**4-5 g**	**5-6 g**	**6-7 g**	**7-8 g**	**8-9 g**	**>9 g**	
Length, mm	21.21±2.60	23.24±2.50	23.94±2.57	26.20±2.54	27.62±2.70	28.33±2.89	29.31±2.09	30.63±2.50	32.31±3.30	0.96
Width. mm	13.54±1.77	15.52±1.58	17.37±1.51	20.98±1.78	22.57±2.10	24.46±2.03	26.58±1.91	27.88±2.10	30.95±2.91	0.73
Thickness, mm	10.91±1.40	12.16±1.50	13.27±1.36	16.38±1.56	17.67±1.75	18.81±1.49	19.41±1.58	20.99±2.29	22.63±2.15	0.62
GMD, mm	14.54±0.96	16.31±1.04	17.60±0.79	20.73±0.86	22.16±0.73	23.46±0.89	24.68±1.06	26.08±1.04	28.22±2.04	0.42
Sphericity	0.69±0.08	0.70±0.07	0.74±0.07	0.79±0.06	0.80±0.07	0.83±0.08	0.84±0.05	0.85±0.07	0.87±0.06	0.02
Shape Index	1.78±0.32	1.711±0.25	1.59±0.25	1.42±0.19	1.39±0.19	1.33±0.19	1.29±0.11	1.27±0.17	1.22±0.14	0.07
Projected Area, cm^2	1.55±0.30	2.125±0.28	2.72±0.25	3.225±0.26	3.68±0.30	3.97±0.255	4.53±0.29	4.96±0.21	5.5±0.51	0.55
One hundred onion bulb weight (g)	121.6±6.30	226.6±2.79	320.2±2.77	413±2.82	503.8±34.38	595.8±3.56	866.2±12.93	900.6±18.83	1185±19.59	25.31
Bulk Density (kg m^{-3})	480.19±13.13	517.31±10.61	533.66±6.66	557.58±7.87	611.54±6.33	656.83±7.60	708.52±6.36	741.71±7.21	793.20±9.45	14.10
True Density (kg m^{-3})	1013.61±348.85	950.70±257.92	1012.1±257.87	968.18±182.01	984.58±218.49	989.066±110.53	977.75±122.60	955.52±97.86	1086±205.22	326.59
Moisture content (%)	79.325±1.23	79.4±1.317	80.42±1.57	80.14±1.15	80.26±1.24	80.2±0.50	80.62±0.87	79.6±1.12	80.24±1.03	1.88

*GMD = Geometric Mean Diameter

Table 4.2. Mechanical properties of multiplier onion

Mechanical Properties	Grades									CD (.01)
	<2 g	**2-3 g**	**3-4 g**	**4-5 g**	**5-6 g**	**6-7 g**	**7-8 g**	**8-9 g**	**>9 g**	
Angle of repose (degrees)	40.61±3.68	38.64±0.99	37.17±2.29	36.91±1.21	33.85±2.07	29.53±2.58	22.17±1.64	21.37±1.70	20.71±1.92	3.51
Coefficient of friction										
1. Mild steel	0.548±0.05	0.58±0.035	0.628±0.03	0.56±0.02	0.51±0.016	0.50±0.013	0.456±0.01	0.538±0.01	0.48±0.014	0.011
2. Wood	0.23±0.02	0.2228±0.020	0.236±0.01	0.23±0.01	0.17±0.010	0.178±0.01	0.182±0.01	0.174±0.01	0.182±0.010	0.020
3. Galvanized iron	0.324±0.01	0.324±0.016	0.32±0.016	0.324±0.016	0.30±0.016	0.31±0.017	0.32±0.02	0.324±0.016	0.344±0.016	0.035

4.3 Effect of Different Planting Orientation on Growth Parameters of Onion Bulbs

Field experiments were conducted to study the effect of different planting orientation on growth parameters of onion bulbs during two seasons namely Kharif and Rabi season as explained in section 3.3.1. The design of experiment was Randomized Block Design (RBD), having four treatments and five replications. The observation recorded were germination percentage on 7^{th} and 15^{th} days after planting, plant height on 15^{th} and 30^{th} days after planting and yield. The results for the both seasons and pooled data are presented in Tables 4.3, 4.4 and 4.5 and discussed below:

4.3.1 Rabi season

4.3.1.1 Effect on germination of onion bulbs

The germination of onion bulbs were recorded on 7 DAP. From Fig. 4.4, it was observed that, the Treatment T_2 had the highest germination percentage (86.50 %) followed by T_4 (85.75 %), T_3 (81.50 %) and T_1 (64.25 %). However, when means of treatment were compared by LSD (Least Significant Difference) method, it was observed that the treatments T_2, T_3 and T_4 had the highest germination percentage and were at par. The Treatment T_1 had the lowest germination percentage. (Table 4.3) (Appendix, B1).

The germination of onion bulbs were also recorded after 15 DAP. From Fig. 4.4, it was observed that, the Treatment T_2 had the highest germination percentage (87.50 %) followed by T_4 (86.50 %), T_3 (85.50 %) and T_1 (69.25 %). However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2, T_3 and T_4 had the highest germination percentage and were at par. The Treatment T_1 had the lowest germination percentage. (Table 4.3) (Appendix, B2).

4.3.1.2 Effect on plant height of onion bulbs

The height of onion plants were recorded on 15 DAP during the crop period. From the Fig. 4.5, it was observed that, the Treatment T_2 had the highest plant height (33.85 cm) followed by T_4 (32.98 cm), T_3 (31.83 cm) and T_1 (31.36

cm). However, when means of treatment were compared by LSD method, it was observed that there was no significant difference between treatments (Table 4.3) (Appendix, B3).

The height of onion plants were also recorded on 30 DAP. From the Fig. 4.5, it was observed that, the Treatment T_2 had the highest plant height (39.50 cm) followed by T_4 (38.59 cm), T_3 (37.11 cm) and T_1 (36.10 cm). However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2 had the highest plant height followed by Treatments T_4 and T_3 which were at par. The Treatment T_1 had the lowest plant height. (Table 4.3) (Appendix, B4).

4.3.1.3 Effect on yield of onion bulbs

The yield of onion crop was recorded on 90 DAP. From Fig. 4.6, it was observed that, the Treatment T_2 had the highest yield of 19.46 t/ha followed by T_4 (18.69 t/ha), T_3 (17.10 t/ha) and T_1 (13.26 t/ha). However, when means of Treatment were compared by LSD method, it was observed that the Treatments T_2, T_4 and T_3 had the highest yield and were at par. The Treatment T_1 had the lowest yield. (Table 4.3) (Appendix, B5).

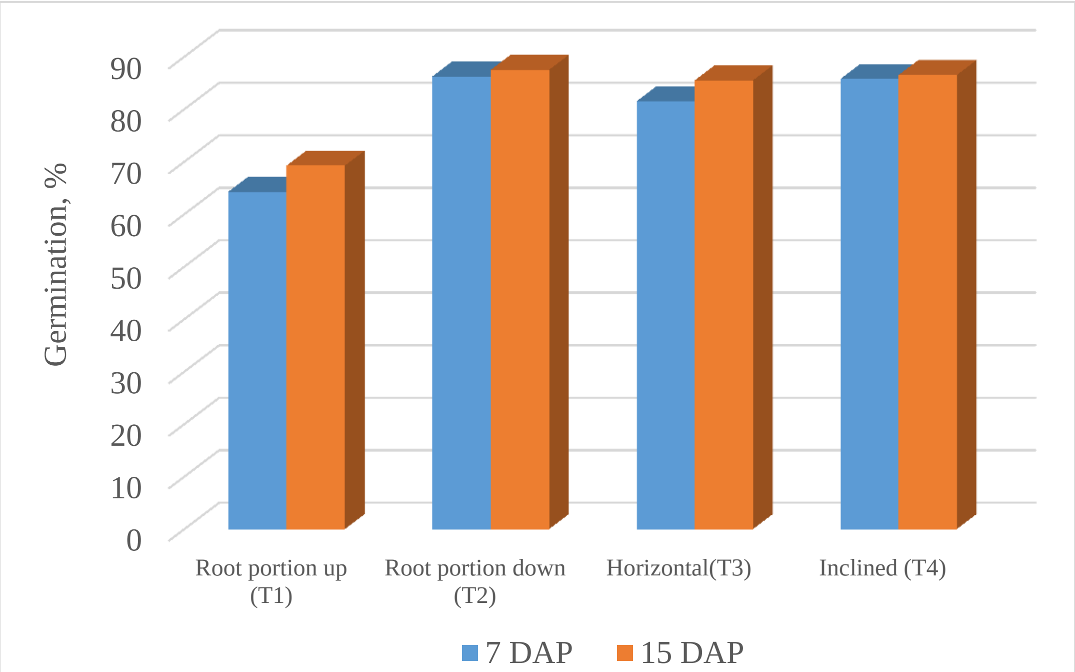


Fig. 4.4 Effect on germination of onion bulbs on 7DAP and 15 DAP

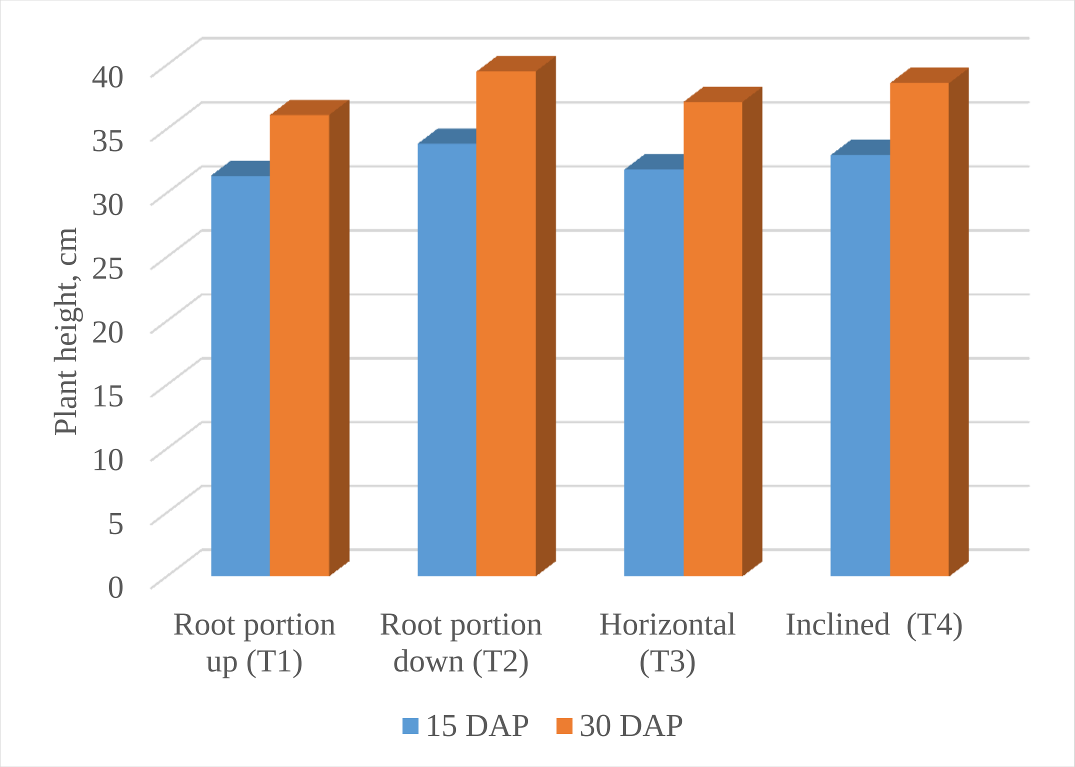


Fig. 4.5 Effect on plant height of onion bulbs on 15 DAP and 30 DAP

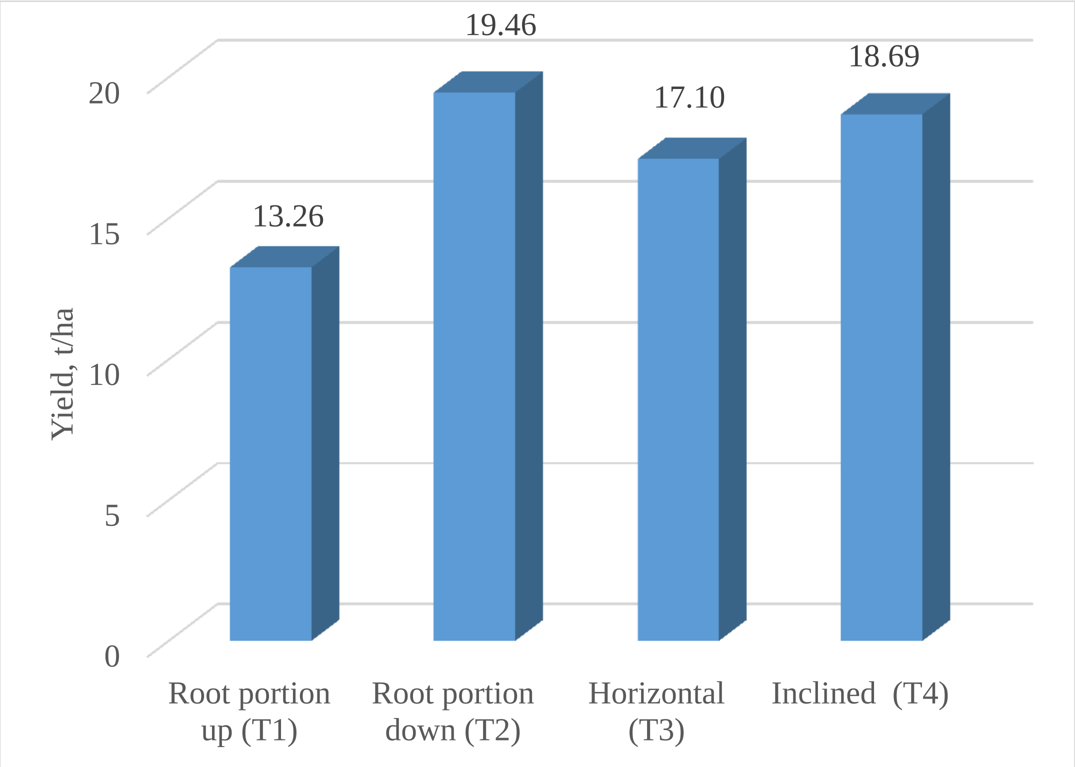


Fig. 4.6 Effect of different planting position on yield

Table 4.3. Effect of different orientation of onion bulb planting on different parameters in Rabi season.

Treatment	Germination, % (7 DAP)	Germination, % (15 DAP)	Plant height, cm (15 DAP)	Plant height, cm (30 DAP)	Yield, (t/ha)
T_1 (Root portion up)	64.25	69.25	31.36	36.10	13.26
T_2 (Root portion down)	86.25	87.50	33.85	39.50	19.46
T_3 (Horizontal)	81.50	85.50	31.83	37.11	17.10
T_4 (Inclined)	85.75	86.50	32.98	38.59	18.69
F-Value	**	**	NS	*	**
SEm	3.360	0.842	0.827	0.769	0.855
CD (p = 0.01/0.05)	14.516	3.636	-	2.371	3.696

** 1 % significant level; * 5 % significant level; NS-non significant

4.3.2 Kharif season

4.3.2.1 Effect on germination of onion bulbs

The germination of onion bulbs were recorded on 7 DAP. From Fig. 4.7, it was observed that 7 days after planting, the treatment T_2 had the highest germination efficiency (93.41 %) followed by T_4 (92.37 %), T_3 (91.59 %) and T_2 (58.01 %). However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2, T_4 and T_3 had the highest germination efficiency and were at par, the Treatment T_1 had the lowest germination efficiency. (Table 4.4.) (Appendix, B6).

The germination of onion bulbs were also recorded on 15 DAP. From Fig. 4.7, It was observed that 15 days after planting, the Treatment T_2 had the highest germination efficiency (95.40 %) followed by T_4 (95.00 %), T_3 ((93.64 %) and T_1 (61.20 %). However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2, T_3 and T_4 had the highest germination efficiency and were at par, the Treatment T_1 had the lowest germination efficiency. (Table 4.4) (Appendix, B7).

4.3.2.2 Effect on plant height of onion bulbs

The height of onion plants were recorded on 15 DAP. From Fig. 4.8, it was observed that, the treatment T_2 had the highest plant height (37.97 cm) followed by T_4 (36.93 cm), T_3 (35.86 cm) and T_1 (34.40 cm). However, when means of

Treatment were compared by LSD method, it was observed that the Treatments T_2 had the highest plant height followed by Treatments T_4 and T_3 which were at par. The Treatment T_1 had the lowest plant height, it was shown in (Table 4.4) (Appendix, B8).

The height of onion plants were also recorded on 30 DAP. From Fig. 4.8, it was observed that, the treatment T_2 had the highest plant height (37.97 cm) followed by T_4 (36.93 cm), T_3 (35.86 cm) and T_1 (34.40 cm). However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2 had the highest plant height followed by Treatments T_4 and T_3 which were at par. The Treatment T_1 had the lowest plant height, it was shown in (Table 4.4) (Appendix, B9).

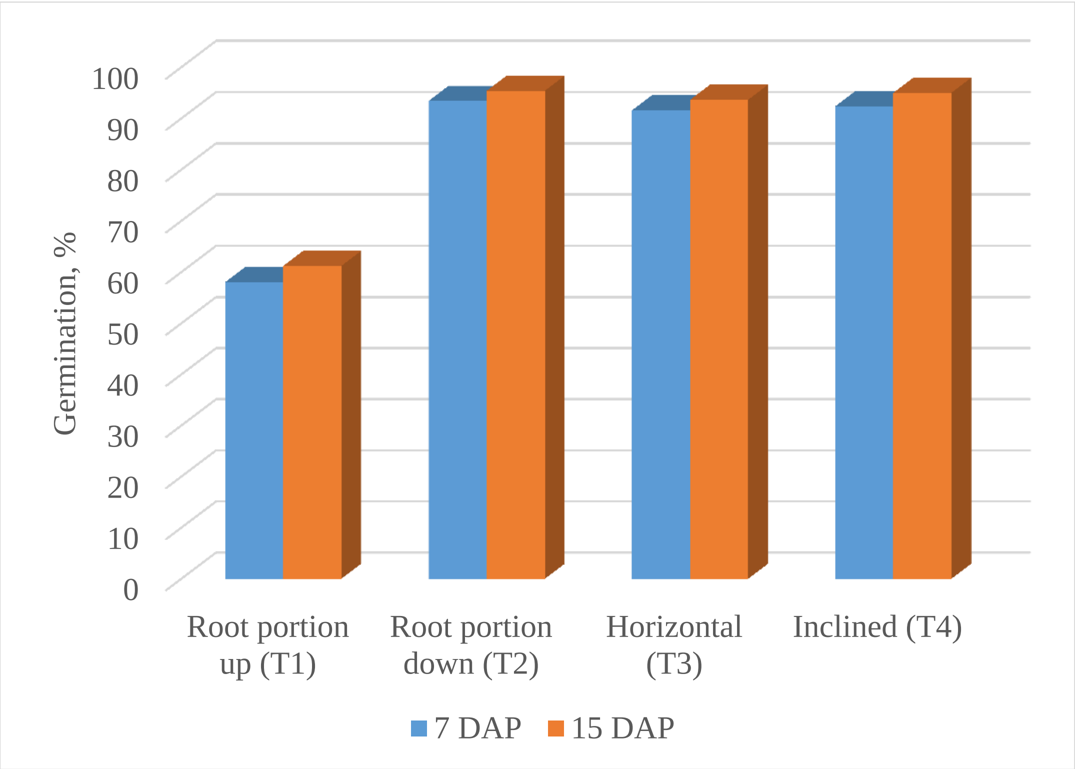


Fig. 4.7 Effect on germination of onion bulbs on 7DAP and 15 DAP

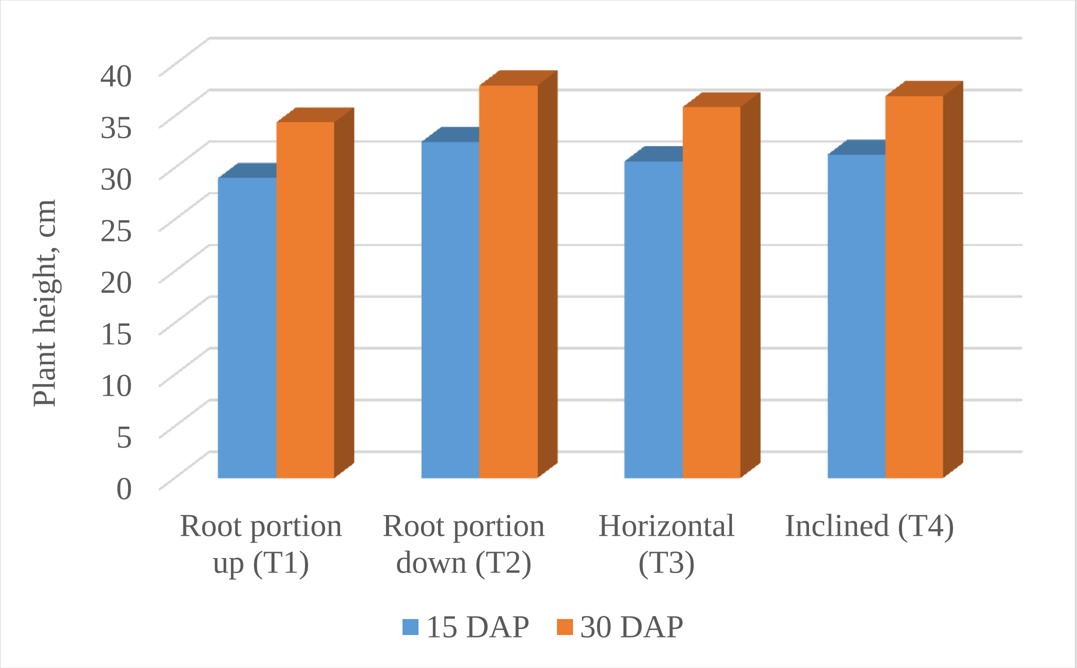


Fig. 4.8 Effect on plant height of onion bulbs on 15 DAP and 30 DAP

4.3.2.3 Effect on yield of onion bulbs

The yield of onion crop was recorded on 90 DAP. From Fig. 4.9, it was observed that, the Treatment T_2 had the highest yield of 12.62 t/ha followed by T_4 (12.08 t/ha), T_3 (11.78 t/ha) and T_1 (8.97 t/ha). However, when means of Treatment were compared by LSD method, it was observed that the Treatments T_2, T_4 and T_3 had the highest yield and were at par, the Treatment T_1 had the lowest yield. (Table 4.4) (Appendix, B10).

Table 4.4. Effect of different orientation of onion bulb planting on different parameters in Kharif season.

Treatment	Germination% (7 DAP)	Germination, % (15 DAP)	Plant height, cm (15 DAP)	Plant height, cm (30 DAP)	Yield, (t/ha)
T_1 (Root portion up)	58.01	61.20	29.02	34.40	8.97
T_2 (Root portion down)	93.41	95.40	32.51	37.97	12.62
T_3 (Horizontal)	91.59	93.64	30.63	35.86	11.73
T4 (Inclined)	92.37	95.00	31.25	36.93	12.08
F-Value	**	**	**	*	**
SEm	2.47	1.343	0.277	0.635	0.455
CD (p = 0.01/0.05)	9.576	5.801	1.197	1.957	1.966

** 1 % significant level; * 5 % significant level

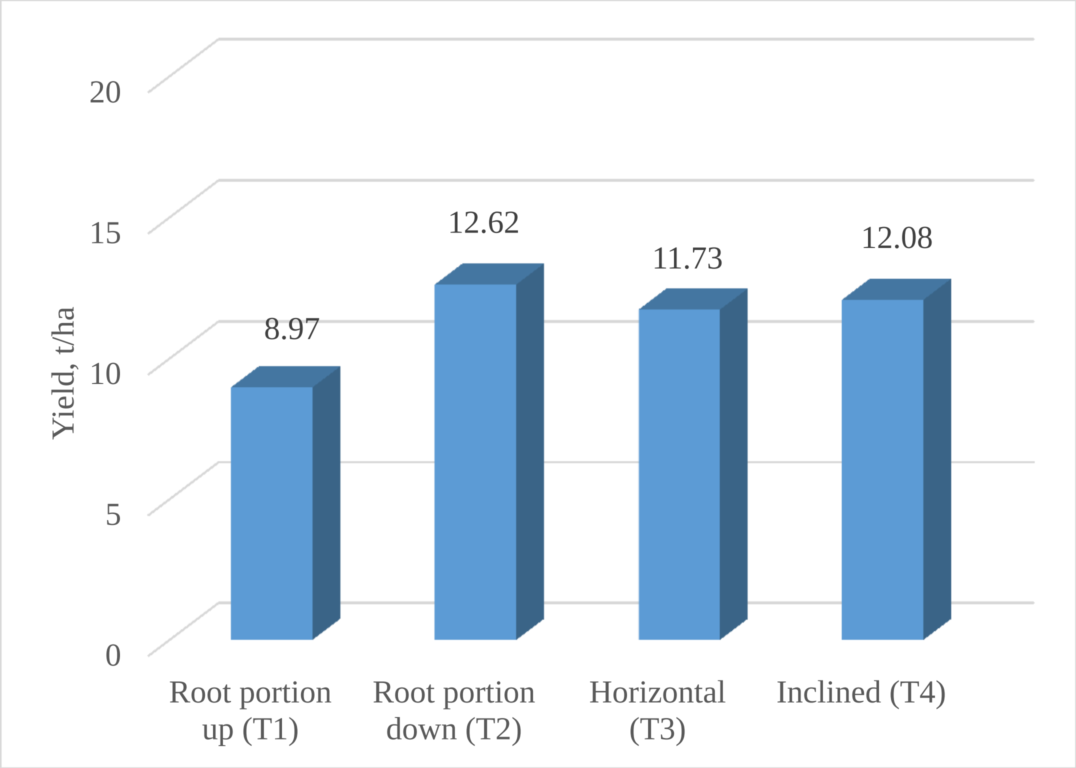


Fig. 4.9 Effect of different planting position on yield

4.3.3 Pooled data

The pooled data of the both the seasons (Kharif and Rabi) of plant growth parameters *viz*., germination percentage (7 DAP and 15 DAP), plant height (7 DAP and 15 DAP) and yield were statistically analyzed and results were presented in the Table 4.5.

4.3.3.1 Effect on germination of onion bulbs

The germination of onion bulbs were recorded on 7 DAP. From Fig. 4.10, It was observed that 7 days after planting, the Treatment T_2 had the highest germination efficiency (89.83 %) followed by T_4 (89.06 %), T_3 (86.54 %) and the Treatment T_1 had the lowest germination efficiency of (61.13 %). However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2, T_4 and T_3 had the highest germination efficiency and were at par. The treatment T_1 had the lowest germination efficiency. (Table 4.5) (Appendix, B11).

The germination of onion bulbs were recorded on 15 DAP. From Fig. 4.10, It was observed that 15 days after planting, the Treatment T_2 had the highest germination efficiency (91.45 %) followed by T_4 (90.75 %), T_3 ((89.57 %) and the Treatment T_1 had the lowest germination efficiency of (65.23 %). However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2, T_3 and T_4 had the highest germination efficiency and were at par, the Treatment T_1 had the lowest germination efficiency. (Table 4.5) (Appendix, B12).

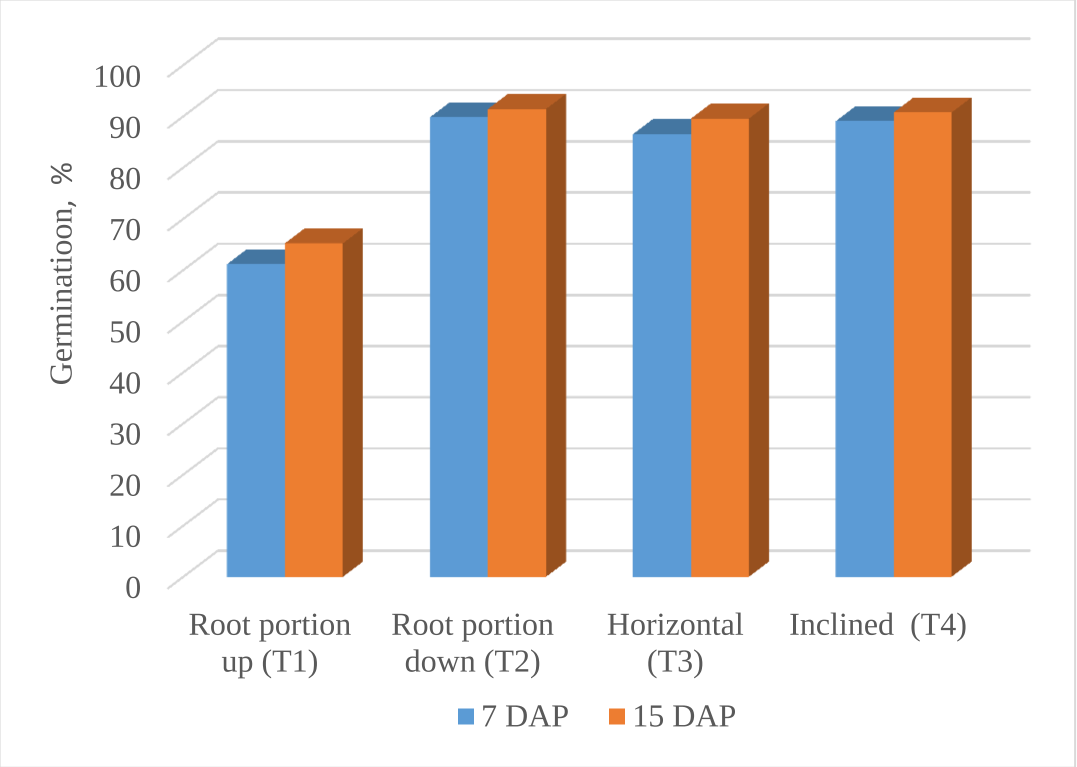


Fig. 4.10 Effect on germination of onion bulbs on 7DAP and 15 DAP

4.3.3.2 Effect on plant height of onion bulbs

The height of onion plants were recorded on 15 DAP. From Fig. 4.11, it was observed that, the Treatment T_2 had the highest plant height (33.18 cm) followed by T_4 (32.12 cm), T_3 (31.23 cm) and the Treatment T_1 had the lowest plant height of (30.19 cm). However, when means of treatment were compared by LSD method, it was observed that the Treatment T_2 had the highest plant height followed by Treatment T_4 and were at par. Further this was followed by Treatment

T_3 and Treatments T_4 and T_3 were at par. The Treatment T_1 had the lowest plant height and were at par with Treatment T_3 (Table 4.5) (Appendix, B13).

The height of onion plants were recorded on 30 DAP. From Fig. 4.11, it was observed that, the Treatment T_2 had the highest plant height (38.74 cm) followed by T_4 (37.76 cm) and were on par. This was followed by T_3 (36.49) and Treatments T_3 and T_4 were on par. Treatment T_1 had the lowest plant height of (35.25 cm) and were at par with T_3 (Table 4.5) (Appendix, B14).

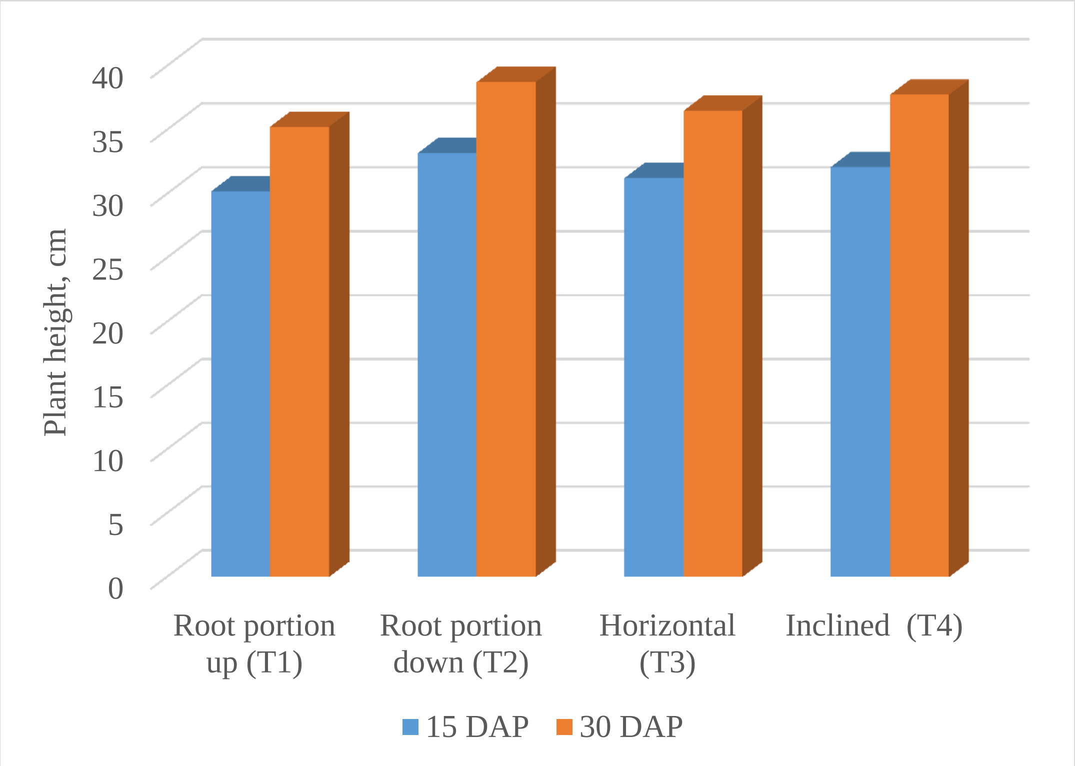


Fig. 4.11 Effect on plant height of onion bulbs on 15 DAP and 30 DAP

4.3.3.3 Effect of different onion bulb planting position on yield

The yield of onion crop was recorded on 90 DAP. From Fig.4.12, it was observed that, the Treatment T_2 had the highest yield of 16.04 t/ha followed by T_4 (15.39 t/ha), T_3 (14.42 t/ha) and the Treatment T_1 had the lowest yield of 11.12 t/ha. However, when means of treatment were compared by LSD method, it was observed that the Treatments T_2 had the highest yield followed by Treatment T_4 and were on par. This was followed by Treatment T_3 and treatments T_4 and T_3 were at par (Table 4.5) (Appendix, B15).

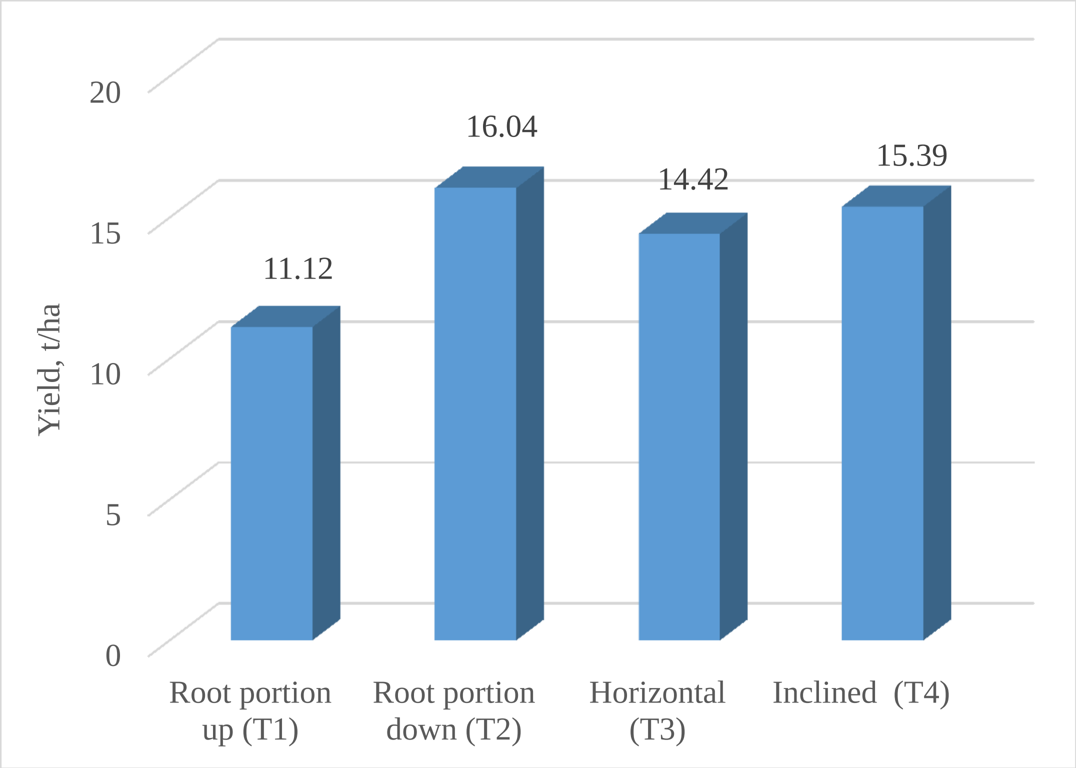


Fig. 4.12 Effect of different planting position on yield

Table 4.5. Effect of pooled data of different orientation of onion bulb planting on different parameters

Treatment	Germination, % (7 DAP)	Germination, % (15 DAP)	Plant height, cm (15 DAP)	Plant height, cm (30 DAP)	Yield, (t/ha)
T_1 (Root portion up)	61.13	65.23	30.19	35.25	11.12
T_2 (Root portion down)	89.83	91.45	33.18	38.74	16.04
T_3 (Horizontal)	86.54	89.57	31.23	36.49	14.42
T_4 (Inclined)	89.06	90.75	32.12	37.76	15.39
F-Value	**	**	**	**	**
SEm	2.33	0.722	0.481	0.483	0.402
CD (p = 0.01)	10.104	3.119	2.077	2.086	1.735

** 1% significant level

From the above results, 4.3.1 to 4.3.3, it was clear that onion planting positions root portion down, horizontal and inclined had the highest growth parameters and were at par.

4.4 Optimization of Design and Operation Parameters of Onion Bulb Planter

After studying the planters adopted for planting onion bulbs, garlic and bold seeds, cup type metering mechanism was selected for this present study. An experimental set up was constructed to optimize the design and operational parameters of onion bulb metering unit (section 3.4) .Experiment was carried out to optimize the following design and operational parameters.

I. Planting material
   a. Size of onion bulb
II. Metering cup design parameter
   a. Cup size
III. Metering cup operational parameters
   a. Peripheral speed of metering unit
   b. Angle of inclination of metering unit

The effect of a) different cup sizes C_1 (34 mm), C_2 (31 mm), C_3 (29 mm) and C_4 (25 mm) and different peripheral speeds S_1 (0.5 km h^{-1}), S_2 (1 km h^{-1}), S_3 (1.5 km h^{-1}) and S_4 (2 km h^{-1}) and different angle of inclination A_1 (60° **)**, A_2 (75° **)** and A_3 (90° **)** on performance of metering unit performance in terms of i) percent singles, ii) percent doubles, iii) percent multiples, iv) percent missings and v) percent bulb damages were studied, discussed for each selected grade of onion bulbs and presented below:

The effect of different peripheral speeds of S_1 (0.5 km h^{-1}), S_2 (1 km h^{-1}), S_3 (1.5 km h^{-1}) and S_4 (2 km h^{-1}) and angles of inclination of A_1 (60°**)** , A_2 (75°**)** and A3 (90°**)** for cup sizes C_1 (34 mm), C_2 (31 mm), C_3 (29 mm) and C_4 (25 mm) of meeting unit on percent singles, doubles, multiples, missings, bulb damage was statistically analyzed to optimize the design operational parameters for all the four categories of onion grades I - (2-3 g weight), grade –II (3-4 g weight), grade-III (4-5 g weight), and grade-IV (5-6 g weight). The criteria chosen for the optimum combination of above parameters was, which would yield minimum missings, maximum singles, minimum doubles and minimum multiples.

4.4.1 Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-I category (2-3 g weight) of onion bulbs

4.4.1.1 Per cent singles

From Figs. 4.13 and 4.17 (Appendix D1). It was observed that when peripheral speed increased from 0.5 (S_1) to 1 km h^{-1} (S_2), the per cent singles also increased. Further when the peripheral speed increased from 1 (S_3) to 2 (S_4) km h^{-1} with an increment of 0.5 km h^{-1} speed the per cent singles decreased. From this, it was evident that beyond certain peripheral speed the onion bulb might be thrown out of the cup which caused reduction in per cent singles. It was further observed that when the angle of inclination increased, per cent singles also increased. From this it was clear that cup position maintained in vertical position could hold the onions effectively.

The results of variance obtained for singles is presented in Table 4.6. From the Table 4.6, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent singles.

When the means compared by LSD method, it was clear that cup size, C_4 (54.81 %) had the highest per cent singles followed by C_1 (43.77 %) and C_2 (43.75 %). The lowest per cent singles was found in C_3 (42.20 %). Further, it was evident that peripheral speed, S_2 (49.91 %) had the highest per cent singles followed by S_1 (45.88 %) and S_3 (45.79 %). The lowest per cent singles was found in S_4 (42.96 %). Similarly, it was observed that the angle of inclination, A_3 (47.71 %) had the highest per cent singles followed by A_2 (46.70 %) and A_1 (43.99 %). It was observed that the treatment combinations $C_4S_2A_3$ had the highest per cent singles (62.80 %), treatment combinations $C_3S_4A_1$ (34.26 %) and $C_3S_1A_2$ (33.77 %) had the lowest per cent singles and were at par. (Appendix C1).

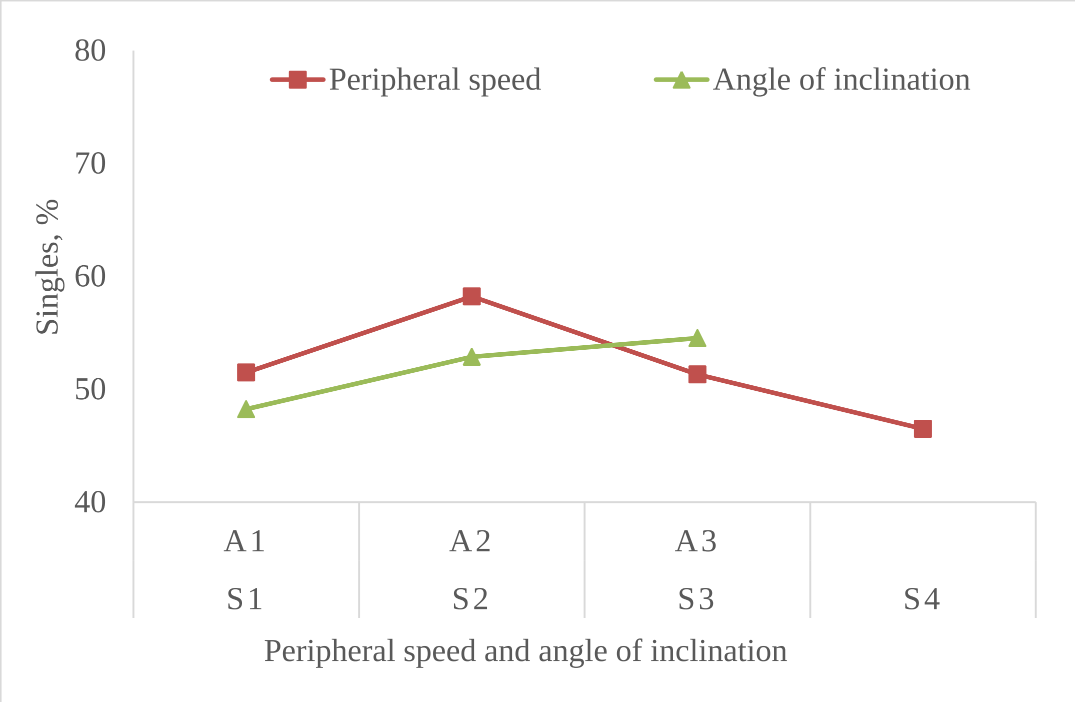


Fig. 4.13 Effect of peripheral speed and angle of inclination on per cent singles - Onion bulb size (Grade 2-3 g)

Table 4.6. Analysis of variance for per cent singles for grade –I category (2-3 g weight) of onion bulbs

	Singles			
Cup size	C_1 43.77	C_2 43.75	C_3 42.20	C_4 54.81
Peripheral speed	S_1 45.88	S_2 49.91	S_3 45.79	S_4 42.96
Angle of inclination	A_1 43.99	A_2 46.70	A_3 47.71	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.10	0.46	
Peripheral speed (S)	**	0.10	0.46	
Angle of inclination (A)	**	0.08	0.40	
C×S	**	0.20	0.92	
S×A	**	0.17	0.80	
C×A	**	0.176	0.80	
C×S×A	**	0.35	1.60	

** 1% significant level

4.4.1.2 Per cent doubles

From Figs. 4.14 and 4.18 (Appendix D2). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent doubles decreased. From this, it was clear that, at lower peripheral speed the onion bulbs were held in the cups which contributed for higher per cent doubles. It was further observed that when the angle of inclination increased, per cent doubles decreased. This might be due to, cups in vertical position.

The results of variance obtained for doubles is presented in Table 4.7. From the Table 4.7, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent doubles.

When the means compared by LSD method, it was clear that the cup size, C_4 (3.82 %) had the lowest per cent doubles followed by C_3 (4.26 %) and C_2 (4.50 %). The highest per cent doubles was found in C_1 (4.74 %). When mean compared, it was evident that peripheral speed, S_4 (3.98 %) had the lowest per cent doubles followed by S_3 (4.20 %) and S_2 (4.35 %). The highest per cent doubles was found in S_1 (4.79 %). Similarly, it was observed that the angle of inclination, A_3 (3.72 %) had highest per cent doubles followed A_2 (4.58 %). The lowest per cent doubles was found in A_1 (4.68 %). It was also observed that the treatment combinations $C_3S_4A_1$ (2.32 %) and $C_3S_3A_3$ (2.42 %) had the lowest per cent doubles and treatment $C_3S_1A_1$ (5.68 %), $C_1S_1A_1$ (5.66 %) and $C_3S_1A_2$ (5.60 %) had highest per cent doubles and were at par. (Appendix C2).

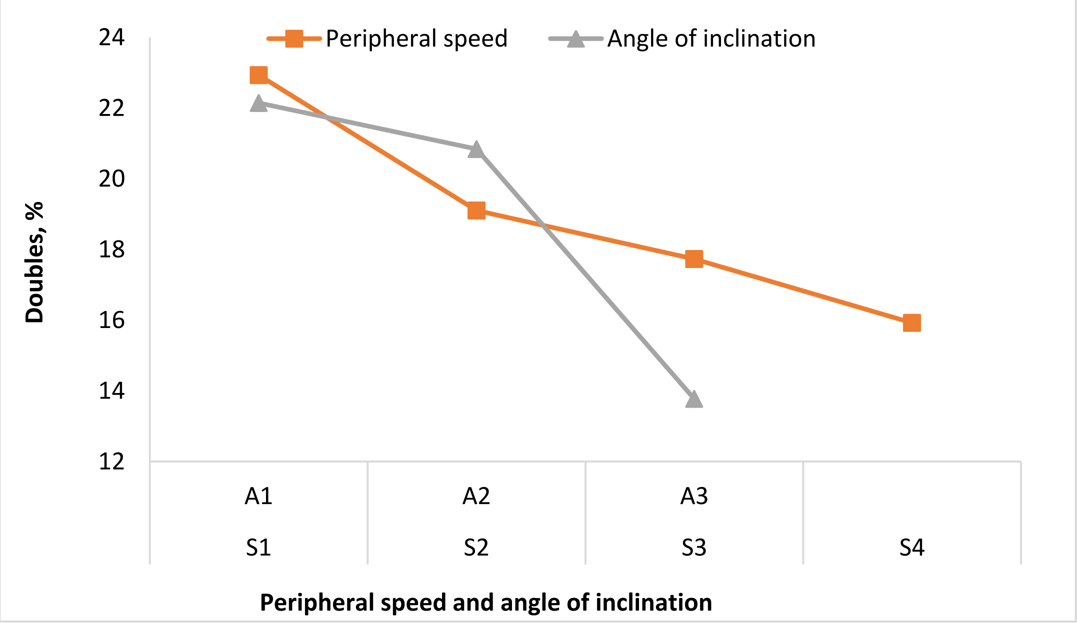


Fig. 4.14 Effect of peripheral speed and angle of inclination on per cent doubles - Onion bulb size (Grade 2-3 g)

Table 4.7. Analysis of variance for per cent doubles for grade –I category (2-3 g weight) of onion bulbs

	Doubles			
Cup size	C_1	C_2	C_3	C_4
	4.74	4.50	4.26	3.82
Peripheral speed	S_1	S_2	S_3	S_4
	4.79	4.35	4.20	3.98
Angle of inclination	A_1	A_2	A_3	
	4.68	4.58	3.72	
	F-value	SEm	CD (p =0.01)	
Cup size (C)	**	0.01	0.06	
Peripheral speed (S)	**	0.01	0.06	
Angle of inclination (A)	**	0.01	0.06	
C×S	**	0.03	0.13	
S×A	**	0.02	0.12	
C×A	**	0.02	0.12	
C×S×A	**	0.05	0.24	

** 1% significant level

4.4.1.3 Per cent multiples

From Figs. 4.15 and 4.19 (Appendix D3). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent multiples decreased. The reason might be, higher peripheral speed would have made the onion bulbs to fall from the cups. It was further observed that when the angle of inclination increased, per cent multiples decreased. This was due to vertical cup position could hold less number of onion bulbs.

The results of variance obtained for multiples was presented in Table 4.8. From the Table 4.8, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on multiples.

When the means compared by LSD method, it was clear that the cup size, C_3 (3.25 %) had the lowest per cent multiples followed by C_4 (3.55 %) and C_2 (4.07 %). The cup size, C_1 (4.17 %) had the highest per cent multiples. It was further observed that, the speed, S_4 (3.34 %) had the lowest per cent multiples followed by S_2 (3.73 %) and S_3 (3.58 %). The speed S_1 (4.40 %) had highest per cent multiples. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_3 (3.14 %) had the lowest per cent multiples followed by A_2 (3.86 %). The angle of inclination, A_1 (4.29 %) had the highest per cent multiples. It was also observed that the treatment combinations $C_3S_4A_1$ (1.63 %), $C_3S_2A_3$ (1.75 %) and $C_3S_3A_3$ (1.70 %) had the lowest per cent multiples and treatment $C_3S_1A_2$ (6.010 %) had highest per cent multiples and were at par. (Appendix C3).

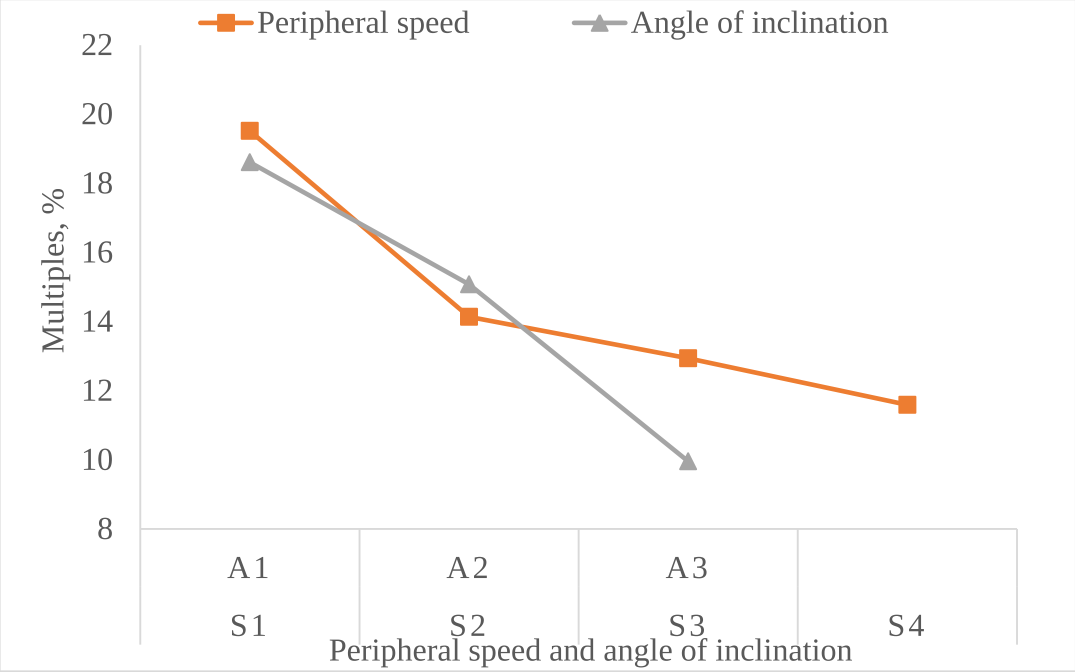


Fig. 4.15 Effect of peripheral speed and angle of inclination on per cent multiples Onion bulb size (Grade 2-3 g)

Table 4.8. Analysis of variance for per cent multiples for grade –I category (2-3 g weight) of onion bulbs

	Multiples			
Cup size	C_1 4.17	C_2 4.07	C_3 3.25	C_4 3.55
Peripheral speed	S_1 4.40	S_2 3.73	S_3 3.58	S_4 3.34
Angle of inclination	A_1 4.29	A_2 3.86		A_3 3.14
	F-value	SEm		CD (p = 0.01)
Cup size (C)	**	0.02		0.10
Peripheral speed (S)	**	0.02		0.10
Angle of inclination (A)	**	0.02		0.09
C×S	**	0.04		0.21
S×A	**	0.04		0.18
C×A	**	0.04		0.18
C×S×A	**	0.08		0.37

** 1% significant level

4.4.1.4 Per cent missings

From Figs. 4.16 and 4.20 (Appendix D4). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent missings increased. At higher peripheral speed of metering unit, cups were unable to hold the onion bulbs. This might have caused higher per cent missings at higher peripheral speed. It was further observed that when the angle of inclination increased, per cent missings increased. This might be due to vertical position of cup was unable to hold onion bulbs.

The results of variance obtained for missings is presented in Table 4.9. From the Table 4.9, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on missings.

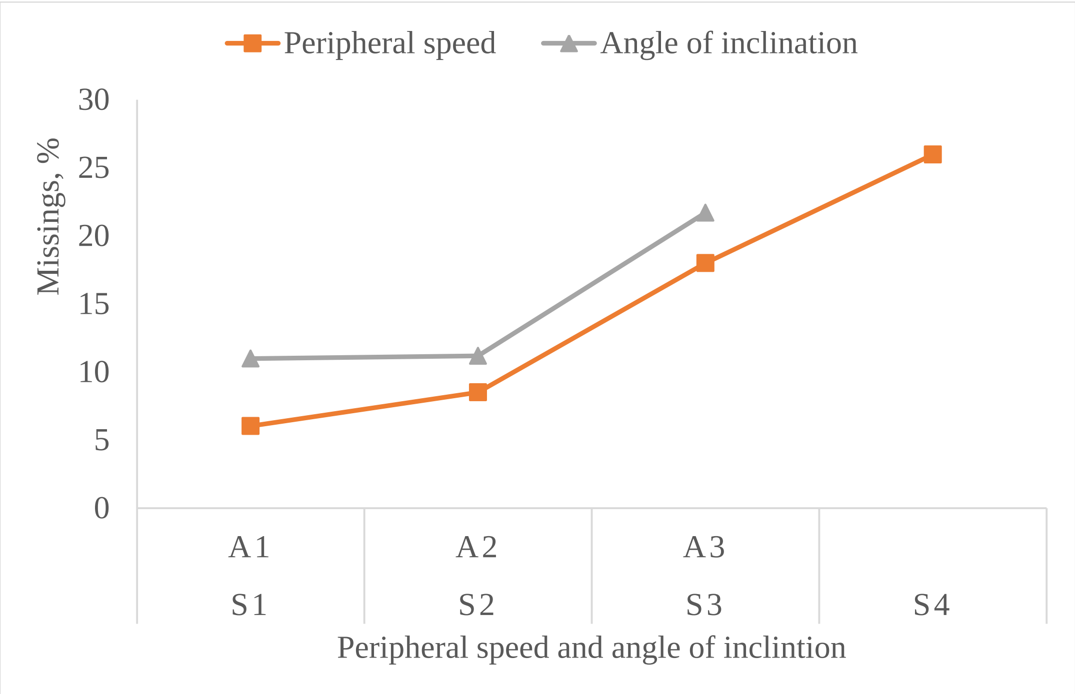


Fig. 4.16 Effect of peripheral speed and angle of inclination on per cent missings - Onion bulb size (Grade 2-3 g)

When the means compared by LSD method, it was clear that the cup size, C_4 (2.55 %) had the lowest per cent missngs followed by C_1 (3.30 %) and C_2 (3.89 %). The cup size, C_3 (4.50 %) had the highest per cent missings. It was further observed that, the speed, S_1 (2.39 %) had lowest per cent missings followed by S_2 (2.79 %) and S_3 (4.11 %). The cup size, S_4 (4.94 %), had the highest per cent multiples. When the means of angle of inclination was compared, it was observed that the angle of inclination A_1 (3.04 %) had the lowest per cent missings followed by A_2 (3.24 %). The angle of inclination, A_3 (4.39 %) had the highest per cent missings. It was also observed that the treatment combinations $C_4S_1A_1$ (1.51 %), $C_4S_2A_1$ (1.49 %), $C_1S_1A_1$ (1.57 %), $C_3S_1A_2$ (1.72 %), $C_4S_1A_2$ (1.61 %) had the lowest per cent missings and treatment $C_3S_4A_1$ (7.85 %) had highest per cent missings and were at par. (Appendix C4).

Table 4.9. Analysis of variance for per cent missings for grade –I category (2-3 g weight) of onion bulbs

	Missings			
Cup size	C_1 3.30	C_2 3.89	C_3 4.50	C_4 2.55
Peripheral speed	S_1 2.39	S_2 2.79	S_3 4.11	S_4 4.94
Angle of inclination	A_1 3.04	A_2 3.24	A_3 4.39	
	F-value	SeM	CD (p = 0.01)	
Cup size (C)	**	0.02	0.11	
Peripheral speed (S)	**	0.02	0.11	
Angle of inclination (A)	**	0.02	0.10	
C×S	**	0.05	0.23	
S×A	**	0.04	0.20	
C×A	**	0.04	0.20	
C×S×A	**	0.08	0.40	

1% significant level

Cup type 1 C_1 Size of onion-2-3 g (Grade I)

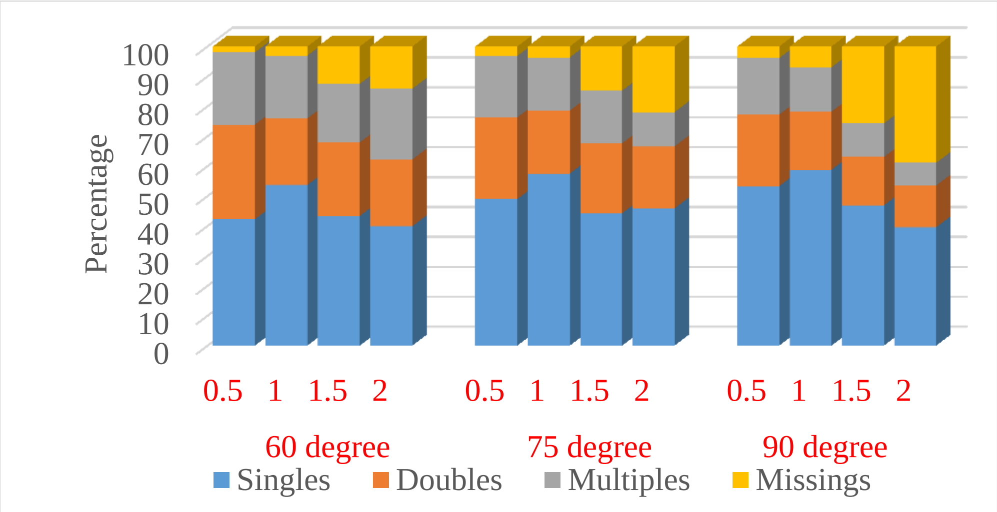


Fig. 4.17 Effect of angle of inclination and peripheral speed on cell filling efficiency of onion bulb metering unit

Cup type 2 C_2 Size of onion-2-3 g (Grade I)

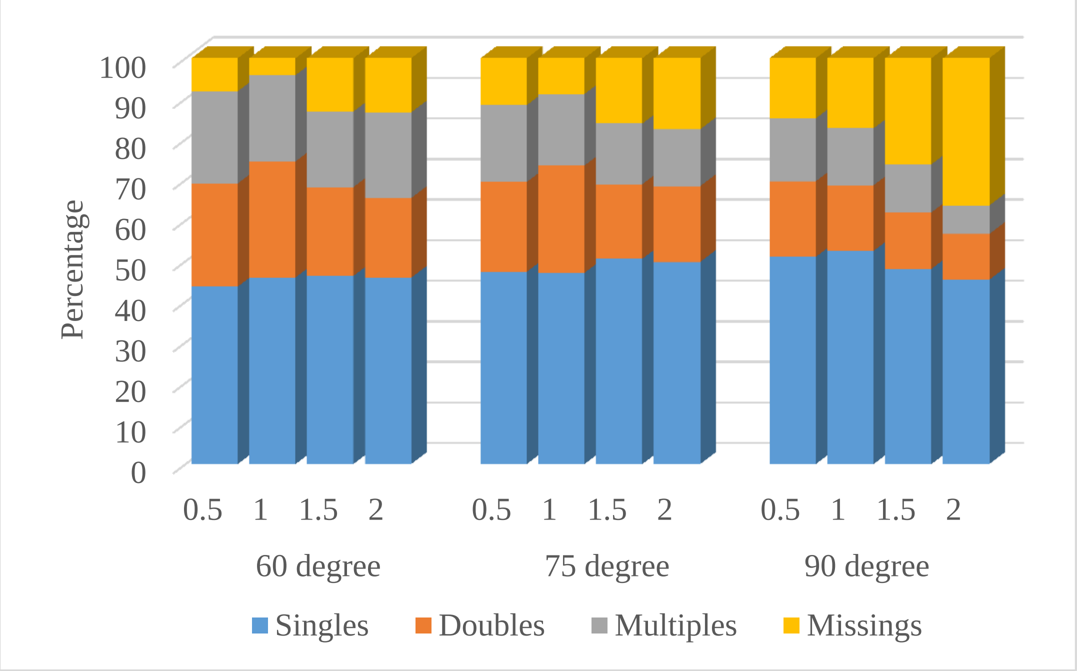


Fig. 4.18 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 3 C_3 Size of onion-2-3 g (Grade I)

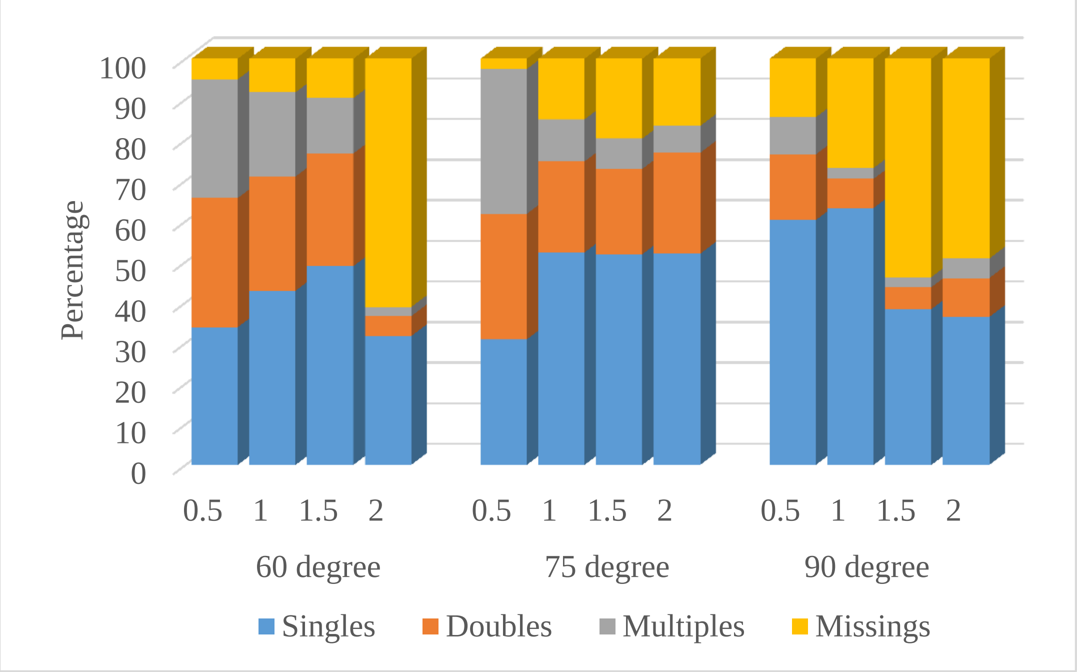


Fig. 4.19 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 4 C_4 Size of onion-2-3 g (Grade I)

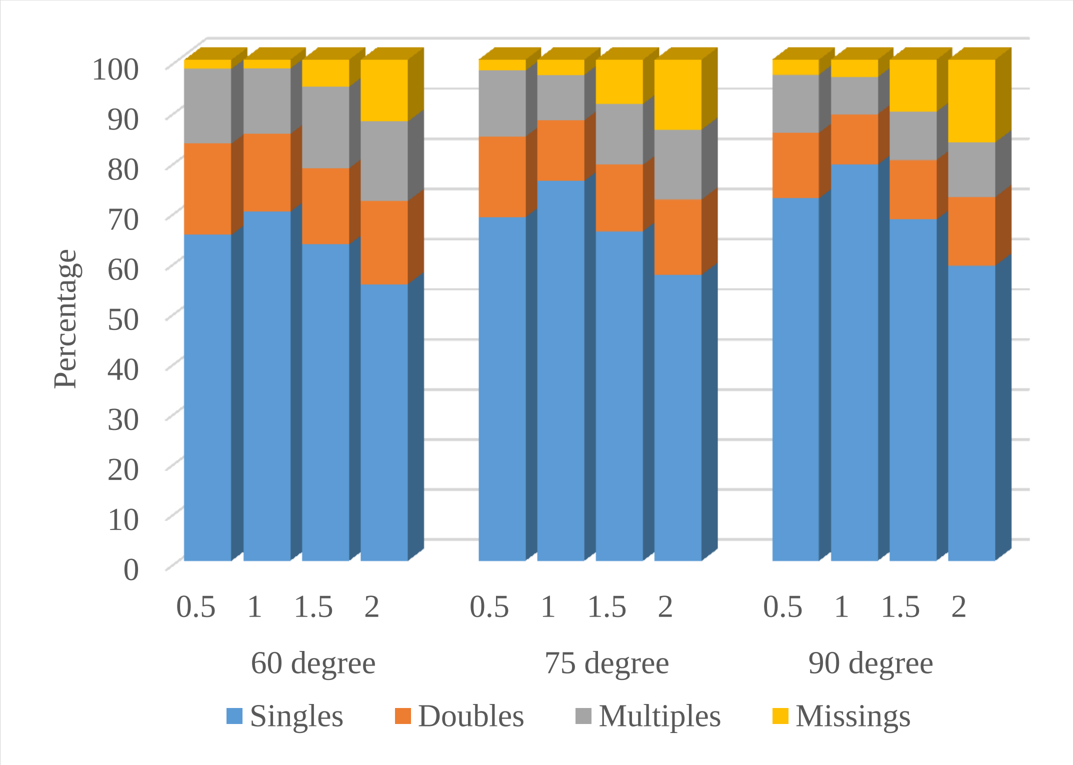


Fig. 4.20 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

4.4.1.5 Per cent bulb damage

From Fig. 4.21. It was observed that when peripheral speed increased, from 0.5 (S_1) to 1 (S_2) km h^{-1}, the per cent of bulb damage decreased. Further when the peripheral speed increased from 1 (S_2) to 1.5 (S_3) km h^{-1}, the per cent of singles increased. Further increment of speed from 1.5 (S_3) to 2 (S_4) km h^{-1}, the per cent of singles decreased. It was further observed that when the angle of inclination increased 60 (A_1) to 75 (A_2) degree, percentage of bulb damage increased further increasing of angle of inclination, the per cent of bulb damage decreased.

The results of variance obtained for bulb damage is presented in Table 4.10. From the Table 4.10, it was inferred that, the cup size, peripheral speed and angle of inclination had non-significant effect on bulb damage.

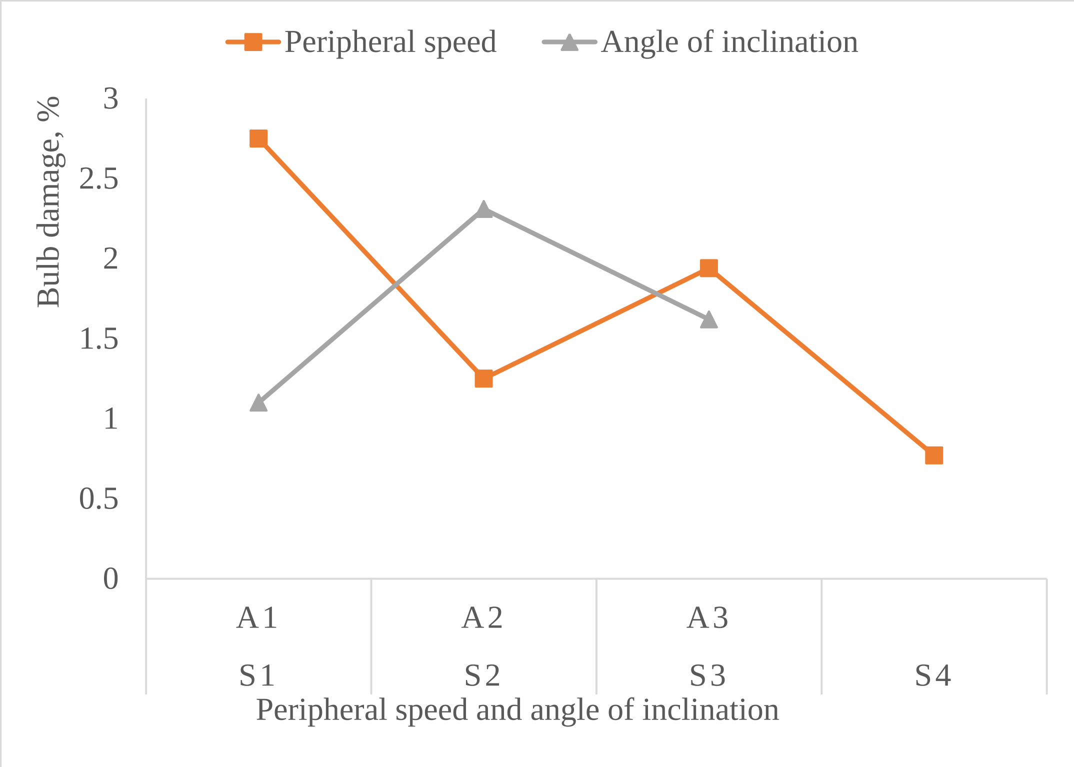


Fig. 4.21 Effect of peripheral speed and angle of inclination on per cent bulb damage - Onion bulb size (Grade 2-3 g)

Table 4.10 Analysis of variance for per cent bulb damage for grade –I category (2-3 g weight) of onion bulbs

	Bulb damage			
Cup size	C_1 1.48	C_2 1.35	C_3 3.31	C_4 1.50
Peripheral speed	S_1 3.51	S_2 1.46	S_3 1.67	S_4 1.00
Angle of inclination	A_1 1.22	A_2 2.69	A_3 1.81	
	F-value	SEm	CD (p = 0.01/0.05)	
Cup size (C)	NS	0.81	-	
Peripheral speed (S)	NS	0.81	-	
Angle of inclination (A)	NS	0.70	-	
C×S	NS	1.62	-	
S×A	NS	1.40	-	
C×A	NS	1.40	-	
C×S×A	NS	2.81	-	

NS-non significant

When the means compared by LSD, it was clear that the cup size, C_2 (1.35 %) had the lowest per cent bulb damage followed by C_1 (1.48 %) and C_3 (3.31 %). The cup size, C_4 (1.50 %) had the highest per cent bulb damage. It was further observed that, the speed, S_4 (1.00 %) had the lowest per cent of bulb damage followed by S_2 (1.46 %) and S_3 (1.67 %). The speed, S_1 (3.51 %) of had highest per cent bulb damage. When the means of angle of inclination was compared, it was observed that the angle of inclination A_1 (1.22 %) had lowest per cent bulb damage followed by A_3 (1.81 %). The angle of inclination, A_2 (2.69 %) had highest per cent bulb damage. From the table it was observed that, there was no significant effect due to interaction between the treatments. (Appendix C5).

4.4.2 Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-II category (3-4 g weight) of onion bulbs

4.4.2.1 Per cent singles

From Figs. 4.22, and 4.26 (Appendix D5). It was observed that when peripheral speed increased from 0.5 (S_1) to 1 km h^{-1} (S_2), the per cent singles also increased. Further when the peripheral speed increased from 1(S_3) to 2 (S_4) km h^{-1} with an increment of 0.5 km h^{-1} speed the per cent singles decreased. From this, it is evident that beyond certain peripheral speed the onion bulb might be thrown out of the cup which caste reduction in per cent singles. It was further observed that when the angle of inclination increased, per cent singles also increased. From this it is clear that when the cup position is maintained in vertical position could hold the onions.

The results of variance obtained for per cent singles is presented in Table 4.11. From the Table 4.11, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on singles.

When the means compared by LSD method, it was clear that cup size, C_4 (54.92 %) had the highest per cent singles followed by C_2 (43.70 %) and C_1 (43.58 %). The lowest per cent singles was found in C_3 (40.18 %). When means compared, it was evident that the speed, S_2 (48.49 %) had highest per cent singles followed by S_1 (46.12 %) and S_3 (45.28 %). The lowest per cent singles was found in S_4 (42.49 %). Similarly, it was observed that the, angle of inclination, A_3 (46.05

%) had highest per cent singles followed by A_2 (45.92 %) and A_1 (44.81 %). It was also observed that the treatment combinations $C_4S_2A_3$ had the highest per cent of singles (63.33 %) and treatment $C_3S_2A_3$ (32.44 %) had the lowest per cent singles and were at par. (Appendix C6).

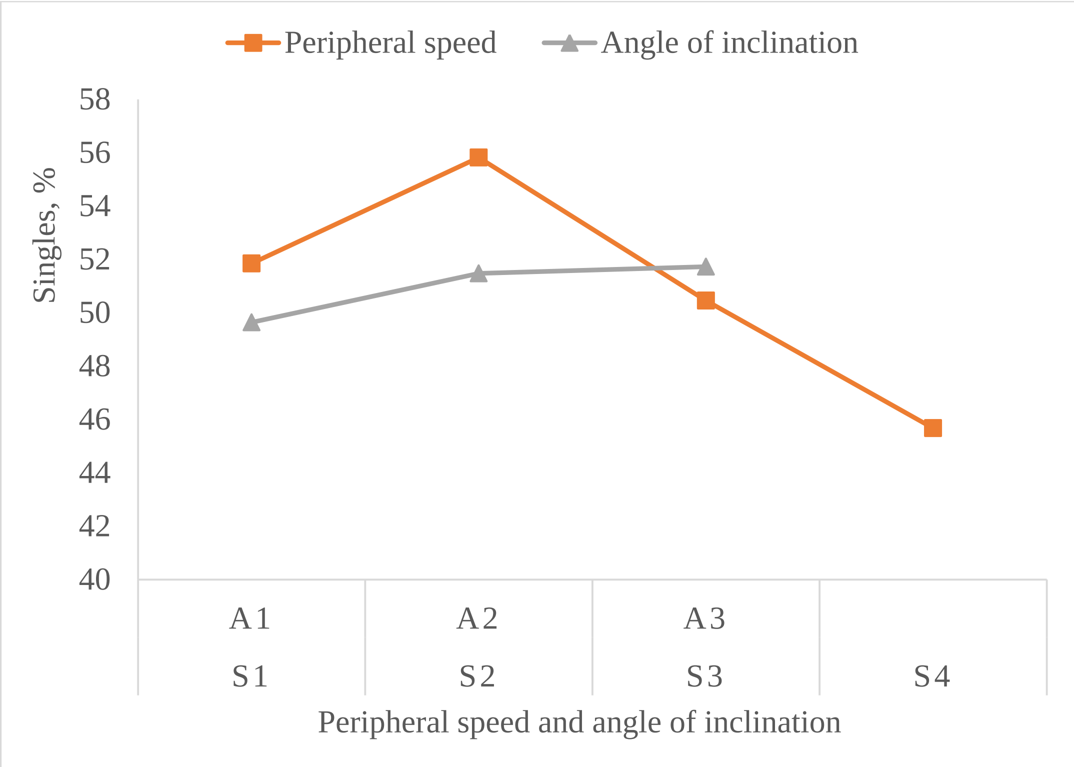


Fig. 4.22 Effect of peripheral speed and angle of inclination on per cent singles - Onion bulb size (Grade 3-4 g)

4.4.2.2 Per cent doubles

From Figs. 4.23 and 4.27 (Appendix D6). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent doubles decreased. From this, it was clear that, at lower peripheral speed the onion bulbs were held in the cups which contributed for higher per cent doubles. It was further observed that when the angle of inclination increased, per cent doubles decreased. This might be due to, cups in vertical position.

The results of variance obtained for doubles is presented in Table 4.12. From the Table 4.12, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on doubles.

When the means compared by LSD method, it was evident that the cup size, C_4 (3.73 %) had the lowest per cent doubles followed by C_3 (4.03 %) and C_2 (4.40 %). The highest per cent doubles was found in C_1 (4.69 %). When mean compared, it was evident that speed S_4 (3.85 %) had the lowest per cent doubles followed by S_3 (3.95 %) and S_2 (4.32 %). The highest per cent doubles was found in S_1 (4.72 %). When the means of angle of inclination compared, it was observed that the angle of inclination, A_3 (3.55 %) had the lowest per cent doubles followed A_2 (4.41 %). The highest per cent doubles was found in A_1 (4.67 %). It was also observed that the treatment combinations $C_3S_3A_3$ (1.62 %) had lowest per cent of doubles and treatment $C_3S_1A_1$ (5.43 %), $C_1S_1A_1$ (5.60 %) and $C_4S_2A_2$ (5.53 %) had the highest per cent doubles and were at par. (Appendix C7).

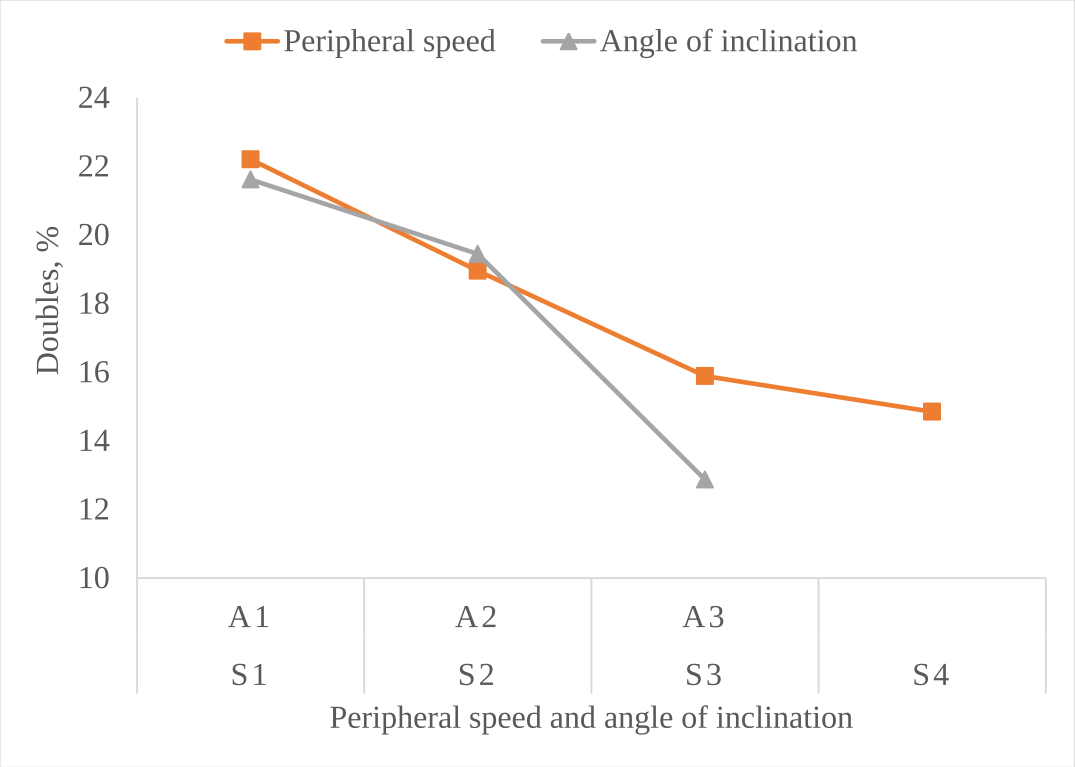


Fig. 4.23 Effect of peripheral speed and angle of inclination on per cent doubles - Onion bulb size (Grade 3-4 g)

Table 4.11. Analysis of variance for per cent singles for grade –II category (3-4 g weight) of onion bulbs

Singles				
Cup size	C_1 43.58	C_2 43.70	C_3 40.18	C_4 54.92
Peripheral speed	S_1 46.12	S_2 48.49	S_3 45.28	S_4 42.49
Angle of inclination	A_1 44.81	A_2 45.92	A_3 46.05	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.09	0.44	
Peripheral speed (S)	**	0.09	0.44	
Angle of inclination (A)	**	0.08	0.38	
C×S	**	0.19	0.88	
S×A	**	0.16	0.76	
C×A	**	0.16	0.76	
C×S×A	**	0.33	1.53	

** 1% significant level

Table 4.12. Analysis of variance for per cent doubles for grade –II category (3-4 g weight) of onion bulbs

Doubles				
Cup size	C_1 4.69	C_2 4.40	C_3 4.03	C_4 3.73
Peripheral speed	S_1 4.72	S_2 4.32	S_3 3.95	S_4 3.85
Angle of inclination	A_1 4.67	A_2 4.41	A_3 3.55	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.01	0.09	
Peripheral speed (S)	**	0.02	0.09	
Angle of inclination (A)	**	0.01	0.07	
C×S	**	0.03	0.18	
S×A	**	0.03	0.15	
C×A	**	0.03	0.15	
C×S×A	**	0.06	0.31	

** 1% significant level

4.4.2.3 Per cent multiples

From Figs. 4.24 and 4.28 (Appendix D7). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent multiples decreased. The reason might be, higher peripheral speed would have made the onion bulbs to fall from the cups. It was further observed that when the angle of inclination increased, per cent multiples decreased. This was due to vertical cup position could hold less number of onion bulbs.

The results of variance obtained for multiples is presented in Table 4.13. From the Table 4.13, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on multiples.

When the means compared by LSD, it was clear that the cup size, C_3 (3.12 %) had the lowest per cent multiples followed by C_4 (3.44 %) and C_2 (4.00 %). The cup size, C_1 (4.06 %) had highest per cent of multiples. It was further observed that, the speed, S_4 (3.25 %) had lowest per cent multiples followed by S_3 (3.46 %) and S_2 (3.63 %). The speed, S_1 (4.29 %) had highest per cent multiples. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_3 (2.98 %) had lowest percentage of multiples followed by A_2 (3.77 %). The angle of inclination, A_1 (4.22 %) had highest per cent multiples. It was also observed that the treatment combinations $C_3S_4A_3$ (1.24 %) had lowest per cent multiples and treatment $C_3S_1A_2$ (6.56 %) had highest per cent multiples and were at par. (Appendix C8).

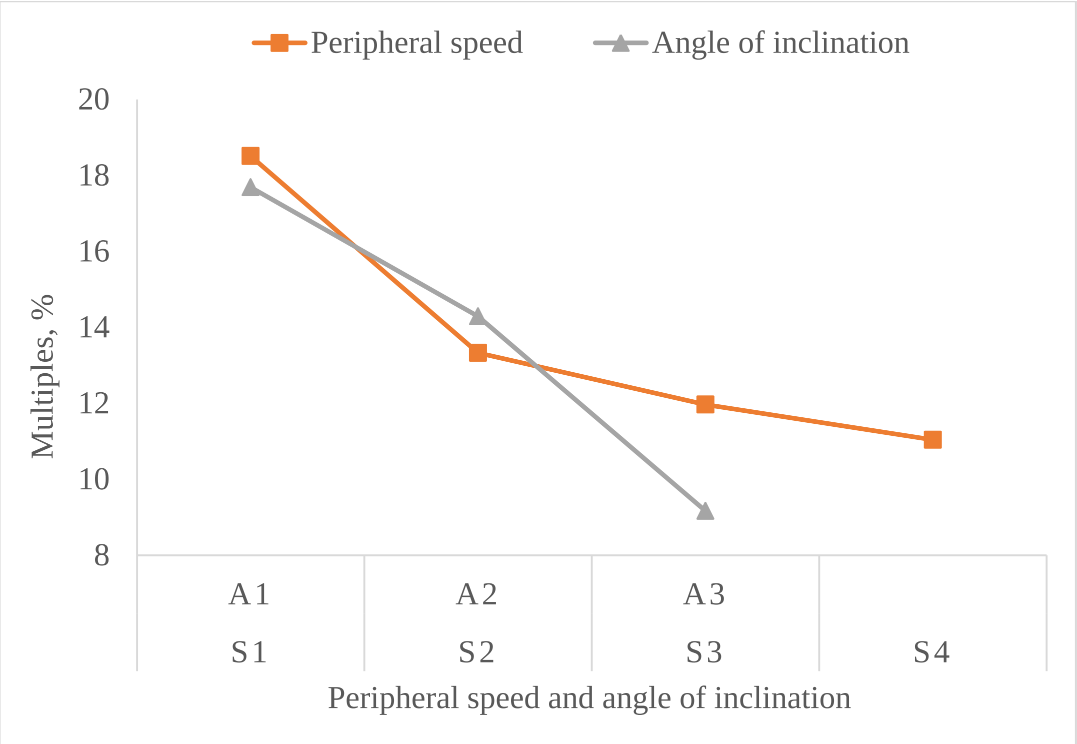


Fig. 4.24. Effect of peripheral speed and angle of inclination on per cent multiples-Onion bulb size (Grade 3-4 g)

4.4.2.4 Per cent missings

From Figs. 4.25 and 4.29 (Appendix D8). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent missings increased. At higher peripheral speed of metering unit, cups were unable to hold the onion bulbs. This might have caused higher per cent missings at higher peripheral speed. It was further observed that when the angle of inclination increased, per cent missings increased. This might be due to vertical position of cup was unable to hold onion bulbs.

The results of variance obtained for missings is presented in Table 4.14. From the Table 4.14, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on missings.

When the means compared by LSD method, it was clear that the cup size, C_4 (2.78 %) had the lowest per cent missngs followed by C_1 (3.52 %) and C_2 (34.08 %). The cup size, C_3 (5.14 %) had highest per cent missings. It was further observed that, the speed, S_1 (2.67 %) had lowest per cent missings followed by S_2 (3.13 %) and S_3 (4.52 %). The speed, S_4 (5.21 %), had the highest per cent missings. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_1 (3.20 %) had the lowest per cent missings followed by A_2 (3.64 %). The angle of inclination, A_3 (4.80 %) had highest per cent missings. It was also observed that the treatment combinations $C_4S_1A_1$ (1.66 %), $C_4S_2A_1$ (1.81 %), $C_1S_1A_1$ (1.76 %), $C_4S_1A_2$ (1.76 %) had the lowest per cent missings and treatment $C_3S_2A_3$ (7.88 %), $C_3S_3A_3$ (7.96 %) and $C_3S_4A_3$ (7.87 %) had highest per cent missings and were at par. (Appendix C9).

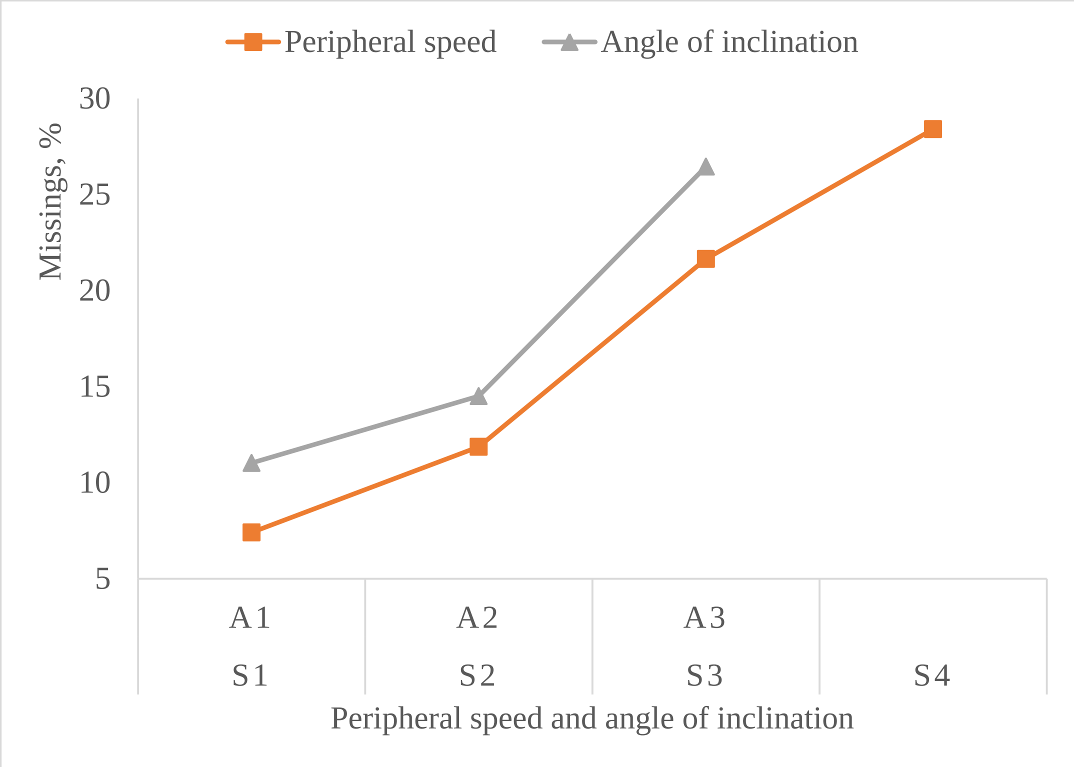


Fig. 4.25 Effect of peripheral speed and angle of inclination on per cent missings - Onion bulb size (Grade 3-4 g

Table 4.13. Analysis of variance for per cent multiples for grade –II category (3-4 g weight) of onion bulbs

	Multiples			
Cup size	C_1 4.06	C_2 4.00	C_3 3.12	C_4 3.44
Peripheral speed	S_1 4.29	S_2 3.63	S_3 3.46	S_4 3.25
Angle of inclination	A_1 4.22	A_2 3.77	A_3 2.98	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.02	0.13	
Peripheral speed (S)	**	0.02	0.13	
Angle of inclination (A)	**	0.02	0.11	
C×S	**	0.05	0.26	
S×A	**	0.04	0.22	
C×A	**	0.04	0.22	
C×S×A	**	0.09	0.45	

** 1% significant level

Table 4.14. Analysis of variance for per cent missings for grade –II category (3-4 g weight) of onion bulbs

	Missings			
Cup size	C_1 3.52	C_2 4.08	C_3 5.14	C_4 2.78
Peripheral speed	S_1 2.67	S_2 3.13	S_3 4.52	S_4 5.21
Angle of inclination	A_1 3.20	A_2 3.64	A_3 4.80	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.02	0.09	
Peripheral speed (S)	**	0.02	0.09	
Angle of inclination (A)	**	0.01	0.07	
C×S	**	0.04	0.18	
S×A	**	0.03	0.15	
C×A	**	0.03	0.15	
C×S×A	**	0.06	0.31	

** 1% significant level

Cup type 1 C_1 Size of onion-3-4 g (Grade II)

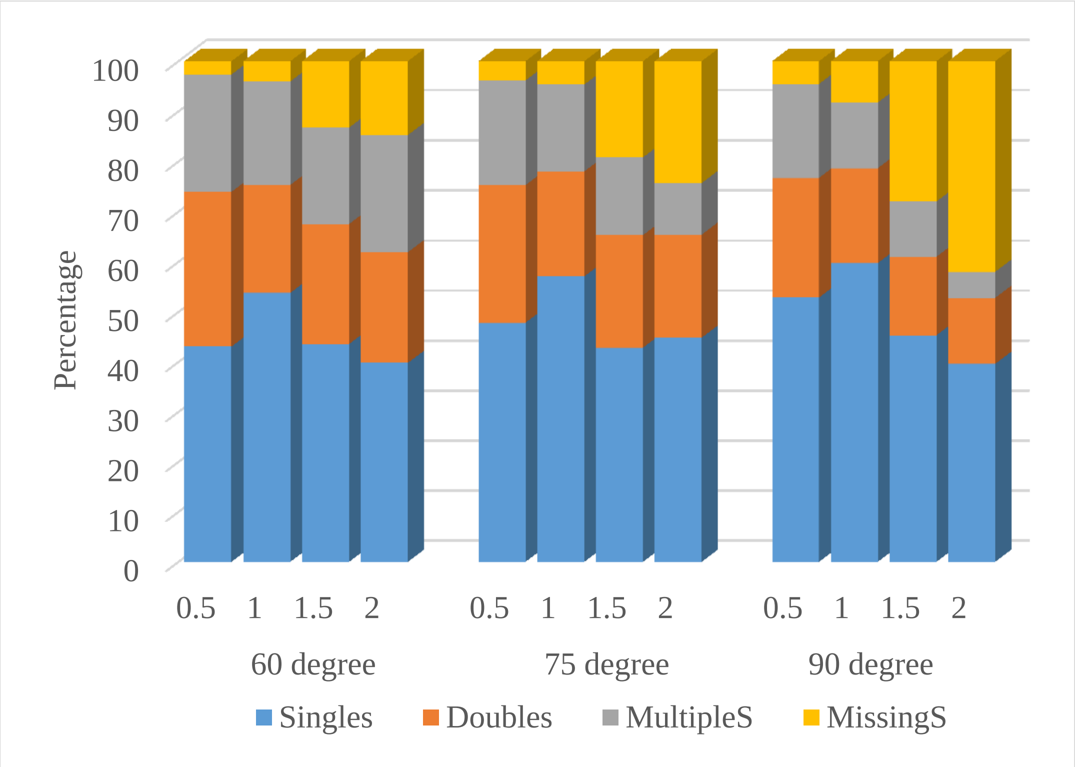


Fig. 4.26 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 2 C_2 Size of onion-3-4 g (Grade II)

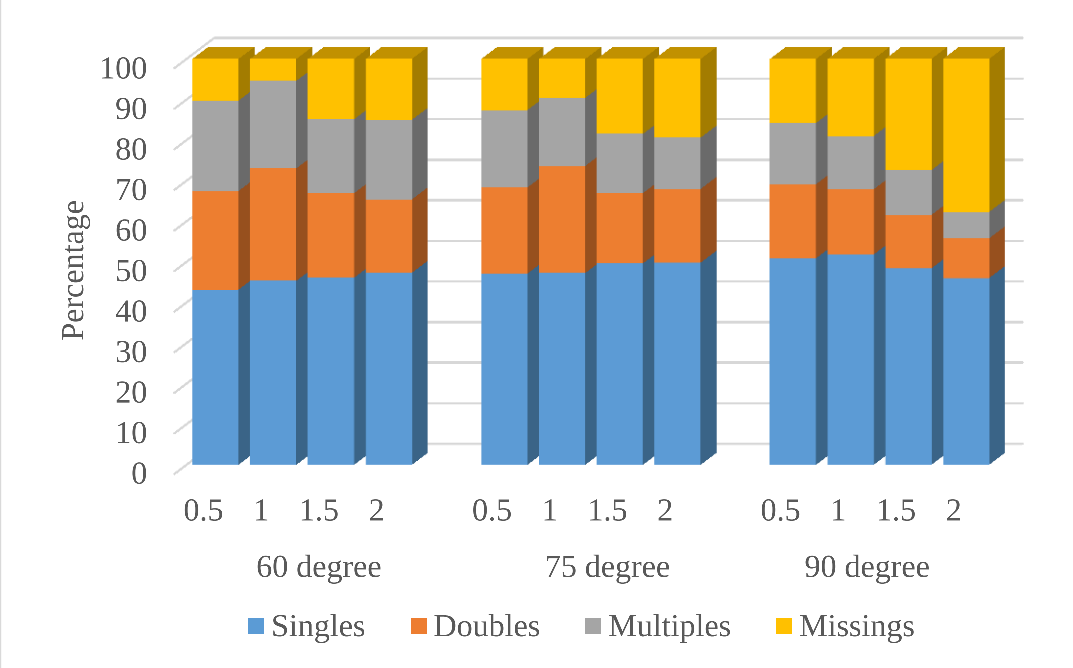


Fig. 4.27 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells

Cup type 3 C_3 Size of onion-3-4 g (Grade II)

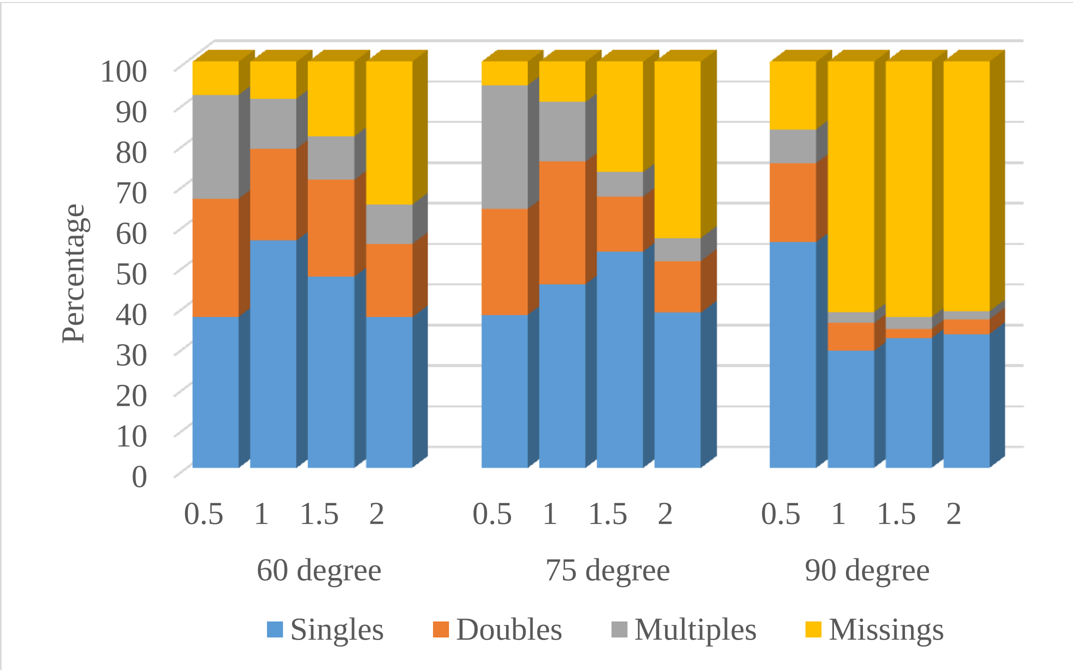


Fig. 4.28 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 4 C_4 Size of onion-3-4 g (Grade II)

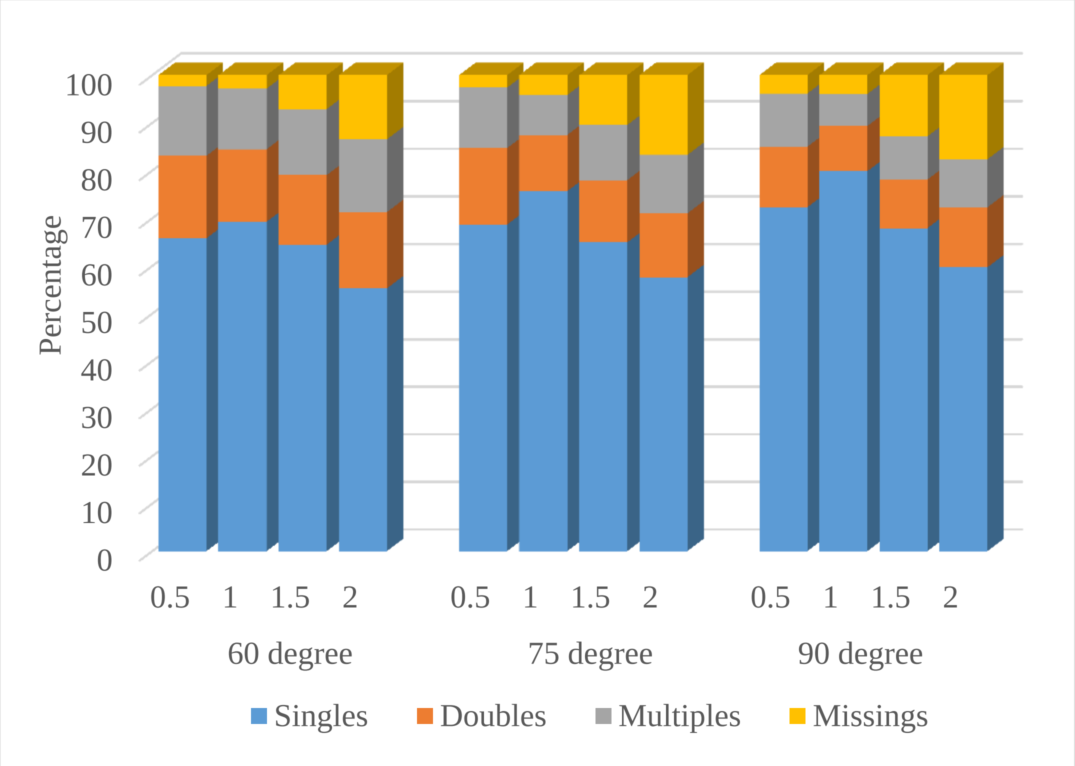


Fig. 4.29 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

4.4.2.5 Per cent bulb damage

From Fig. 4.30. It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent bulb damage increased. It was also further observed that when the angle of inclination increased, per cent bulb damage increased.

The results of variance obtained for bulb damage is presented in Table 4.15. From the Table 4.15, it was inferred that, the cup size, peripheral speed and angle of inclination had non-significant effect on bulb damage.

When the means compared by LSD, it was clear that the cup size, C_3 (1.11 %) had the lowest per cent bulb damage followed by C_2 (1.47 %) and C_4 (1.69 %). The cup size, C_1 (1. 85 %) had the highest per cent bulb damage. It was further observed that, the speed, S1 (1.25 %) had lowest per cent bulb damage followed by

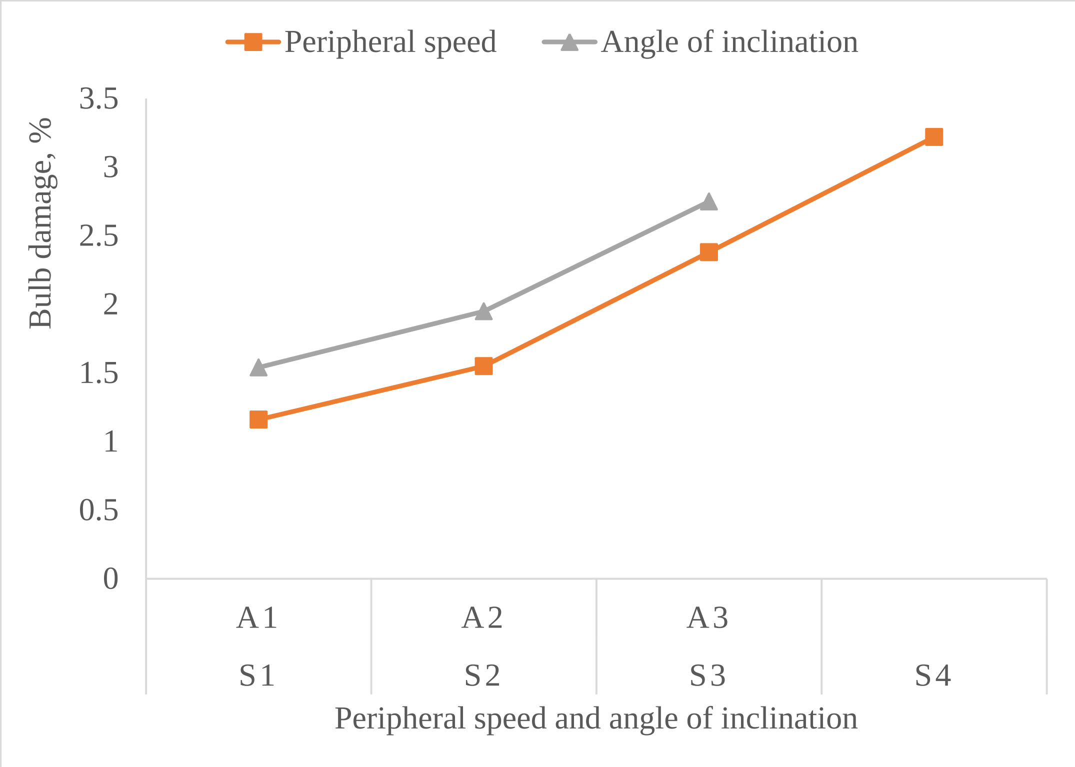


Fig.4.30 Effect of peripheral speed and angle of inclination on per cent bulb damage- Onion bulb size (Grade 3-4 g)

Table 4.15. Analysis of variance for per cent bulb damage for grade –II category (3-4 g weight) of onion bulbs

	Bulb damage			
Cup size	C_1	C_2	C_3	C_4
	1.85	1.47	1.11	1.69
Peripheral speed	S_1	S_2	S_3	S_4
	1.25	1.37	1.63	1.86

Angle of inclination	A_1	A_2	A_3
	1.37	1.50	1.73
	F-value	SEm	CD (p = 0.01/0.05)
Cup size (C)	**	0.03	0.15
Peripheral speed (S)	**	0.03	0.15
Angle of inclination (A)	**	0.02	0.13
C×S	**	0.06	0.30
S×A	NS	0.05	-
C×A	NS	0.05	-
C×S×A	NS	0.11	-

** 1% significant level; NS-non significant

S_2 (1.37 %) and S_3 (1.63 %). The speed S_4 (1.86 %) of had highest per cent bulb damage. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_1 (1.37 %) had the lowest per cent bulb damage followed by A_2 (1.50%). The angle of inclination, A_3 (1.73 %) had the highest per cent bulb damage there was no significant effect due to interaction between the treatments. (Appendix C10).

4.4.3 Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-III category (4-5 g weight) of onion bulbs.

4.4.3.1 Per cent singles

From Figs. 4.31 and 4.35 (Appendix D9). It was observed that when peripheral speed increased from 0.5 (S_1) to 1 km h^{-1} (S_2), the per cent singles also increased. Further when the peripheral speed increased from 1(S_3) to 2 (S_4) km h^{-1} with an increment of 0.5 km h^{-1} speed the per cent singles decreased. From this it was evident that beyond certain peripheral speed the onion bulb might be thrown out of the cup which caste reduction in per cent singles. It was further observed that when the angle of inclination increased, per cent singles also increased. From this it is clear that when the cup position is maintained in vertical position could hold the onions.

The results of variance obtained for singles is presented in Table 4.16. From the Table 4.16, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent singles.

When the means compared by LSD method, it was clear that cup size, C_4 (55.03 %) had highest per cent singles followed by C_2 (43.64 %) and C_1 (43.61 %). The lowest per cent singles was found in cup size C_3 (41.13 %). When means compared, it was evident that speed, S_2 (49.68 %) had highest per cent singles followed by S_1 (47.02 %) and S_3 (44.38 %). The lowest per cent singles was found in S_4 (42.33 %). Similarly it was observed that the angle of inclination, A_3 (46.61 %) had the highest per cent singles followed by A_2 (46.31 %). The lowest per cent singles was found A_1 (44.63 %). It was also observed that the treatment combinations $C_4S_2A_3$ had the highest per cent singles (63.61 %) and treatment $C_2S_4A_1$ (53.70 %) had the lowest per cent singles and were at par. (Appendix C11).

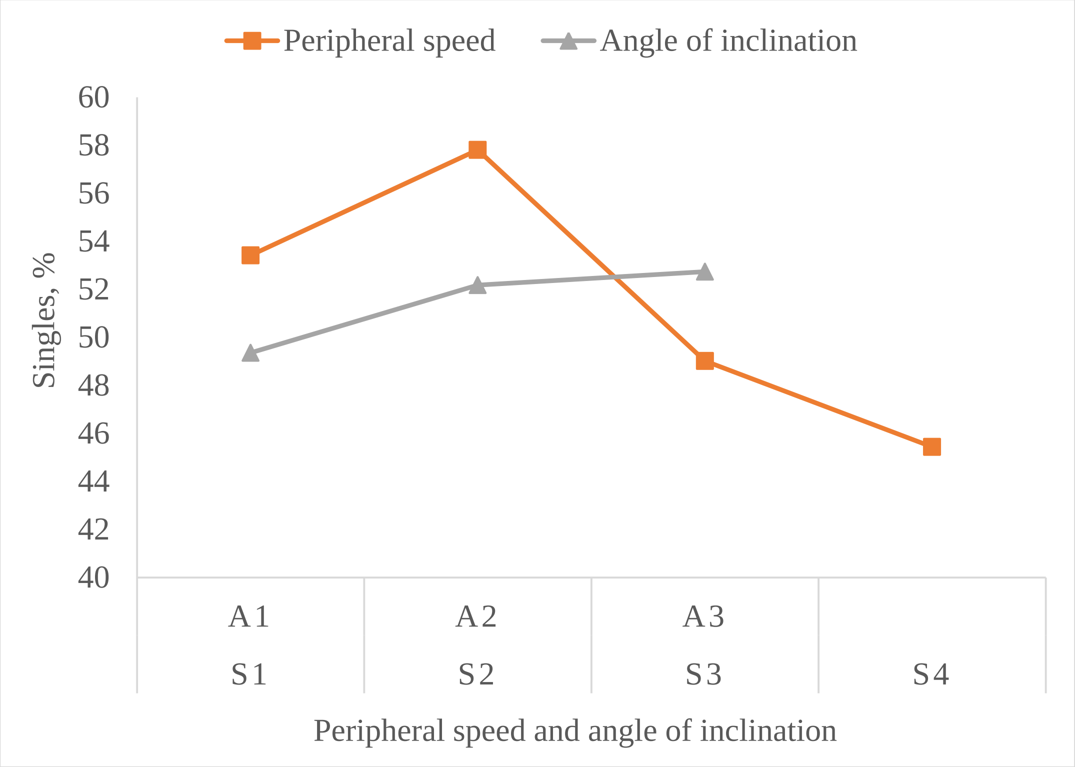


Fig.4.31 Effect of peripheral speed and angle of inclination on per cent singles - Onion bulb size (Grade 4-5 g)

Table 4.16. Analysis of variance for per cent singles for grade –III category (4-5 g weight) of onion bulbs

	Singles			
Cup size	C_1 43.61	C_2 43.64	C_3 41.13	C_4 55.03
Peripheral speed	S_1 47.02	S_2 49.68	S_3 44.38	S_4 42.33
Angle of inclination	A_1 44.63	A_2 46.31	A_3 46.61	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.09	0.44	
Peripheral speed (S)	**	0.09	0.44	
Angle of inclination (A)	**	0.08	0.38	
C×S	**	0.19	0.89	
S×A	**	0.170	0.77	
C×A	**	0.17	0.77	
C×S×A	**	0.34	1.55	

** 1% significant level

4.4.3.2 Per cent doubles

From Figs. 4.32 and 4.36 (Appendix D10). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent doubles decreased. From this, it was clear that, at lower peripheral speed the onion bulbs were held in the cups which contributed for higher per cent doubles. It was further observed that when the angle of inclination increased, per cent doubles decreased. This might be due to, cups in vertical position.

The results of variance obtained for doubles was presented in Table 4.17. From the Table 4.17, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent doubles.

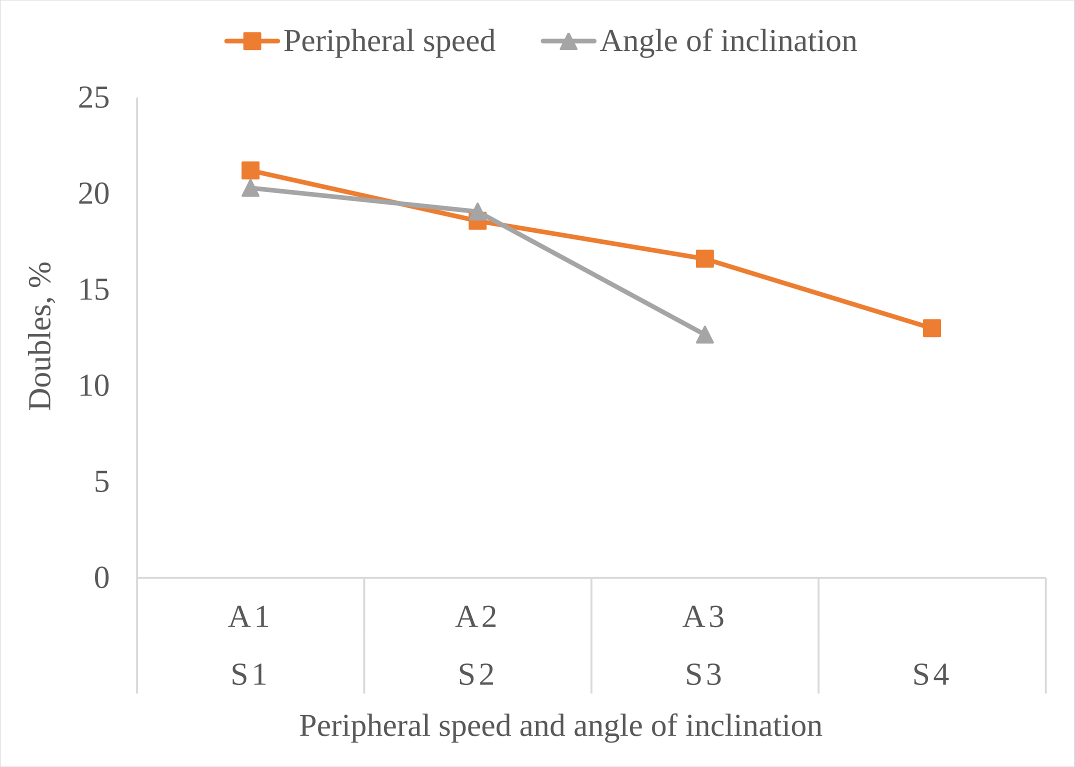


Fig.4.32 Effect of peripheral speed and angle of inclination on per cent doubles - Onion bulb size (Grade 4-5 g)

When the means compared by LSD method, it was evident that the cup size, C_4 (3.63 %) had lowest per cent doubles followed by C_3 (3.94 %) and C_2 (4.36%). The highest per cent doubles was found in C_1 (4.61 %). When mean compared, it was evident that speed, S_4 (3.59 %) had lowest per cent doubles followed by S_3 (4.02 %) and S_2 (4.31 %). The highest per cent doubles was found in S_1 (4.62 %). When the means of angle of inclination compared, it was observed that, the angle of inclination, A_3 (3.53 %) had lowest per cent doubles followed A_2 (4.36 %). The highest per cent doubles was found in A_1 (4.52 %). It was also observed that the treatment combinations $C_3S_3A_3$ (1.69 %) and $C_3S_4A_3$ (1.82 %) had lowest per cent doubles and treatment $C_1S_1A_1$ (5.54 %), $C_3S_3A_2$ and (5.57 %) had highest per cent doubles and were at par. (Appendix C12).

Table 4.17. Analysis of variance for per cent doubles for grade –III category (4-5 g weight) of onion bulbs

Doubles				
Cup size	C_1 4.61	C_2 4.36	C_3 3.94	C_4 3.63
Peripheral speed	S_1 4.62	S2 4.31	S3 4.02	S4 3.59
Angle of inclination	A_1 4.52	A_2 4.36	A_3 3.53	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.01	0.07	
Peripheral speed (S)	**	0.01	0.07	
Angle of inclination (A)	**	0.01	0.06	
C×S	**	0.03	0.14	
S×A	**	0.02	0.12	
C×A	**	0.02	0.12	
C×S×A	**	0.05	0.24	

** 1% significant level.

4.4.3.2 Per cent multiples

From Figs. 4.33 and 4.37(Appendix D11). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent multiples decreased. The reason might be, higher peripheral speed would have made the onion bulbs to fall from the cups. It was further observed that when the angle of inclination increased, per cent multiples decreased. This was due to vertical cup position could hold less number of onion bulbs.

The results of variance obtained for multiples is presented in Table 4.18. From the Table 4.18, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent multiples.

When the means compared by LSD, it was evident that the cup size, C_3 (3.05 %) had lowest per cent multiples followed by C_4 (3.36 %) and C_2 (3.92 %). The cup size, C_1 (3.98 %) had highest per cent multiples. It was further observed that, the speed S_4 (3.17 %) had lowest per cent multiples followed by S_3 (3.34 %) and S_2 (3.59 %). The speed, S_1 (4.21 %) had highest percent multiples. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_3 (2.98 %) had lowest per cent multiples followed by A_2 (3.68 %). The angle of inclination, A_1 (4.07 %) had the highest per cent multiples. It was also observed that the treatment combinations $C_3S_3A_3$ (1.69 %) and $C_3S_4A_3$ (1.65 %) lowest per cent multiples and treatment $C_3S_1A_1$ (6.20 %) had highest per cent multiples and were at par. (Appendix C13).

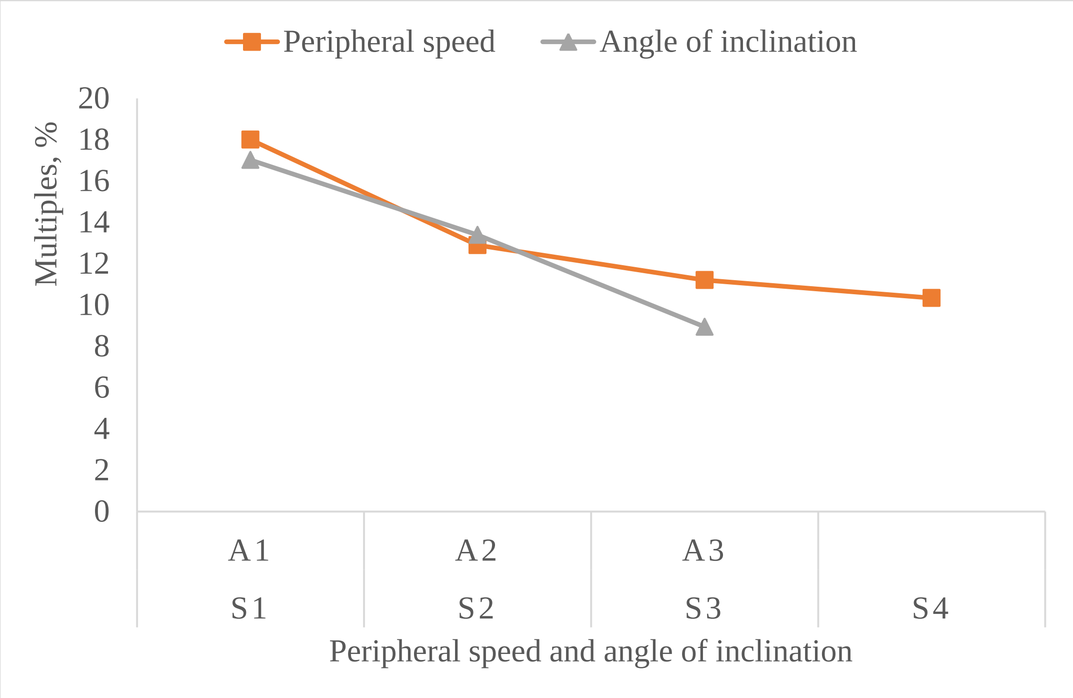


Fig. 4.33 Effect of peripheral speed and angle of inclination on per cent multiples - Onion bulb size (Grade 4-5 g)

4.4.3.4 Per cent missings

From Figs. 4.34 and 4.38 (Appendix D12). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent missings increased. At higher peripheral speed of metering unit, cups were unable to hold the onion bulbs. This might have caused higher per cent missings at higher peripheral speed. It was further observed that when the angle of inclination increased, per cent missings increased. This might be due to vertical position of cup was unable to hold onion bulbs.

Table 4.18. Analysis of variance for per cent multiples for grade –III category (4-5 g weight) of onion bulbs

Multiples				
Cup size	C_1 3.98	C_2 3.92	C_3 3.05	C_4 3.36
Peripheral speed	S_1 4.21	S_2 3.59	S_3 3.34	S_4 3.17
Angle of inclination	A_1 4.07	A_2 3.68	A_3 2.98	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.02	0.11	
Peripheral speed (S)	**	0.02	0.11	
Angle of inclination (A)	**	0.02	0.09	
C×S	**	0.05	0.23	
S×A	**	0.04	0.19	
C×A	**	0.04	0.19	
C×S×A	**	0.08	0.39	

** 1% significant level.

The results of variance obtained for missings is presented in Table 4.19. From the Table 4.19, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent missings.

When the means compared by LSD method, it was observed that the cup size, C_4 (2.96 %) had lowest per cent missngs followed by C_1 (3.70 %) and C_2 (4.23 %). The cup size, C_3 (5.03 %) had highest per cent missings. It was further observed that, the speed, S_1 (2.64 %) had lowest per cent missings followed by S_2 (3.16 %) and S_3 (4.65 %).The speed, S_4 (5.47 %), had highest per cent misings. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_1 (3.41 %) had lowest per cent missings followed by A_2 (3.76 %). The angle of inclination, A_3 (4.77 %) had the highest per cent missings. It was also observed that the treatment combinations $C_3S_1A_1$ (1.60 %), $C_4S_1A_1$ (1.78 %), had lowest per cent missings and treatment $C_3S_3A_3$ (8.63 %) had highest per cent missings and were on par. (Appendix C14).

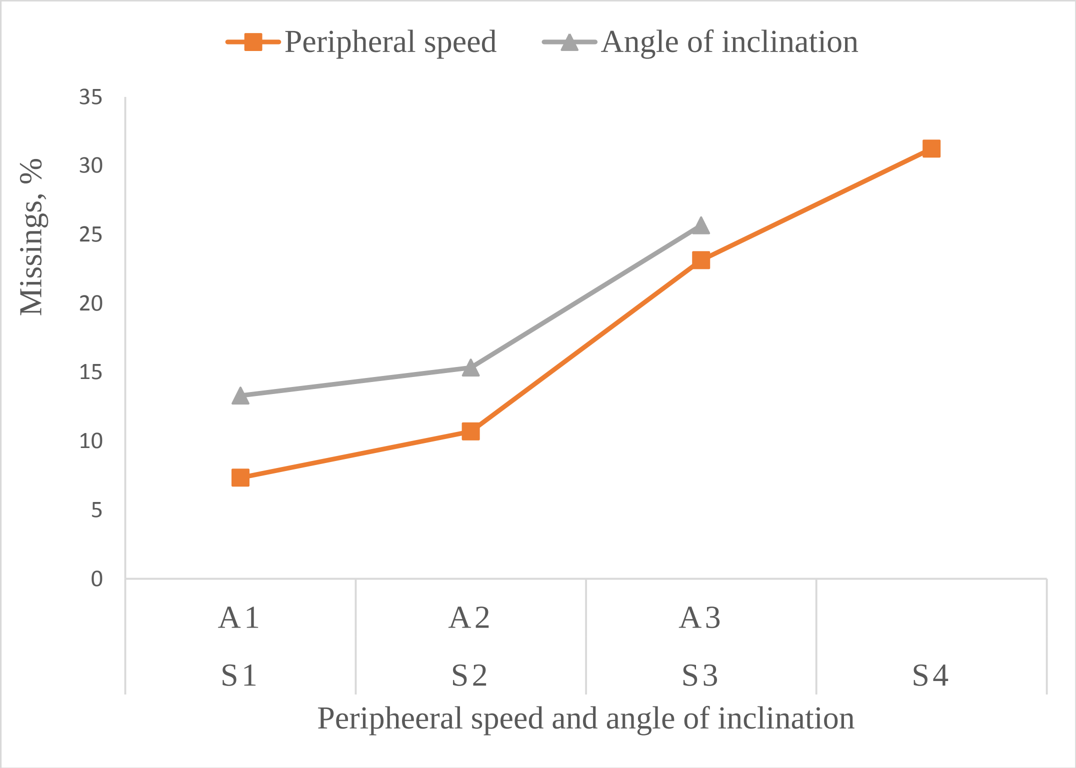


Fig. 4.34 Effect of peripheral speed and angle of inclination on per cent missings - Onion bulb size (Grade 4-5 g)

Table 4.19. Analysis of variance for per cent missings for grade –III category (4-5 g weight) of onion bulbs

	Missings			
Cup size	C_1	C_2	C_3	C_4
	3.70	4.23	5.03	2.96
Peripheral speed	S_1	S_2	S_3	S_4
	2.64	3.16	4.65	5.47
Angle of inclination	A_1	A_2		A_3
	3.41	3.76		4.77
	F-value	SEm		CD (p =0.01)
Cup size (C)	**	0.02		0.10
Peripheral speed (S)	**	0.02		0.10
Angle of inclination (A)	**	0.01		0.08
C×S	**	0.04		0.20
S×A	**	0.03		0.17
C×A	**	0.03		0.17
C×S×A	**	0.07		0.35

** 1% significant level

Cup type 1 C_1 Size of onion-4-5 g (Grade III)

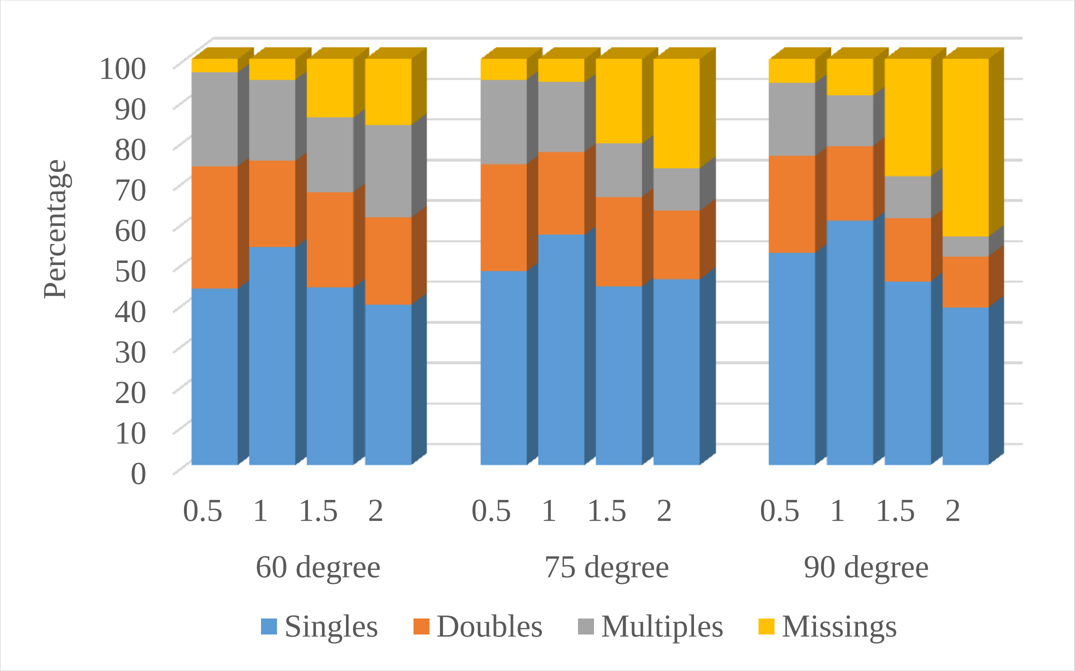


Fig. 4.35. Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells

Cup type 2 C_2 Size of onion-4-5 g (Grade III)

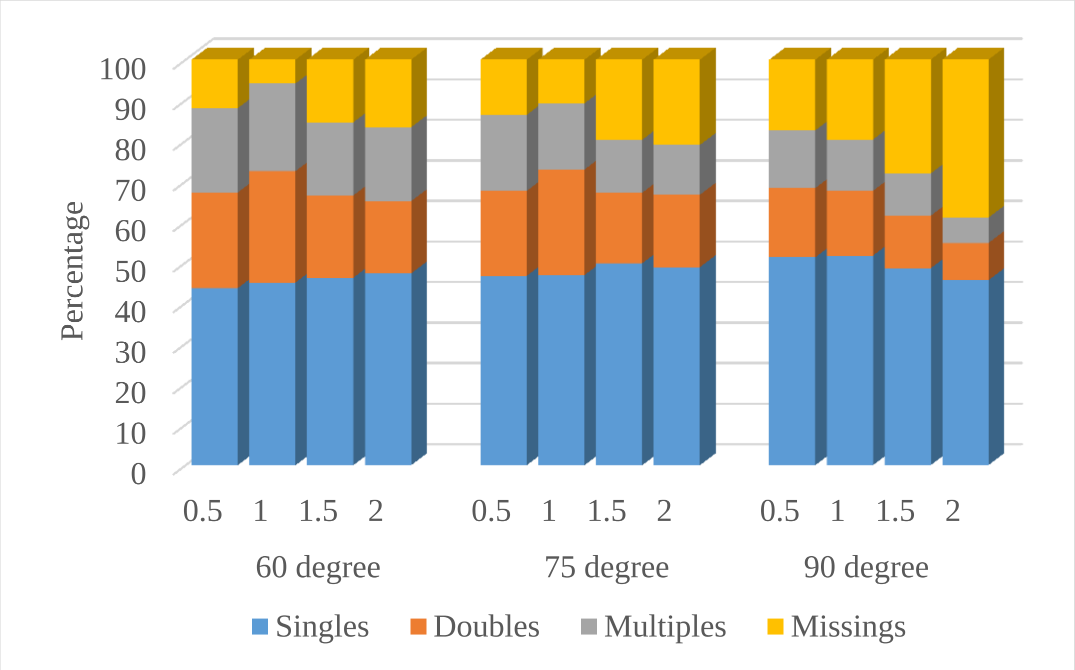


Fig. 4.36 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 3 C_3 Size of onion-4-5 g (Grade III)

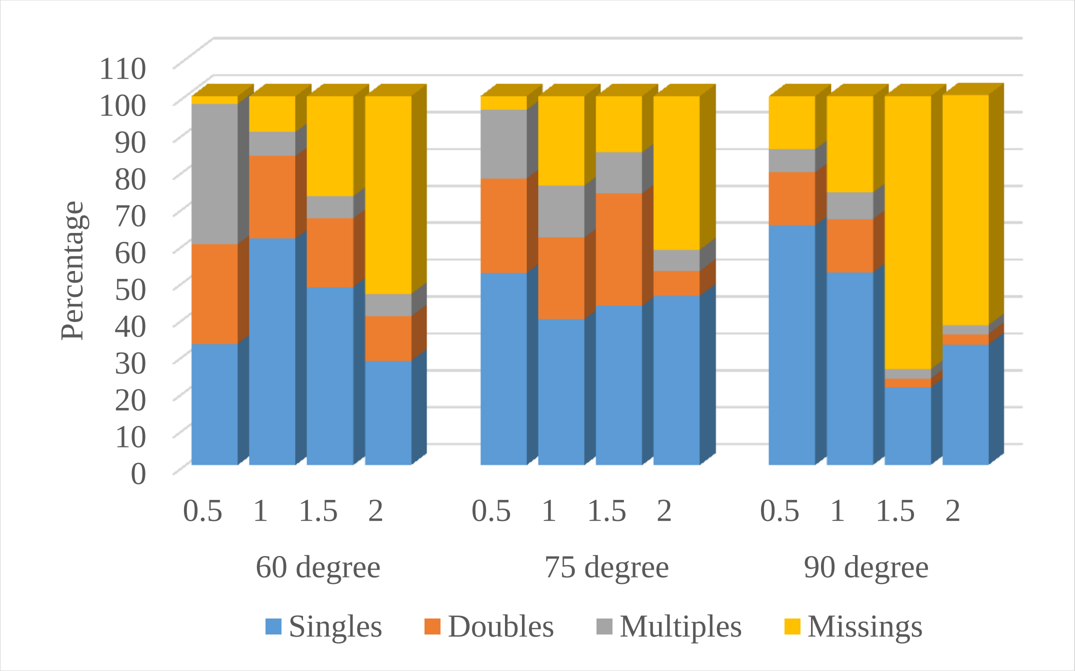


Fig. 4.37 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 4 C_4 Size of onion-4-5 g (Grade III)

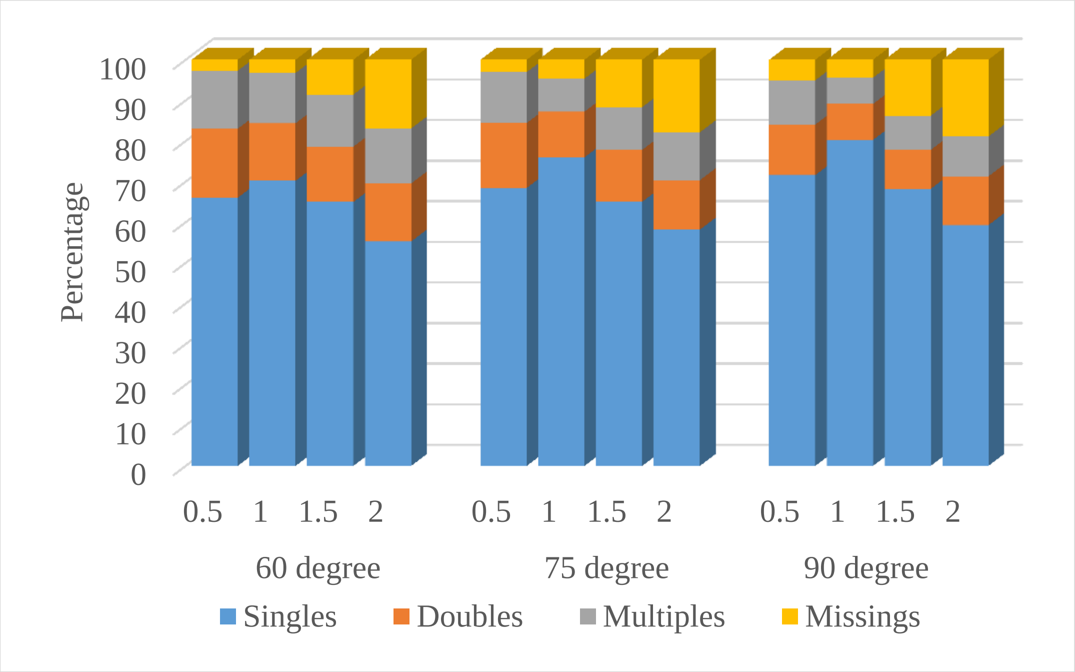


Fig. 4.38 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

4.4.3.5 Per cent bulb damage

From Fig. 4.39, It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent bulb damage increased. It was also further observed that when the angle increased per cent bulb damage increased.

The results of variance obtained for bulb damage is presented in Table 4.20. From the Table 4.20, it was inferred that, the cup size, peripheral speed and angle of inclination had non-significant effect on bulb damage.

When the means compared by LSD, it was evident that the cup size, C_3 (1.29 %) had lowest per cent bulb damage followed by C_2 (1.58 %) and C_4 (1.82 %). The cup size C_1 (1.95 %) had highest per cent bulb damage. It was further observed that, the speed S_1 (1.40 %) had lowest per cent bulb damage followed by S_2 (1.52 %) and S_3 (1.75 %). The speed S_4 (1.98 %) of had highest per cent bulb damage. When the means of angle of inclination was compared, it was observed that, the angle of inclination A_1 (1.52 %) had lowest per cent bulb damage followed by A_2 (1.63 %). The angle of inclination, A_3 (1.83 %) had highest per cent bulb damage there was no significant effect due to interaction between the treatments. (Appendix C15).

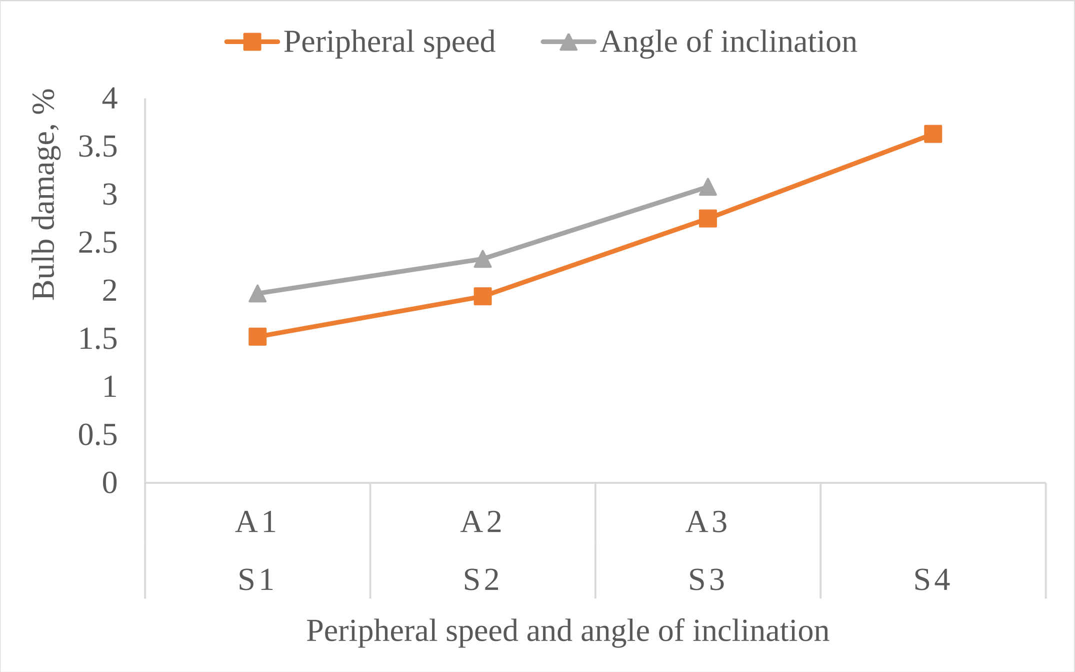


Fig. 4.39 Effect of peripheral speed and angle of inclination on per cent bulb damage - Onion bulb size (Grade 4-5 g)

Table 4.20. Analysis of variance for per cent bulb damage for grade –III category (4-5 g weight) of onion bulbs

Bulb damage				
Cup size	C_1 1.95	C_2 1.58	C_3 1.29	C_4 1.82
Peripheral speed	S_1 1.40	S_2 1.52	S_3 1.75	S_4 1.98
Angle of inclination	A_1 1.52	A_2 1.63	A_3 1.83	
	F-value	SEm	CD (p = 0.01/0.05)	
Cup size (C)	**	0.03	0.14	
Peripheral speed (S)	**	0.03	0.14	
Angle of inclination (A)	**	0.02	0.12	
C×S	**	0.06	0.28	
S×A	NS	0.05	-	
C×A	NS	0.05	-	
C×S×A	NS	0.10	-	

** 1% significant level; NS-non significant

4.4.4. Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-IV category (5-6 g weight) of onion bulbs

4.4.4.1 Per cent singles

From Figs. 4.40, and 4.44 (Appendix D13). It was observed that when peripheral speed increased from 0.5 (S_1) to 1 km h^{-1} (S_2), the per cent singles also increased. Further when the peripheral speed increased from 1(S_3) to 2 (S_4) km h^{-1} with an increment of 0.5 km h^{-1} speed the per cent singles decreased. From this it is evident that beyond certain peripheral speed the onion bulb might be thrown out of the cup which caste reduction in per cent singles. It was further observed that when the angle of inclination increased, per cent singles also increased. From this it is clear that when the cup position is maintained in vertical position could hold the onions.

The results of variance obtained for per cent singles is presented in Table 4.21. From the Table 4.21, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on singles.

When the means compared by LSD method, it was clear that cup size, C_4 (54.85%) had highest per cent singles followed by C_2 (43.63 %) and C_1 (43.44 %). The lowest per cent singles was found in C_3 (40.10 %). When mean compared, it was evident that speed of S_2 (49.47%) had highest per cent singles followed by S_1 (46.34 %) and S_3 (44.58 %). The lowest per cent singles was found in S_4 (41.63 %). Similarly, it was observed that the angle of inclination, A_3 (46.97 %) had highest per cent singles followed by A_2 (45.09 %) and A_1 (44.63 %). It was also observed that the treatment combinations $C_4S_2A_3$ had the highest per cent singles (64.20 %) and treatment $C_3S_4A_1$ (25.79 %) had the lowest per cent singles and were at par. (Appendix C16).

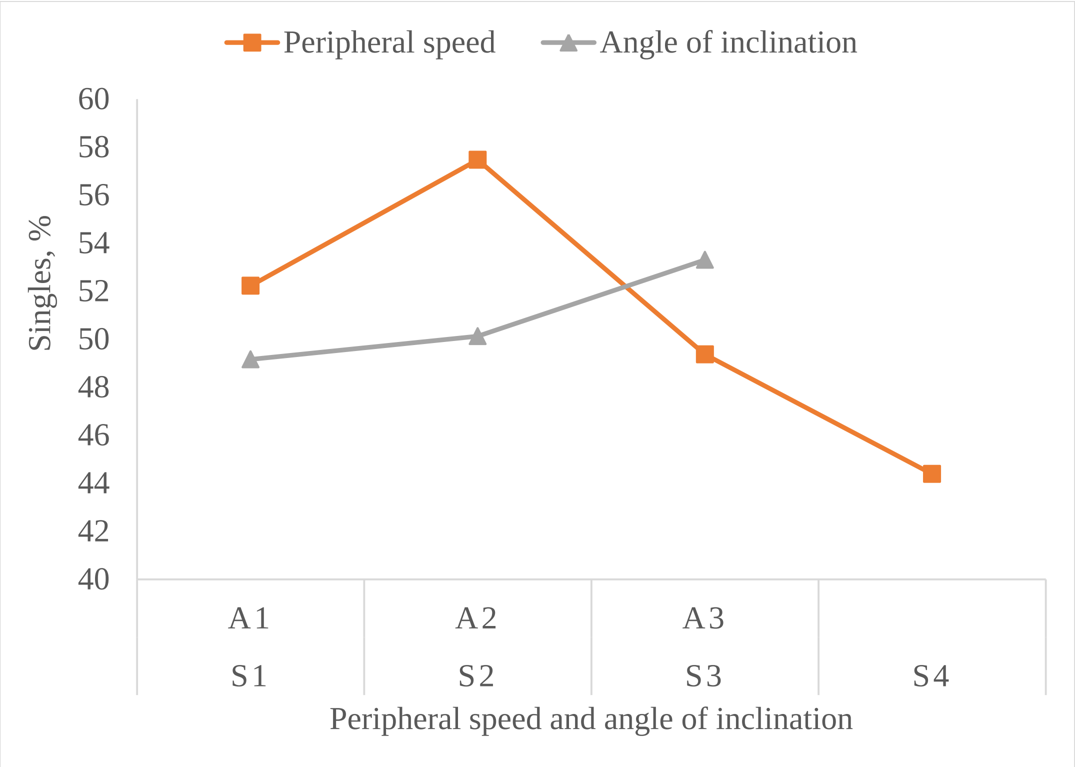


Fig. 4.40 Effect of peripheral speed and angle of inclination on per cent singles - Onion bulb size (Grade 5-6 g)

4.4.4.2 Per cent doubles

From Figs. 4.41 and 4.45 (Appendix D14). It was observed that when peripheral speed increased 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent doubles decreased. From this, it was clear that, at lower peripheral speed the onion bulbs were held in the cups which contributed for higher per cent doubles. It was further observed that when the angle of inclination increased, per cent doubles decreased. This might be due to, cups in vertical position.

The results of variance obtained for doubles is presented in Table 4.22. From the Table 4.22, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent doubles.

When the means compared by LSD method, it was evident that the cup size C_4 (3.57 %) had lowest per cent doubles followed by C_3 (3.60 %) and C_2 (4.30 %). The highest per cent doubles was found in C_1 (4.56 %). When mean compared, it was evident that speed, S_4 (3.62 %) had lowest per cent doubles followed by S_3 (3.82 %) and S_2 (3.98 %). The highest per cent doubles was found in speed, S_1 (4.61 %). When the means of angle of inclination compared, it was observed that the angle of inclination, A_3 (3.42 %) had lowest per cent doubles followed A_2 (4.26 %). The highest per cent doubles was found in A_1 (4.34 %). It was also observed that the treatment combinations $C_3S_2A_3$ (1.77 %) and $C_3S_3A_3$ (1.69 %) had lowest per cent doubles and treatment $C_2S_2A_1$ (5.29 %), $C_1S_1A_1$ (5.46 %) and $C_3S_1A_2$ (5.24 %) had highest per cent doubles and were at par. (Appendix C17).

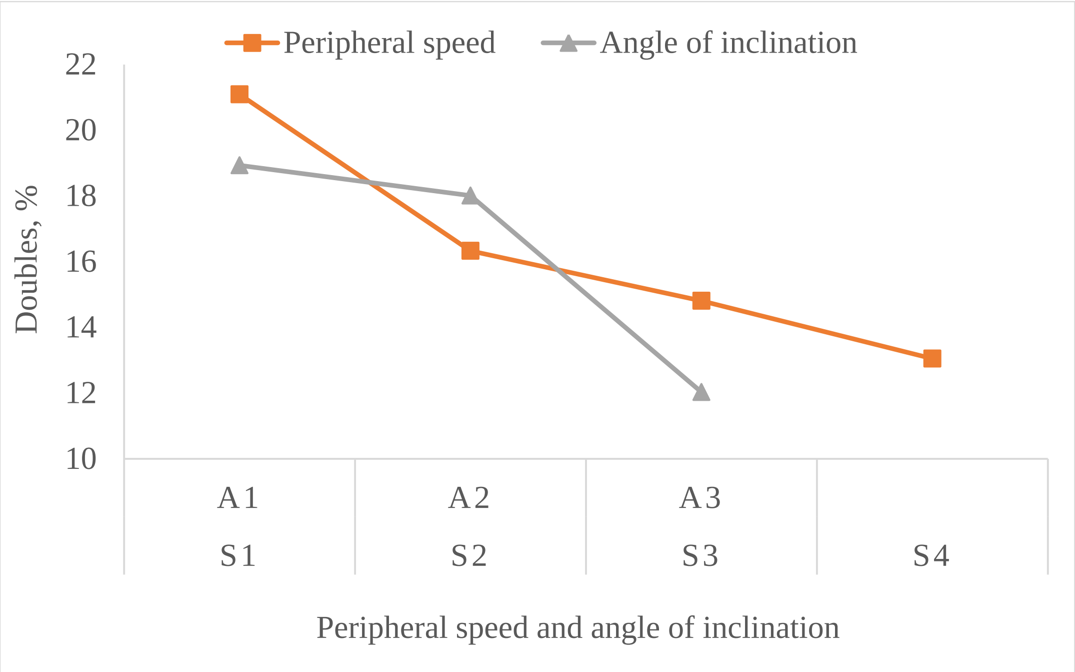


Fig. 4.41 Effect of peripheral speed and angle of inclination on per cent doubles-Onion bulb size (Grade 5-6 g)

Table 4.21. Analysis of variance for singles for grade –IV category (5-6 g weight) of onion bulbs.

Singles				
Cup size	C_1	C_2	C_3	C_4
	43.44	43.63	40.10	54.85
Peripheral speed	S_1	S_2	S_3	S_4
	46.34	49.47	44.58	41.63
Angle of inclination	A_1	A_2	A_3	
	44.46	45.09	46.97	
	F-value	SEm	CD (p=0.01)	
Cup size (C)	**	0.10	0.46	
Peripheral speed (S)	**	0.10	0.46	
Angle of inclination (A)	**	0.08	0.39	
C×S	**	0.20	0.92	
S×A	**	0.17	0.79	
C×A	**	0.17	0.79	
C×S×A	**	0.35	1.59	

** 1% significant level

Table 4.22. Analysis of variance for doubles for grade –IV category (5-6 g weight) of onion bulbs.

Doubles				
Cup size	C_1	C_2	C_3	C_4
	4.56	4.30	3.60	3.57
Peripheral speed	S_1	S_2	S_3	S_4
	4.61	3.98	3.82	3.62
Angle of inclination	A_1	A_2	A_3	
	4.34	4.26	3.42	
	F-value	SEm	CD (p=0.01)	
Cup size (C)	**	0.01	0.08	
Peripheral speed (S)	**	0.01	0.08	
Angle of inclination (A)	**	0.01	0.07	
C×S	**	0.03	0.16	
S×A	**	0.03	0.14	
C×A	**	0.03	0.14	
C×S×A	**	0.06	0.29	

** 1% significant level

4.4.4.3 Per cent multiples

From Figs. 4.42 and 4.46 (Appendix D15). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent multiples decreased. The reason might be, higher peripheral speed would have made the onion bulbs to fall from the cups. It was further observed that when the angle of inclination increased, per cent multiples decreased. This was due to vertical cup position could hold less number of onion bulbs.

The results of variance obtained for per cent multiples is presented in Table 4.23. From the Table 4.23, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on per cent multiples.

When the means compared by LSD, it was evident that the cup size, C_3 (2.58 %) had lowest per cent multiples followed by C_4 (3.28 %) and C_2 (3.84 %). The cup size, C_1 (3.90 %) had highest per cent multiples. It was further observed that, the speed, S_4 (2.99 %) had lowest per cent multiples followed by S_3 (3.19 %) and S_2 (3.40%). The speed, S_1 (4.02 %) had highest per cent multiples. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_3 (2.81 %) had lowest per cent multiples followed by A_2 (3.55 %). The angle of inclination, A_1 (3.84 %) had highest per cent multiples. It was also observed that the treatment combinations $C_3S_4A_1$ (1.18 %) and $C_3S_1A_3$ (1.53%) lowest per cent multiples and $C_3S_1A_1$ (4.78 %) $C_2S_1A_1$ (4.54 %) $C_2S_2A_1$ (4.65 %) $C_1S_1A_1$ (4.78 %) $C_1S_4A_1$ (4.82 %) $C_3S_1A_2$ (4.94 %) and $C_1S_1A_2$ (4.59 %) highest per cent of multiples and were at par. (Appendix C18).

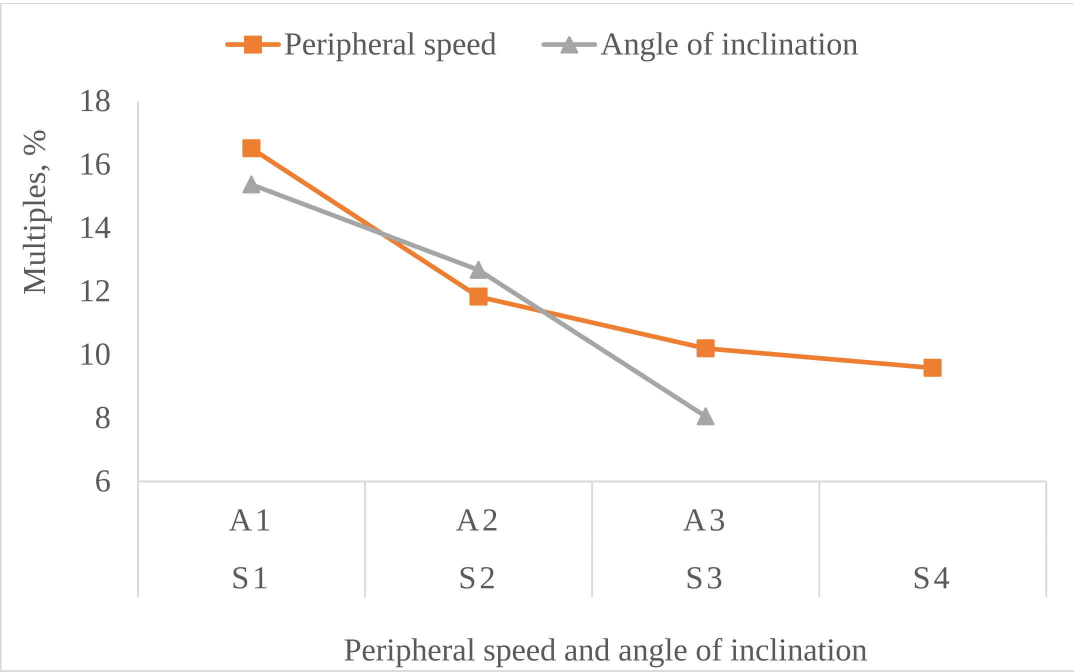


Fig. 4.42 Effect of peripheral speed and angle of inclination on per cent multiples- Onion bulb size (Grade 5-6 g)

Table 4.23. Analysis of variance for multiples for grade –IV category (5-6 g weight) of onion bulbs

Multiples				
Cup size	C_1 3.90	C_2 3.84	C_3 2.58	C_4 3.28
Peripheral speed	S_1 4.02	S_2 3.40	S_3 3.19	S_4 2.99
Angle of inclination	A_1 3.84	A_2 3.55	A_3 2.81	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.03	0.16	
Peripheral speed (S)	**	0.03	0.16	
Angle of inclination (A)	**	0.03	0.14	
C×S	**	0.07	0.32	
S×A	**	0.06	0.28	
C×A	**	0.06	0.28	
C×S×A	**	0.12	0.56	

** 1% significant level

4.4.4.4 Per cent missings

From Figs. 4.43 and 4.47 (Appendix D16). It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent missings increased. At higher peripheral speed of metering unit, cups were unable to hold the onion bulbs. This might have caused higher per cent missings at higher peripheral speed. It was further observed that when the angle of inclination increased, per cent missings increased. This might be due to vertical position of cup was unable to hold onion bulbs.

The results of variance obtained for missings is presented in Table 4.24. From the Table 4.24, it was inferred that, the cup size, peripheral speed and angle of inclination had highly significant effect on missings.

When the means compared by LSD method, it was clear that the cup size, C_4 (3.17 %) had lowest per cent missngs followed by C_1 (3.88 %) and C_2 (4.35 %). The cup size, C_3 (5.74 %) had highest per cent missings. It was further observed that, the speed, S_1 (3.09 %) had lowest per cent missings followed by S_2 (3.52 %) and S_3 (4.93 %). The speed, S_4 (5.61%), had highest per cent missings. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_1 (3.80 %) had lowest per cent missings followed by A_2 (3.91 %).

The angle of inclination, A_3 (5.15%) had highest per cent missings. It was also observed that the treatment combinations $C_4S_1A_1$ (1.90 %), $C_4S_1A_2$ (2.08 %), had lowest per cent of missings and treatment $C_3S_4A_1$ (8.50 %) and $C_3S_3A_3$ (8.56 %) had highest per cent missings and were at par. (Appendix C19).

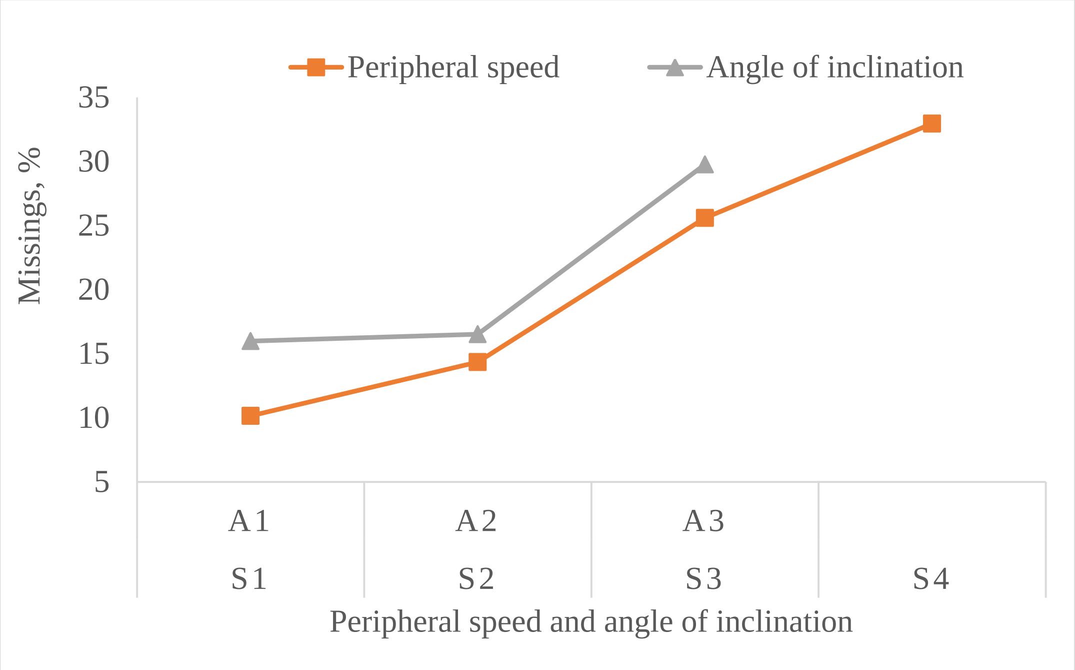


Fig. 4.43. Effect of peripheral speed and angle of inclination on per cent missings - Onion bulb size (Grade 5-6 g)

Table 4.24. Analysis of variance for missings for grade –IV category (5-6 g weight) of onion bulbs

	Missings			
Cup size	C_1 3.88	C_2 4.35	C_3 5.74	C_4 3.17
Peripheral speed	S_1 3.09	S_2 3.52	S_3 4.93	S_4 5.61
Angle of inclination	A_1 3.80	A_2 3.91	A_3 5.15	
	F-value	SEm	CD (p = 0.01)	
Cup size (C)	**	0.02	0.09	
Peripheral speed (S)	**	0.02	0.09	
Angle of inclination (A)	**	0.01	0.08	
C×S	**	0.04	0.18	
S×A	**	0.03	0.16	
C×A	**	0.03	0.16	
CSA	**	0.07	0.32	

** 1% significant level

Cup type 1 C_1 Size of onion-5-6 g (Grade IV)

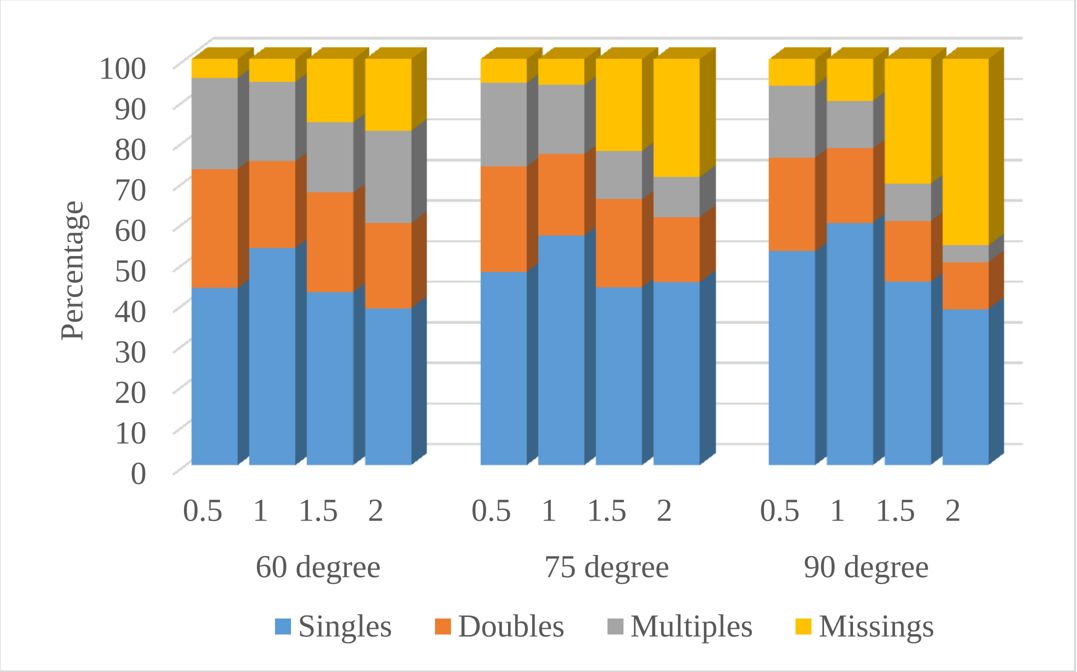


Fig. 4.44. Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 2 C_2 Size of onion-5-6 g (Grade IV)

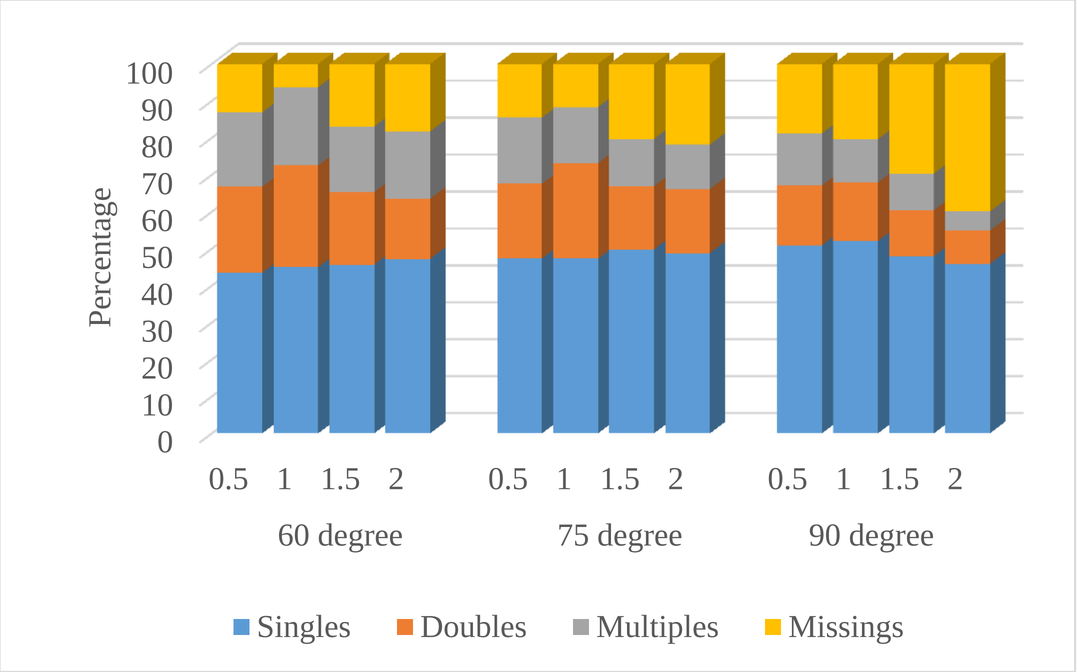


Fig. 4.45 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells.

Cup type 3 C_3 Size of onion-5-6 g (Grade IV)

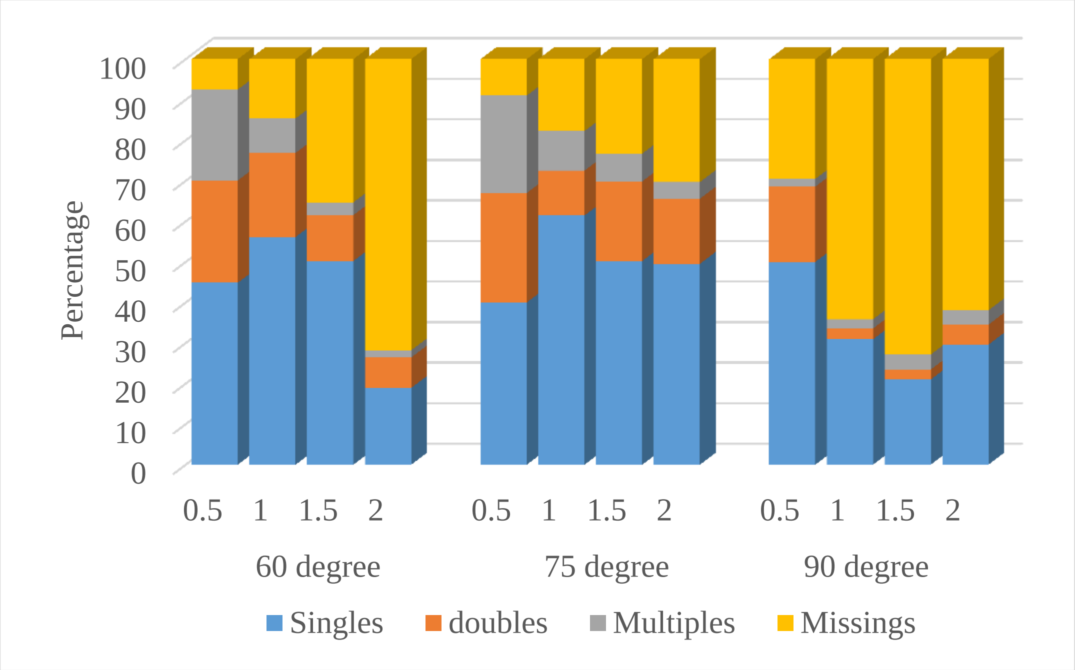


Fig. 4.46 Effect of angle of inclination and peripheral speed of onion bulb metering unit on filling efficiency of cells

Cup type 4 C_4 Size of onion-5-6 g (Grade IV)

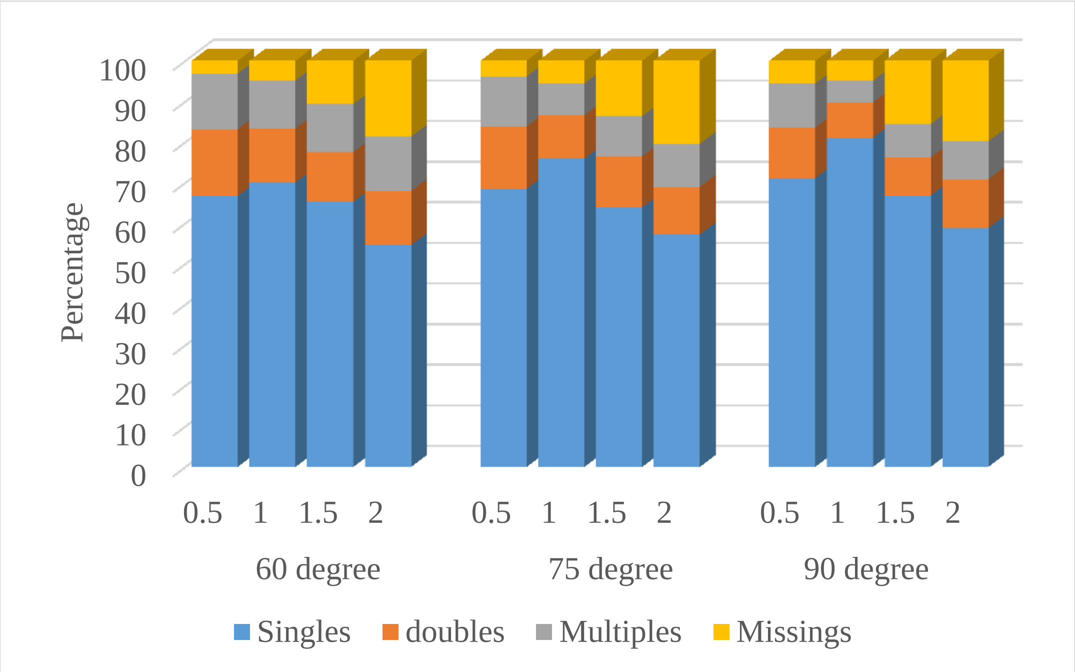


Fig. 4.47 Effect of angle of incrimination and peripheral speed of onion bulb metering unit on filling efficiency of cells

4.4.4.5 Per cent bulb damage

From Fig. 4.48. It was observed that when peripheral speed increased from 0.5 (S_1) to 2 (S_4) km h^{-1}, the per cent of bulb damage increased. It was further observed that, when the angle of inclination increased, percentage of bulb damage increased.

The results of variance obtained for bulb damage is presented in Table 4.25. From the Table 4.25, it was inferred that, the cup size, peripheral speed and angle of inclination had non-significant effect on per cent bulb damage.

When the means compared by LSD, it was evident that the cup size, C_3 (1.42 %) had lowest per cent bulb damage followed by C_2 (1.69 %) and C_4 (1.95 %). The cup size C_1 (2.05 %) had highest per cent bulb damage. It was further observed that, the speed, S_1 (1.54 %) had lowest per cent bulb damage followed by S_2 (1.65 %) and S_3 (1.85 %). The speed S_4 (2.08 %) of had highest per cent bulb damage. When the means of angle of inclination was compared, it was observed that the angle of inclination, A_1 (1.64 %) had lowest per cent of bulb damage followed by A_2 (1. 74 %). The angle A_3 (1.95 %) had highest per cent of bulb damage there was no significant effect due to interaction between the treatments. (Appendix C20).

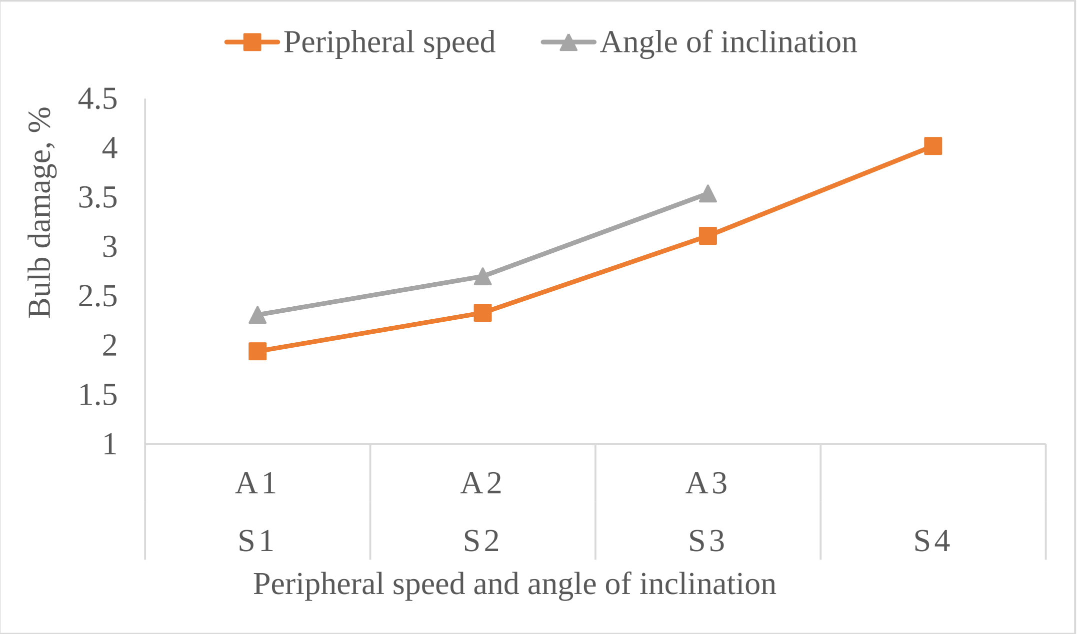


Fig. 4.48 Effect of peripheral speed and angle of inclination on per cent bulb damage- Onion bulb size (Grade 5-6 g)

Table 4.25. Analysis of variance for bulb damage for grade –IV category (5-6 g weight) of onion bulbs

Bulb damage				
Cup size	C_1	C_2	C_3	C_4
	2.05	1.69	1.42	1.95
Peripheral speed	S_1	S_2	S_3	S_4
	1.54	1.65	1.85	2.08
Angle of inclination	A_1	A_2	A_3	
	1.64	1.74	1.95	
	F-value	SeM	CD (p = 0.01/0.05)	
Cup size (C)	**	0.02	0.13	
Peripheral speed (S)	**	0.02	0.13	
Angle of inclination (A)	**	0.02	0.11	
C×S	**	0.05	0.26	
S×A	NS	0.05	-	
C×A	NS	0.05	-	
C×S×A	NS	0.10	-	

** 1% significant level; NS-non significant

From the above results (Table 4.11 to 4.25), it was inferred that the treatment combination $C_4S_2A_3$ (C_4' cup size: 25 mm, S_2' speed: 1 kmph and A_3' angle: 90 degree) resulted the maximum per cent singles. Hence, a seed metering unit having this optimized design and operational parameters was used to design and develop a prototype entitled tractor operated raised bed onion bulb planter.

4.5 Prototype tractor operated raised bed onion bulb planter

The planters developed by previous researcher for planting onions, garlic and bold seeds were reviewed in Section 2.4. Experiments were conducted and results discussed in earlier sections to optimize suitable seed metering unit for the onion bulb planter. There after prototype tractor operated raised bed onion bulb planter was designed and fabricated.

The tractor operated raised bed onion bulb plater consists of i. Main frame, ii. Ridger, iii. leveler, iv. Seed hopper. v. chute. vii. seed metering unit. vii. seed tube, viii. furrow opener and ix. ground wheel (Plates 4.56 and 4.57)

Main frame was fabricated out of 75×40×5 mm (W× L ×T), mild steel 'C' channel having dimension of 1480 ×580 mm (L×W) to which all the other components were mounted. Commercially available ridger two numbers were procured from the market and mounted on either side of the main frame. This ridger penetrates the soil, displaces the soil both sides and furrow are created. Leveler was fabricated out of 1 mm mild steel thickness having dimension of 900×300 mm (L× H). This was fitted to the main frame at the rear side of the ridger at a distance of 100 mm. The soil heaped in between the ridgers was levelled by this leveler, thus creates raised bed.

A seed hopper having dimensions of bottom width of hopper was 80 cm and top width of hopper was 160 cm, height of hopper was 50 cm and length of hopper was 30 cm was fabricated out 1 mm thickness mild steel sheet. The hopper was trapezoidal in shape. Four numbers of elevating type seed metering unit were fabricated and mounted to the main frame at the rear side of the leveler. On the basis of optimized values seeed metering cup of 25 mm was selected and the elevating unit was mounted at 90 degrees in the seed metering unit. A chute was fabricated out of mild steel sheet of 1 mm thickness and was attached to the seed hopper and seed metering unit. This chute conveyed the onion bulbs from the seed hopper to seed metering unit. A sliding unit was also provided in chute to regulate the flow of onion bulbs from seed hopper to seed metering unit. A seed tube was fitted at the delivery mouth of seed metering unit to guide the onion bulb. Seed tube was braided PVC (Poly Vinyl Chloride) material, having diameter of 45 mm (ID), thickness 2.5 mm and length 710 mm. Inverted T type furrow opener fabricated and fitted at the delivery end of seed tube. A star type ground wheel having diameter of 380 mm was fabricated 50 mm ×5 mm (W ×T) MS flat and mounted to the main frame with necessary bearings and fittings. The drive for the seed metering unit was provided from the ground wheel through necessary sprockets and chains.

4.6 Performance Evaluation of tractor operated raised bed onion bulb planter

The performance of tractor operated raised bed onion bulb planter was evaluated at Block No-8 of Division of Vegetable crops at ICAR-Indian Institute of Horticultural Research. Bengaluru, Karnataka. Rectangular field was selected for the evaluation and sowing was done lengthwise to reduce the turning losses of the bulb planter. The field was prepared with two pass of cultivator and one pass of rotavator. The onion bulbs were planted by developed tractor operated raised bed onion bulb planter.

The observations recorded during the evaluation mentioned in the below: i. Per cent Singles, ii. Per cent Doubles, iii. Per cent Multiples, iv. Per cent Missings, v. Performance indices parameters, vi. Per cent Bulb damage, vii. Theoretical field capacity, viii. Effective field capacity, ix. Field efficiency, x. Speed of operation, xi. Fuel consumption, xii. Depth of planting, xiii. Row to row spacing, xiv. Plant to plant spacing

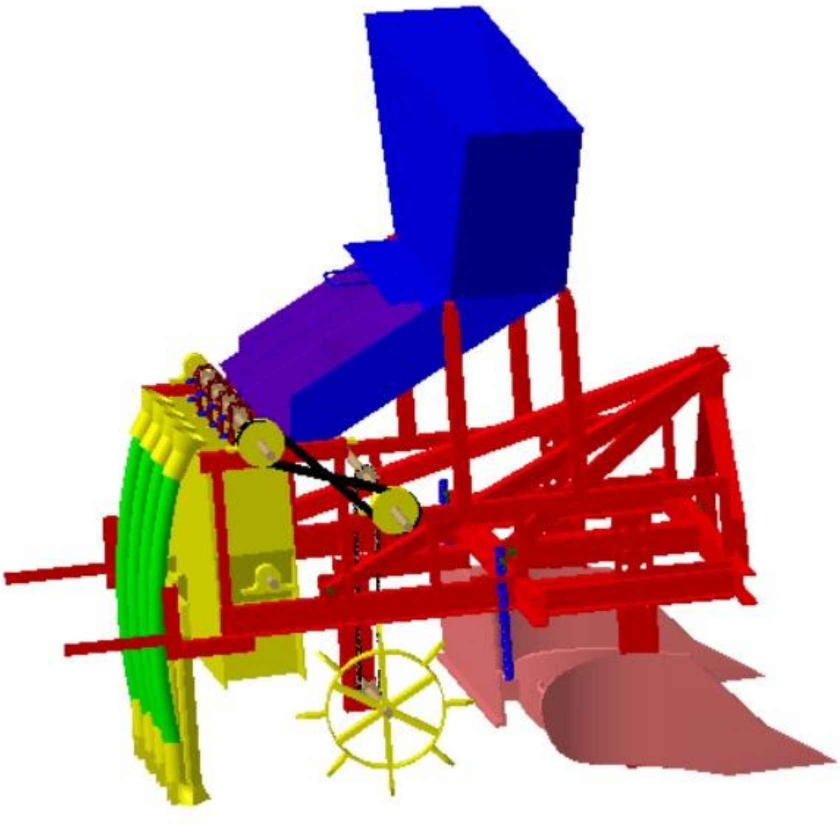


Fig 4.49 3D view of raised bed onion bulb planter

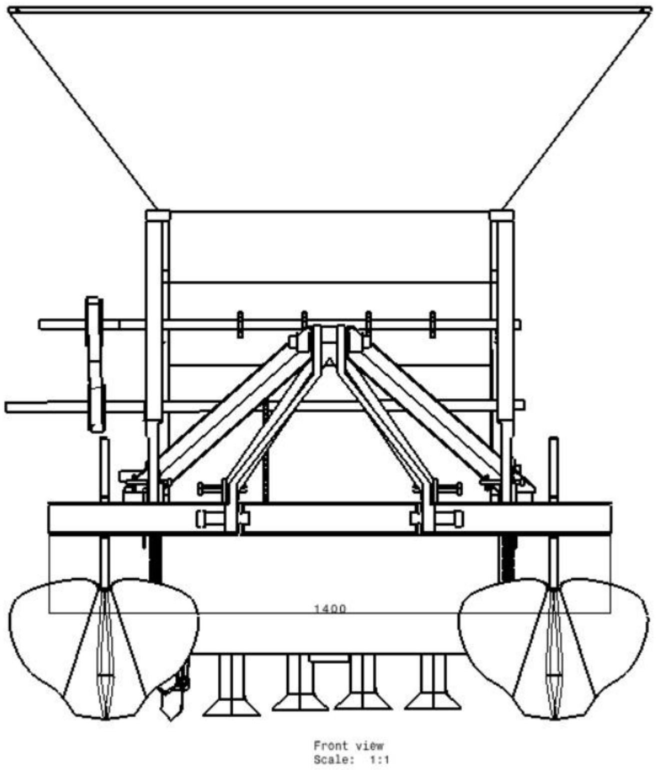


Fig 4.50 Front view of raised bed onion bulb planter

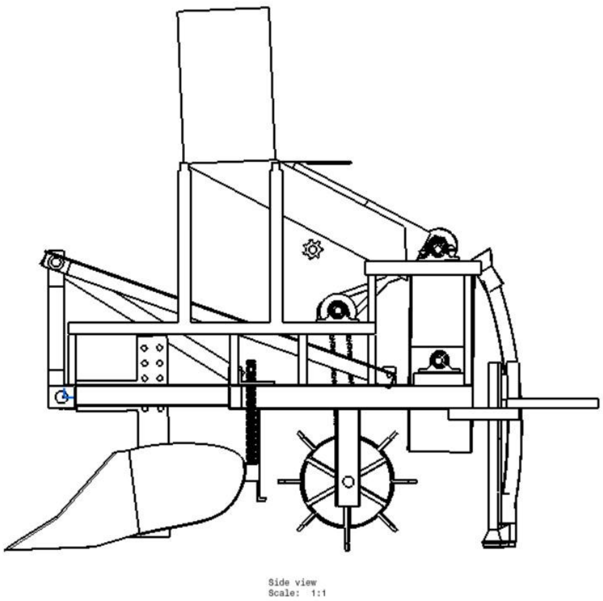


Fig 4.51 Side view of raised bed onion bulb planter

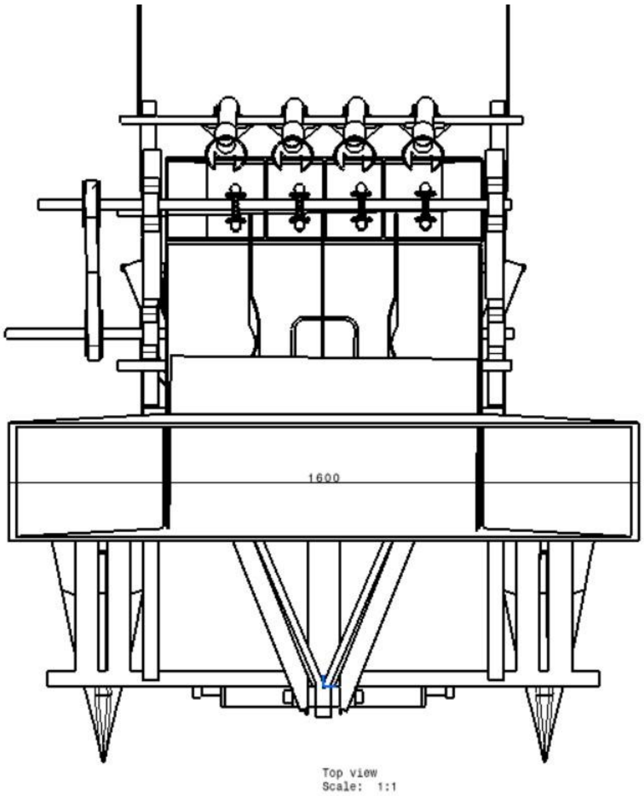


Fig 4.52 Top view of raised bed onion bulb planter

Plate 4.1 Front view of onion bulb planter

Plate 4.2 Side view of onion bulb planter

4.6.1 Per cent singles

The number of single bulbs fallen in 10 m length row were recorded (Plate 4.3). The average per cent singles was found to be 71.84 ± 1.14 % (Table 4.26).

Table: 4.26. Singles of onion bulb planter

S. No	Test run	Per cent singles, (%)				
		R1	R2	R3	R4	Mean
1	Test run 1.	72.72	73.40	71.87	72.67	72.66
2	Test run 2.	74.69	76.00	75.60	75.00	75.32
3	Test run 3.	68.89	69.39	66.67	68.09	68.26
4	Test run 4.	71.13	68.24	71.58	72.63	70.89
5	Test run. 5.	70.45	71.59	72.92	73.33	72.08
					Mean	71.84
					SD	2.57
					SEm	1.14

Plate 4.3 Singles of onion bulbs

4.6.2 Per cent doubles

The number of double bulbs fallen in 10 m length row were recorded (Plate 4.4). The average per cent doubles was found to be 8.94 ± 0.63 % (Table 4.27).

Plate 4.4 Doubles of onion bulbs

Table: 4.27. Doubles of onion bulb planter

S. No	Test run	Per cent doubles, (%)				
		R1	R2	R3	R4	Mean
1	Test run 1.	7.95	8.51	8.33	8.33	8.28
2	Test run 2.	7.22	7.60	7.31	7.60	7.43
3	Test run 3.	10	10.20	11.11	12.76	11.01
4	Test run 4.	9.27	11.76	9.47	8.42	9.73
5	Test run. 5.	9.09	7.95	8.33	7.77	8.28
					Mean	8.94
					SD	1.42
					SEm	0.63

4.6.3 Per cent multiples

The number of multiples bulbs fallen in 10 m length row were recorded (Plate 4.5). The average per cent multiples was found to be 11.48 ± 0.42 % (Table 4.28).

Table: 4.28. Multiple index of onion bulb planter

S. No	Test run	Per cent multiples, (%)				
		R1	R2	R3	R4	Mean
1	Test run 1.	11.34	11.76	12.63	11.57	1.82
2	Test run 2.	10.84	8.69	9.75	9.78	9.76
3	Test run 3.	13.33	11.22	12.12	11.70	12.09
4	Test run 4.	11.36	12.5	12.5	11.11	11.86
5	Test run. 5.	11.36	11.70	12.5	11.90	11.86
					Mean	11.48
					SD	0.96
					SEm	0.42

Plate 4.5 Multiples of onion bulbs

4.6.4 Per cent missings

The number of missings bulbs fallen in 10 m length row were recorded (Plate 4.6). The average per cent missings was found to be 7.70 ± 0.24 % (Table 4.29).

Table: 4.29. Missing index of onion bulb planters

S. No	Test run	Per cent missings, (%)				
		R1	R2	R3	R4	Mean
1	Test run 1. (%)	9.09	7.95	6.25	7.77	7.76
2	Test run 2. (%)	7.77	9.18	10.10	7.44	8.62
3	Test run 3. (%)	7.95	6.38	7.29	7.14	7.19
4	Test run 4. (%)	7.22	7.60	7.31	7.60	7.43
5	Test run. 5. (%)	8.24	8.23	6.31	7.36	7.53
					Mean	7.70
					SD	0.55
					SEm	0.24

Plate 4.6 Missings of onion bulb

4.6.5 Performance indices of raised bed onion bulb planter

The performance indices namely miss index, multiple index, quality feed index, precision, mean and standard deviation of tractor operated raised bed onion bulb planter for 5 test runs were measured as explained in 3.12.1 to 3.12.4 section and presented in the Table 4.30. From the table 4.30, it was observed that the developed tractor operated raised bed onion bulb planter had miss index of 0.076 ±0.002, multiple index of 0.114±0.004, quality feed index of 0.808 ±0.002, precision of 0.14±0.005, mean of 10.63±0.144 and stand deviation of 1.49±0.05. This precision (14%) was very well in the acceptable range for indicating the good performance of planter in terms of planting single onion bulbs (Katchman and Smith, 1995). Katchman and Smith (1995) suggests that the theoretical upper limit for precision is 50 %. The upper limit of 50 % occurs when half the spacings are at the lower limit of the target range and the other half are the upper limit of the target range. A practical upper limit on the value for precision is 29 %. A precision of 29 % would be indicative of all the spacing being spread uniformly within target range. In this developed planter the precision value was recorded as 14%, which suggests the good performance of planter.

Table: 4.30. Performance indices of onion bulb planter during laboratory test run.

S. No	Test run	Performance indices parameter					
		Miss index	Multiple index	Quality feed index	Precision	Mean, cm	Standard deviation, cm
1	Test run 1.	0.077	0.118	0.804	0.149	10.07	1.50
2	Test run 2.	0.086	0.097	0.816	0.154	10.88	1.68
3	Test run 3.	0.071	0.120	0.807	0.138	10.76	1.49
4	Test run 4.	0.074	0.118	0.807	0.124	10.72	1.33
5	Test run. 5.	0.075	0.118	0.806	0.135	10.75	1.47
6	Mean	0.076	0.114	0.808	0.14	10.63	1.49
7	SD	0.005	0.009	0.004	0.011	0.322	0.124
8	SEm	0.002	0.004	0.002	0.005	0.144	0.055

4.6.6 Bulb damage

The procedure followed to measure the bulb damage of onion bulb planter was explained under 3.12.5 Section. The number of bulbs damaged in 10 m length row were recorded. The average per bulb damage was found to be 1 ± 0.138 % (Table 4.31).

Table: 4.31 Bulb damage of onion bulb planter

S. No	Test run	Per cent bulb damage, (%)					
		R1	R2	R3	R4	R5	Mean
1	Test run 1.	0	1	1	0	1	0.6
2	Test run 2.	2	0	1	2	2	1.4
3	Test run 3.	1	2	0	1	2	1.2
4	Test run 4.	1	1	1	0	1	0.8
5	Test run. 5.	0	2	1	2	0	1
						Average	1
						SD	0.31
						SEm	0.138

4.6.7 Theoretical field capacity

The procedure followed to measure the theoretical field capacity of the onion bulb planter was explained under 3.12.6 Section. The width of the onion bulb planter was 150 cm and speed of operation was 1 km h^{-1}. The theoretical field capacity of the onion bulb planter was 0.15 ha h^{-1} (Table 4.32)

4.6.8 Effective or actual field capacity

The procedure followed to measure the effective or actual field capacity of the onion bulb planter was explained under 3.12.7 Section. The average effective or actual field capacity of the onion bulb planter was found to be 0.122 ±0.002 ha h^{-1}. (Table 4.32).

4.6.9 Field efficiency

The procedure followed to measure the field efficiency of the onion bulb planter was explained under 3.12.8 Section. The average field efficiency of the onion bulb planter was found to be 81.7±0.146 % (Table 4.32). The field capacity of tractor operated raised bed onion bulb planter was 8.15±0.146 h (Table 4.32).

Table 4.32 Performance parameters of tractor operated raised bed onion bulb planter

S. No	Test run	Performance parameters					
		Speed, km/h	Width, m	TFC, ha h^{-1}	AFC, ha h^{-1}	FE, %	Time required, h/ha
1	Test run 1.	0.97	1.5	0.15	0.130	86.6	7.69
2	Test run 2.	0.93	1.5	0.15	0.117	78.00	8.54
3	Test run 3.	0.90	1.5	0.15	0.125	83.3	8.00
4	Test run 4.	0.93	1.5	0.15	0.121	80.6	8.26
5	Test run. 5.	0.97	1.5	0.15	0.120	80.00	8.33
6	Mean	0.94	1.5	0.15	0.122	81.7	8.15
7	SD	0.03	0	0	0.005	3.330	0.327
8	SEm	0.013	0	0	0.002	1.493	0.146

4.6.10 Fuel consumption

The procedure followed to measure the fuel consumption of onion bulb planter was explained under 3.12.10 Section. The average fuel consumption of onion bulb planter was found to be 3.17±0.035 l h^{-1} (Table. 4.33).

4.6.11 Depth of planting

The procedure followed to measure the depth of onion bulb planter was explained under 3.12.11 section (Plate 4.7). The average depth of planting of onion bulb planter was found to be 4.112 ±0.134 cm (Table.4. 34).

Table: 4.33 Fuel consumption of bulb planter

S. No	Test run	Fuel consumption (l h^{-1})
1	Test run 1.	3.2
2	Test run 2.	3.1
3	Test run 3.	3.15
4	Test run 4.	3.1
5	Test run. 5.	3.3
6	Mean	3.17
7	SD	0.08
8	SEm	0.035

Table: 4.34 Depth of planting of onion bulb planter

S. No	Test run	Depth of planting, cm					
		R1	R2	R3	R4	R5	Mean
1	Test run 1.	3.7	3.9	4.3	4.8	4.6	4.26
2	Test run 2.	3.8	4	3.6	4.5	4.9	4.16
3	Test run 3.	5.2	4.9	4.7	3.8	4	4.52
4	Test run 4.	4.4	3.5	3.4	3.7	3.8	3.76
5	Test run. 5.	4.1	3.8	3.8	3.9	3.7	3.86
						Mean	4.112
						SD	0.30
						SEm	0.134

Plate 4.7 Measurement of depth of planting

4.6.12 Row to row spacing

Row to row spacing of onion bulb planter was measured as explained under Section 3.12.12. The average row to row spacing was found to be 15.00±0.053 cm (Table 4.35).

4.6.13 Plant to plant spacing

The procedure followed to measure plant to plant spacing was explained under 3.12.13 section (Plate 4.8). The average plant to plant spacing was found to be 10.44±0.084 cm (Table.4.36).

Plate 4.8 Measurement of plant to plant spacing

Table: 4.35 Row to row spacing of onion bulb planter

S. No	Test run	Row to row spacing, cm					
		R1	R2	R3	R4	R5	Average
1	Test run 1. (cm)	14.9	14.7	15.2	14.8	14.5	14.82
2	Test run 2. (cm)	15.1	15.4	14.8	15.7	14.6	15.12
3	Test run 3. (cm)	14.7	15.2	14.8	14.9	15.2	14.96
4	Test run 4. (cm)	15.2	15.3	14.9	14.8	15.3	15.1
5	Testrun. 5. (cm)	14.7	14.8	15.2	15.3	15.1	15.02
						Average	15.00
						SD	0.12
						SEm	0.053

Table. 4.36 Plant to plant spacing of bulb planter

S. No	Test run	Plant to plant spacing, cm					
		R1	R2	R3	R4	R5	Mean
1	Test run 1.	9.9	9.5	10.2	11.3	11.8	10.54
2	Test run 2.	10.7	9.8	10.3	10.5	9.9	10.24
3	Test run 3.	11.2	11.7	9.4	10.6	10.7	10.72
4	Test run 4.	10.2	10.5	10.9	9.9	10.3	10.36
5	Test run. 5.	11	9.8	10.3	9.7	10.9	10.34
						mean	10.44
						SD	0.19
						SEM	0.084

4.7 Cost Economics

The cost economics of tractor operated raised bed onion bulb planter was worked out and given in (Appendix, F). The field capacity of the onion bulb planter was 0.122 ±0.002 ha h^{-1} and cost of operation with onion bulb planter and manual planting was Rs. 4211.91 and 10,000 ha^{-1}. The cost saved over manual planting was about 58 per cent. The cost of onion bulb planter was Rs.49,300/-.

CHAPTER – V
SUMMARY AND CONCLUSION

Agricultural mechanization has become important in crop production to resolve problems such as drudgery, high production costs, and poor quality, low crop intensity and above all, labour shortage. There is, in general a declining trend in the usage of family labour in farming practices. Because the value of machinery usage has now been realized, development of machinery for mechanizing the cultivation operations of economically important crops are immediate requirement. The value of horticulture is widely recognized for improving land productivity, creating jobs, improving the economic conditions of farmers and entrepreneurs, improving exports and above all providing people with nutritional security. Onion (*Allium cepa* L.) is one of the most important crops widely used in world and has a very high potential for export. Recent day's government encourages raised bed cultivation of onions to adopt micro irrigation and mulching etc. Raised bed cultivation of onion will also lead to end to end mechanization of onion cultivation. Aggregatum type of onions grown in India. It was traditionally cultivated by paired row system. However, due to the close spacing of onion plants, the cost of cultivation is very high when compared to other vegetable crops. Hence, a study was carried out to develop a tractor operated raised bed onion bulb planter with the following aspects:

1. The physical and mechanical properties of onion bulbs relevant for mechanical metering system were determined.
2. During manual planting the onion bulbs are pressed having their basal root portion down into the irrigated field. However, in a planter the planting material will be dropped in any position. A field experiment (two seasons) was conducted to evaluate the impact of four different planting orientations on the percentage of germination (7 DAP and 15 DAP), plant height (15 DAP and 30 DAP) and yield of onion crop.
3. An experimental setup was fabricated and crop, design and operational parameters of the onion bulb metering unit were optimized and experiments were performed.

4. A prototype tractor operated raised bed onion bulb planter having optimal metering unit was fabricated.
5. The test run was carried out for the onion bulb planter to determine the performance.
6. A field trial was conducted at a forward speed of 0.94 kmph for planting of onion bulb and planter performance in the field was determined.
7. The cost economics of onion bulb planter was worked out.

After conducting above mentioned studies, experiment, development work in laboratory, workshop and evaluation work in the field following results were obtained and those are summarized as below:

5.1 Planter related physical and mechanical properties of onion bulbs

The onions were graded in to nine grades *viz.*, < 2 g, 2-3 g, 3-4 g, 4-5 g, 5-6 g, 6-7 g, 7-8 g, 8-9 g, > 9 g based on individual weight and planter related important physical and mechanical properties of onion bulbs namely, linear dimensions (length, width and thickness), geometric mean diameter, sphericity, shape index, projected area, one hundred onion bulb weight, bulk density, true density, moisture content, angle of repose and coefficient of friction were determined.

i) The length, width and thickness ranged from 21.21±2.60 to 32.31±3.30, 13.54±1.77 to 30.95±2.91 and 10.91±1.40 to 22.63±2.15 mm. The geometric mean diameter of onion bulb ranged from 14.54±0.96 to 28.22±2.04 mm. The sphericity of onion bulb ranged from 0.69±0.08 to 0.87±0.06. The shape index for grades <2 g, 2-3 g and 3-4 g were found to be 1.78±0.32, 1.711±0.25, 1.59±0.25 respectively, > 1.5 and for the remaining grades i.e. 4-5 g to > 9 g the shape index values were found to be < 1.5. The projected area of onion bulb ranged from 1.55±0.30 to 5.5±0.51 cm^2. The one hundred onion bulb weight ranged from 121.6±6.30 to 1185±19.59 g. The bulk density of onion bulb ranged from 480.19±13.13 (< 2 g) to 1086±205.22 (> 9 g) kg m^{-3}. The size of the onion bulbs had significant effect on geometric mean diameter, sphericity, shape index, projected area, one hundred onion bulbs weight and bulk density.

ii) The maximum true density of onion bulb was 1086±205.22 kg m^{-3} obtained in > 9 g, while minimum true density of onion bulb was 950.70±257.92 kg m^{-3} in < 2-3 g. The average moisture content of onion bulb was found to be 80.02 ±0.43 %. The size of the onion bulbs did not show any significant effect on true density and moisture content.

iii) The angle of repose ranged from 20.71±1.92 to 40.61±3.68º. The coefficient of friction was determined for onion bulbs on different surfaces such as, mild steel, ply wood and galvanized iron. The coefficient of friction for mild steel, ply wood, and galvanized iron ranged 0.628±0.03 to 0.456±0.016, 0.236±0.03 to 0.174±0.016 and 0.344±0.01 to 0.310±0.017 respectively. The angle of repose of onion bulb had significant difference between different grades.

5.2 Effect of different planting orientations of onion bulbs on germination percentage, height of plant and yield

To understand the effect of planting orientation on germination percent, height of plant and yield, experiments were carried out during rabi and kharif season. It is important for developing any mechanical device of planting. The summary of the results of both the season for different growth parameters of onion along with pooled analysis of observations are given below.

I) Rabi season

i) Effect on germination of onion bulb

a**)** Onion bulb germination was recorded on 7 DAP. Planting orientation, root portion down (T_2) had the highest percentage of germination (86.50 %), followed by 85.75 percent inclined (T_4) and 81.50 percent horizontal (T_3) and were on par. The lowest germination per cent age (64.25 per cent) was for the root portion up (T_1).

b**)** Onion bulb germination was recorded on 15 DAP. The root section down (T_2) had the highest rate of germination (87.50 per cent), followed by 86.50 percent inclined (T_4) and 85.50 percent horizontal (T_3) and were on par. The lowest germination percentage (69.25 per cent) was for root portion up (T_1).

ii) Effect on plant height of onion bulbs

a) On 15 DAP, the height of the onion plants was recorded. The root portion downward (T_2) was found to have the maximum plant height (33.85 cm), followed by 32.98 cm inclined (T_4) and 31.83 cm horizontal (T_3). The lowest plant height (31.36 cm) was found in root portion upwards (T_1)

b) On 30 DAP, the plant height of onion bulbs was recorded. The root portion down (T_2) was found to have the maximum plant height (39.50 cm), followed by inclined (T_4) 38.59 cm and horizontal (T_3) 37.11 cm, and the lowest plant height (36.10 cm) was the root portion up (T_1). The treatment T_2 were seen to have the largest plant height, led by the T_4 and T_3 treatments, which were at par.

iii) Effect on yield of onion bulbs

a) The root portion down (T_2) was found to have maximum yield of 19.46 t/ha. Accompanied by inclined (T_4) 18.69 t/ha and horizontal (T_3) 17.10 t/ha, and were at par. The lowest yield was 13.26 t/ha with the root portion up (T_1).

II) Kharif season

i) Effect on germination of onion bulbs

a) The root portion down (T_2) had the maximum germination efficiency (93.41 per cent) followed by 92.37 per cent, inclined (T_4) and 91.59 per cent horizontal (T_3) and were on par. The root section up (T_1) had the lowest germination efficiency (58.01 per cent) in 7 DAP.

b) The root portion downwards (T_2) had the highest germination efficiency (95.40 per cent), followed by 95.00 per cent inclined (T_4) and 93.64 per cent horizontal (T_3) and were on par. The root portion up (T_1) had the lowest germination efficiency of 61.20 per cent in 15 DAP.

ii) Effect on plant height of onion bulbs

a) The root portion down (T_2) had the maximum plant height (37.97 cm) preceded by inclined (T_4) 36.93 cm and horizontal (T_3) 35.86 cm, and the lowest plant height (34.40 cm) was the root portion up (T_1). Treatment T_2 was seen to have the largest plant height, led by treatments T_4 and T_3 that were at par on 15 DAP.

b) The root portion downwards (T_2) ha the maximum plant height (37.97 cm), accompanied by inclined (T_4) 36.93 cm and horizontal (T_3) 35.86 cm, and the lowest plant height (34.40 cm) was the root portion upwards (T_1). Treatments T_2 were seen to have the largest plant height, led by treatments T_4 and T_3 that were at par. For 30 DAP.

iii) Effect on yield of onion bulbs

a) The root portion down (T_2) had the highest yield of 12.62 t/ha followed by inclined (T_4) 12.08 t/ha and horizontal (T_3) (11.78 t/ha) and were on par. The root portion up (T_1) had the lowest yield of 8.97 t/ha.

III. Pooled data

i) Effect on germination of onion bulbs

a) The root portion down (T_2) had the highest germination efficiency (89.83 %) followed by inclined (T_4) (89.06 %) and horizontal (T_3) (86.54 %) and root portion down and inclined were on par. The root portion up (T_1) had the lowest germination efficiency of (61.13 %) in 7 DAP.

b) The root portion down (T_2) had the highest germination efficiency (91.45 %) followed by inclined (T_4) (90.75 %) and horizontal (T_3) (89.57 %) and were on par. The treatment T_1 had the lowest germination efficiency of (65.23 %) in 15 DAP.

iii) Effect on plant height of onion bulbs

a) The root portion down (T_2) had the highest plant height (33.18 cm) followed by inclined (T_4) 32.12 cm and horizontal (T_3) 31.23 cm and the root portion up (T_1) had the lowest plant height of (30.19 cm). It was observed that the Treatment T_2 had the highest plant height followed by Treatment T_4 and were on par. Further this was followed by Treatment T_3 and Treatments T_4 and T_3 were on par in 15 DAP.

b) The root portion down (T_2) had the highest plant height (38.74 cm) followed by inclined (T_4) 37.76 cm and were on par. This was followed by T_3 (36.49) and Treatments T_3 and T_4 were on par. Treatment T_1 had the lowest plant height of (35.25 cm) and were on par with T_3 in 30 DAP.

ii) Effect on yield of onion bulbs

i) The root portion down (T_2) had the highest yield of 16.04 t/ha followed by inclined (T_4) 15.39 t/ha and horizontal (T_3) 14.42 t/ha and the root portion down and inclined were on par. The root portion up (T_1) had the lowest yield of 11.12 t/ha.

5.3 Operational parameters of design and development of onion bulb planter

The effect of different peripheral speeds of S_1 (0.5 km h^{-1}), S_2 (1 km h^{-1}), S_3 (1.5 km h^{-1}), S_4 (2 km h^{-1}) and angles of inclination of A_1 (60 °), A_2 (75 °) and A_3 (90 °) for cup sizes C_1 (34 mm), C_2 (31 mm), C_3 (29 mm) and C_4 (25 mm) of metering unit on per cent singles, doubles, multiples, missings, bulb damage were statistically analyzed to optimize the design and operational parameters for all four grades I - (2-3 g weight), grade –II (3-4 g weight), grade-III (4-5 g weight), and grade-IV (5-6 g weight). The criteria chosen for the optimum combination of above parameters was, which would yield minimum missings, maximum singles, minimum doubles, minimum multiples and minimum bulb damage.

a) Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-I category (2-3 g weight) of onion bulbs

i)The per cent singles, doubles, multiples, missings and bulb damage ranged from 39.60 to 58.80, 13.95 to 31.65, 7.57 to 24.11 , 2.00 to 38.88 and 0.66 to 6.66 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 34.4 mm (C_1).

ii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 43.73 to 52.53, 11.26 to 28.58, 7.04 to 22.71, 4.16 to 36.27 and 0.33 to 2.33 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 31 mm (C_2).

iii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 30.90 to 63.25, 4.90 to 31.79, and 2.26 to 35.66. 2.55 to 61.15 and 0.00 to 1.33 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 29 mm (C_3).

iv) The per cent singles, doubles, multiples, missings and bulb damage ranged from 55.28 to 79.09, 10.08 to 18.18, 7.36 to 16.24, 1.76 to 16.50 and 0.66 to

3.66 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 25 mm (C_4).

b) Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-II category (3-4 g weight) of onion bulbs

i) The per cent singles, doubles, multiples, missings and bulb damage ranged from 39.61 to 59.74, 13.20 to 30.88, 5.20 to 23.40, 2.65 to 42.00 and 1.00 to 7.00 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 34.4 mm (C_1).

ii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 43.15 to 51.83, 9.78 to 27.70, 6.50 to 22.26, 5.38 to 37.71 and 1.00 to 37.71 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 31 mm (C_2).

iii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 28.80 to 55.98, 2.21 to 30.17, 1.93to 30.43, 5.79 to 62.87 and 0.33 to 1.66 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 29 mm (C_3).

iv) The per cent singles, doubles, multiples, missings and bulb damage ranged from 55.28 to 79.85, 9.48 to 17.30, 6.72 to 15.27, 2.26 to 17.64 and 1.00 to 4.33 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 25 mm (C_4).

c) Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-III category (4-5 g weight) of onion bulbs

i) The per cent singles, doubles, multiples, missings and bulb damage ranged from 38.85 to 60.22, 12.55 to 30.23, 4.86 to 23.08, 3.25 to 43.74 and 1.33 to 7.33 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 34.4 mm (C_1).

ii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 43.66 to 51.67, 9.19 to 27.47, 6.25 to 21.61, 5.86 to 38.97 and 1.33 to 3.66 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 31 mm (C_2).

iii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 20.99 to 64.25, 2.46 to 30.55, 2.37 to 37.97, 2.12 to 37.97 and 0.66 to 2.00 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 29 mm (C_3).

iv) The per cent singles, doubles, multiples, missings and bulb damage ranged from 55.26 to 80.25, 8.87 to 16.99. 6.46 to 14.29, 2.70 to 18.91 and 1.66 to 4.66 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 25 mm (C_4).

d) Effect of peripheral speed, angle of inclination and cup size on cell filling performance for Grade-IV category (5-6 g weight) of onion bulbs

i) The per cent singles, doubles, multiples, missings and bulb damage ranged from 38.43 to 59.70, 11.57 to 29.33, 4.13 to 22.74, 4.59 to 45.87 and 1.66 to 7.66 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 34.4 mm (C_1).

ii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 43.46 to 52.07, 8.94 to 27.53, 5.22 to 21.18, 6.29 to 39.95 and 1.66 to 4.33 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 31 mm (C_2).

iii) The per cent singles, doubles, multiples, missings and bulb damage ranged from 18.93

to 61.46, 2.46 to 26.99, 1.77 to 24.02, 7.50 to 72.85 and 1.00 to 2.33 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 29 mm (C_3).

iv) The per cent singles, doubles, multiples, missings and bulb damage ranged from 54.59 to 81.03, 8.67 to 16.46, 5.36 to 13.72, 3.13 to 20.45 and 2.00 to 5.33 (%) for the angle of inclinations of 60º, 75º and 90º and peripheral speeds of 0.5, 1, 1.5, and 2 kmph of onion metering unit for the cup size 25 mm (C_4).

e) The metering unit having cup size C_4 (25 mm) operated at peripheral speed S_2 (1 kmph) and angle of inclination A_3 (90 degrees) resulted the best metering performance.

5.4 Prototype tractor operated raised bed onion bulb planter

The tractor operated raised bed onion bulb plater consists of main frame, ridger. Ridger forms a raised bed of having 90 cm width, 15 cm depth. The seed hopper is in trapezoidal in shape having a capacity of 110 kg, side wall of hopper was slope of 45 degree for easy flowing of onion bulbs to seed metering unit. Seed metering unit consisted compressed of elevator fitted with cups. The seed tube was a braided poly vinyl chloride fitted to delivery mouth of seed metering unit. Furrow opener inverted –T type which opens the furrow for placing the onion bulbs. A star type ground wheel was fitted and seed metering unit was driven by this ground wheel with necessary power transmission systems.

5.5 Performance evaluation of tractor operated raised bed onion bulb planter

On the basis of optimized parameters the bulb planter was designed and fabricated successfully

i) Under the field trials, the performance parameters were found to 71.84 ± 1.14 per cent singles, 8.94 ± 0.63 per cent doubles, 11.48 ± 0.42 per cent multiples 7.70 ± 0.24 per cent missings and 1 ± 0.138 per cent bulb damage.

ii) Performance indices in terms of miss index, multiple index, quality feed index, precision, mean and standard deviation were found to be 0.076±0.002, 0.114±0.004,0.808±0.002, 0.14±0.005, 10.63±0.144 and 0.49±0.05, respectively.

iii) The raised bed onion bulb planter performance parameters in terms of theoretical field capacity, effective field capacity, field efficiency, fuel consumption, depth of planting, row to row spacing and plant to plant spacing 0.15 ha h^{-1}, 0.122 ±0.002 ha h^{-1} 81.7±0.146 %, 3.17±0.035 l h^{-1} , 4.112 ±0.134 cm, 15.00±0.053 cm and 10.44±0.084 cm.

iv) The cost of onion bulb planter was Rs.49, 300/-. The cost of operation of onion bulb planter was Rs. 4, 211.91/ ha and manual planting was Rs.10, 000/ha. The cost saved over manual planting was about 58 per cent. For good performance of machine, the precision value should be less than 29 per cent as per standards (Katchman and Smith, 1995). The developed onion bulb planter, the precision value is 14 per cent, hence the machine falls under the category of good performance.

Effect of size of onion was significant in all the selected physical and mechanical properties except true density and moisture content. The individual observations of kharif, rabi and pooled data analysis of effect of planting orientation suggests that root portion down planting gave highest germination, plant height and yield of onion followed by root portion inclined and horizontal. The cup size C_4 (25 mm), speed of travel S_2 (1 kmph) and angle of inclination as A_3 (90 degree) was optimized for metering mechanism. Based on these results a protype of raised bed tractor operated onion bulb planter was successfully designed, fabricated and evaluated in the field as per standard methodology. The precision value of developed planter was observed 14 per cent, hence the machine falls under the category of good performance.

Future Suggestions

1. The developed planter may be attached with facility of fertilizer application and also facility of chemical application.
2. The prototype can be vigorously tested for other varieties of onion.

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APPENDICES

APPENDIX-A1

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	10667.30	1333.41	189.68	0.000 **
Error	891	6263.50	7.02		
Total	899	16930.80	18.83		

SEd = 0.37 CD (.05) = 0.73 CD (.01) = 0.96 CV% = 9.83

ANOVA on Length

APPENDIX-A2

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	27804.91	3475.61	863.79	0.000 **
Error	891	3585.06	4.02		
Total	899	31389.98	34.91		

SEd = 0.28 CD (.05) = 0.55 CD (.01)=0.73 CV% = 9.03

ANOVA on Width

APPENDIX-A3

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	13200.39	1650.04	566.04	0.000 **
Error	891	2597.29	2.915		
Total	899	15797.68	17.57		

SEd = 0.24 CD (.05) = 0.47 CD (.01) =0.62 CV% = 10.09

ANOVA on thickness

APPENDIX-A4

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	17191.45	2148.93	1618.49	0.000 **
Error	891	1183.01	1.32		
Total	899	18374.46	20.43		

SEd = 0.16 CD (.05) = 0.31 CD (.01) = 0.42 CV% = 5.34

ANOVA on Geometric mean diameter

APPENDIX-A5

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	3.558516	0.444815	85.7455	0.000 **
Error	891	4.622165	0.005188		
Total	899	8.180681	0.009100		

SEd = 0.0102 CD (.05) = 0.0200 CD (.01) = 0.0263 CV% = 9.05

ANOVA on Sphericity

APPENDIX-A6

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	79.767160	9.970895	234.2564	0.000 **
Error	891	37.924553	0.042564		
Total	899	117.691713	0.130914		
SEd = 0.0292		CD (.05) = 0.0573	CD (.01) = 0.0753	CV% = 15.07	

ANOVA on Shape index

APPENDIX-A7

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	72.777778	9.097222	78.4431	0.000 **
Error	36	4.175000	0.115972		
Total	44	76.952778	1.748927		
SEd = 0.2154		CD (.05) = 0.4227	CD (.01) = 0.5560	CV% = 9.40	

ANOVA on Projected area

APPENDIX-A8

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	4931690.84	616461.355	2563.6042	0.000 **
Error	36	8656.800000	240.466667		
Total	44	4940347.644	112280.628		
SEd = 9.80		CD (.05) = 19.248	CD (.05) = 19.248	CV% =2.72	

ANOVA on One hundred onion bulb weight

APPENDIX-A9

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	484688.93	60586.11	811.51	0.000 **
Error	36	2687.68	74.65		
Total	44	487376.61	11076.74		
SEd = 5.46		CD (.05) = 10.72	CD (.01)=14.10	CV% = 1.39	

ANOVA on Bulk density

APPENDIX-A10

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	246206.72192	30775.840241	0.7691	0.632 NS
Error	36	1440486.5529	40013.515359		
Total	44	1686693.2748	38333.938065		
SEd = 126.51		CD (.05) = 248.2993	CD (.01) = 326.59	CV% = 21.41	

ANOVA on True density

APPENDIX-A11

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	7.000000	0.875000	0.6558	0.726 NS
Error	36	48.032000	1.334222		
Total	44	55.032000	1.250727		
SEd = 0.7305		CD (.05) = 1.4338	CD (.01) = 1.8859	CV % = 1.44	

ANOVA on Moisture content

APPENDIX-A12

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	8	2496.65	312.08	67.47	0.000 **
Error	36	166.50	4.62		
Total	44	2663.15	60.52		
SEd = 1.36		CD (.05) = 2.66	CD (.01)= 3.51	CV% = 6.86	

ANOVA on Angle of repose

APPENDIX-A13

Source of variation	DF	SS	MS	F-calculated	PROB
Treatment	26	2.701575	0.103907	231.6665	0.553 NS
Error	108	0.048440	0.000449	1.0000	
Total	134	2.750015	0.020522	45.7562	
M	2	2.553797	1.276899	2846.9249	0.000 **
G	8	0.081961	0.010245	22.8423	0.000 **
MG	16	0.065816	0.004114	9.1713	0.000 **
Err	108	0.048440	0.000449	1.0000	

CV = 6.02%

	SED	CD (0.05)	CD (0.01)
M	0.00446	0.00885	0.01171
G	0.00773	0.01533	0.02028
MG	0.01339	0.02655	0.03513

ANOVA on Coefficient of friction

Rabi Season

APPENDIX-B1
ANOVA on Germination at 7 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	262.0312	65.5078	1.16	0.3758
Treatments	3	1605.8594	535.2865	9.48	0.0017
Error	12	677.3438	56.4453		
Total	19	2545.2344			

APPENDIX-B2
ANOVA on Germination at 15 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	34.3750	8.5937	2.43	0.1052
Treatments	3	1125.8594	375.2865	105.96	0.0000
Error	12	42.5000	3.5417		
Total	19	1202.7344			

APPENDIX-B3
ANOVA on Plant height at 15 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	33.4508	8.3627	2.45	0.1033
Treatments	3	19.0065	6.3355	1.85	0.1914
Error	12	41.0373	3.4198		
Total	19	93.4945			

APPENDIX-B4
ANOVA on Plant height at 30 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	18.0763	4.5191	1.53	0.2561
Treatments	3	34.3885	11.4628	3.87	0.0378
Error	12	35.5128	2.9594		
Total	19	87.9775			

APPENDIX-B5
ANOVA on Yield

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	108.3300	27.0825	7.40	0.0030
Treatments	3	113.9701	37.9900	10.38	0.0012
Error	12	43.8982	3.6582		
Total	19	266.1983			

Kharif Season

APPENDIX-B6
ANOVA on Germination at 7 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	107.4389	26.8597	1.09	0.4033
Treatments	3	4456.4200	1485.4733	60.47	0.0000
Error	12	294.7696	24.5641		
Total	19	4858.6284			

APPENDIX-B7
ANOVA on Germination at 15 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	31.6785	7.9196	0.88	0.5051
Treatments	3	4211.8067	1403.9356	155.77	0.0000
Error	12	108.1551	9.0129		
Total	19	4351.6403			

APPENDIX-B8
ANOVA on Plant height at 15 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	3.7143	0.9286	2.42	0.1058
Treatments	3	31.5644	10.5215	27.42	0.0000
Error	12	4.6038	0.3836		
Total	19	39.8824			

APPENDIX-B9
ANOVA on Plant height at 30 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	9.0443	2.261	1.12	0.3916
Treatments	3	34.9450	11.6483	5.78	0.0111
Error	12	24.1938	2.0161		
Total	19	68.1830			

APPENDIX-B10
ANOVA on Yield

Source of variation	DF	SS	MS	F-calculated	PROB
Replications	4	6.1276	1.5319	1.48	0.2689
Treatments	3	39.9344	13.3115	12.86	0.0005
Error	12	12.4198	1.0350		
Total	19	58.4818			

Pooled data

APPENDIX-B11

ANOVA on Germination at 7 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Season	1	194	194.0	4.791	0.0386 *
Treatment	3	5667	1889.1	46.638	3.64e-10 ***
Season x Replication	8	369	46.2	1.140	0.3734
Season x Treatment	3	395	131.7	3.251	0.0394*
Residuals	24	972	40.5		

APPENDIX-B12

ANOVA on Germination at 15 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Season	1	170	169.9	27.067	2.49e-05 ***
Treatment	3	4843	1614.4	257.189	2e-16 ***
Season x Replication	8	66	8.3	1.315	0.283
Season x Treatment	3	494	164.8	26.249	9.41e-08 ***
Residuals	24	151	6.3		

APPENDIX-B13

ANOVA on Plant Height at 15 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Season	1	27.31	27.308	14.359	0.000896***
Treatment	3	48.62	16.206	8.522	0.000498***
Season x Replication	8	37.17	4.646	2.443	0.043246*
Season x Treatment	3	1.95	0.651	0.342	0.794969
Residuals	24	45.64	1.902		

APPENDIX-B14

ANOVA on Plant Height at 30 DAP

Source of variation	DF	SS	MS	F-calculated	PROB
Season	1	23.56	23.562	9.471	0.005158**
Treatment	3	69.02	23.008	9.248	0.000302***
Season x Replication	8	27.12	3.390	1.363	0.262154
Season x Treatment	3	0.31	0.103	0.042	0.988420
Residuals	24	59.71	2.488		

APPENDIX-B15

ANOVA on Yield

Source of variation	DF	SS	MS	F-calculated	PROB
Season	1	333.3	333.3	142.050	1.44e-11 ***
Treatment	3	143.5	47.8	20.382	8.72e-07 ***
Season x Replication	8	114.5	14.3	6.097	0.000254***
Season x Treatment	3	10.4	3.5	1.480	0.245105
Residuals	24	56.3	2.3		

APPENDIX-C

ANOVA of metering system

APPENDIX-C1
ANOVA on singles for grade –I category (2-3 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	6320.155899	44.196894	79.0425	
Treatment	47	6266.477166	133.329301	238.4485	0.000 **
Error	96	53.678733	0.559153	1.0000	
Cup size (C)	3	3674.078208	1224.692736	2190.2622	0.000 **
Speed (S)	3	881.716874	293.905625	525.6260	0.000 **
Angle of inclination (A)	2	355.232743	177.616372	317.6523	0.000 **
C×S	9	347.617462	38.624162	69.0761	0.000 **
S×A	6	421.889374	70.314896	125.7524	0.000 **
C×A	6	55.767307	9.294551	16.6225	0.000 **
C×S×A	96	53.678733	0.559153	1.0000	
C.V.= 1.62 %	SED=0.176	CD(0.05)= 0.349		CD(0.01)=0.463	

APPENDIX-C2
ANOVA on doubles for grade –I category (2-3 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	92.761264	0.648680	50.9629	
Treatment	47	91.539331	1.947645	153.0149	0.000 **
Error	96	1.221933	0.012728	1.0000	
Cup size (C)	3	16.577369	5.525790	434.1283	0.000 **
Speed (S)	3	12.665058	4.221686	331.6726	0.000 **
Angle of inclination (A)	2	26.68572	13.340286	1048.0666	
C×S	9	8.025503	0.891723	70.0573	0.000 **
S×A	6	4.634100	0.772350	60.6789	0.000 **
C×A	6	9.661089	1.610181	126.5023	
C×S×A	18	13.295639	0.738647	58.0310	
C.V.= 2.60 %	SED=0.0265	CD(0.05)= 0.0527		CD(0.01)= 0.0698	

APPENDIX-C3
ANOVA on multiples for grade –I category (2-3 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	123.642344	0.864632	28.3731	
Treatment	47	120.716877	2.568444	84.2842	0.000 **
Error	96	2.925467	0.030474	1.0000	
Cup size (C)	3	20.448441	6.816147	223.6738	0.000 **
Speed (S)	3	22.068097	7.356032	241.3902	0.000 **
Angle of inclination (A)	2	32.362079	16.18104	530.9853	0.000 **
C×S	9	21.614451	2.401606	78.8094	0.000 **
S×A	6	1.168993	0.194832	6.3935	0.000 **
C×A	6	5.376299	0.896050	29.4041	0.000 **
C×S×A	18	17.678518	0.982140	32.2292	0.000 **
C.V.= 4.63 %	SED=0.4114	CD(0.05)= 0.08167		CD(0.01) = 0.10813	

APPENDIX-C4

ANOVA on missings for grade –I category (2-3 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	351.488033	2.457958	68.6900	
Treatment	47	348.052833	7.405379	206.9505	0.000 **
Error	96	3.435200	0.035783	1.0000	
Cup size (C)	3	75.456285	25.152095	702.8997	0.000 **
Speed (S)	3	150.264535	50.088178	1399.7628	0.000 **
Angle of inclination (A)	2	50.805039	25.402519	709.8981	0.000 **
C×S	9	19.516367	2.168485	60.6004	0.000 **
S×A	6	8.775650	1.462608	40.8740	0.000 **
C×A	6	15.685700	2.614283	73.0587	0.000 **
C×S×A	18	27.549256	1.530514	42.7717	0.000 **
C.V.= 5.31 %	SED=0.04459	CD(0.05)= 0.08850		CD(0.01) =0.11718	

APPENDIX-C5

ANOVA on bulb damage for grade –I category (2-3 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	4964.608263	34.717540	0.9734	
Treatment	47	1540.797167	32.782918	0.9192	0.619 NS
Error	96	3423.811096	35.664699	1.0000	
Cup size (C)	3	94.842282	31.614094	0.8864	0.451 NS
Speed (S)	3	131.508159	43.836053	1.2291	0.303 NS
Angle of inclination (A)	2	52.590744	26.295372	0.7373	0.481 NS
C×S	9	410.971206	45.663467	1.2804	0.258 NS
S×A	6	166.767751	27.794625	0.7793	0.588 NS
C×A	6	182.401728	30.400288	0.8524	0.533 NS
C×S×A	18	501.715297	28.873072	0.7815	0.717 NS
C.V.= 312.11%					

APPENDIX-C6

ANOVA on singles for grade –II category (3-4 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	6733.485244	47.087309	91.9498	
Treatment	47	6684.323844	142.21965	277.7197	0.000 **
Error	96	49.161400	0.512098	1.0000	
Cup size (C)	3	4464.038535	1488.0128	2905.7194	0.000 **
Speed (S)	3	661.627708	220.542569	430.6648	0.000 **
Angle of inclination (A)	2	44.341267	22.170633	43.2937	0.000 **
C×S	9	416.398934	46.266548	90.3471	0.000 **
S×A	6	262.507494	43.751249	85.4353	0.000 **
C×A	6	247.266067	41.211011	80.4749	0.000 **
C×S×A	18	588.143839	32.674658	63.8055	0.000 **
C.V.= 1.57 %	SED=0.16867		CD(0.05)= 0.33484	CD(0.01)=0.44328	

APPENDIX-C7

ANOVA on doubles for grade –II category (3-4 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	102.391264	0.716023	32.8587	
Treatment	47	100.299331	2.134028	97.9318	0.000 **
Error	96	2.091933	0.021791	1.0000	
Cup size (C)	3	19.230081	6.410027	294.1597	0.000 **
Speed (S)	3	17.227314	5.742438	263.5237	0.000 **
Angle of inclination (A)	2	33.292476	16.646238	763.9053	0.000 **
C×S	9	10.372269	1.152474	52.8877	0.000 **
S×A	6	2.643490	0.440582	20.2185	0.000 **
C×A	6	11.344007	1.890668	86.7638	0.000 **
C×S×A	18	6.189693	0.343872	15.7805	0.000 **
C.V.= 3.50 %	SED=0.03479		CD(0.05)= 0.06907	CD(0.01)=0.09144	

APPENDIX-C8

ANOVA on multiples for grade –II category (3-4 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	117.752042	0.823441	18.5960	
Treatment	47	113.501117	2.414917	54.5369	0.000 **
Error	96	4.250925	0.044280	1.0000	
Cup size (C)	3	22.037951	7.345984	165.8967	0.000 **
Speed (S)	3	22.214041	7.404680	167.2223	0.000 **
Angle of inclination (A)	2	37.685832	18.842916	425.5356	0.000 **
C×S	9	15.456450	1.717383	38.7842	0.000 **
S×A	6	3.149069	0.524845	11.8527	0.000 **
C×A	6	7.458257	1.243043	28.0720	0.000 **
C×S×A	18	5.499518	0.305529	6.8999	0.000 **
Total	96	4.250925	0.044280	1.0000	
C.V.= 5.75 %	SED=0.04960		CD(0.05)= 0.09845	CD(0.01)= 0.130.5	

APPENDIX-C9

ANOVA on missings for grade –II category (3-4 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	392.986444	2.748157	123.8683	
Treatment	47	390.856577	8.316097	374.8335	0.000 **
Error	96	2.129867	0.022186	1.0000	
Cup size (C)	3	107.138885	35.712962	1609.6990	0.000 **
Speed (S)	3	151.686847	50.562282	2279.0061	0.000 **
Angle of inclination (A)	2	65.354637	32.677319	1472.8728	0.000 **
C×S	9	20.007645	2.223072	100.2011	0.000 **
S×A	6	7.133668	1.188945	53.5896	0.000 **
C×A	6	23.660229	3.943372	177.7405	0.000 **
C×S×A	18	15.874665	0.881926	39.7513	0.000 **
C.V.= 3.83 %	SED=0.03511		CD(0.05)= 0.06969	CD(0.01)= 0.09227	

APPENDIX-C10

ANOVA on bulb damage for grade –II category (3-4 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	32.214183	0.225274	3.6867	
Treatment	47	26.348116	0.560598	9.1744	0.000 **
Error	96	5.866067	0.061105	1.0000	
Cup size (C)	3	11.399308	3.799769	62.1844	0.000 **
Speed (S)	3	8.132147	2.710716	44.3617	0.000 **
Angle of inclination (A)	2	3.218001	1.609001	26.3318	0.000 **
C×S	9	2.296062	0.255118	4.1751	0.000 **
S×A	6	0.339776	0.056629	0.9268	0.479 NS
C×A	6	0.489782	0.081630	1.3359	0.249 NS
C×S×A	18	0.473040	0.026280	0.4301	0.978 NS

C.V.= 16.11 % SED=0.05826 CD(0.05)= 0.11565 CD(0.01)=0.15312

APPENDIX-C11

ANOVA on singles for grade –III category (4-5 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	7519.680966	52.585182	100.3892	
Treatment	47	7469.394899	158.923296	303.3969	0.000 **
Error	96	50.286067	0.523813	1.0000	
Cup size (C)	3	4189.328608	1396.442869	2665.9177	0.000 **
Speed (S)	3	1101.569341	367.189780	700.9938	0.000 **
Angle of inclination (A)	2	109.972156	54.986078	104.9727	0.000 **
C×S	9	490.640128	54.515570	104.0744	0.000 **
S×A	6	542.448178	90.408030	172.5959	0.000 **
C×A	6	56.835411	9.472569	18.0839	0.000 **
C×S×A	18	978.601078	54.366727	103.7903	0.000**

C.V.= 1.58 % SED=0.17059 CD(0.05)= 0.33862 CD(0.01)= 0.44832

APPENDIX-C12

ANOVA on doubles for grade –III category (4-5 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	102.350556	0.715738	54.1116	
Treatment	47	101.080756	2.150654	162.5948	0.000 **
Error	96	1.269800	0.013227	1.0000	
Cup size (C)	3	20.402200	6.800733	514.1521	0.000 **
Speed (S)	3	20.653350	6.884450	520.4813	0.000 **
Angle of inclination (A)	2	27.138310	13.569155	1025.8614	0.000 **
C×S	9	13.278672	1.475408	111.5445	0.000 **
S×A	6	3.080562	0.513427	38.8163	0.000 **
C×A	6	7.862246	1.310374	99.0675	0.000 **
C×S×A	18	8.665415	0.481412	36.3959	0.000 **

C.V.= 2.78 % SED=0.02711 CD(0.05)= 0.05381 CD(0.01)= 0.07124

APPENDIX-C13

ANOVA on multiples for grade –III category (4-5 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	113.056056	0.790602	22.8994	
Treatment	47	109.741656	2.334929	67.6301	0.000 **
Error	96	3.314400	0.034525	1.0000	
Cup size (C)	3	21.519506	7.173169	207.7674	0.000 **
Speed (S)	3	22.426067	7.475356	216.5201	0.000 **
Angle of inclination (A)	2	29.471493	14.735747	426.8138	0.000 **
C×S	9	13.115639	1.457293	42.2098	0.000 **
S×A	6	2.516279	0.419380	12.1471	0.000 **
C×A	6	4.656807	0.776134	22.4804	0.000 **
C×S×A	18	16.035865	0.890881	25.8040	0.000 **

C.V.= 5.19 % SED=0.04380 CD(0.05)= 0.08693 CD(0.01)= 0.1151

APPENDIX-C14

ANOVA on missings for grade –III category (4-5 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	392.362194	2.743792	98.1630	
Treatment	47	389.678860	8.291040	296.6235	0.000 **
Error	96	2.683333	0.027951	1.0000	
Cup size (C)	3	82.587191	27.529064	984.8907	0.000 **
Speed (S)	3	184.317930	61.439310	2198.0772	0.000 **
Angle of inclination (A)	2	47.396404	23.698202	847.8363	0.000 **
C×S	9	35.408873	3.934319	140.7558	0.000 **
S×A	6	5.389551	0.898259	32.1365	0.000 **
C×A	6	13.032390	2.172065	77.7087	0.000 **
C×S×A	18	21.546521	1.197029	42.8254	0.000 **

C.V.= 4.20 % SED=0.03941 CD(0.05)= 0.07822 CD(0.01)= 0.10356

APPENDIX-C15

ANOVA on bulb damage for grade –III category (4-5 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	27.281800	0.190782	3.5384	
Treatment	47	22.105733	0.470335	8.7233	0.000 **
Error	96	5.176067	0.053917	1.0000	
Cup size (C)	3	8.917933	2.972644	55.1333	0.000 **
Speed (S)	3	7.225806	2.408602	44.6721	0.000 **
Angle of inclination (A)	2	2.390787	1.195394	22.1709	0.000 **
C×S	9	2.199950	0.244439	4.5336	0.000 **
S×A	6	0.236140	0.039357	0.7299	0.627 NS
C×A	6	0.587213	0.097869	1.8152	0.104 NS
C×S×A	18	0.547904	0.030439	0.5646	0.916 NS

C.V.= 13.95 % SED=0.05473 CD(0.05)= 0.10864 CD(0.01)= 0.14383

APPENDIX-C16

ANOVA on singles for grade –IV category (5-6 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	8139.849694	56.922026	102.7400	
Treatment	47	8086.661894	172.056636	310.5494	0.000 **
Error	96	53.187800	0.554040	1.0000	
Cup size (C)	3	4475.939674	1491.97989	2692.9121	0.000 **
Speed (S)	3	1162.466008	387.488669	699.3881	0.000 **
Angle of inclination (A)	2	163.539538	81.769769	147.5883	0.000 **
C×S	9	399.603301	44.400367	80.1393	0.000 **
S×A	6	344.115040	57.352507	103.5170	0.000 **
C×A	6	636.632807	106.105468	191.5124	0.000 **
C×S×A	18	904.365526	50.242529	90.6840	0.000 **

C.V.= 1.64 %   SED=0.17544   CD(0.05)= 0.34825   CD(0.01)= 0.46107

APPENDIX-C17

ANOVA on doubles for grade –IV category (5-6 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	104.88124	0.733435	39.4866	
Treatment	47	103.09811	2.193577	118.0974	0.000 **
Error	96	1.783133	0.018574	1.0000	
Cup size (C)	3	26.973858	8.991286	484.0712	0.000 **
Speed (S)	3	19.625719	6.541906	352.2019	0.000 **
Angle of inclination (A)	2	24.733662	12.366831	665.8032	0.000 **
C×S	9	12.786867	1.420763	76.4908	0.000 **
S×A	6	2.921821	0.486970	26.2174	0.000 **
C×A	6	8.162365	1.360394	73.2407	0.000 **
C×S×A	18	7.893818	0.438545	23.6103	0.000 **

C.V.= 3.40 %   SED=0.03212   CD(0.05)= 0.06376   CD(0.01)= 0.08442

APPENDIX-C18

ANOVA on multiples for grade –IV category (5-6 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	136.500950	0.954552	13.7708	
Treatment	47	129.846498	2.762691	39.8558	0.000 **
Error	96	6.654452	0.069317	1.0000	
Cup size (C)	3	40.816071	13.605357	196.2767	0.000 **
Speed (S)	3	21.558148	7.186049	103.6690	0.000 **
Angle of inclination (A)	2	27.208732	13.604366	196.2624	0.000 **
C×S	9	10.509049	1.167672	16.8453	0.000 **
S×A	6	2.011341	0.335224	4.8361	0.000 **
C×A	6	7.578495	1.263083	18.2218	0.000 **
C×S×A	18	20.164662	1.120259	16.1613	0.000 **

C.V.= 7.74 %   SED=0.06206   CD(0.05)= 0.12318   CD(0.01)= 0.16309

APPENDIX-C19

ANOVA on missings for grade –IV category (5-6 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	412.342175	2.883512	125.5293	
Treatment	47	410.136975	8.726319	379.8869	0.000 **
Error	96	2.205200	0.022971	1.0000	
Cup size (C)	3	127.031225	42.343742	1843.3699	0.000 **
Speed (S)	3	149.866636	49.955545	2174.7381	0.000 **
Angle of inclination (A)	2	53.680662	26.840331	1168.4527	0.000 **
C×S	9	20.000247	2.222250	96.7422	0.000 **
S×A	6	3.286210	0.547702	23.8434	0.000 **
C×A	6	31.673721	5.278953	229.8111	0.000 **
C×S×A	18	24.598274	1.36657	59.4916	0.000 **

C.V.= 3.53 % SED=0.03572 CD(0.05)= 0.07091 CD(0.01)= 0.09388

APPENDIX-C20

ANOVA on bulb damage for grade –IV category (5-6 g weight) of onion bulbs

Source of variation	DF	SS	MS	F-calculated	PROB
Total	143	25.040700	0.175110	3.8150	
Treatment	47	20.634233	0.439026	9.5647	0.000 **
Error	96	4.406467	0.045901	1.0000	
Cup size (C)	3	8.592306	2.864102	62.3978	0.000 **
Speed (S)	3	6.131150	2.043717	4 4.5247	0.000 **
Angle of inclination (A)	2	2.501204	1.250602	27.2458	0.000 **
C×S	9	2.010622	0.223402	4.8671	0.000 **
S×A	6	0.187813	0.031302	0.6820	0.665 NS
C×A	6	0.566024	0.094337	2.0552	0.066 NS
C×S×A	18	0.645115	0.035840	0.7808	0.717 NS

C.V.= 12.02 % SED=0.05050 CD(0.05)= 0.10024 CD(0.01)= 0.13271

APPENDIX-D

APPENDIX-D1

Cup type 1 C1 **Size of onion-2-3 g**

(Grade I)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	42.25	31.65	24.11	2.00	0.66
	1	53.71	22.26	20.96	3.06	1
	1.5	43.36	24.57	19.58	12.48	1.33
	2	39.92	22.32	23.61	14.15	4
75 degree	75	48.96	27.34	20.51	3.19	1
	75	57.53	21.01	17.80	3.66	1.33
	75	44.27	23.36	17.62	14.75	3.33
	75	45.88	20.68	11.48	21.96	5.33
90 degree	0.5	53.33	23.90	18.88	3.88	1.33
	1	58.80	19.43	14.82	6.94	3.33
	1.5	46.89	16.17	11.20	25.73	5.33
	2	39.60	13.95	7.57	38.88	6.66

APPENDIX-D2

Cup type 2 C2 **Size of onion-2-3 g**

(Grade I)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	43.73	25.42	22.71	8.14	0.33
	1	46.00	28.58	21.26	4.16	1
	1.5	46.35	21.89	18.61	13.14	1.33
	2	45.92	19.63	21.10	13.34	1.33
75 degree	0.5	47.37	22.13	18.94	11.57	0.66
	1	47.13	26.44	17.62	8.80	1.33
	1.5	50.57	18.39	14.94	16.09	1
	2	49.81	18.67	14.00	17.51	2
90 degree	0.5	51.05	18.63	15.51	14.81	1
	1	52.53	16.18	14.03	17.26	2
	1.5	48.09	13.93	11.84	26.14	1.33
	2	45.42	11.26	7.04	36.27	2.33

APPENDIX-D3

Cup type 3 C3 **Size of onion-2-3 g**

(Grade I)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	33.91	31.79	29.23	5.07	0
	1	42.87	28.14	20.72	8.27	0
	1.5	48.93	27.75	13.62	9.70	0.33
	2	31.69	4.90	2.26	61.15	0.66
75 degree	0.5	30.90	30.90	35.66	2.55	0
	1	52.31	22.40	10.37	14.93	0.33
	1.5	51.87	21.01	7.47	19.65	0.66
	2	52.00	24.85	6.61	16.55	1
90 degree	0.5	60.28	16.16	9.16	14.40	0.33
	1	63.25	7.17	2.68	26.90	0.66
	1.5	38.35	5.41	2.48	53.75	0.66
	2	36.42	9.58	4.78	49.22	1.33

APPENDIX-D4

Cup type 4 C4 **Size of onion-2-3 g**

(Grade I)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	65.09	18.18	14.91	1.82	0.66
	1	69.72	15.49	13.03	1.76	0.66
	1.5	63.18	15.17	16.24	5.41	2
	2	55.28	16.55	15.85	12.32	2
75 degree	0.5	68.62	16.06	13.14	2.19	1.33
	1	75.85	12.07	9.06	3.02	1.33
	1.5	65.83	13.23	12.12	8.82	2.66
	2	57.15	15.00	13.93	13.92	2.66
90 degree	0.5	72.39	13.06	11.57	2.98	1.66
	1	79.09	10.08	7.36	3.48	2
	1.5	68.15	11.85	9.63	10.38	3.33
	2	58.95	13.68	10.87	16.50	3.66

APPENDIX-D5

Cup type 1 C1 **Size of onion-3-4 g**

(Grade II)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	43.08	30.88	23.40	2.65	1
	1	53.81	21.52	20.63	4.04	1.33
	1.5	43.59	23.95	19.22	13.24	2
	2	39.81	22.10	23.36	14.73	4.33
75 degree	0.5	47.85	27.44	20.88	3.84	1.33
	1	57.09	20.93	17.31	4.67	1.66
	1.5	42.85	22.46	15.51	19.18	3.66
	2	44.86	20.56	10.28	24.30	5.66
90 degree	0.5	52.88	23.87	18.73	4.53	1.66
	1	59.74	18.92	13.09	8.25	3.66
	1.5	45.34	15.67	11.02	27.97	5.66
	2	39.61	13.20	5.20	42.00	7

APPENDIX-D6

Cup type 2 C2 **Size of onion-3-4 g**

(Grade II)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	43.15	24.31	22.26	10.27	1
	1	45.34	27.70	21.58	5.38	1.33
	1.5	46.10	20.83	18.21	14.87	1.66
	2	47.32	18.08	19.61	14.99	1.66
75 degree	0.5	47.12	21.22	19.07	12.59	1
	1	47.26	26.38	16.77	9.60	1.66
	1.5	49.62	17.32	14.61	18.46	1.33
	2	49.81	18.17	12.64	19.38	2.33
90 degree	0.5	50.88	18.25	15.08	15.78	1.33
	1	51.83	16.06	13.14	18.98	2.33
	1.5	48.40	13.17	11.03	27.40	2
	2	46.01	9.78	6.50	37.71	3.33

APPENDIX-D7

Cup type 3 C3 **Size of onion-3-4 g**

(Grade II)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	37.24	29.06	25.57	8.12	0.33
	1	55.98	22.64	12.33	9.05	0.33
	1.5	47.11	23.80	10.74	18.35	0.66
	2	37.06	18.04	9.70	35.20	1
75 degree	0.5	37.69	26.08	30.43	5.79	0.33
	1	45.24	30.17	14.68	9.92	0.66
	1.5	53.29	13.55	6.00	27.16	1
	2	38.23	12.72	5.65	43.40	1.33
90 degree	0.5	55.62	19.43	8.30	16.65	0.33
	1	28.80	6.83	2.72	61.65	1
	1.5	31.98	2.21	2.94	62.87	1.33
	2	32.93	3.63	1.98	61.46	1.66

APPENDIX-D8

Cup type 4 C4 **Size of onion-3-4 g**

(Grade II)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	65.80	17.30	14.65	2.26	1.66
	1	69.26	15.20	12.71	2.83	1
	1.5	64.45	14.59	13.84	7.12	2.66
	2	55.28	16.00	15.27	13.46	2.66
75 degree	0.5	68.66	16.04	12.68	2.61	1.66
	1	75.67	11.79	8.36	4.18	1.66
	1.5	64.93	13.06	11.57	10.45	3
	2	57.62	13.38	12.26	16.74	3.33
90 degree	0.5	72.31	12.68	11.15	3.85	2
	1	79.85	9.48	6.72	3.95	2.33
	1.5	67.92	10.18	9.06	12.84	3.66
	2	59.71	12.59	10.07	17.64	4.33

APPENDIX-D9

Cup type 1 C1 **Size of onion-4-5 g**

(Grade III)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	43.44	30.23	23.08	3.25	1.33
	1	53.65	21.35	19.98	5.02	1.66
	1.5	43.69	23.57	18.33	14.41	2.33
	2	39.47	21.49	22.80	16.24	4.66
75 degree	0.5	47.76	26.41	20.80	5.03	1.66
	1	56.71	20.49	17.13	5.68	2
	1.5	44.08	22.03	13.12	20.76	4
	2	45.79	16.92	10.44	26.85	6
90 degree	0.5	52.32	23.84	18.03	5.82	2
	1	60.22	18.42	12.43	8.93	4
	1.5	45.28	15.51	10.34	28.88	6
	2	38.85	12.55	4.86	43.74	7.33

APPENDIX-D10

Cup type 2 C2 **Size of onion-4-5 g**

(Grade III)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	43.66	23.59	20.78	11.97	1.33
	1	45.06	27.47	21.61	5.86	1.66
	1.5	46.24	20.30	18.04	15.42	2
	2	47.29	17.83	18.22	16.67	2
75 degree	0.5	46.69	20.95	18.75	13.61	1.33
	1	46.88	26.04	16.32	10.76	2
	1.5	49.80	17.40	13.04	19.76	1.66
	2	48.84	17.85	12.28	21.03	2.66
90 degree	0.5	51.26	17.07	14.23	17.44	1.66
	1	51.67	15.98	12.64	19.71	2.33
	1.5	48.57	12.95	10.43	28.06	2.33
	2	45.59	9.19	6.25	38.97	3.66

APPENDIX-D11

Cup type 3 C3 **Size of onion-4-5 g**

(Grade III)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	32.90	27.01	37.97	2.12	0.66
	1	61.41	22.36	6.50	9.74	0.66
	1.5	48.26	18.61	5.99	27.13	1
	2	28.23	12.08	6.03	53.65	2
75 degree	0.5	52.06	25.62	18.59	3.72	1
	1	39.58	22.13	14.04	24.25	1
	1.5	43.10	30.55	11.09	15.26	1.33
	2	45.93	6.70	5.76	41.62	1.66
90 degree	0.5	64.95	14.40	6.25	14.40	1
	1	52.19	14.47	7.22	26.12	1.33
	1.5	20.99	2.46	2.46	74.08	1.66
	2	32.66	2.86	2.37	62.46	2

APPENDIX-D12

Cup type 4 C4 **Size of onion-4-5 g**

(Grade III)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	66.03	16.99	14.29	2.70	2
	1	70.20	14.17	12.37	3.26	1.66
	1.5	64.99	13.62	12.83	8.56	3.33
	2	55.26	14.28	13.54	16.92	3.33
75 degree	0.5	68.45	15.96	12.53	3.05	2
	1	75.97	11.24	8.14	4.64	2
	1.5	65.03	12.78	10.53	11.65	3.33
	2	58.18	12.17	11.79	17.86	3.66
90 degree	0.5	71.60	12.45	10.90	5.06	2.33
	1	80.25	8.87	6.46	4.43	2.66
	1.5	68.20	9.58	8.43	13.79	4
	2	59.28	12.00	9.81	18.91	4.66

APPENDIX-D13

Cup type 1 C1 **Size of onion-5-6 g**

(Grade IV)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	43.65	29.33	22.43	4.59	1.66
	1	53.50	21.39	19.54	5.57	2
	1.5	42.69	24.43	17.32	15.56	2.66
	2	38.67	20.92	22.74	17.67	5
75 degree	0.5	47.64	25.89	20.58	5.89	2
	1	56.59	20.01	17.07	6.34	2.33
	1.5	43.81	21.67	11.94	22.59	4.33
	2	45.08	16.06	9.85	29.02	6.33
90 degree	0.5	52.68	23.08	17.74	6.50	2.33
	1	59.70	18.35	11.73	10.22	4.33
	1.5	45.18	14.91	9.21	30.70	6.66
	2	38.43	11.57	4.13	45.87	7.66

APPENDIX-D14

Cup type 2 C2 **Size of onion-5-6 g**

(Grade IV)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	43.46	23.32	20.15	13.08	1.66
	1	45.00	27.53	21.18	6.29	2
	1.5	45.67	19.63	17.73	16.97	2.33
	2	47.23	16.29	18.23	18.25	2.33
75 degree	0.5	47.34	20.23	17.94	14.50	2
	1	47.34	25.80	15.19	11.67	2.33
	1.5	49.80	17.14	12.75	20.31	2
	2	48.81	17.34	12.06	21.79	2.66
90 degree	0.5	50.90	16.24	14.09	18.77	2
	1	52.07	15.85	11.70	20.38	3
	1.5	47.99	12.45	9.89	29.67	2.66
	2	45.90	8.94	5.22	39.95	4.33

APPENDIX-D15

Cup type 3 C3 **Size of onion-5-6 g**

(Grade IV)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	44.86	25.22	22.42	7.50	1
	1	56.15	20.72	8.51	14.62	1
	1.5	50.22	11.31	3.17	35.30	1.33
	2	18.93	7.49	1.77	71.80	2.33
75 degree	0.5	40.00	26.99	24.02	8.99	1.33
	1	61.46	11.06	9.76	17.72	1.33
	1.5	50.23	19.63	6.85	23.29	1.66
	2	49.54	16.05	4.11	30.30	2
90 degree	0.5	50.00	18.56	1.91	29.53	1.33
	1	30.92	2.67	2.27	64.15	1.66
	1.5	20.98	2.46	3.70	72.85	2
	2	29.60	4.92	3.54	61.95	2.33

APPENDIX-D16

Cup type 4 C4 **Size of onion-5-6 g**

(Grade IV)

Angle	Speed (km/h)	Singles (%)	Doubles (%)	Multiples (%)	Missings (%)	Bulb damage (%)
60 degree	0.5	66.68	16.46	13.72	3.13	2.33
	1	70.00	13.33	11.85	4.81	2
	1.5	65.25	12.25	11.85	10.66	3.66
	2	54.59	13.36	13.35	18.70	3.66
75 degree	0.5	68.47	15.38	12.31	3.84	2.33
	1	75.89	10.67	7.90	5.54	2.66
	1.5	63.89	12.55	9.88	13.68	3.66
	2	57.19	11.75	10.61	20.45	4.33
90 degree	0.5	71.09	12.46	10.83	5.62	3.33
	1	81.03	8.67	5.36	4.94	3.33
	1.5	66.80	9.39	8.19	15.62	4.33
	2	58.81	11.99	9.36	19.85	5.33

APPENDIX- E

Specification and cost of developed tractor operated raised bed onion bulb planter

No	Description	Size	Quantity	Rate	Amount (Rs.)
1	75 × 40 × 5mm MS C-Channel	6.5 m	46.319 kg	Rs. 45/kg	2084.36
2	50 × 50 × 5 mm MS angle	2.6 m	9.88 kg	Rs. 45/kg	444.60
3	40 × 40×5 mm MS square	2 m	7.32 kg	Rs. 58/kg	424.56
4	25 × 25× 5 mm MS square	3.36 m	7.056 kg	Rs.62/kg	437.47
5	25 ×25 ×3 mm MS angle	10.1 m	11.11 kg	Rs. 45/kg	499.95
6	40 × 40 × 5 mm MS angle	6.1 m	18.3 kg	Rs. 45/kg	823.50
7	8' ×4 '1 mm of M.S Sheet	1.825 square meter	14.32 kg	Rs. 56/kg	802.27
8	50 ×25 ×5 mm MS Rectangle	1 m	5 kg	Rs. 56/kg	280.00
9	100 ×20 mm MS flat	1.4 m	21.98 kg	Rs. 45/kg	989.00
10	25 mm Φ MS round bar	4 m	15.41 kg	Rs. 70/kg	1078.70
11	Screws	6 mm	192 no	Rs. 1.8/pc	345.00
12	Pulley	3 inch	2 no	Rs. 300/pc	600.00
13	Belt	42-B	1 no	Rs.220/pc	220.00
14	Sprockets	8 tooth	10 no	Rs.115/pc	1150.00
15	½ th Industrial chain with k-2 type	6 m		Rs.600/m	3600.00
16	Cups		48 nos	Rs.15/pc	720.00
17	Ridger		2 nos	Rs.5000/pc	10000.00
18	3-Point linkage		1 pc	Rs.5000/pc	5000.00
19	Pillow bearing	25 mm	6 pc	Rs.250/pc	1500.00
20	U-Clamps		4 nos	Rs.20/pc	80.00
21	Paint orange, green, blue and red		4 lit	Rs.300/lit	1200.00
22	Nylon braided hose pipe 2 " dia with 5 mm thickness		3 m	Rs.300/m	900.00
23	Miscellaneous (Nuts, bolts and washers		6 kg	Rs.120/kg	720
24	Welding rods		5 packets	Rs.200/packet	1000
25	Chain (Seed covering purpose)	6 mm	2 m	Rs.150/m	300
	Cost of machine				35199
26	Cost of fabrication	40 percent of cost of above materials)			14079
	Total cost of the machine				49278.00
		Grand Total			49300

APPENDIX – F

Cost economics of a tractor operated raised bed onion bulb planter

Estimating the cost of operation of tractor operated raised bed onion bulb planter

The initial cost of tractor operated raised bed onion bulb planter has been calculated by adding up the cost of individual components involved in the fabrication at the prevalent market price. The cost of onion bulb planter is divided under the two heads as fixed cost and variable cost.

Initial cost of machine

The initial cost of onion bulb planter was calculated on the basis of total materials used in fabrication and the cost of fabrication.

Cost of onion bulb planter/Capital cost = 49,300/-

Economic analysis

Following assumptions was made for economic analysis of bulb planter

1. Cost of tractor = 700,000/-
2. Expected life of tractor = 10 years
3. Annual use of tractor = 10000 h/year
4. Excepted life of bulb planter = 10 years
5. Annual use of bulb planter can be calculated as follows
6. Working hour (H) = 300 h/year, when working hour is 8 h/day
7. Salvage value (S) = 10 per cent of initial cost
8. Rate of interest = 12 per cent per annum
9. Labour required = 2
10. Fuel cost = 75/l
11. Fuel consumption = 3.17 l/h
12. Repair and maintenance = 2 per cent of initial cost
13. Shelter, insurance and tax cost = 2 per cent of initial cost

a) Fixed cost of tractor

1. Depreciation (D)

It is the cost of value of machine with passage of time

$$D = \frac{C-S}{LH} = \frac{700,000-70000}{10\times1000} = \text{Rs.}63.00/\text{ h}$$

Where,

D = Depreciation per cost,

C = Capital investment

S = Salvage value, 10 per cent of initial cost

H = Number of working hour per year

L = Life of machine in year

2. Interest

$$I = \frac{700,000+70000}{2} \times \frac{0.12}{1000} = \text{Rs. }46.2/\text{h}$$

3. Shelter, insurance and tax cost

2 per cent of initial cost

= Rs.14000/year

= Rs. 14.00/h

Total fixed cost = Rs.63.00 +Rs. 46.2 + Rs.14.00)/h =Rs. 123.2/h

b) Fixed cost for tractor operated raied bed onion bulb planter

4. Depreciation (D)

It is the cost of value of machine with passage of time

$$D = \frac{C-S}{LH} = \frac{49300-4930}{10\times300} = \text{Rs.}14.79/\text{ h}$$

Where,

D = Depreciation per cost,

C = Capital investment

S = Salvage value, 10 per cent of initial cost

H = Number of working hour per year

L = Life of machine in year

5. Interest

$$I = \frac{49300+4930}{2} \times \frac{0.12}{300} = \text{Rs. }10.84/\text{h}$$

6. **Shelter, insurance and tax cost**

2 per cent of initial cost

= Rs.986/year

= Rs. 3.2/h

Total fixed cost = Rs.14.79 +Rs. 10.84 + Rs.3.2)/h = Rs. 28.83/h

c) Variable cost of tractor operated raised bed onion bulb planter

7. **Fuel cost/h**

Fuel cost @ Rs.75/l

Fuel consumption was 3.17 l/h

Fuel cost = Rs.237.7/h

8. **Repair and maintenance @ 2 per cent of initial cost**

= Rs. 986/year

= Rs. 3.2 /h

9. **Labour charge = Rs. 900/ day = Rs.112.5 /h**

Total variable cost = (Rs. 237.7+Rs. 3.2 +Rs. 112.5)/h

= Rs.353.40/h

Total cost of onion bulb planter = Fixed cost of tractor (a) + fixed cost of bulb planter (b) + variable cost of bulb planter (c)

= (Rs. 123.20 + Rs.28.83+ Rs.353.40)/h = Rs. 505.43/ h

Average effective field capacity of onion bulb planter = 0.12 ha/h

Cost of operation of onion bulb planter = Rs. 505.43/0.12

= Rs. 4211.91/ ha

Comparison of manual planting with machine

1. Number of labours required per planting of onion bulbs in one ha = 50
2. Labour charges per person per day = 200
3. Cost per planning in one hectare with manual = 50×200 = 10,000/-
4. Cost per planting in one hectare with machine = Rs.4211.91/-
5. Saving of cost with machine = ($\frac{(10,000-4211.91)}{10,000} \times 100$ = 57.88 % = 58 %

RESUME

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