A SENSOR BASED TRACTOR DRAWN GINGER PLANTER

By

T. MAHESH BABU

(2020-28-001)

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY

TAVANUR - 679573

KERALA, INDIA

2024

A SENSOR BASED TRACTOR DRAWN GINGER PLANTER

by

T. MAHESH BABU
(2020-28-001)

THESIS
Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

AGRICULTURAL ENGINEERING
(Farm Machinery and Power Engineering)

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY
TAVANUR - 679573
KERALA, INDIA
2024

DEDICATION

This thesis is dedicated with profound gratitude and admiration to my Grandparents ***Sri. T. Devadanam*** *and* ***Smt. T. Narasamma*** *as well as* ***My Parents*** *whose unwavering love and support have been the cornerstone of my journey. To my major advisor* ***Dr. Preman P. S.*** *for his unwavering support and guidance have been instrumental in my growth, and I am deeply grateful for your mentorship.* ***To my teachers****, whose wisdom and guidance have illuminated my path, inspiring me to strive for excellence.* ***To my friends****, whose camaraderie and encouragement have been a constant source of strength and joy.* ***To my colleagues****, whose collaboration and shared passion have enriched this endeavor. Each of you has played an invaluable role in shaping this achievement and for that, I am deeply thankful.*

DECLARATION

I, hereby declare that this thesis entitles **“A Sensor Based Tractor Drawn Ginger Planter”** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Place: Tavanur **T. MAHESH BABU**
Date: **(2020-28-001)**

CERTIFICATE

Certified that this thesis entitled **“A Sensor Based Tractor Drawn Ginger Planter”** is a record of research work done independently by **Er. T. MAHESH BABU (2020-28-001)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Place: Tavanur
Date:

Dr. Preman P. S.
(Chairman, Advisory Committee)

Associate Professor (FPME),
Agricultural Research Station,
Kerala Agricultural University,
Mannuthy.

CERTIFICATE

We, the undersigned members of the advisory committee of **Er. T. MAHESH BABU (2020-28-001)** a candidate for the degree of Doctor of Philosophy in Agricultural Engineering with major in Farm Machinery and Power Engineering, agree that the thesis entitled **“A SENSOR BASED TRACTOR DRAWN GINGER PLANTER”** may be submitted by **Er. T. MAHESH BABU,** in partial fulfilment of the requirement for the degree.

Dr. Preman P. S.
(Major Advisor, Advisory Committee)
Associate Professor (FPME),
Agricultural Research Station,
Kerala Agricultural University,
Mannuthy.

Dr. Jayan P. R.
(Member, Advisory Committee)
Professor & Head (FMPE),
Dean of Faculty (Agrl. Engg.)
KCAEFT,
Kerala Agricultural University,
Tavanur.

Dr. Sureshkumar P. K.
(Member, Advisory Committee)
Professor (FPME)
Dept of Agricultural Engineering,
College of Agriculture,
Kerala Agriculture University,
Vellanikkara.

Dr. Jalaja S. Menon
(Member, Advisory Committee)
Assistant Professor and Head
Cashew Research station,
Kerala Agricultural University,
Madakkathra.

20/9/24

Sri. Gopi C.
(Member, Advisory Committee)
Assistant Professor
Dept. of Electronics and
Communication Engineering,
Government Engineering
College, Mananthavady, Wayanad.

Prakash
20/09/2024

Dr. Prakash K.V.
Professor and Head,
Department of Renewable Energy
Engineering,
College of Agricultural Engineering,
UAS Raichur.

EXTERNAL EXAMINER

ACKNOWLEDGEMENT

Reflecting on the journey of diligent effort brings immense joy. Looking back, it's truly gratifying to remember the individuals who supported me along the way – teachers, friends, and loved ones. It feels essential to express my heartfelt gratitude for the overwhelming assistance I received throughout this endeavor.

I express my sincerest appreciation to my esteemed advisor, ***Dr. Preman P. S, Associate Professor (FPME), Agricultural Research Station, Kerala Agricultural University, Mannuthy.*** *His unwavering inspiration, timely assistance, invaluable guidance, and moral support were pivotal throughout my study period. I am deeply grateful for his genuine mentorship, impeccable advice, continuous encouragement, and genuine interest in my research. His friendly demeanor, constructive criticism, and affectionate approach have been instrumental in the successful culmination of my research endeavors.*

I wish to convey my deepest gratitude to ***Dr. Jayan P.R. Professor and Head (FMPE), Dean of Kelappaji College of Agricultural Engineering and Food Technology, Kerala Agricultural University, Tavanur****, for his consistent interest and generous advice provided to me during every phase of my academic pursuit.*

I would like to take this opportunity to express my sincere gratitude to my advisory committee members: ***Dr. Jayan P.R.,*** *Professor and Head & Dean of the Department of Farm Machinery and Power Engineering at Kelappaji College of Agricultural Engineering and Food Technology, Tavanur*, ***Dr. Suresh Kumar P.K.,*** *Professor in the Department of Agricultural Engineering at College of Agriculture, Kerala Agricultural University, Vellanikkara*, ***Dr. Jalaja S. Menon****, Assistant Professor and Head of Cashew Research Station, Kerala Agricultural University, Madakkathra; and* ***Sri. Gopi C.,*** *Assistant Professor in the Department of Electronics and Communication Engineering at Government Engineering College, Mananthavady, Wayanad. Their invaluable counsel, remarkable guidance, and cordial cooperation greatly contributed to the success of my research program.*

I wish to extend my sincere appreciation to ***Dr. Manoj Mathew****, Retired Professor (FPME) at Rice Research Station, Moncompu, Alappuzha, for his unwavering interest and generous guidance provided to me throughout my academic journey.*

I phase my special thanks to ***Dr. Dhalin D, Professor, Er. Sindhu Bhasker****, Assistant Professor and* ***Er. Sanchu Sukumaran,*** *Assistant Professor, Department of Farm Machinery and Power Engineering KCAEFT, Tavanur for their grateful suggestions and research support.*

I would like to express my deepest thanks to ***Dr. Sathiyan KK,*** *Professor Department of Soil and Water Conservation Engineering, KCAEFT, Tavanur for facilities in his department.*

I extend my sincere thanks towards ***Er. Vipin, Dr. Deepak S Khatawkar, Dr, Edwin Benjamin, Dr. Rajesh, and Er. Shamin M K*** *(Assistant Professors (Contract basis), Department of FMPE, KCAEFT, Tavanur for their immense help and deemed support to complete the research successfully.*

I would like to place my special thanks to Workshop Technicians ***Dhanish, Shobith, Likesh, David, Vipin, prejith, Lenin, Krishob, Rahul, Athul, Sarath, and Vishnu*** *for their help and support during my study.*

I would like to place my special thanks to my friends, ***Dr. N.L Kalyan Chakravarthi, Dr. Venkat Reddy, Dr. J Srinivas, Er. Amit kumar, Er. K Venkata Sai, Dr. Chandhra shekar, Er. Athira Prasad, Er. K Vamshi, Er. A Ajay, Dr. Raju Er, S. Sai Mohan, Er, Alankar, and Er. Chethan*** *for their sincere help and support during my laboratory and field Testing. I would like to thank* ***Dr. G Gopi, Er. Sambasiva Rao, Er. Siddharam, Er. Abhishek, Er. Sharanbasava, Er, Rajesh, Er. Arvind and Er. Harish*** *for their invaluable help during study.*

I Express my thanks to all the Faculty Members of KCAEFT, Tavanur, for their ever-willing help and cooperation. I express my sincere thanks and gratitude to Kelappaji College of Agricultural Engineering and Food Technology for giving me an opportunity to undergo my Ph. D. studies and Keral Agricultural University for having offered me a chance to study in this institution.

Above all, I bow to the lotus feet of Lord Shiva and Jesus Almighty for the grace and blessings bestowed on me.

T. Mahesh Babu

CONTENTS

Chapter No.	Title	Page No.
	LIST OF TABLES	i-ii
	LIST OF FIGURES	iii-iv
	LIST OF PLATES	v
	SYMBOLS AND ABBREVIATIONS	vi-viii
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	5
III	MATERIALS AND METHODS	41
IV	RESULTS AND DISCUSSION	107
V	SUMMARY AND CONCLUSION	156
	REFERENCES	163
	APPENDICES	175-229
	ABSTRACT	230-231

List of Tables

Table No.	Title	Page No.
3.1	Ginger planting parameters	48
3.2	Specifications of laboratory set up	61
3.3	Arduino Nano pin configurations	64
3.4	Experimental design of rhizome planter testing for forward speeds and speed of chain	100
4.1	Determination of Soil consistency limits	108
4.2	Properties of soil parameters at the time of sowing	110
4.3	Linear dimensions	111
4.4	Moisture content	112
4.5	Sphericity	113
4.6	Bulk density	114
4.7	True density	115
4.8	Angle of repose	116
4.9	Coefficient of friction	116
4.10	Analysis of variance on hill-to-hill distance for ginger	120
4.11	Analysis of variance on missing index for ginger	123
4.12	Analysis of variance on multiple index for ginger rhizome	126
4.13	Analysis of variance of quality of feed index for ginger rhizome	129
4.14	Analysis of variance on Cell fill efficiency	132
4.15	Calibration results for a sensor-based tractor drawn ginger planter	133
4.16	Specifications of the sensor based ginger planter	135
4.17	Effect of forward speed and speed of chain on ginger planting performance of rhizome planter	141
4.18	Analysis of variance on hill-to-hill distance for ginger	143
4.19	Analysis of variance on missing index for ginger	145
4.20	Analysis of variance on multiple index for ginger	147

4.21	Analysis of variance on quality of feed index for ginger	149
4.22	Analysis of variance on cell fill efficiency for ginger	151
4.23	Depth of rhizome placement for ginger	154

List of Figures

Fig. No	TITLE	Page No.
3.1	Cross sectional view of rhizome hopper	55
3.2	Schematic view of the different cell sizes	58
3.3	Schematic view of the laboratory set up for the sensor-based tractor drawn ginger planter	60
3.4	DC Geared motor	62
3.5	Arduino Nano	64
3.6	Cytron 30 Amp DC Motor Driver	65
3.7	Cytron 30 Amp DC Motor Driver Board layout	65
3.8	LCD display	68
3.9	Rotary Encoder	70
3.10	Amaron 12 V DC Battery	70
3.11	Schematic diagram of electronic circuit for a sensor-based tractor drawn ginger planter	72
3.12	Cross sectional view of rhizome hopper	82
3.13	Schematic view of a sensor-based tractor drawn ginger planter	86
3.14	Side view of a sensor-based tractor drawn ginger planter	87
3.15	Orthographic views of sensor-based tractor drawn ginger planter	88
3.16	Detailed views of sensor-based tractor drawn ginger planter	88
3.17	Schematic view of the main hopper, seed metering, seed delivery tube, seed collector, frame, tool box and chain with cups	89
3.18	Isometric view of the main hopper, seed metering, seed delivery tube, seed collector, frame, tool box, chain with cups and tool box	89
3.19	Orthographic views of the rhizome hopper supporting frame	90
3.20	Orthographic views of the rhizome hopper	91
3.21	Orthographic view of rhizome collecting device	92
3.22	Seed deliver hopper	93
3.23	Ground wheel	94
3.24	Schematic view of power transmission system	97

3.25	Orthographic view of ridger bottom	98
3.26	Orthographic view of shoe type furrow opener	99
4.1	Effect of belt linear speed and speed of chain on hill-to-hill distance for different cell sizes (a) 40 mm, (b) 50 mm, (c) 60 mm	120
4.2	Effect of belt linear speed and speed of chain on missing index for different cell sizes (a) 40 mm, (b) 50 mm, (c) 60 mm	122
4.3	Effect of belt linear speed and speed of chain on multiple index for different size of cells (a) 40 mm, (b) 50 mm and (c) 60 mm	125
4.4	Effect of belt linear speed and speed of chain on quality of feed index for different size of cells (a) 40 mm, (b) 50 mm, and (c) 60 mm.	128
4.5	Effect of belt linear speed and speed of chain on cell fill efficiency with different cell sizes (a) 40 mm, (b) 50 mm, (c) 60 mm.	131
4.6	Effect of planter forward speed and speed of chain on hill-to-hill distance of ginger	142
4.7	Effect of planter forward speed and speed of chain on missing index with 50 mm cell size	144
4.8	Effect of forward speed and speed of chain on multiple index with 50 mm cell size	146
4.9	Effect of forward speed and speed of chain on quality of feed index with 50 mm cell size	148
4.10	Effect of forward and speed of chain on cell fill efficiency with 50 mm cell size	150
4.11	Optimum setting of forward speed and speed of chain for minimum missing index, multiple index, cell fill efficiency, plant to plant distance and maximum quality of feed index for ginger.	153

LIST OF PLATES

Plate No.	Title	Page No.
3.1	Determination of liquid limit of soil	43
3.2	Determination of plastic limit soil	44
3.3	Determination of shrinkage limit of soil	45
3.4	View of the ginger rhizomes with one or two buds	50
3.5	Views of the ginger varieties selected for measuring physical properties	50
3.6	Measurements of Length (l), Breadth (b) and Thickness (t) of ginger rhizomes	51
3.7	Measurements of coefficient of friction of ginger rhizomes	55
3.8	Developed cell size	58
3.9	Developed laboratory set up for the sensor-based tractor drawn ginger planter	77
3.10	Top view of the sensor based ginger hopper	90
3.11	Isometric view of the developed rhizome collecting device	93
3.12	Measurement of hill-to-hill distance	101
3.13	Row to row spacing measurement	101
3.14	Developed sensor-based tractor drawn ginger planter	103
3.15	Working of a developed sensor-based tractor drawn ginger planter	103
3.16	Draft measurement in field	104
4.1	Plant population	107
4.2	View of the crop stand on 30 Days after planting	155
4.3	View of the crop stand on 60 Dyas after planting	155

LIST OF APPENICES

Appendices No.	Title	Page No.
I	Arduino Nano IDE program for a sensor-based tractor drawn ginger planter under Laboratory Conditions	175
II	Distribution of seeds on the row at selected levels of forward speed (S) Speed of chain (V) and cell sizes (C) under laboratory condition	198
III	Arduino Nano IDE program for a sensor-based tractor drawn ginger planter under Field evaluation	202
IV	Physical properties of Athira variety of ginger	210
V	Physical properties of Aswathy variety of ginger	211
VI	Physical properties of Chithra variety of ginger	212
VII	Physical properties of Karthika variety of ginger	213
VIII	Calibration test for the developed sensor based ginger planter	214
IX	Determination of moisture content	215
X	Determination of bulk density	216
XI	Determination of Soil resistance	217
XII	Field testing of cup feed type metering device for ginger	218
XIII	Field capacity and field efficiency	219
XIV	Estimated cost of the machine	221
XV	Cost of operation for tractor operated sensor based ginger planter	223
XVI	Observation table under field evaluation	229

SYMBOLS AND ABBREVIATIONS

Symbols		**Abbreviations**
<	:	Less than
>	:	Greater than
%	:	Per cent
±	:	Plus or minus
×	:	Multiplication
÷	:	Division
≤	:	Less than or equal to
≥	:	Greater than or equal to
°	:	Degree
°C	:	Degree centigrade
ANOVA	:	Analysis of variance
ASAE	:	American Society of Agricultural Engineers
cm	:	Centimeter
cm^2	:	Square centimeter
cm^3	:	Cubic centimeter
CV	:	Coefficient of Variation
DAP	:	Days After Planting
db	:	dry basis
et al.	:	and others
etc.	:	et cetera
Fig.	:	Figure
g	:	Gram
$g\ cm^{-3}$	:	Gram per cubic centimeter
ha	:	Hectare
$ha\ h^{-1}$	:	Hectare per hour
hp	:	Horse power
hr	:	Hou

hr ha^{-1} : Hour per hectare

Hz : Hertz

i.e. : that is

I_{fq} : Quality of feed index

I_{miss} : Missing index

I_{mult} : Multiple index

I_{p} : Precision index

IS : Indian standards

KAU : Kerala Agricultural University

KCAEFT : Kelappaji College of Agricultural Engineering and Food Technology

kg : Kilogram

kg cm : Kilogram centimeter

kg cm^{-2} : Kilogram per square

centimeter kg ha^{-1}: Kilogram per hectare

kg m : Kilogram meter

kg m^{-3} : Kilogram per cubic meter

kg mm^{2} : Kilogram per square

millimeter kgf : Kilogram force

km h^{-1} : Kilometer per hour

l hr^{-1} : Liter per hour

m : Meter

m min^{-1} : Meter per minute

m s^{-1} : meters per second

m^{2} : Square meter

m^{3} : Cubic meter

mm : Millimeter

mm^{2} : Square millimeter

MS : Mild Steel

MT : Million/tonnes

GP : Galvanised Plain

N : Newton

N cm^{-2} : Newton per square centimeter

N m^{-1} : Newton per meter

GI : Galvanised Iron

pH : Potential of Hydrogen

PVC : Poly Vinyl Chloride

Q : Quintal

RNAM : Regional Network of Agricultural Machinery

rpm : revolution per minute

Rs : Rupees

Rs ha^{-1} : Rupees per hectare

Rs h^{-1} : Rupees per hour

SD : Standard Deviation

SI. No : Serial Number

t : Tons

viz. : Namely

wb : Wet basis

α : Alpha

θ : Theta

μ : mue

π : Pi

ρ : Rho

σ : Sigma

CHAPTER I

INTRODUCTION

Ginger (*Zingiber officinale*) is a tropical monocotyledon and herbaceous perennial plant in the Zingiberaceae family. It is the oldest rhizome regularly grown as a spice and well known for its particular sharp and fiery flavour, which is attributed to an oily substance known as gingerol. Ginger is a medicinal plant that is used in food and chemical industries as well as in Indian ayurvedic medicine to promote purification of the body through perspiration, to soothe sickness and to increase hunger.

Ginger holds significant importance as a cash crop and primary spice in both India and International markets (Bartley and Jacobs 2000). The perennial plant grows to a height ranging from 600 to 900 mm from underground rhizomes in tropical and subtropical climates (Mendi *et al.*, 2009). Ginger cultivation is adaptable to both rain-fed and irrigated conditions. Successful growth of this root crop requires moderate rainfall during the sowing period until the rhizomes sprout, followed by sufficiently heavy and evenly distributed showers throughout the growing period and a dry spell of approximately a month before harvesting. Ginger flourishes in well-drained soils such as sandy loam, clay loam or lateritic loam. Ginger is one of the spices that support a significant number of farmers in the states of Kerala, Karnataka, Arunachal Pradesh, Orissa, West Bengal, Sikkim and Madhya Pradesh (Karthick *et al.*, 2015), and together contribute 65.00 per cent of the country’s total production. Ginger reaches full maturity within 210-240 days after planting. Harvesting for vegetable purposes typically commences after 180 days, based on demand. In the process of producing dry ginger, matured rhizomes are harvested at full maturity, indicated by the yellowing and drying of the leaves. Usually, in India the crop is harvested between January and March months.

Most of the spice are native to our Indian conditions hence, India is known as the land of spice crops and also the largest producer, consumer and exporter of spices crops. India alone contributes around 43.87 per cent to the world production of ginger. There is an increase from 160.14 thousand ha area and 1118.16 thousand tonnes production in 2017-18 to 187.73 thousand ha area and 2304.25 thousand tonnes production in 2022-23. The productivity has increased from 19.74 million tonnes in 2017-18 to 20.98 million tonnes in 2022-23. The primary states for ginger cultivation are Kerala, Karnataka, Sikkim, Meghalaya, Himachal Pradesh, West Bengal, Assam and other Northeastern states. In Kerala, it is cultivated in area of 2.82 thousand ha with production of 59.4 million tonnes in 2022-23 (Indiastat, 2023).

Ginger is a perennial plant, commonly cultivated as an annual crop for harvesting as a spice. Ginger thrives best in climates that are warm and humid. It is cultivated from almost sea level to an altitude of 1500 m above mean sea level either under heavy rainfall conditions (150-300 cm year^{-1}) or under irrigation. Ginger thrives in sandy or clayey loam, red loam or laterite loam soils with excellent drainage and humus content. Propagated vegetatively through rhizomes, the size of the planting material varies depending on location and variety. Ginger planting is manually done by digging the soil and placing the rhizomes into it then covered with soil by using hands. The bits are made from rhizomes having 3-5 cm in length 15-20 g weight (15 g is optimum) and at least one or two buds. A seed rate of about 1500-2000 kg ha^{-1} is considered to be optimum for planting. The recommended spacing for planting ginger is 25-45 cm between rows and 15-20 cm between individual plants (KAU, 2016).

Spice crops provide significant opportunities to increase farmers income, even in arid regions. The current study focuses on ginger, as these crops demonstrate higher unit productivity and offer substantial opportunities for value addition. Higher productivity can be timely farm operations with appropriate farm machines. Nowadays, the labour availability in rural areas is low due to labour migration. Hence, to increase the productivity of ginger cultivation and mechanize the farm operations, development of suitable machines is essential (Kandiannan *et al*., 2008).

In the recent years, no machinery has been developed in sensor-based technology for planting ginger rhizomes, which are close spacing crops that require approximately 200 – 250 man h ha^{-1} which increase cultivation cost (Mathanker and Mathew, 2002). Also, the rhizome planting coincides with field operations of other crops at the onset of monsoon rains in Kharif season. Delays in planting due to labour shortages and rains adversely affect yield and production of ginger. Currently, farmers in the state had encountered difficulties in ginger planting due to a shortage of labour.

The ginger is planted in beds or ridges. Traditionally, the rhizomes are sown manually by walk behind plough which is time consuming, less efficient and drudgery. Mechanical rhizome planters have some of the drawbacks as seed metering mechanism picks up multiple seeds than desired, leading to higher seed rate, poor picking, missing affects efficiency of planter, very larger hill to hill distance is difficult to achieve, thinning to achieve desired plant population requires considerable labour and wastage of inputs. Among different sowing techniques, precision sowing is the preferred method, since it provides accurate spacing of single seeds in the row with proper planting depth and creating a uniform germination environment for each seed (Karayel *et al.,* 2004). To overcome the above cited difficulties, it is proposed to develop a sensor-based tractor drawn ginger planter.

A sensor-based tractor drawn ginger planter offers several advantages compared to traditional planting and basic mechanical planters. Here are some of the key benefits:

Precision planting: Sensor technology allows for precise and consistent planting depth and spacing, resulting in uniform crop growth. This can lead to better crop yields and more efficient land use.

Time and labour savings: Mechanized planting with sensor reduces the need for manual labour, making the process faster and more efficient. It allows farmers to cover larger areas in less time, optimizing their work schedule and potentially reducing overall labour costs.

Reduced seed wastage: The sensor-based planter ensures that each seed is planted at the desired depth and with appropriate spacing. This reduces seed wastage and optimizes seed usage, saving costs for the farmer.

Improved crop health: By providing accurate placement of seeds and avoiding overcrowding, the planter helps to reduce competition among plants for nutrients and sunlight. This, in turn, promotes healthier and more robust crop growth.

Data collection and analysis: Many modern sensor-based planters are equipped with data logging capabilities. They can collect valuable information during the planting process, such as planting density, soil conditions and weather data. Farmers can analyse this data to make informed decisions for future planting cycles and crop management.

Adjustable settings: The sensor-based planter often allows farmers to adjust planting parameters, such as seed spacing and planting depth, based on the specific requirements of the crop and soil conditions. This flexibility enhances adaptability to varying field conditions and crop types.

Reduced operator fatigue: Automating the planting process with sensor technology reduces the physical strain on the operator, leading to less fatigue and better overall comfort during extended planting sessions.

Improved overall efficiency: Combining sensors with a tractor drawn ginger planter streamlines the entire planting process. It eliminates the need for manual operations like bending and squatting, enabling farmers to plant more ginger with higher accuracy and less time.

Environmental benefits: Precision planting reduces the need for excessive use of seeds, fertilizers and water there by promoting sustainable agricultural practices and minimizing environmental impacts.

Long-term cost savings: Though initial investment costs may be higher for sensor-based planters, the improved efficiency, reduced labour expenses and potential for higher yields can lead to significant cost savings over the long term.

Under these circumstances, a project entitled "**A Sensor Based Tractor Drawn Ginger Planter**" has been undertaken at Kelappaji College of Agricultural Engineering and Food Technology (KCAEFT), Tavanur, Kerala with the following objectives:

1. To study the physical and engineering properties of the ginger rhizomes and soil
2. To develop a laboratory set up for the sensor based tractor drawn ginger planter
3. To develop a sensor based tractor drawn ginger planter
4. To evaluate the performance of the sensor based tractor drawn ginger planter in the field.

CHAPTER II

REVIEW OF LITERATURE

This chapter provides a comprehensive review of research conducted on various aspects of ginger cultivation, including its physical and engineering properties. It also explores the development of planters for crops such as onion, garlic, potato and peanut, examines different types of seed metering mechanisms used in various planters and discusses planter design and operational parameters that affect planter performance. When seeds are manually planted without the aid of suitable machinery, it becomes challenging to meet objectives, ultimately leading to suboptimal seeding and increased cultivation costs. Precision crop planting plays a crucial role in achieving the desired plant population and recommended planting patterns. This precision can be attained by ensuring that seeds are sown at the appropriate rate and spacing. Optimizing the design of a precision planter requires a comprehensive consideration of various design parameters, encompassing aspects related to the crop, soil conditions and machine itself. This optimization process involves thorough a review of prior research endeavours pertaining to precision planting, exploration of the electronic planter concept and an assessment of how factors such as crop types, machinery specifications and operational parameters impact the design of these planters. The following subheadings delineate the key areas of focus.

- Cultivation methods of ginger
- Engineering properties of rhizomes
- Development of various planters
- Furrow openers for planters
- Ridger type furrow opener
- Design factors affecting the planter performance
- Electronic seed metering mechanism for precision planting
- Performance evaluation of different types of planters

2.1 CULTIVATION METHODS OF GINGER

Monnaf *et al*. (2010) conducted a field experiment to investigate the impact of planting method and rhizome size on the growth and yield of ginger. The study assessed the main effects and combined effects of three planting methods: ridge method, furrow method, and flat bed method, along with five rhizome sizes ranging from 10-15 g to 30-35 g. In planting methods, rhizome sizes and their combined effects significantly influenced the yield and yield components of ginger. Results indicated that the ridge method produced the highest yield (18.78 t ha^{-1}), followed by the furrow method (14.56 t ha^{-1}) and the flat bed method (11.06 t ha^{-1}). Moreover, the largest rhizome size (30-35 g) yielded the highest (19.64 t ha^{-1}), while the smallest size (10-15 g) yielded the lowest (11.30 t ha^{-1}). The most favourable yield (22.78 t ha^{-1}) was achieved with the ridge method combined with 30-35 g rhizome size, whereas the lowest yield (8.34 t ha^{-1}) was obtained from the flat bed method combined with 10-15 g rhizome size.

Mahender *et al.* (2013) carried out an experiment to investigate the effect of seed rhizome size and plant spacing impact the growth, yield and quality of ginger. Three different seed rhizome sizes were used, namely 20 g, 30 g and 40 g in combination with five distinct plant spacing configurations: 25×15 cm, 25×25 cm, 30×20 cm, 30×30 cm and 40×20 cm. Their findings revealed that the 40 g seed rhizomes exhibited the shortest time to initial rhizome sprouting with just 12.73 days, closely followed by the 30 g rhizomes. Likewise, the 40 g seed rhizomes resulted in the highest plant height at harvest (67.87 cm), the greatest number of tillers per plant (11.51), the highest leaf area index (3.59), the most substantial yield (27.41 t ha^{-1}), the highest essential oil content (1.83 per cent) and greatest starch content (30.27 per cent). Concerning plant spacing, the closest configuration of 25 cm × 15 cm led to the tallest plants (35.07 cm), the highest leaf area index (5.25) and a yield of 26.40 t ha^{-1}. Remarkably, the most satisfactory rhizome yield of 38.06 t ha^{-1} was achieved when combining the 40 g seed rhizomes with the 25 cm ×15 cm plant spacing.

2.2 PHYSICAL PROPERTIES OF GINGER RHIZOMES

2.2.1 Physical properties

The significance of physical properties cannot be understated when it comes to designing specific equipment or assessing the performance of a product in various machinery and handling processes, as highlighted by Sahay and Singh (1994). This review focuses on the physical characteristics of ginger, including moisture content, size, shape and bulk density, as documented by various researchers.

2.2.1.1 Size

Size and shape are intertwined physical attributes, typically both essential for effectively characterizing the form of any solid object. Irregularly shaped objects like seeds, grains, fruits, and vegetables demand a comprehensive description of their structure, theoretically necessitating an infinite number of measurements along orthogonal axes. Size is primarily pertaining to an object's quality that defines its spatial occupation within set boundaries. Numerous researchers have successfully characterized the size of various biological materials by measuring them in three primary, mutually perpendicular dimensions: length, width and thickness.

Mathanker and Mathew (2002) conducted the study to analyze the design attributes of seed rhizomes with the aim of determining the essential parameters for designing precise metering devices. Their findings indicated that the typical dimensions of seed rhizomes were as follows: an average length of 72.35 mm, an average width of 49.28 mm, an average thickness of 19.23 mm and an angle of repose ranging between 38 to 41.5°. Furthermore, they noted that the average weight of manually prepared rhizomes was 26.75 g.

Jayashree (2009) studied that measurements for the dimensions of ginger rhizomes, which exhibit a shape resembling that of turmeric. Specifically, at a moisture content of 81.70 per cent (wb), the average size of fresh ginger rhizomes was determined to be 14.99 cm in length, 8.17 cm in width and 4.49 cm in thickness.

Mishra and Kulkarni (2009) determined several engineering properties of turmeric, focusing on the Sangli variety. Specifically, they measured the average length, width and thickness of turmeric at 12.4 per cent moisture content (db) to be 42.77 mm, 10.85 mm, and 9.51 mm, respectively**.**

Balami *et al*. (2012) conducted a study to determine the engineering properties of sweet potatoes with a moisture content of 81.20 per cent (w.b). The maximum major, intermediate, and minor diameters were recorded as 70.92 mm, 63.01 mm, and 44.73 mm, respectively. Sphericity and aspect ratio fell within ranges of 0.68 to 0.72 and 0.48 to 0.56, with mean values of 0.68 and 0.58, respectively. Particle density varied from 1.03 g cm^{-3} to 1.09 g cm^{-3}, with a mean of 1.3 g cm^{-3}. The compressive loads at break for five sweet potato samples were observed in both horizontal and vertical positions. In the horizontal position, the loads were 7.07 kN, 4.58 kN, 3.93 kN, 4.23 kN, and 4.71 kN, while in the vertical position, they were 3.32 kN, 5.62 kN, 3.22 kN, 5.07 kN, and 2.89 kN.

Balasubramanian *et al.* (2012) observed the physical properties of turmeric (Curcuma longa) rhizomes which were categorized into three grades based on their major dimensions. Grade I encompassed rhizomes with dimensions ranging from 25-35 mm, Grade II from 35-45 mm, and Grade III from 45-55 mm. The average geometric properties included lengths ranging from 30.38 to 50.60 mm, breadths from 9.77 to 10.64 mm, thicknesses from 5.18 to 6.44 mm, arithmetic mean diameters from 15.82 to 21.91 mm, geometric mean diameters from 12.77 to 13.76 mm, square mean diameters from 24.24 to 28.58 mm, equivalent diameters from 17.61 to 21.41 mm, sphericity from 0.27 to 0.42, aspect ratio from 0.20 to 0.35, unit volume from 1641 to 29.1 mm^3, surface area from 771 to 1265 mm^2, and shape factor from 1.63 to 1.77 for Grades I, II and III respectively.

Simonyan *et al.* (2013) reported on physical properties of two varieties of ginger rhizomes, Umudike ginger I (UG I) and Umudike ginger II (UG II), which were investigated at moisture contents of 73.64 per cent and 77.13 per cent (wb) respectively. The properties examined included geometric mean diameter, arithmetic mean diameter, U-square mean diameter, equivalent mean diameter, mass, volume, sphericity, aspect ratio, and particle density. The findings revealed that both varieties shared similar widths and thicknesses statistically but exhibited differences in length. Variety I had a sphericity of 0.43±0.07, while Variety II had a sphericity of 0.50±0.08. The aspect ratios for Variety I and II were 0.46 and 0.58, respectively. The mass of Variety I ranged from 21.86 to 9654 g, while Variety II varied from 12.92 to 54.04 g. The diameter of Variety I varied by 22.59 per cent compared to Variety II. These parameters provided valuable insights for designing processing machines with adjustable components.

Ajav and Ogunlade (2014) investigated the physical properties of ginger rhizomes yielded several key findings. The study reported average values for major, minor, and intermediate diameters as well as the geometric mean, sphericity, bulk volume, and surface area. These measurements were found to be 112 mm, 38.3 mm, 72.3 mm, 67.6 mm, 0.61, 832.5 cm^3 and 147 cm^2, respectively.

Subhashini *et al.* (2015) investigated the physical properties of turmeric rhizomes across various moisture contents, including 8 per cent, 12 per cent, and 16 per cent. They provided findings indicating that at 12 per cent moisture content, the bulk density and true density of turmeric rhizome were 647.5 kg m^{-3} and 1303.3 kg m^{-3}, respectively. Furthermore, they determined the porosity of turmeric rhizomes to be 67.3 per cent.

Dhinesh Kumar and Anand Kumar (2016) determined the physical and engineering properties of three grades of turmeric rhizome, divided as I : 30- 40 mm, II 40-50 mm and III: 50-60 mm according to its major dimensions. Geometric properties viz., length, breadth, thickness, arithmetic mean diameter geometric mean diameter, square mean diameter, equivalent diameter, sphericity aspect ratio, unit volume, surface area and shape factor were found out in the range of 30.18-48.54 mm, 9.72-10.62 mm, 5.12-6.38 mm, 14.72-22.84 mm, 12.72-14.64 mm, 23.21-26.54 mm, 17.54-21.32 mm, 0.24-0.38, 0.18-0.32, 1591-2904 mm^3, 772-1268 mm^2 and 1.61-1.74 for grade I, II and III respectively.

Wasiya *et al.* (2017) analysed the physical properties of PTS 10 turmeric variety with a sample of 30 rhizomes. The average values of their geometric properties viz., length (90.73±12.12 mm), breadth (22.03±2.25 mm), thickness (20.64±2.2 mm), geometric mean diameter (34.45±2.96 mm), arithmetic mean diameter (44.46±4.49 mm), square mean diameter (44.46±4.49 mm), equivalent diameter (48.18±4.41 mm), aspect ratio (0.25±0.04), unit volume (12413.53±3185.09 mm^2), surface area (3451.72±585.87 mm^3) sphericity (0.38±0.04), shape factor (0.97±0.03) were reported.

Bhawna *et al.* (2018) determined the physical properties of fresh mahima variety of ginger rhizomes. The range of moisture content of fresh rhizomes was 76.18-78.84 per cent. The average length, width and thickness of fresh ginger rhizome were 109.94 mm, 71.71 mm and 25.24 mm respectively. The mean values of geometric mean and sphericity of fresh rhizomes were 57.97 mm and 0.53 mm respectively. The average mass, volume and surface area of fresh rhizomes were 81.55 g, 77.75 cm^3 and 174.99 cm^2 respectively.

2.2.1.2 Bulk density

Bulk density refers to the mass per unit bulk volume of a substance under specific conditions, including temperature, moisture content, etc.

Athmaselvi and Varadharaju (2002) investigated the correlation between moisture content and bulk density for various turmeric varieties. They found that the bulk density of BSR-1 ranged from 779 to 809 kg m^{-3}, while for BSR-2, it ranged from 693 to 853 kg m^{-3}, and for Erode local, it ranged from 753 to 801 kg m^{-3}. These measurements were taken within a moisture range of 40 per cent to 70 per cent (wb). Study concluded that bulk density increased with an increase in moisture content.

Jayashree (2009) study was determined the average bulk density of ginger rhizomes. Specifically, at a moisture content of 81.70 per cent (wb), the average bulk density of fresh ginger rhizomes was calculated to be 471.49 kg m^{-3}.

Mishra and Kulkarni (2009) investigated the bulk density of turmeric rhizomes, specifically the Sangli variety. The average bulk density of fresh turmeric rhizome at a moisture content of 12.4 per cent (db) was determined to be 622.33 kg m^{-3}.

Ajav and Ogunlade (2014) determined the average bulk density of ginger rhizomes at different moisture contents. Specifically, at moisture levels of 10.9 per cent and 51.6 per cent (db). the average bulk density of fresh ginger rhizomes was recorded as 0.92 g cm^{-3}.

2.2.2 Frictional properties

Frictional properties such as the coefficient of friction and the angle of repose, play a crucial role in the design of various systems like hoppers, conveying systems and threshers, as highlighted by (Sahay and Singh 1994). These properties provide valuable insights into how a given material interacts and behaves when in motion on different surfaces.

2.2.2.1 Angle of repose

The angle of repose is defined as the angle between the base and the slope of a cone created when granular materials freely fall vertically onto a horizontal surface. Sahay and Singh (1994) pointed out that the angle of repose can be influenced by various factors, including the size, shape, moisture content and orientation of the grains.

Mishra and Kulkarni (2009) determined angle of repose of fresh turmeric rhizome using a specific method. They employed a bottomless cylinder positioned on a flat surface and filled it with turmeric rhizomes. Gradually lifting the cylinder allowed the rhizomes to flow, forming a natural cone-shaped slope. Subsequently, the diameter and height of the cone were measured to calculate the angle of repose. The determined angle of repose for fresh turmeric rhizome was found to be 33°.

Ajav and Ogunlade (2014) determined the angle of repose for fresh ginger rhizomes. Their method involved using a specially crafted box made of plywood, which had both its top and bottom open and featured a removable front panel. Through this setup, they found that the angle of repose for fresh ginger rhizome as 48°.

2.2.2.2 Coefficient of friction

The frictional coefficient of granular materials is directly related to the tangent of the angle of internal friction characteristic to the material. This coefficient is influenced by various factors, including the shape of the grains, surface properties and moisture content present within the material.

Athmaselvi and Varadharaju (2002) examined the static coefficient of friction of turmeric rhizomes from BSR-1, BSR-2, and Erode varieties in relation to moisture content across four metallic surfaces: aluminium, mild steel, galvanized iron and stainless steel. They observed that the static coefficient of friction rose as the moisture content of the rhizomes increased across all metal surfaces.

Jayashree (2009) frictional coefficients of ginger rhizomes were measured under different conditions. Specifically, when fresh ginger rhizomes had a moisture content of 81.70 per cent (wb), they exhibited frictional coefficients of 0.53, 0.57, 0.68, 0.72 and 0.74 when placed against surfaces made of plywood, stainless steel, aluminium, galvanized iron and mild steel respectively.

Mishra and Kulkarni (2009) investigated the coefficient of friction of turmeric rhizomes of Sangli variety. They determined the static coefficient of friction across four metal surfaces: mild steel (ranging from 0.51 to 0.66), galvanized iron (ranging from 0.47 to 0.64), aluminum (ranging from 0.40 to 0.56), and stainless steel (ranging from 0.37 to 0.54). The coefficient of friction increased as the moisture content of the rhizomes varied from 12.40 per cent to 21.85 per cent (db).

Ajav and Ogunlade (2014) reported on frictional coefficients of ginger rhizomes with measurements taken on three distinct structural materials. The resulting values were 0.40 when tested on glass, 0.49 when tested on stainless steel and 0.55 when tested on wood.

2.3 DEVELOPMENT OF VARIOUS PLANTERS

Sadhu (1982) designed and developed a two-row onion set planter that can be operated using a tractor. The planter incorporates a horizontal plate-type metering mechanism. The onion set hopper is a vertical cylindrical shell positioned concentrically above the metering mechanism. To facilitate the process, an outer shell is affixed around the bottom of the hopper, creating an annular space between the two cylinders. This annular space serves as a passage to direct the onion sets into the drop chute during operation. Additionally, within the annular space, two guide plates are securely fastened to the inner cylinder near the outlet openings. These guide plates effectively divert the flow of onions into the drop chutes.

Odigdoh and Akubuo (1991) developed and evaluated a two-row automatic minisett yam planter equipped with a unique two-row ridging mechanism. This specialized device is capable of creating compact 50 cm ridges with a row spacing of

90 cm. The prototype can efficiently operate at speeds of up to 7 km h^{-1} and handles the ridge formation, metering, and planting of yam minisetts within the ridges seamlessly. It ensures consistent spacing of approximately 24 cm within each row and maintains a planting depth of 4 cm.

Sahoo and Srivastava (2000) introduced a three-row ridge planter specially designed for the purpose of planting pre-soaked okra seeds on ridges. This planter features an inclined plate-type seed metering mechanism and the power is efficiently transferred from the ground wheel to the metering system through a chain and sprocket arrangement. The machine is equipped with four ridger bottoms, each incorporating a runner-type furrow opener, which is instrumental in forming the ridges. The seeds are meticulously placed within these ridges at the desired planting depth. Notably, both the size and depth of the ridges can be customized to meet specific planting requirements. The planter is compatible with a 35 hp tractor for its operation and has demonstrated a field capacity of 0.2 ha h^{-1} at an average operating speed of 2.27 km h^{-1}. The field efficiency of this planter has been calculated at an impressive 66.5 per cent.

Singh (2004) observed that potato planting in significant regions of eastern Uttar Pradesh relied heavily on manual labour. This manual approach often led to inconsistent and uneven plant distribution, demanding a substantial labour force for both field preparation and planting activities. To address the challenges of labour shortages, timeliness in operations and planting-related issues, a tractor-operated two-row potato planter ridger was subjected to rigorous testing. Based on the test outcomes, necessary adjustments and enhancements were implemented in the machine. Subsequently, this improved potato planter gained widespread acceptance and popularity among potato cultivators in eastern Uttar Pradesh.

Kazmeinkhah *et al.* (2007) designed a semi-automatic transplanter machine tailored for sugar beet seedling cultivation. This innovative machine efficiently handled seedlings with a row spacing of 65 cm, seedling spacing of 50.3 cm and a planting depth of 13 cm. The deviations from the desired positioning were notably low with a standard deviation of 4.5 per cent along the cultivation row and 3.6 per cent perpendicular to the cultivation row, ensuring precise and reliable planting.

Bakhtiari and Loghavi (2009) introduced a precision planter designed for garlic cloves on raised beds, which could be conveniently mounted on a tractor and operated with ground-wheel drive. The machine featured three rows for planting. The metering drums and sweepers were efficiently powered by two ground wheels using a chain drive system. Comprehensive performance tests were conducted, evaluating parameters such as seeding mass rate, seeding depth, seed spacing, miss index, multiple index, and seed damage. The results of these tests demonstrated the machine's capability to plant 220,000 plants per hectare, achieving a seeding depth and spacing of 12.3 cm and 22.7 cm, respectively. Moreover, the miss index, multiple index and seed damage measurements recorded were 12.23 per cent, 2.43 per cent, and 1.41 per cent respectively. This highlighted the precision and effectiveness of the newly developed planter.

Jiraporn *et al.* (2010) innovatively designed and developed a 10-row garlic planter. The metering mechanism employed buckets affixed to a rotating disc. They noted that these buckets achieved an impressive maximum scoop efficiency of 90.42 per cent, when the disc spun at 40 rpm while the tractor advanced at speed of 1.67 km h^{-1}. Notably, the seed delivery point was positioned approximately 30 cm above ground level. The planter’s furrow opener adopted a shoe-type design and was arranged in two parallel lines, maintaining a spacing of 250 mm between lines. This development aimed to optimize the planting process for garlic cultivation.

Anon (2010) developed MPUAT model a tractor-operated garlic planter, equipped with a star wheel-type mechanism for precise seed and fertilizer metering. The standout features of this 12-row unit include a two-row paired hopper and an adjustable seed rate, all designed to accommodate a minimum row spacing of 150 mm. During testing, the observed seed rate ranged between 500 to 700 kg ha^{-1}, primarily influenced by the size of the garlic cloves. The spacing between garlic cloves was adjustable, falling within the range of 50 to 100 mm. In terms of performance, the planter exhibited a field capacity of 0.35 ha h^{-1} with a field efficiency of 70 per cent. The cost of planting was estimated as Rs 1300 ha^{-1}. This development aimed to streamline and enhance the efficiency of garlic planting processes.

Kumari (2011) introduced a tractor-operated planter specifically designed for planting onion sets. This planter comprised three main components: an inclined plate seed metering unit, a seed hopper, and a furrow opener. To assess its performance, the onion set planter underwent laboratory evaluations, yielding several performance indices. Notably, these indices included a multiple index of 0.05, a miss index of 0.18, a quality of feed index of 0.77, a precision index of 0.27 and mean and standard deviation measurements of 11.71 cm and 5.22 cm respectively. Furthermore, the planter exhibited a field capacity of 0.09 ha h^{-1} when operated at a forward speed of 0.6 km h^{-1}. This development aimed to enhance the efficiency and precision of onion set planting processes.

Turbatmath *et al.* (2011) developed and evaluated a tractor operated onion transplanter. They conducted evaluations focusing on the engineering physical properties of onion seedlings at different growth stages, including height, weight, diameter, moisture content and compressive strength during the sixth, seventh and eighth weeks. Two metering mechanisms, namely finger type and plug type were selected to laboratory testing at three distinct travel speeds: 0.75 km h^{-1}, 1 km h^{-1} and 1.25 km h^{-1}, using onion seedlings of varying ages. The results indicated that the plug type metering mechanism, particularly at a speed of 0.75 km h^{-1} with seventh-week seedlings, proved to be the most suitable for transplanting. In field trials, the semi-automatic transplanter equipped with the plug type metering mechanism achieved row-to-row spacing ranging from 20.4 to 21.2 cm, hill to hill distance between 11 to 11.6 cm and a planting depth of 2.8 to 4 cm. The observed missing rate ranged from 9 per cent to 10.9 per cent. The machine exhibited a capacity of 0.1088 to 0.1174 ha h^{-1}, with field efficiency of 70.49 per cent to 71.6 per cent. The draft force required for the machine fell within the range of 450 to 469.8 kgf. Notably, the utilization of this transplanter resulted in a 40.17 per cent reduction in the cost of operation compared to manual transplanting methods. This innovation aimed to enhance the efficiency and cost-effectiveness of onion transplantation processes.

Vasuki (2012) designed and developed a tractor operated turmeric planter. This innovative planter was equipped with various essential components, including a ridger bottom, rhizome hopper, cup feed rhizome metering mechanism, main frame, shoe-type furrow opener, ground wheel and chain-sprocket power transmission drive. To evaluate the turmeric planter's performance, laboratory tests were conducted, which yielded several key performance indices. These indices included singles at 67.9 per cent, doubles at 12.55 per cent, triples at 3.52 per cent and a missing index of 15.95 per cent. Additionally, the mean and standard deviation of rhizome spacing in laboratory tests were recorded at 28.95 cm and 9.73 cm, respectively. Subsequently, the tractor-operated turmeric planter underwent field testing, operating at an optimized speed of 1.5 km h^{-1}. After 30 days post-planting (DAP), an average hill to hill distance of 22.68 cm was achieved. The planter exhibited a commendable field capacity of 0.27 ha h^{-1}. The total time required for the planting operation was 5.78 hours per ha, with a field efficiency of 64.28 per cent. Notably, the use of this developed planter led to a significant reduction in seed rate, down to 1027 kg ha^{-1}. This advancement aimed to enhance the efficiency and cost-effectiveness of turmeric planting processes.

Zamani (2014) designed and developed a fully automatic tomato transplanter. This advanced machine consisted of a primary chassis, a mechanism for transferring seedling trays to the pick-up arm position, the seedling pick-up arm mechanism, crash tube, furrower and comprehensive control system. To evaluate the transplanter's performance, field tests were conducted, considering three forward speed levels 1 km h^{-1}, 1.5 km h^{-1} and 2 km h^{-1} and two cultivation depths of 5 cm and 10 cm. The assessment focused on various performance indices, including mechanical damage, the establishment angle concerning the vertical line and the distance between planted seedlings. The findings highlighted that the forward speed and cultivation depth significantly influenced the distance between planted seedlings, seedling establishment angle and seedling damage. The optimal performance was achieved at a forward speed of 1 km h^{-1}, where these factors exhibited minimal impact, with damage levels remaining at 5 per cent. The theoretical capacity of the single-row machine was estimated at 0.06 ha h^{-1}. This technological advancement aimed to enhance the efficiency and precision of tomato transplanting processes. Both the horizontal and vertical forces also experienced an increment.

2.4 FURROW OPENERS FOR PLANTERS

Shaaf *et al.* (1981) conducted an evaluation of various types of furrow openers, viz., the shoe type, hoe type and disc type. Their findings indicated that, particularly in loamy soil, the hoe opener demonstrated a greater ease of penetration compared to the disc opener.

Dubey and Srivastava (1985) conducted an assessment of various furrow openers used in bullock-operated seed cum fertilizer drills in black soils. The evaluation was based on several factors, including the furrow opener’s ability to penetrate the soil, their resistance to clogging with seed and fertilizer, the extent of soil disruption and the required draft. Their findings indicated that the shoe-type furrow opener consistently delivered the best performance.

Collins and Fowler (1996) observed a notable rise in draft forces, ranging from 1,700 to 4,300 N, across all furrow openers when the seeding depth was extended from 1 to 5 cm. Additionally, they noted that there was an average 4 per cent increase in draft for all furrow openers for each km h^{-1} increase in speed, when seeding depth ranged from 1 to 5 cm.

Verma and Dewangan (2007) developed the mechanical aspects of designing furrow openers for seed cum fertilizer drills. Their study focused on evaluating three types of furrow openers: the shoe, shovel and inverted-T designs. To assess their potential, they compared these furrow openers based on draft requirements, soil disruption and seed emergence. Their analysis led to the conclusion that the inverted-T type furrow opener exhibited the lowest draft requirement, at 32.12 kgf. It also caused minimal soil disturbance, ranging from 4 to 5 cm, and experienced fewer instances of clogging compared to the shovel and shoe-type furrow openers. The reduced soil disruption in the inverted-T furrow opener was attributed to its narrower boot width.

Marakoglu and carman (2009) conducted a study to examine the impact of various parameters of a cultivator share on draft force and soil loosening within a controlled soil bin. The variables tested included rake angles relative to the horizontal, with values of 12.5^0, 17.5^0, and 22.5^0 degrees, as well as working depths of 70 mm, 110 mm, and 150 mm, and forward speeds of 1.08 m s^{-1}, 1.55 m s^{-1} and 2.08 m s^{-1}. The results of the study revealed that the draft force experienced a notable increase, ranging from 420 N to 2025 N. The study reveals that the most extensive distribution of forces occurred with rake angle of 22.5^0, forward speed of 2.08 m s^{-1} and a working depth of 150 mm.

Jiraporn *et al.* (2010) conducted experiments to evaluate the performance of three types of furrow openers – namely, the shoe, shovel and hoe – in the context of a tractor-operated 10-row garlic planter. Their evaluation focused on various aspects, including the depth at which garlic cloves were placed, the extent of disturbance in clove spacing, draft requirements and the degree of soil disruption during the operation. With an increase in the operating depth, there was a corresponding rise in soil disturbance and backflow. Notably, the shovel-type opener exhibited the highest germination percentage, reaching 83.3 per cent, and it required a draft force of 1.067 kgf per opener. This draft force was 27 per cent higher than that required by the hoe-type opener.

Chaudhuri (2011) conducted a performance evaluation of various furrow openers designed for seed drills. The findings revealed that an increase in the rake angle corresponded to higher draft forces and increased vertical forces acting on the furrow opener. Generally, the rake angle values that resulted in the lowest draft forces typically fell within the range of 25 to 30^0. Expanding the width of the furrow opener led to greater draft forces and reduced the amount of soil covering the seed within the furrow. Disc-type furrow openers were found to be well-suited for conventional tillage due to their lower draft requirements, minimal soil disturbance and consistent depth control. In contrast, hoe-type furrow openers placed the seed closer to the bottom of the furrow, but they caused more soil disruption, which resulted in increased moisture loss from the furrow. For zero tillage conditions, the chisel, winged chisel, inverted-T and winged furrow openers delivered the best performance. Runner-type furrow openers were primarily suitable for sowing under conventional tillage systems, particularly for shallow planting under irrigated conditions. Winged, inverted-T and hoe-type furrow openers proved to be well-suited for use with seed cum fertilizer drills.

2.5 RIDGER TYPE FURROW OPENER

According to Raghavendra *et al.*, (2013), ridge planting is an agricultural technique that either completely eliminates the need for traditional seed bed preparation or integrates it into the planting process. This method involves the simultaneous creation of ridges and furrows, typically accomplished with a semi-automatic rhizome planter pulled by a tractor. The ridges are formed by the wings of a ridger, and seeds are sown as the ridges take shape. The primary purpose of ridge formation is to facilitate weed management, enhance water infiltration and store runoff water, all aimed at conserving moisture in the soil.

Mathur and Pandey (1992) conducted a study in which they found that the lowest specific draft for lateritic sandy clay loam soil occurred when the rake angle of the furrow opener was set at 28^0.

Zhang and Araya (2001) observed a significant increase in the draft force of a mouldboard plough when the rake angle exceeded 30^0.

Abd EI Tawaab *et al*. (2007) found that certain design parameters of the furrow opener, specifically the share rake angle and wing shape and angle, have a substantial impact on the resulting shape of the ridge profile. Moreover, one of the critical factors influencing the necessary draft force is the share rake angle. To ensure effective soil penetration, the rake angle of the share should ideally be set at 25^0 or greater relative to the ground.

Marey (2015) conducted a comprehensive study to assess the influence of design parameters in ridger furrow openers and planting methods on sugar beet yield and water use rake angles (20^0, 25^0 and 30^0), opener wing angles (35^0 and 45^0) and wing shape configurations (straight and curved) on furrow characteristics, transverse scattering, draft force, and (ii) evaluating various planting methods, such as ridges with 50 cm row spacing and pairs of rows on beds with row spacings of 30 cm, 35 cm and 40 cm, while considering the wing shape and angles in terms of emergence, sugar percentage, root and sugar yield, applied water and water use efficiency. The results of the study indicated that furrows generated by the curved wing shape and a 45^0 wing angle were wider compared to those created by the straight wing shape and a 35^0 wing angle. The lowest transverse scattering occurred with the curved wing, a 35^0 wing angle and a 20^0 share rake angle. An increase in the share rake and wing angles correlated with higher required draft forces. The highest root and sugar yields were achieved with beet planting in beds with 30 cm row spacing, followed by beds with 35 cm and 40 cm row spacing. Water use efficiency was lowest when planting on ridges as opposed to other planting methods. The highest emergence percentage, root and sugar yields, sugar percentage and water use efficiency were associated with a 45^0 wing angle and the curved wing shape.

2.6 DESIGN FACTORS AFFECTING THE PLANTER PERFORMANCE

Buitenwerf *et al.* (2006) reported that the precision of planting, particularly the spacing within the seeding furrow is significantly affected by the cup-belt unit of the potato planter. It is important to note that having a more uniform shape, indicated by a lower shape factor, doesn’t necessarily guarantee improved accuracy. Surprisingly, in many cases, a potato was deposited with greater precision than a sphere (like a golf ball). This discrepancy was attributed to the specific shapes of the guiding duct and cups used in the planting process.

Jiraporn *et al.* (2010) carried out experiments aimed at determining the optimal height of the seed delivery tube above the ground for a 10-row garlic planter operated by a tractor. Their findings indicated that setting the height of the seed delivery tube at 30 cm above the ground level resulted in the least variation, measuring 25 mm from the line of motion when the planter was moving at a forward speed of 1.67 km h^{-1}.

Kocher *et al.* (2011) conducted a study to analyze corn seed spacing variation using a John Deere Max Emerge and Vacuum meter planter in a laboratory setting. The evaluation involved two seed tube conditions (new or worn) and two types of corn seed shapes (round or flat). Seed spacing uniformity was assessed using three parameters: i) Coefficient of Precision (CP), ii) multiples index, and iii) miss index. Significant differences were observed in all three seed spacing uniformity parameters based on the seed tube condition. New seed tubes consistently demonstrated superior seed spacing uniformity compared to worn seed tubes, regardless of the seed shape (round or flat). Interestingly, round corn seeds exhibited better seed spacing uniformity than flat seeds in this experiment, irrespective of the seed tube condition (new or worn).

2.6.1 Operational seed parameters

Bjerkan (1947) reported that irregular planting could be attributed to several factors, including slippage on ground wheels, excessively high planting speeds, and variations in seed size. To mitigate these issues, it was recommended to maintain an average slippage rate of 5 per cent for rubber tires and 15 per cent for steel wheels.

Chhinnan *et al.* (1975) investigated the impact of planting speed on metering and seed accuracy. Their findings indicated that increased planting speeds led to a higher incidence of skipped placements, greater seed placement errors and wider average spacing between seeds.

Hamad and Banna (1980) and Amin (1983) demonstrated that the speed of the feeding-wheel mechanism and the transmission rotor length have a beneficial impact on the sowing rate. The precision of seed spacing varies across different machines, influenced by factors such as wheel slip and whether the potatoes are permitted to roll in the furrow bottom. The machine operated at a forward speed of 3.2 km h^{-1}.

Ismail (1989) indicated that the operational speed for manually filling buckets within the metering mechanism of a planting machine is quite modest, typically falling within the range of 1.5 to 1.6 km h^{-1} (or 0.4 to 0.44 m s^{-1}). According to his findings, the time required for the process of extracting potato seeds from the hopper and depositing them into the bucket is approximately 0.75 seconds.

2.6.2 Seed hopper parameters

Kual and Egbo (1985) examined that planters should have seed boxes or hoppers with shapes that are either trapezoidal, rectangular or oval. The capacity of these boxes can vary and it’s often determined by the size of the machines. The trapezoidal shape of a seed box is particularly beneficial as it promotes the smooth and unobstructed flow of seeds.

Awadi and EI-Said (1985) developed a small planter that features a hopper constructed from iron sheeting, designed with a bottom slope of 45^0 angle.

Bosai *et al.* (1987) emphasized that the hopper’s capacity should be optimized to guarantee consistent seed feeding and continuous operation of the seed metering mechanism, regardless of the sowing unit’s direction of motion.

2.7 ELECTRONIC SEED METERING MECHANISM FOR PRECISION PLANTERS

Panning *et al.* (2000) employed an opto-electronic sensor to measure seed spacing in a laboratory setting. This sensor effectively functioned for seeds with a diameter greater than 3 mm, but it was unable to accurately measure the spacing of seeds smaller than 3 mm in diameter.

Heege and Feldhaus (2002) introduced a method that featured a compensatory program designed to address errors arising from seed clusters passing through a delivery tube. The system utilized a control computer, which received data from a light detector positioned beneath the seed delivery tube. When the number of seeds passing through the detector deviated from the pre-set seed frequency, an electronic mechanism was activated, adjusting the transmission ratio for seed metering. Furthermore, the control computer was linked to a speed sensor to adapt the seed frequency based on changes in travel speed. Their findings demonstrated that the method effectively limited discrepancies in the recorded number of seeds, even when using contemporary seed rates to less than 2.5 per cent. This method proved to be well-suited for automatic closed-loop computer control and site-specific sowing.

Raheman and Singh (2002) introduced a sensor utilizing light interference technique to monitor flow of seeds from the seed metering mechanism in seed drills and planters. The sensor consisted of an infrared emitter, a phototransistor, and a voltage divider network, IC 4033B and a seven-segment display unit, all of which were mounted on the seed delivery tube. The sensor's performance was assessed by testing various metering mechanisms commonly employed in seed drills and planters. The experimental setup included a moving grease-coated canvas belt, simulating the ground speed of a seed drill. It also offered the flexibility to adjust the operating speed. Additionally, a universal mounting frame was used to accommodate different seed metering mechanisms. The developed sensor effectively detected seed droppings for mustard and wheat seeds with a maximum error of 18 per cent. These errors primarily stemmed from the sensor's challenge in identifying multiple seeds in a short time frame. For maize seeds, the sensor demonstrated even more accurate results, with errors remaining under 10 per cent.

Minjin *et al.* (2003) introduced a precision seeder specifically designed for coated rice seeds, incorporating photoelectric closed-loop controls. The metering mechanism of this seeder was effectively managed by a single-chip CPU. Notably, test results indicated an impressive operational efficiency of approximately 98.5 per cent, with a minimal 1.4 per cent planting rate and zero seed losses. This innovation established coated rice seeds as the preferred choice for mechanized rice seedling nurseries when it came to machine seeding.

Rai *et al.* (2003) devised an electronic system for detecting seed tube blockages in tractor-drawn seed drills. This innovative solution featured optoelectronic transducers strategically placed at the lower end of the seed drill channels, near the furrow opener. These transducers continuously monitored the seed's path and promptly conveyed audio-visual signals to the tractor driver, alerting them to take corrective actions. Through field testing, this electronic seed tube blockage detector for tractor-drawn seed drills proved to be both effective and satisfactory in its performance.

Geometry of cells significantly influences the percentage of cell fill and achieving a 100 per cent cell fill is crucial for ensuring there are no gaps in the formation of hills and maintaining the desired uniform spacing Santos *et al.* (2003).

Singh *et al.* (2005) conducted an extensive investigation into the performance of a seed metering device for a pneumatic planter, both in laboratory and field settings, with the aim of optimizing design and operational parameters for planting cottonseeds. Their study encompassed the assessment of several key factors, including the operational speed of the seed plate (disc), vacuum pressure and the shape of the seed hole entry. They also evaluated precision in spacing, miss index, multiple index and the quality of feed index. Their findings revealed that for cotton seeds, an ideal seed hole diameter was 2.5 mm and the optimal entry cone angle for the planter disc was 120 degrees. The results further indicated that a metering system operating at a speed of 0.42 m s^{-1} and vacuum pressure of 2 kPa yielded superior results, achieving a remarkable quality of feed index at 94.7 per cent and a coefficient of variation in spacing of 8.6 per cent, resulting in a mean seed spacing of 251 mm. Upon optimizing regression equations that incorporated disc speed, the pneumatic planter exhibited consistent performance within a range of speeds from 0.34 to 0.44 m s^{-1} when paired with a vacuum pressure of 2 kPa. With these optimized operational parameters in mind, the researchers assessed the pneumatic planter's performance under field conditions, measuring the distribution of cotton plant spacing. They recorded an average plant spacing of 298 mm with a precision of 19.1 per cent (as indicated by the coefficient of variation) in the field.

Karayel *et al.* (2006) conducted a study focusing on seed uniformity and distribution in planters. They addressed the challenge of random seed distribution caused by fluted wheel metering systems, in which each metering system could hold multiple seeds. To enhance seed spacing accuracy, they emphasized the need for fast and reliable assessment of distribution quality in laboratory tests. To address this, the researchers developed a high-speed camera system capable of evaluating seed spacing uniformity and the velocity at which seeds fell. They compared the performance of this high-speed camera system with a sticky belt test stand used as a reference. The study involved the simultaneous evaluation of identical seed patterns, employing both methods and using wheat and soybean seeds. The metering roller speed of the seed drill was varied at 10, 20, 30 and 40 rpm, with the seed drill moving at a simulated speed of 1 m s^{-1}. Overall, the high-speed camera system proved effective in assessing seed spacing and the velocity of seed descent in all the tests involving wheat and soybean seeds. The study revealed that the uniformity of seed distribution in the seed drill was influenced by the speed of the metering rollers. As the speed of the metering rollers increased, there was a decrease in the coefficient of variation for seed spacing, the velocity of seed fall and the coefficient of variation for seed fall velocity.

Ebrahim *et al.* (2008) developed a precision seed drill for oilseed rape, aiming to address the issues of non-uniform seed spacing along rows and the lack of control over planting depth. Their solution incorporated a roller-type metering device and a depth control system. To enhance the uniformity of seed distribution, they investigated various design parameters related to the geometry of rollers and brushes. The design process involved the use of computer software packages to model and simulate the machine's operational performance. In laboratory tests, the precision seed drill demonstrated satisfactory performance, with the added finding that factors such as speed and vibration did not significantly impact the metering system's effectiveness. In field tests, the precision seed drill achieved a consistent and even distribution of seeds with reasonable spacing along the rows, successfully addressing the issue of non-uniformity. Furthermore, seed scattering during planting fell within an acceptable range.

Boydas *et al.* (2007) conducted a study to investigate the impact of vibration, roller design and seed rates on the evenness of seed flow using a studded feed roller mechanism. The behaviour of the seed flow within the studded feed roller was subject to both structural and operational variables, as well as the varying levels of vibration induced by factors such as soil roughness, large aggregates, small stones and tractor movement. The research involved the assessment of four different vibration levels to gauge their influence on the evenness of seed flow, focusing on both wheat and barley. This evaluation considered three distinct studded feed roller designs and two different seed rate scenarios. The study measured the coefficient of variation in seed flow evenness through laboratory experiments. The seed rates employed were 130 kg ha^{-1}, 180 kg ha^{-1} for wheat and 150 kg ha^{-1}, 200 kg ha^{-1} for barley. Throughout the experiments, a consistent simulated ground speed of 6.5 km ha^{-1} was maintained. The findings revealed that while the levels of vibration had no observable effect on the evenness of wheat seed flow, they significantly impacted the evenness of barley seed flow. Furthermore, the research highlighted that increasing the seed rate had a substantial and positive effect on the evenness of seed flow.

Zhang *et al.* (2008) developed an automatic reseeding monitoring system for seed drills with the aim of minimizing the occurrence of seeding gaps, enhancing the quality of mechanical operations, and increasing automation. This system was built around the AT89C51 single-chip microcomputer, serving as the central component of the monitoring system. They meticulously crafted the monitoring program using assembly language and concurrently designed the corresponding treatment circuit and reseeding mechanism. In the event of technical issues, the monitoring system not only alerted users through both sound and light signals but also engaged a small stepper motor to activate the reseeding mechanism. This ensured that the seeding process continued until it could be properly inspected and repaired. Experimental results demonstrated that monitoring system was highly responsive, with a sensitivity of just

0.3s. This level of precision enabled a significant reduction in the duration of seeding gaps, effectively improving the overall efficiency of the seed drill.

Singh (2009) developed and assessed a microcontroller-based pneumatic seed metering device. The performance of the pneumatic seed collecting and picking unit proved to be effective for low-speed operations, particularly when handling soybean seeds. However, there were limitations in the seed counter's ability, as it could not accurately count between 21 per cent to 23 per cent of the seeds. On the other hand, the metering device demonstrated the capability to control seed rates within a range of 1 to 50 kg ha^{-1}, maintaining seed distances between 4 and 33.6 cm. Optimal seeding uniformity was achieved for distances of 14.4 cm and above, with a planting error rate of 0 per cent when the hill-to-hill distance was set at 28.8 cm and 33.6 cm. The coefficient of variation increased as the hill-to-hill distance widened.

Anantachar *et al.* (2010) developed a feed-forward artificial neural network (ANN) model designed to calculate the ideal input parameters-including the forward speed of the planting equipment, rotary speed of the metering plate and the cell area on the plate needed to achieve specific goals: attaining the desired seed rate and seed spacing while minimizing seed damage and ensuring 100 per cent cell fill. To generate the necessary data for this model, laboratory experiments were conducted using a sticky belt test stand equipped with a seed metering device and an opto-electronic seed counter. This data was employed to create both statistical and neural network models. Ultimately, the optimal input parameter values were determined, enabling the achievement of a seed rate of 33.33 seeds/m², a seed spacing of 100 mm, 0.2 per cent seed damage and 100 per cent of cell fill. The research identified an optimal peripheral speed of the metering plate at 0.237 m s^{-1}, which was most effective for seed sizes ranging from 95.42 mm² to 123.01 mm².

Hajahmed *et al.* (2011) designed an opto-electronic monitoring system specifically tailored for monitoring the seed metering unit of crop planter. This innovative system was employed to track seed flow from the metering mechanism of a row crop planter and to calculate seed spacing. The system's components included an opto-electronic sensor for detecting seeds, a rotary encoder to measure forward speed and seed positions, amplifiers to fine-tune sensor signals, a microcontroller to synchronize these signals, and a PC to operate the program and display the data. This opto-electronic monitoring system underwent successful development and testing using chickpea seeds, which occurred at two different operating speeds (1.3 m s^{-1} and 1.9 m s^{-1}) and three various metering system gear combinations. The system accurately detected both the number and positions of the dropped seeds. Notably, the results demonstrated the system's reliability, with a strong linear relationship ($R^2 = 0.993$) between the measured data and the actual measurements.

Jafari *et al.* (2011) conducted an investigation into the impact of various factors, including the seed metering drive shaft, ground speeds and outlet positions, within a grain drill. They aimed to understand the variations in wheat seeding rates and the evenness of seed flow across different outlets, analysing the data using the coefficient of variation (CV) and the non-uniformity coefficient (NUC) over short time intervals. The study involved evaluating a grain drill equipped with straight fluted metering mechanisms on a test rig. They examined two rotational speeds, 16 and 23 rpm, for the seed meter drive shaft and two speeds, 2.5 and 3.6 km h^{-1}, for the movement of the test rig. The findings indicated that, for a given test rig speed, the seed rate changed proportionally with the seed meter drive shaft speed. Conversely, with a constant speed of the seed meter drive shaft, the seeding rate decreased as the speed of the test rig increased. Moreover, not all outlets yielded the same seed rates, and some outlet outputs exhibited autocorrelation. To address this, randomly selecting 12 or 24 seed samples out of 36 consecutive samples was found to mitigate autocorrelation issues. Increasing the rotational speed of the seed meter drive shaft notably improved the uniformity coefficient for all outlets. However, it also led to increased seed breakage. The coefficient of variation and the non-uniformity coefficient displayed similar trends. In conclusion, the study suggested that, in the evaluation of grain drills, both the coefficient of variation and the non-uniformity coefficient could serve as useful indicators of seed flow uniformity.

Yehuala *et al.* (2012) developed and assessed an electro-mechanical seed metering device tailored for raised bed planters. The research findings revealed that, during laboratory tests, there was no statistically significant difference in seed rates between rows when considering different operational speeds for both the designed electro-mechanical raised bed planter and the traditional ground wheel raised bed planter. Moreover, the study determined that the maximum deviation in seed rates from the recommended levels, caused by variations in operational speeds ranging from 1.0 to 5.4 km h^{-1} was only 2.72 per cent for maize and 0.54 per cent for groundnut in the electro-mechanical raised bed planter. In contrast, the ground wheel raised bed planter exhibited larger deviations with rates of 5.69 per cent for maize and 2.74 per cent for groundnut, highlighting the superior performance of the electro-mechanical system in maintaining seed rate consistency.

Koley (2012) designed and implemented a controlled metering unit for planters, subsequently assessing its performance in a laboratory setting. The results of the study indicated that, when the rotational speed of the metering plate increased at a constant tractor forward speed, both the seed rate and the hill-to-hill distance decreased. Conversely, the cell fill percentage saw an increase as the metering plate speed increased. Statistical analysis revealed that the interaction between the plate rpm, forward speed, and metering plates had no significant effect on seed breakage for groundnut and maize. However, the study did find a significant impact on soybean seed breakage due to these factors.

Kamgar *et al.* (2012) designed and developed a sophisticated mechatronics transmission system that incorporated an encoder coupled with a transducer to continuously monitor forward velocity. This system also featured a microprocessor for data processing and an electromotor to drive the metering system. In contrast, a control mechanism using traditional mechanical transmission was employed. To simulate various slippage conditions, the study utilized two types of wheels (rubber tires and steel wheels) and implemented two distinct soil preparation and residue management techniques as experimental treatments. The field evaluation results demonstrated significant improvements with the mechatronics mechanism. The planter equipped with this innovative system, in combination with rubber tires, yielded a higher percentage in the quality of feed index, which is highly desirable outcome. Moreover, the implementation of the mechatronics mechanism led to a reduction in both miss index and precision index, enhancing the overall performance of the system. Additionally, the adoption of mechatronics technology in row crop planters highlighted the importance of calibration to ensure optimal functionality.

Mansuriya (2013) introduced a seven-row electronic planter featuring an inclined plate seed metering mechanism. This planter was equipped with a DC motor responsible for driving the metering plate through an electronic circuit. Operational testing was conducted at speeds of 2.3, 3 and 3.5 km h^{-1}. The evaluation of this innovative unit involved the use of an opto-electronic sensor and a grease belt system. The obtained R^2 values were highly satisfactory, measuring at 0.98 and 0.97 for the opto-electronic sensor and grease belt method, respectively. Particularly noteworthy was the groundnut seed, which displayed minimal variations in both seed rate and seed spacing when the planter was operated at speed of 3.5 km h^{-1}.

Aware *et al.* (2014) designed and implemented a microprocessor-based electronic metering system for a three-row planter, specifically tailored for cowpea seed metering. This advanced metering mechanism relied on opto-electric rotary sensing. Input information was conveyed to the microcontroller in the form of electrical pulses, generated by both the sensor and switches, which defined the precise seed spacing. Their research revealed that traditional mechanical metering mechanisms suffered from multiple losses within their mechanical linkages, resulting in reduced precision. To assess the performance of their newly developed planter, laboratory tests were conducted. When a 15 cm input was provided, the achieved seed spacing output was measured at 16.2 cm. Notably, they observed that the actual seed spacing obtained for the specified 15 cm input was consistently 16.2 cm, indicating the reliability and accuracy of their electronic metering mechanism.

Rajaiah *et al.* (2016) devised an electronic experimental setup to assess three distinct seed-metering mechanisms: slanting, semicircular, and rectangular shapes, specifically for three varieties of paddy. Their investigation sought to determine how selected variables, such as forward speed, cell shape, and the inclination of the seed-metering plate, influenced the performance parameters of seed metering. The outcomes of the study revealed that the slanting type metering plate, set at a 35º angle with the horizontal and operated at a forward speed (belt speed) of 2 km h^{-1}, produced the most favourable results. Notably, this configuration achieved mean seed spacing of 14.8 cm, closely approaching the theoretical seed spacing of 15 cm. Additionally, it yielded the highest quality feed index at 88.1 per cent, the lowest miss index at 6.1 per cent, and minimized seed damage to just 0.38 per cent. Consequently, for the precision design of a paddy planter, optimal parameters, including the use of a slanting type metering plate set at a 35° inclination and a forward speed of 2 km h^{-1} can be recommended to attain the best results.

Niu Kang *et al.* (2017) studied the prevailing use of cup-chain metering devices in potato planters. Challenges such as missing-seeding, double-seeding, and ground wheel sliding were persisted. In response, a mechanical-electrical design was engineered to address these issues. A regression experiment was carried out, examining three key factors: chain speed, chain tightening distance and cup tilting. The experiment considered two crucial indicators: the missing-seeding rate and the double-seeding rate. Utilizing the results from the regression experiment, a numerical regression model was constructed. A multi-objective optimization method was employed to determine the optimal solution. Following these, the refined device underwent field testing. This advanced design features a tilting seed cup with a protective guard plate and an integrated electric control system. Laboratory tests yielded valuable insights. The missing-seeding rate was observed to rise with increased chain speed. It exhibited an initial decrease, followed by an increase with variations in the chain tightening distance and cup tilting angle. In contrast, the double-seeding rate showed a decline with higher chain speed. It initially increased and then decreased with changes in the chain tightening distance. Optimization led to impressive results with a missing-seeding rate of 4.39 per cent and a double-seeding rate of 8.78 per cent under specific parameters: a seeding speed of 0.32 m s^{-1}, a chain tightening distance of 0.94×10^{-3} m and a cup tilting angle of 12.5°. Field tests conclusively demonstrated the advantages of electric control over ground wheel-driven chains, enabling swift seeding and precise intra-row seeding distances. This development represents a significant stride towards enhancing the efficiency and precision of potato planting.

Hadi *et al*. (2017) devised a practical seed drill performance monitoring system, aiming to facilitate the comparative design of non-contact sensing systems for detecting seed flow rates. In their pursuit of determining the actual seed flow rate, they developed three distinct sensing units: light detection resistors (LDR), infra-red (IR) and laser diodes (LD). These sensing units included sensors equipped with LED emitters and radiation receivers. To assess the capabilities of these sensing units when applied to the same seed flow, they conducted experiments for various flow rates. Their findings revealed a robust linear relationship (with an R-value of 0.87) between the actual changes in seed mass and the corresponding voltage output of the infra-red sensing unit. In their comparative analysis of different sensing methods, they concluded that the infra-red technique proved to be the most suitable and effective approach for estimating seed flow rates.

Kumar *et al.* (2019) conducted that cultivation of Gladiolus, a beloved flowering plant highly regarded for its exquisite cut spikes, has traditionally involved labour-intensive corn planting methods, leading to substantial drudgery. The mechanized planting of Gladiolus corms has received limited attention so far. To address the need for timely and efficient planting, a novel cup-chain type metering mechanism was developed and assessed in a linear soil bin. The study encompassed three distinct nominal spacing levels (15cm, 20cm). Various performance parameters, including hill to hill distance, multiple index, missing index, quality feed index, coefficient of uniformity, precision, coefficient of precision (CP3), visible damage and the number of corms per meter length, were rigorously analysed. The data underwent statistical examination utilizing a two-factor completely randomized design (CRD). The results demonstrate that, at a forward speed of 1.5 km h^{-1}, the metering mechanism consistently achieved the desired nominal spacing with a 100 per cent quality feed index. The precision remained consistently below 10 per cent for all three nominal spacings and four forward speeds., and 25 cm) and four forward speed settings (1.5 km h^{-1}, 2.0 km h^{-1}, 2.5 km h^{-1}, and 3.0 km h^{-1}). In conclusion, the metering mechanism exhibited superior performance at 25 cm nominal spacing and forward speeds of 1.5 km h^{-1} and 2.0 km h^{-1}. This advancement marks a significant step towards mechanizing the Gladiolus corm planting process, reducing labour intensity and enhancing overall efficiency.

Wang *et al.* (2020) reported that mis-seeding in spoon-type potato seed-metering devices can lead to significant yield losses. Traditional solutions, like adding extra seeding devices, complicate the planter’s structure and often fail to ensure accurate compensation. To address this, a new "integrated seeding and compensating potato planter based on a one-way clutch" has been developed. This system uses a one-way clutch to supply power from the land wheels for normal operation and another one-way clutch to power a compensating motor during the compensation phase. This setup allows for seamless power transfer, enabling a "catching-up compensation" strategy where subsequent potato seeds can accelerate to fill gaps left by their predecessors. A seeding-monitoring system based on infrared radiation was designed, employing a simple open-loop compensation control plan. Field tests of a prototype machine, within a seed-metering chain speed range of 0.2–0.8 m s^{-1}, showed minimal mis-seeding and error detection rates, not exceeding 1 per cent. The new system reduced the miss-seeding rate from nearly 4 per cent to around 1 per cent, even at the highest chain speed, with a success rate of less than 2/3 in suppressing miss-seeding issues.

Wanzhi *et al.* (2020) developed an innovative combination of a vacuum and spoon belt metering device to enhance the precision and efficiency of potato seeding. This study explores the device's structure, operation, and the stresses on potato seeds, analysing key components through in-depth calculations. Experiments based on a three-factor, three-level response surface methodology (using Box–Behnken central composite design) focused on seeding speed, spoon aperture, and cleaning-seed air volume. The performance was evaluated using the missing seed index, multiple seed index, and qualified seed index. Design-Expert 10.0.4 software was employed to establish a mathematical model and analyse the impact of each factor. Results showed that for the missing seed index, the seeding belt speed had the highest impact, followed by cleaning air pressure and spoon aperture. For the multiple seed index, spoon aperture was the most influential, followed by cleaning air pressure and seeding belt speed. For the qualified seed index, seeding belt speed was the most significant, followed by cleaning air pressure and spoon aperture. The optimal conditions seeding belt speed of 0.43 m s^{-1}, spoon aperture of 15.72 mm, and cleaning air pressure of 2.94 kPa achieved highly efficient and precise seeding. The missing seed index was 3.97 per cent, the multiple seed index was 4.65 per cent and the qualified seed index was 91.38 per cent. This research provides valuable insights for improving potato seeding precision and efficiency.

Guo *et al.* (2021) analysed in accordance with the specific agronomic demands of garlic sowing, an in-depth analysis of garlic morphology which paved the way for the design of an efficient garlic seed metering mechanism. This mechanism has been meticulously crafted to deliver exceptional seeding performance. Building upon this innovative design, a novel garlic seeding machine equipped with an adjustable-size seeding device has been engineered. This machine is designed to facilitate precise single-seed metering and seeding for various garlic varieties. To materialise the concept, a comprehensive design scheme for the garlic seeder prototype has been established. Key components of the garlic seeding process have been meticulously designed, drawing inspiration from the garlic seeding mechanism. The realization of single-seed metering for diverse garlic varieties hinges on determining the optimal adjustment size of the garlic seed metering device, a feat achieved through discrete element simulation analysis. A field experiment has successfully validated the efficacy of deploying this garlic planter for sowing, as evidenced by metrics such as the reduction of missing seeds and multiple seed rates. The discrete element simulation testing results have underscored that an adjustment size of 40 mm yields the best single-seed metering performance. Operating within the range of 15-35 rpm, the metering device consistently attains an impressive qualification rate of over 80 per cent for single-seed metering with maintaining a unit speed within the range of 0.628-1.465 m s^{-1}. Consequently, the developed garlic seeding device effectively fulfils the precision sowing requirements in China, marking a significant step towards mechanized garlic planting that enhances efficiency and accuracy.

Shouhua and Shujuan (2022) reported that traditional mechanical seeders operating at high speeds, often encounter issues such as reduced sowing accuracy, higher rates of missing seeds, and imprecise grain spacing adjustments. These problems significantly hamper both the precision and efficiency of the seeding process. In this study, a cutting-edge brushless DC motor sliding film variable structure control system has been developed for an air-suction corn seeder. This system aims to achieve precise control over the rotational speed and seed metering quantity of the seed metering disc. Experimental findings indicate that as the electrically driven air-suction seed metering device operates at higher speeds, the standard deviation of sowing distances increases. Notably, the electric seeding device outperforms its mechanical counterpart in terms of the qualified seeding rate, average seed spacing, standard deviation distribution and coefficient of variation. This underscores the improved precision and efficiency achieved by the electric seeding device, particularly when operating at elevated speeds.

Pandey and Sawant (2023) told that manual planting of ginger is labour-intensive and time-consuming, often causing discomfort for workers. To address this, a seed metering mechanism was developed and tested at the ICAR-Central Institute of Agricultural Engineering in Bhopal. The mechanism includes a vertical rotating disc, specialized fingers, a lever and cam system, a seed hopper, an agitator, and a rhizome delivery system. Laboratory experiments used a sticky belt to analyze seed distribution under different conditions: forward speeds (0.42 m s^{-1}, 0.56 m s^{-1}, 0.69 m s^{-1}, 0.83 m s^{-1}), rhizome sizes (small, medium, large), and two finger types (P1 and P2). Performance parameters measured included average seed spacing, missing index, multiple index, quality of feed index (QFI), and visible damage. The study found that speed, seed size, and finger type significantly affected seed spacing. Higher speeds and larger seed sizes reduced the multiple index and QFI but increased the missing index and damage percentage for both finger types. The most influential factor was the speed of operation. The highest QFI (77.14 per cent) was achieved at 0.56 m s using P_2 fingers, which also had lower missing index, multiple index, and visible damage compared to P_1 fingers. The metering system performed best with P2 fingers at 0.56 m s^{-1}, especially for medium-sized seeds. This automatic seed metering mechanism shows high potential for improving the precision, efficiency, yields and cost-effectiveness in ginger planting.

According to above studies electronic seed metering effectively eliminate non-uniformity of seed spacing caused by slippage of ground wheel, which in turn gives increased working speed and improve planting accuracy. Although most of the above electronic seed meters are based upon concept of ground wheel speed synchronization. Electronic seed metering systems have revolutionized modern agriculture by providing precision planting, increased efficiency and cost savings. They enable variable rate planting and real-time monitoring of seed populations, contributing to higher crop yields and reduced environmental impact. User-friendly interfaces and compatibility with various seed types make these systems accessible to a wide range of operators. However, to maintain their effectiveness, regular maintenance and calibration are crucial. In summary, electronic seed metering systems are an indispensable tool in contemporary farming, optimizing resource use and improving overall agricultural productivity.

2.8 PERFORMANCE EVALUATION OF DIFFERENT TYPES OF PLANTERS

Misener (1979) conducted an assessment of potato planters with cup and pick designs. They calculated the coefficient of variation for spacing, seed fill and seed piece skips for each planter. Overall, the pick type planter exhibited slightly better performance compared to the cup type planter. The coefficient of variation in spacing for cup and pick planters fell within the ranges of 59.2 to 87.1 and 55.3 to 68.7 respectively. In the case of seed fill with average number of double plantings per 30.5 meters of row length, the cup type planter resulted from 5 (6.2 per cent of seed pieces) to 65 (33.6 per cent), while the pick type planter showed a range from 5 (6.8 per cent) to 52 (29.0 per cent) across various forward speeds and nominal spacings. As for the number of skips, the cup planter had a range of 3 (3.2 per cent) to 22 (14.7 per cent) per 30.5 meters of row length and the pick type planter resulted from 3 (3.0 per cent) to 19 (12.1 per cent).

Griepentrog (1998) presented the key parameters to characterize seed spacing uniformity, including the mean spacing (X), the standard deviation of spacing between plants (SD) and the coefficient of variation (CV). The mean spacing was found to be affected by seed or plant density and longitudinal distribution. In the context of common grain drills, a coefficient of variation (CV) of 20 per cent was considered a satisfactory level of accuracy when mechanical and pneumatic machines were operating at their optimal performance levels.

Panning *et al.* (2000) conducted an evaluation of sugar beet planting performance using three distinct planter types: a precision planter designed for shallow planting of small seeds, a versatile planter suited for row crops and a vacuum metering general-purpose planter specifically designed for row crops, which featured three different seed tube designs. Their field study revealed that the most consistent seed spacing for each planter setup was achieved at the lowest speed of 3.2 km h^{-1}. Across all planter configurations, as the forward speed increased from 3.2 to 8.0 km h^{-1}, seed spacing uniformity declined. Furthermore, the laboratory tests resulted seed spacing uniformity was either greater than or equal to the seed spacing uniformity obtained in the field tests.

Mari *et al.* (2002) conducted an experiment to assess the functionality of a potato planter. This planter was operated using a Fiat-480 diesel tractor, running at a low speed in 3rd gear. The key performance parameters determined for the tractor planter included a moisture content of 15.73 per cent, fuel consumption at a rate of 24.04 l h^{-1}, a travel reduction of 5.04 per cent, a field efficiency of 67.47 per cent and a field capacity of 0.80 ha h^{-1}.

Celik *et al.* (2007) conducted an assessment of four distinct seeders, examining their performance in terms of seed spacing, depth consistency and plant emergence with three different forward speeds (3.6, 5.4 and 7.2 km h^{-1}). These seeders encompassed various types, including the no-till planter, precision vacuum planter, universal planter and semi-automatic potato planter. To characterize the uniformity of seed distribution horizontally, the study employed a range of indices such as the multiple index, miss index, quality of feed index and precision, in addition to the means and standard deviations calculated through sampling methods.

Al Gaadi and Marey (2011) conducted an assessment of the impact of different forward speeds and various tuber characteristics on the spacing of tubers using a cup belt potato planter. They investigated three distinct forward speed levels (1.8 km h^{-1}, 2.25 km h^{-1} and 3 km h^{-1}) and three tuber size ranges (35 to 45 mm, 45 to 55 mm and 55 to 65 mm). The performance of the planter was analysed through several key parameters, including mean tuber spacing (M), the coefficient of variation (CV), the multiple index (MULTI) and the miss index (MISI). The findings of their research indicated that tuber sizes falling within the range of 35 to 45 mm exhibited superior uniformity in tuber spacing when compared to other tested tuber sizes. Furthermore, a forward speed of 2.25 km h^{-1} was identified as the optimal choice, as it maximized planter efficiency while having no significant adverse effects on the uniformity of seed tuber placement.

Al- Gaadi (2011) conducted a comprehensive investigation into the performance of an auto-feed cup-belt potato planter, examining various operational conditions and different tuber shapes, including whole and cut tubers. His study revealed a clear relationship between the coefficient of variation (CV) and the missing index (MISI) with respect to different factors. The results indicated that both the CV and MISI were directly proportional to the forward speed and inversely proportional to the gate height and speed ratio. The highest CV and MISI values, reaching 68.4 per cent and 16.42 per cent, were observed in the case of cut tubers when the planter was operated at a speed of 3 km h^{-1} with a speed ratio of 1.22 and a gate height of 80 mm. Additionally, it was noted that the multi-index (MULTI) values were lower in the context of cut tubers, with the highest MULTI value of 7.76 per cent observed for whole tubers.

Dixit *et al*. (2015) carried out a performance assessment of a tractor-mounted vertical belt-type paired row potato planter for planting Kufri Jyoti potato variety on controlled traffic beds. The paired row planter demonstrated a field capacity of 0.24 ha h^{-1}, maintaining an average forward speed of 2.5 km h^{-1}. In terms of performance, it exhibited low percentages of missing, multiples and seed damage, specifically 3.3 per cent, 1.5 per cent and 1.5 per cent respectively. In contrast, the automatic planter displayed higher rates of 5.0 per cent, 1.8 per cent and 10.0 per cent, respectively. The researchers also conducted a performance evaluation of the vertical belt of the paired row potato planter in a real-world setting, covering an extensive area of approximately 117 ha at a farmer’s field. The results obtained in this practical setting mirrored the patterns observed in the controlled experiments. Overall, the planting performance of the machine and the resulting potato crop stand were deemed satisfactory, particularly for the belt-type paired row planter.

Ghosal and Beher (2016) examined the characteristics of seed patterns produced by a manually operated cup feed metering seed drill for sowing groundnut seeds. Their research findings revealed that the optimal cup dimensions, measuring 12 × 7.36 mm was highly effective for sowing groundnuts at peripheral speed up to 18.84 m min^{-1}. The seed drill demonstrated an impressive field efficiency of 75 per cent and an actual field capacity of 0.048 ha h^{-1}. Consequently, this seed drill not only provided substantial net cost savings of Rs. 664 ha^{-1} for groundnut cultivation but also proved to be a cost-effective investment. The initial cost of the seed drill was Rs. 1850 and its operational expenses amounted to Rs. 13.85 per hour.

Kankan *et al.* (2016) conducted a comprehensive evaluation of a single-row manual cotton planter's performance. This assessment included both laboratory and field tests, with three trials dedicated to planting Bt-cotton crops. Field capacity of planter was found to vary between 0.18 and 0.21 ha h^{-1} operating at forward speeds from 2.24 to 2.5 km h^{-1}, specifically on well-prepared seed beds. The average planting depth fell within the 4.5 to 5 cm range. Field efficiency for the planter ranged from 88.88 to 91.1 per cent.

Gautham *et al.* (2016) designed and tested an inclined plate seed metering device in a laboratory setting to achieve the singulation and uniform placement of onion seeds. They experimented with different pelleting ratios, including 1:1, 1:2 and 1:3. The evaluation involved varying inclinations of 40°, 45° and 50°, as well as adjusting the groove numbers of cells to 18, 24 and 30. The highest feed index quality, reaching 84 per cent, was achieved using a seed metering plate with 24 grooves and a 45° inclination angle, at a forward speed of 2 km h^{-1}. The study primarily focused on performance parameters, such as the quality of the feed index, missing index, multiple index and mean spacing for the developed planter. However, it should be noted that limited attention was given to the development of performance parameters specifically tailored for the check row planting pattern. Therefore, there is a compelling need to establish a suitable evaluation framework for check row planters.

Kumar *et al.* (2017) conducted and assessed the performance of a garlic planter in Uttar Pradesh. Three variations of garlic planters were created, namely: 1) an inclined metering plate garlic planter, 2) a vertical metering plate garlic planter and 3) a spring plate garlic planter. Impressively, the percentage of broken garlic during planting was exceptionally low, at only 0.25 per cent. The newly designed garlic planter prototype featured 10 rows and was designed to be attached to a 5 hp power tiller. Field trials were conducted in Allahabad under real-world conditions. The results revealed that the optimal width for the garlic planter was determined to be 0.9 m or equivalently 9 rows. The ideal soil condition for operation was dry soil. The maximum forward speed achievable with the planter was 3 km h^{-1}, but it was noted that wheel skidding occurred relatively frequently, with a high skid rate of approximately 24.34 per cent. The average planting depth and width were measured at 2.65 cm and 4.68 cm, respectively. When it came to turning at the headland, the time required was 39 seconds. The garlic planter exhibited a field capacity of 0.32 ha h^{-1} and it involved in the participation of three operators for efficient operation. The planter's capacity was determined to be 0.84 hectares per person per day, showcasing its effectiveness in garlic cultivation.

Senthilnathan *et al.* (2018) introduced an automated seed sowing machine, incorporating microcontroller technology and wireless connectivity. They employed relays to manage high-voltage circuits effectively. The inclusion of online command reception and monitoring, utilizing Internet of Things (IoT) capabilities, greatly enhanced the efficiency of their innovative design. Results from comprehensive system testing indicated that consistently dispensing seeds at regular intervals led to increased yields while significantly reducing the need for manual labour. It's worth noting that there has been a lack of research focusing on equidistant planting, precise seed placement and maintaining consistent planting depths. To achieve precision in the operation of robotic planters, controlling operational speed and crop spacing becomes imperative.

Manjunath *et al.* (2019) developed metering system was assessed across three check row spacings (30 × 30, 40 × 40 and 50 × 50 cm), employing two rotor materials (polyurethane rubber and polyurethane foam) and varying forward speeds (0.5, 0.65, and 1.3 km h^{-1}). The mean hill to hill distance of 39.76 cm closely approximated the targeted 40 cm at a speed of 0.65 km h^{-1} for the polyurethane rubber seed metering plate. The optimal feed index of 85.94 per cent was achieved at 0.65 km h^{-1}, specifically with the polyurethane rubber rotor material at a check row spacing of 40 × 40 cm. In summary, the sensor-controlled seed metering mechanism demonstrated superior performance, particularly when utilizing polyurethane rubber as the rotor material at lower speeds, regardless of the spacing employed.

Kus (2021) conducted a study focused on enhancing the uniformity of spatial plant distribution. One of the key factors affecting the precision of seed placement is the interference caused by planter vibration during the seed metering process. To address this issue, a single-seed planter was equipped with vibration meter to quantify the vibrations experienced under both conventional and reduced tillage conditions. The experiment was set up in a complete factorial design, involving three repetitions, three different planter speeds and three distinct furrow opener sizes. The test results revealed a direct correlation between planter vibration and planting speeds, with vibration increasing as planting speed increased. Conversely, vibration decreased as the size of the furrow opener increased, showing a linear relationship. The R_2 values of the corresponding equations, except for reduced tillage (RT) in Field-1 and conventional tillage (CT) in Field-2, consistently exceeded 0.90. Notably, planter vibration was less pronounced during reduced tillage planting. The optimal spatial plant distribution was achieved with a 180 mm furrow opener size and a planting speed of 3.96 km h^{-1}. In summary, it was evident that increased vibration contributed to greater spatial variability in planting.

Pareek *et al.* (2023) introduced an embedded mechatronic seed metering control system, utilizing an electric motor for ground-engaging wheel to drive the seed metering units. The system comprises key components such as an electric motor, motor controller, relay switches, microcontroller board, radar sensor, and 12 V battery. Integrated with conventional inclined plate planter, the system's performance was evaluated in both electric motor-driven (EMD) and ground wheel-driven (GWD) modes. Field tests revealed a notable enhancement in seed spacing uniformity in the EMD mode compared to the GWD mode. This improvement was evident through an 8.12-21.32 per cent increase in the quality of feed index and a reduction of 11.82-19.73 per cent in precision across a speed range of 1.6 to 4.8 km h^{-1}. These results underscore the efficacy of the newly developed control system in addressing the issue of nonuniform seed spacing encountered in conventional planters.

From the above review of literature, it is clear that mechanical rhizome planters have some drawbacks such as seed metering mechanism picks up multiple seeds than desired, leading to higher seed rate, poor picking and missing affects efficiency of planter. Very larger hill to hill distance is difficult to achieve. Thinning to achieve desired plant population requires considerable labour and wastage of inputs. To overcome the above cited difficulties, it is proposed to develop a sensor-based tractor drawn ginger planter.

CHAPTER III

MATERIALS AND METHODS

In this chapter, various practices followed, identification and procedure to determine selected soil parameters are detailed. The procedure for the selection and evaluations of physical properties of ginger rhizomes that affect metering mechanism of a sensor-based tractor drawn ginger planter was explained. Development of laboratory set up for the sensor-based tractor drawn ginger planter for evaluation of the selected levels of parameters is described. The procedure for statistical analysis to optimize the selected levels of parameters for desired performance and development of the sensor-based tractor drawn ginger planter is detailed. The methods followed for actual field evaluation and testing of the developed sensor-based tractor drawn ginger planter was explained.

3.1 DATA COLLECTION ON PRACTICES IN GINGER CULTIVATION

Ginger is a perennial plant grown annually for harvesting as a spice. Ginger requires a warm and humid climate. It is cultivated from coastal plain to altitude of 1500 m above mean sea level either under heavy rainfall conditions (150-300 cm/year) or under irrigation. The ginger grows well in sandy or clayey loam, red loam or laterite loam soils having good drainage and humus content.

3.1.1 Planting season and Planting method

Optimal time of planting ginger is typically in the first half of April, following onset of pre-monsoon showers. For irrigated ginger crop, the ideal planting period is middle of February. The ginger is propagated vegetatively through rhizomes. The size of the planting material varies from the place to place and variety to variety. The ginger planting is manually done by digging the soil and placing the seed into it then it is covered with soil by using hands. The bits are made from mother seed rhizomes having 3-5 cm in length 15-20 g weight (15 g is optimum) with at least one or two buds. A seed rate of about 1500-2000 kg ha^{-1} is considered to be optimum for planting. The spacing of ginger planting is 25-45 cm between rows and 15-20 cm between plants. The improved varieties common in some parts of India are Athira, Chithra, Karthika, Aswathy, IISR-Varada, IISR-Rejatha and IISR-Mahima and plant population is 80000 plants per hectare (KAU, 2016).

3.2 SOIL PARAMETERS

The study focused on examining physical and mechanical properties of soil that affect the operational efficiency of a sensor-based tractor-drawn ginger planter is detailed in the following sections. The investigation specifically considered four key soil properties viz., soil consistency, moisture content, bulk density and cone index. All of them are influencing the performance of the sensor based tractor drawn ginger planter. Soil samples were collected from various locations of the Instructional Farm, KCAEFT Tavanur. The soil analysis tests were carried out at Soil and Water Conservation Engineering Laboratory, KCAEFT, Tavanur.

3.2.1 Soil consistency

The soil consistency refers to interplay of cohesive and adhesive forces within the soil at different moisture levels. Bonding strength between soil particles in clay-rich soils fluctuates with varying moisture content are influencing their behaviour. The moisture contained in the soil plays a crucial role in deciding the bond between soil particles. Consistency limits represent specific moisture contents at which soils exhibit distinct properties. Atterberg (1911) limits serve as a method of measuring the consistency of soils.

3.2.1.1 Liquid limit

The liquid limit (W_L) represents the moisture content at which soil exhibits minimal flow under applied force. It signifies the moisture level which distinguishes between liquid and plastic states of the soil.

The liquid limits of the soil samples of the test locations were determined using Casagrande liquid limit apparatus. The apparatus consisted of a brass cup and a carriage mounted on a hard rubber base (IS: 2720-V). Two types of grooving tools, viz., ASTM and Casagrande (BS) were used for the study. The apparatus comprised of a porcelain dish with a diameter of 150 mm, a palette knife measuring 200 mm in length and 30 mm in width, a 0.425 mm size sieve, a precision weighing balance with an accuracy of 0.01 g, a thermostatically controlled oven and air-tight containers. The brass cup was adjusted in such a way that, at its maximum height, a 10 mm gauge could pass between it and base. A 200 g air-dried soil sample, passed through the 0.425 mm size sieve was taken into the porcelain dish, added distilled water and thoroughly mixed until a stiff and homogeneous soil paste was formed. The soil paste was stored in an airtight container for 24 hours and was subsequently remixed. Top portion of this soil paste was levelled with a spatula up to a maximum height of 10 mm. A straight and clean diametrical groove of 2 mm wide was made in the paste through the centre of hinge with a grooving tool. The ASTM and BS grooving tool were used respectively in low plastic and soil types. The device's handle was rotated at a speed of 2 revolutions per second to lift and drop the brass cup for 10 mm height until the two soil paste parts contact each other at its bottom. The number of blows needed for the above actions were counted. Soil from the closed section was extracted for moisture content determination. The remaining soil paste was then transferred to the porcelain dish, added sufficient distilled water and thoroughly mixed until a stiff and homogeneous soil paste was formed and test was repeated. The apparatus for determination of liquid limit was shown in plate 3.1.

The test was carried out from dry to wet condition of soil with 15 to 40 evenly distributed blows. The test was replicated in 3 times.

Plate 3.1 Determination of liquid limit of soil

A semi-log graph was plotted between water content (in per cent) on linear scale as ordinate and the number of blows on logarithmic scale as abscissa. A best-fit straight line was drawn by connecting with points to form the flow curve. The water content in nearest whole corresponding to 25 blows noted from the graph, represents the liquid limit.

3.2.1.2 Plastic Limit

The plastic limit is the moisture content at which soil can just be rolled out into a wire or a minimum water content at which the soil transitions from a plastic to a rigid state. To ascertain the plastic limit of the soil, a sample that passed through the 0.425 mm size sieve was meticulously mixed with distilled water to achieve a homogeneous mass that was plastic enough to be moulded into a ball**.** A small ball, weighing 5 g was made from this sample. It was then rolled between fingers of one hand and a glass plate with consistent and ample pressure to produce a thread of 3 mm diameter (plate 3.2). The process was repeated by remoulding the soil each time, until the thread just began to crumble. The diameter of the thread was compared with the standard gauge rod. The test was replicated in three times.

Plate 3.2 Determination of plastic limit of soil

The average of these three water contents determined to the nearest whole number is taken as the plastic limit. The plasticity index (I_p) is calculated from the following formula.

$$I_P = W_L - W_P$$

Where,

W_L = Liquid limit

W_P = Plastic limit

3.2.1.3 Shrinkage Limit

A wet soil mass shrinks as it is dried. That is, its volume reduces to some extent as the water is removed from it. Shrinkage occurs due to capillary forces acting on soil surface. At certain moisture content, these forces cease to cause further reduction in volume of the soil mass. The water content at which any further moisture reduction does not result decrease in volume is called shrinkage limit (W_s) (IS-2720 part VI).

From 100 g of soil sample passed through the 0.425 mm size sieve, a 30 g of soil was taken, added distilled water and mixed meticulously to fill all the voids with water, facilitating easy transferring of the soil into a shrinkage dish without any air bubbles. The mass and volume of the shrinkage dish were determined. The volume was determined by the mercury displacement method. The inside of the shrinkage dish was coated with grease and the soil paste was gradually filled up to one-third capacity of the dish. The dish was tapped to eliminate any trapped air and this process was repeated until the shrinkage dish was fully filled with the soil paste. Any excess was trimmed off. Following the determination of the wet mass and volume of the soil pat, the shrinkage dish was placed in a hot air oven at 105°C for 24 hours. Then, dry soil pat was placed on the surface of mercury contained in a glass dish. The dry soil pat was submerged in mercury using a three-pronged glass plate (plate 3.3). The displaced mercury was weighed. From the mass and density of mercury (13.6 g ml^{-1}), the volume of the dry soil pat was calculated.

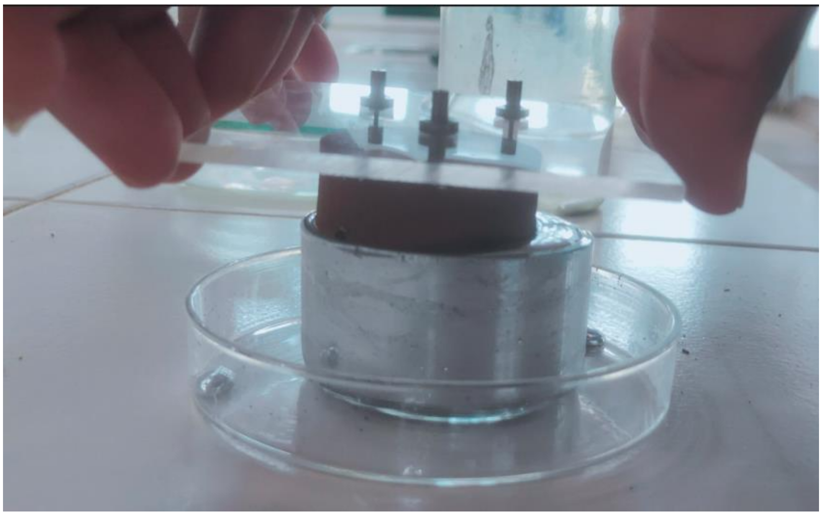


Plate 3.3 Determination of shrinkage limit of soil

The shrinkage limit in per cent was calculated by the formula

$$W_s = W - \frac{V - V_d}{M_s} \times 100$$

Where,

W = water content of the wet soil pat

V = Volume of the wet soil pat, ml

V_d = Volume of dry soil mass, ml

M_s = Mass of dry soil pat, g

3.2.2 Moisture content

Moisture content (MC) is the ratio of the weight of water to the weight of solids. The moisture content of the sample was determined on dry basis by using the following equation (Angelis, 2007).

$$\text{MC (per cent)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W_1 = Initial weight of soil sample, g

W_2 = Final weight of soil sample, g

Moisture content expressed as a percentage, is determined through the oven dry method. Soil samples were collected at depths of 0-7, 7-8, and 8-10 cm from various locations in the field. Each soil sample, weighing 50g was filled in different containers and kept at a temperature of 105°C in an electric hot air oven for 24 hours. The weights of the samples before and after drying were measured using an electronic balance with an accuracy of 0.01g. The moisture content of the soil significantly influences the draft of the implement and its slip. In the context of ginger rhizome germination and growth, soil moisture plays a vital role. Therefore, maintaining optimal soil moisture during sowing was crucial to minimize seed germination losses.

3.2.3 Bulk density

Soil compactness is assessed by determining bulk density through the core cutter method. The bulk density of a soil sample was calculated using the following equation (Ahmed *et al.*, 2018).

$$\text{Bulk density } (\rho) = \frac{M}{V}$$

Where,

ρ = Bulk density, g cm^{-3}

M = Mass of the soil, g

V = Volume of the soil, cm^3

Initially, volume of a cylinder was determined by measuring internal diameter (10 cm) and height of core cutter (12.5 cm). The empty core cutter was weighed. An area of 30 × 30 cm from the experimental field was exposed and levelled. The cylindrical core cutter with a Dolley placed over its top was pressed into the soil mass until the Dolley extended approximately 15 mm above the soil surface. After pressing, the surrounding soil around the core cutter was cleared, and it was extracted. Careful trimming of top and bottom surfaces of the core cutter was performed using a straight edge. Subsequently, the core cutter filled with soil was removed and weighed.

3.2.4 Cone index

The soil penetration resistance was assessed using a soil cone penetrometer by positioning it on the field and driven at a constant rate with its handle. The cone index, expressing soil resistance is defined as the force per square centimetre needed for a cone of standard base area to penetrate the soil at different depths. The cone index can vary for the same soil based on cone apex angle, base area and depth of penetration (Hummel *et al.*, 2004). Applying a uniform force on the handle, deflection of dial gauge was observed for a depth of 5 cm. The solid stem shaft penetrated into the soil and force was measured by noting the deflection of needle on proving ring corresponding to the cone insertion. The cone index was manually recorded for depths of 5, 10, 15, and 20 cm. This procedure was repeated to measure the cone index at various locations within the study area.

$$\text{Resistance} = \frac{PF}{BA}$$

$$\text{Base area of cone} = \frac{\pi}{4} \times D^2$$

$$= \pi/4 \times 3^2 = 7.068 \times 10^{-4}\ \text{m}^2$$

Where,

PF = Penetration force, N

BA = Base area of the cone, cm^2

PF = PR × 0.0098

PR = Mean dial gauge reading, N, D = Diameter of the cone, 3 cm

3.3 CROP PARAMETERS RELATED TO GINGER PLANTER DESIGN

The planting materials and parameters of ginger play a vital role in the design of planters. The ginger crop parameters considered for the design of a sensor-based tractor drawn ginger planter are furnished below.

i. Row to row spacing, cm
ii. Hill to hill distance, cm
iii. Number of seeds per hill
iv. Recommended seed rate kg ha^{-1}
v. Depth of placement of seed, cm

The recommended ginger planting parameters are shown in Table 3.1 below.

Table 3.1 Ginger planting parameters

Sl. No.	Crop parameters	Ginger
1	Row to row spacing, cm	45
2	Hill to hill distance, cm	15-20
3	Number of seeds per hill	1
4	Seed rate, kg ha^{-1}	1500-1800
5	Seed bed configuration	Flat type
6	Depth of placement of seed, cm	4-10

Source: Package & practices (KAU, 2016)

3.4 PHYSICAL PROPERTIES OF GINGER RHIZOMES

The physical properties of ginger rhizomes considered for the design of sensor-based tractor drawn ginger planter are weight, size, moisture content, sphericity, bulk density and true density. These properties were influenced in the design of metering mechanism and other components of the planter (Sahay and Singh, 1994). The ginger varieties selected for the study of the physical properties are Athira, Aswathy, Chithra and Karthika. The methods adopted to assess these properties are elaborated under following sections.

3.4.1. Weight of ginger rhizomes

Ginger bits having 3 to 5 cm in length with one or two buds were cut from all the four varieties of mother seeds (plate 3.4 and 3.5). The weights of each seed varieties were found using an electronic balance with an accuracy of 0.01 g. This was replicated in three times and mean weight of rhizomes were calculated (KAU, 2016).

3.4.2 Size of ginger rhizomes

Initially, the ginger bits of all the four varieties were made as detailed in section 3.4.1. From each variety, 25 each bits were selected and dimensions specifically length (l), breadth (b) and thickness (t) were measured using a digital vernier calliper (plate 3.6). Geometric mean diameter of each bits were calculated using the following equation given by Bahnasawy (2007) and mean values were taken.

$$GMD = (l \times b \times t)^{1/3}$$

Where,

GMD = Geometric Mean Diameter, mm,

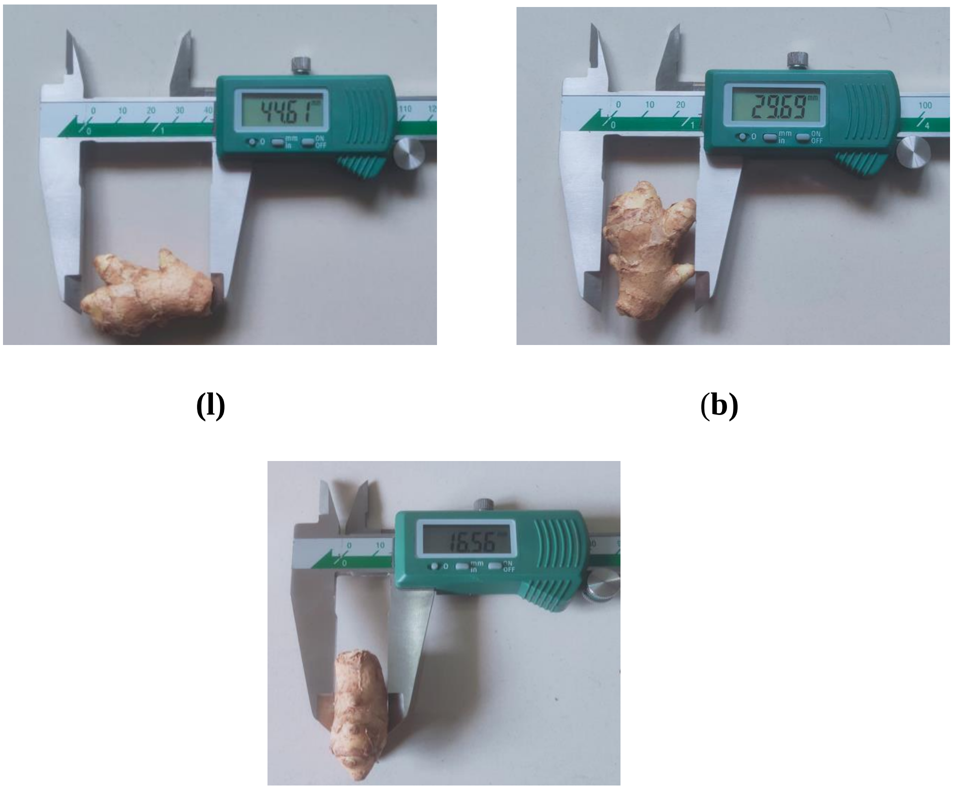
l = length, mm,

b = breadth, mm

t = thickness, mm

Plate 3.4 View of the ginger rhizomes with one or two buds

Plate 3.5 Views of the ginger varieties selected for measuring the physical properties



(l) **(b)**

(t)

Plate 3.6 Measurements of length (l), breadth (b) and thickness (t) of ginger rhizomes

3.4.3 Moisture content

The moisture content of ginger rhizomes was determined by following guidelines of ASAE Standard S358.2 (1993). The sample underwent a drying process in an electric oven at 105°C for 24 hours. Weights were recorded at six-hour intervals to establish four distinct levels of moisture content. The moisture content (per cent) of the sample on a dry basis was calculated using the following formula.

$$\text{MC (per cent)} = \frac{W_i - W_d}{W_i} \times 100$$

Where,

W_i is the initial weight of the ginger rhizomes, g

W_d is the dry weight of the ginger rhizomes, g

3.4.4 Sphericity

Sphericity affects the seed flow through various components of the planter. The sphericity of the rhizomes was computed by using the following equation (Mohsenin, 1986).

$$\text{Sphericity} = \frac{(l.b.t.)^{1/3}}{l}$$

Where,

l = Length of a rhizome, mm

b = Breadth of rhizome, mm, t = Thickness of a rhizome, mm

3.4.5 Bulk density

Bulk density was measured by standard method. Initially an empty cubical container was taken and found out its weight. Then the container was filled with ginger bits and weighed. This was replicated in 5 times. The bulk density was determined by using the following formula (Madhu Kumar, 2017).

$$\text{Bulk density, (kg m}^{-3}\text{)} = \frac{Weight\ of\ rhizome,(kg)}{Volume\ of\ container,(m^3)}$$

3.4.6 True density

The true density of ginger rhizomes was ascertained through a platform scale method (Mohsenin, 1986). Initially, the rhizome sample was weighed by using a precision electronic balance with an accuracy of 0.01 g. Subsequently, the sample was immersed in water contained in a container and mass of the displaced water was measured. These recorded values were substituted in following expression and true volume was calculated. These were replicated in 5 times for determining the true density of ginger rhizomes.

$$\text{True volume, (m}^3\text{)} = \frac{Mass\ of\ displaced\ water,(kg)}{Density\ of\ water,\ \ (kg\ m^{-3})}$$

By having, the mass of ginger rhizomes in air, true volume and true density was calculated as following.

$$\rho_t = \frac{M_a}{V_t}$$

Where,

ρ_t = True density of rhizomes

M_a = Mass of rhizomes in air, kg

V_t = True volume of rhizomes, m^3

3.5 FRICTIONAL PROPERTIES

Angle of repose and coefficient of friction of the different seeds were measured using standard procedures (Tarighi *et al.,* 2011; Mohsenin., 1986).

3.5.1 Angle of repose

The angle of repose was used in determining inclination angle of sides of seed hopper. To measure the angle of repose, a hollow rectangular box was utilized. Initially, the hollow rectangular box was placed on a smooth plain surface and filled it with seeds up to its maximum level. Subsequently, the rectangular box was gently lifted up from the plain surface, allowing the seeds to settle and form a conical heap. Measurements of the diameter and height of the conical heap were taken. This was repeated three times to minimize experimental error. Average values of height and diameter of the heap were measured and the angle of repose was determined using the formula (Mohsenin, 1986).

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right)$$

Where,

θ = Angle of repose

H = Height of the cone, cm

D = Diameter of the cone, cm

3.5.2 Coefficient of friction

Coefficient of friction characterizes resistance experienced between mass of rhizomes and contact surface of container. The coefficient of friction apparatus comprises a horizontal plate, a bottomless open container and a pan connected to the container through a rope and pulley, as depicted in plate 3.7. A known weight of rhizomes was placed in the container and a known weight was added to the surface of the horizontal plate. Weights were incrementally added to the pan connected to the rope in 50 g intervals and moment at which container commenced sliding was considered as the frictional force (F) between the material surface and the seeds. The coefficient of friction was calculated for wood, mild steel, and stainless steel surfaces. A comparison was made to select suitable material for fabricating the rhizome hopper using the following equation given by Chowdareddy and Dronachari (2014).

$$\text{Coefficient of friction, } \mu = \frac{F}{N}$$

Where,

μ = Coefficient of friction

F = Frictional force, N (Force applied)

N = Normal force, N (weight of rhizome)

The procedure was replicated in three times by emptying and refilling the container with different samples on each occasion. The average value was calculated and recorded as the average coefficient of friction.

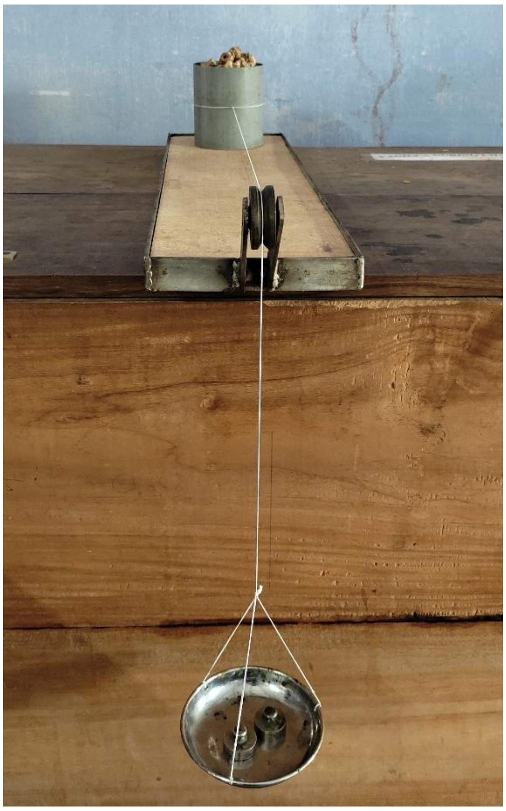


Plate. 3.7 Measurement of coefficient of friction of ginger rhizomes

3.6 DESIGN OF RHIZOME HOPPER FOR LABORATORY SET UP

The rhizome hopper is made of GP sheet.

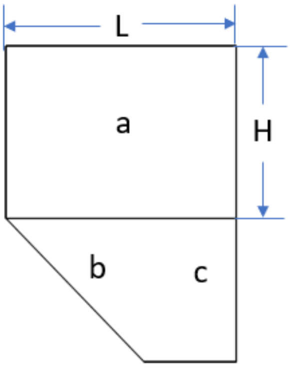


Fig. 3.1 Cross sectional view of rhizome hopper

From above Fig.

$a = L \times W \times H$

$= 250 \times 200 \times 200$

$= 10^7 \text{ cm}^3$

$= 0.01 \text{ m}^3$

$b = \frac{1}{2} \times h \times (a + b) \times w$

$= \frac{1}{2} \times 175 \times (70 + 250) \times 110$

$= 3080 \text{ cm}^3$

$= 0.00908 \text{ m}^3$

$c = \frac{1}{2} \times b \times h \times w$

$= 0.5 \times 0.09 \times 0.175 \times 0.25$

$= 0.00196 \text{ cm}^3$

Total volume of rhizome hopper

= (a + b + c)

= 0.01 + 0.00908 + 0.00196

$= 0.01504 = 0.02 \text{ m}^3$

3.7 POWER TRANSMISSION

Power transmission unit for the laboratory set up was provided. For power transmission, the number of teeth of sprocket mounted on DC motor shaft (T_1) and the rhizome metering shaft (T_2) were 13 and 13 respectively. Pitch of chain (P) was 15.88 mm.

The length of chain between two metering shafts of the laboratory set up was calculated by following equation (Khurmi and Gupta, 2011).

$$L_c = \mathrm{M} \times \mathrm{P}$$

$$\mathrm{M} = \frac{2C}{\mathrm{P}} + \frac{(T_1 + T_2)}{2} + \frac{\mathrm{P}\,(T_2 - T_1)^2}{4\,\pi^2 \times C}$$

Where,

M = Number of links

T_1 = Number of teeth on the drive sprocket = 13

T_2 = Number of teeth on the driven sprocket = 13

C = Centre distance between sprockets = 435 mm

P = Pitch of the chain = 15.88 mm

$$= \frac{2 \times 435}{15.88} + \frac{(13 + 13)}{2} + \frac{15.88\,(13-13)^2}{4\,\pi^2 \times 435}$$

= 54.375 +13 = 67.375

L_C = 67.375 × 15.88

= 1069.91 mm = 1.069 m

3.8 SPEED RATIO OF LABORATORY SET UP

Assuming number of cells selected on the chain is 5 and diameter of ground wheel as 40 cm.

Number of cells per chain = 5

The length of chain, L_c is = 1069 mm
Say, L_c = 1 m
Diameter of ground wheel = 40 cm = 0.40 m
Distance travelled by ground wheel in 1 revolution = π × 40 = 125.66 cm
Number of seeds dropped at a spacing of 15 cm for one revolution of ground wheel

$$= \frac{\text{Distance travelled per revolution,m}}{\text{hill to hill distance, cm}}$$

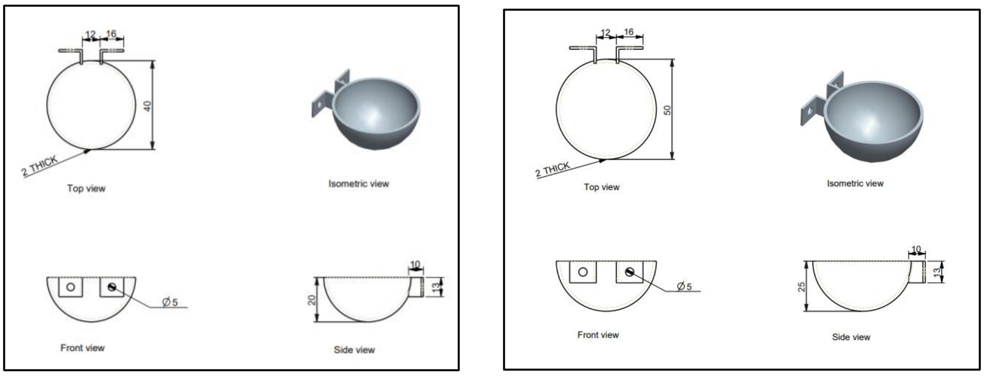
$$= \frac{125.66}{15} = 8.377 \text{ seeds}$$

Length of travel of chain for dropping 8.377 = $\frac{8.377}{5} = 1.675$ m
Length travelled by sprocket in one revolution = π × 6.17= 19.373 cm
= 0.194 m

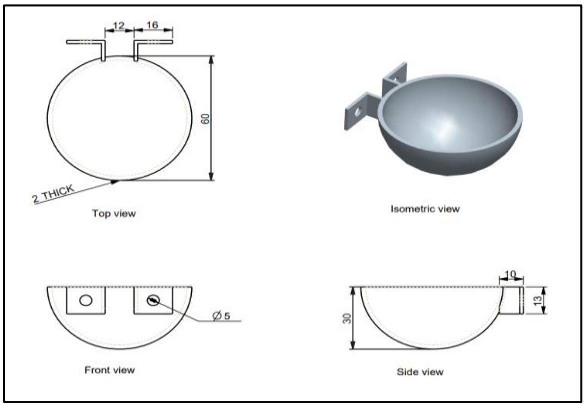
Therefore,

Number of revolutions required for sprocket to cover 1.675 m = $\frac{1.675}{0.194}$ = 8.6

Hence, speed ratio = 1:86 (136±10 rpm)



(a) 40 mm **(b) 50 mm**



(c) 60 mm

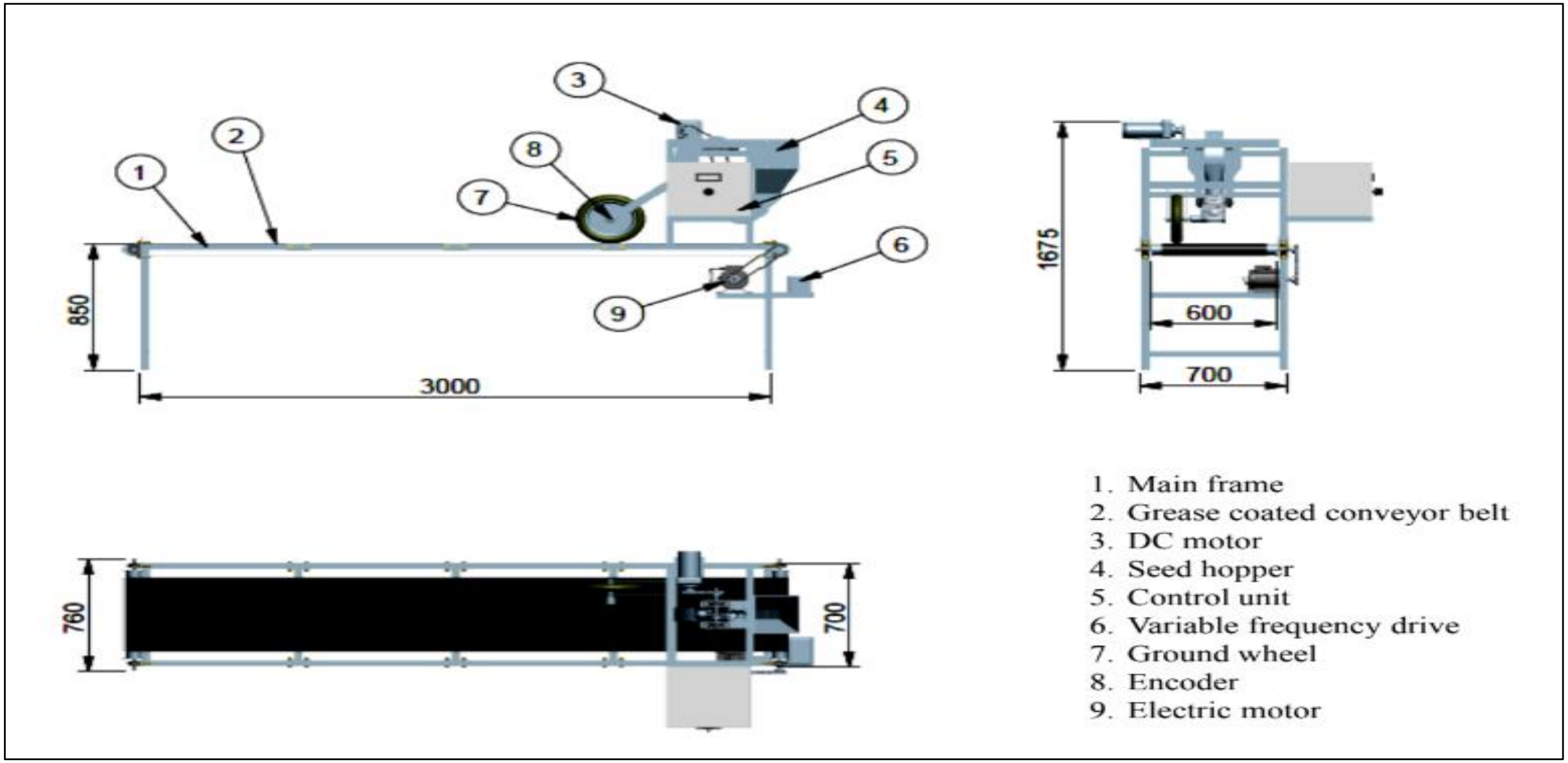
(All dimensions are in mm)

Fig. 3.2 Schematic view of the different cell sizes

Plate 3.8 Developed cell sizes

3.9 DEVELOPMENT OF LABORATORY SET UP FOR THE SENSOR BASED TRACTOR DRAWN GINGER PLANTER

A laboratory experimental set up was developed to investigate the performance of a sensor-based cup feed metering mechanism. The independent variables selected to finding picking efficiency, hill to hill distance, missing index, multiple index, quality of feed index and cell fill efficiency were forward speed (S), Speed of chain (V) and Cell size (C). Laboratory set up was comprising of a mainframe, seed hopper, conveying chain with cells, conveyor belt, AC motor (1hp), DC motor (450 W) and variable frequency drive (VFD). The mainframe was a rectangular section of size 3000 × 850 mm made from 40 × 40 × 3 mm size GI square pipe. The rectangular section was fixed at a height of 800 mm from ground surface with help of 50 × 50 × 5 mm size mild steel (MS), L angle on four sides. Seed metering unit was mounted on the conveyor belt frame with power transmitting unit. Length, width and thickness of endless conveyor belt were 3000, 400 and 2 mm respectively. The conveyor belt was rotated through a pair of 70 mm diameter rollers. These two rollers were mounted on a 20 mm diameter shaft at two ends of the rectangular section with self-aligning bearings. The drive to the conveyor belt was obtained from a 1 hp AC motor through chain and sprocket drive fitted with a 70 mm diameter roller shaft. A variable frequency drive (VFD) unit was used to regulate the belt linear speed. The speed of DC motor was controlled by a speed controller by measuring with a non-contact type tachometer (0 to 1000 rpm). During testing, the grease was applied thoroughly on the conveyor belt to stick the seed for measuring performance parameters. The laboratory set up and cells were shown in Fig. 3.2, 3.3 and Plate 3.8. The specification of the laboratory set up was presented in Table 3.2.



All dimensions are in mm

Fig. 3.3 Schematic view of the laboratory set up for the sensor-based tractor drawn ginger planter

Table 3.2 Specifications of laboratory set up

Sl.	Item	Values
A	**Overall dimensions (L X B X T), mm**	3000 × 400 × 2
B	**Size of the rectangular section (L X B), mm**	3000 × 400
C	**Seed metering unit**	Cup feed type
i.	The shape of the rhizome box	Trapezoidal and rectangular
ii.	Diameter of seed metering shaft, mm	20
iii.	Number of cells on seed metering chain	5
D	**Conveyor belt**	
i	Material	Sandwich nylon belt
ii	Width, mm	400
iii	Length, mm	3000
iv	Thickness, mm	2
E	**DC Motor**	
i	Voltage, V	24
ii	Power, watts	450
iii	Current, amp	24
iv	Type	Geared motor
F	**Power transmission**	
Type	AC power, variable frequency driven type	1 hp
Mode of transmission	Chain and sprockets drive	
i	Diameter of the sprocket attached to the shaft of the AC motor output shaft, mm	600
ii	Speed ratio between the DC motor output shaft and seed metering driveshaft	1: 1
iii	The diameter of the sprocket mounted on a conveyor belt shaft, mm	600

3.9.1 Main frame

Main frame having size 3000 × 850 × 800 mm was fabricated for accommodating 3- phase AC motor (1 hp), variable frequency drive, supporting angular bars, electronic control unit, DC motor, chains and sprockets.

3.9.2 Grease coated conveyor belt

The endless sand witch nylon type conveyor belt of size 3000 × 400 × 2 mm was used and fitted to the laboratory set up.

3.9.3 DC motor

A DC geared motor (Fig. 3.4) is an electromechanical device that integrates a direct current (DC) motor through a gearbox or gearhead to provide controlled and precise motion. These motors are commonly used in a variety of applications, offering options for both brushed and brushless DC motors. They are available in different voltage and current ratings, viz., 12V, 24V and 48V and can be customized with specific gear ratios to achieve desired output speed and torque. DC geared motors are favoured for their efficiency, reliability and suitability for applications requiring energy-efficient and controlled motion, such as in robotics, automation, conveyor systems, automotive systems and medical devices. Their size and mounting options can be tailored to fit various configurations, and additional control mechanisms like pulse-width modulation (PWM) and encoders are often used to fine-tune their performance. The rhizome metering shaft was driven with a 24V DC motor instead of driving with a chain and sprockets system from the ground wheel. It receives the signals from DC motor and transmits the rotational motion of the rhizome metering unit. The power available at the tractor was utilized to operate the DC motor.

Fig. 3.4 DC geared motor

3.9.3.1 Motor specifications

- Rated power: 450W.
- Rated voltage: 24V.
- Base motor RPM: 3000 RPM.
- Actual speed: 450 RPM.
- No load current: 2.5 A.
- Full load current: 24 A.
- Rated Torque: 76 Kg-cm.
- Motor Weight: 5.6 kg**.**

3.9.4 Seed hopper

The seed hopper was made up of 16-gauge GP sheet metal with dimensions of 250 mm length, 200 mm width and 375 mm height. The volume of rhizome hopper is 0.02 m^3.

3.9.5 Control Unit

3.9.5.1 Arduino Nano

Arduino Nano (Fig. 3.5) is a versatile microcontroller board designed for use on a breadboard, featuring integrated USB connectivity. Its pin layout is compatible with other popular microcontrollers like the Mini and Basic Stamp, with TX, RX, ATN, and GND conveniently grouped on one side, and power and ground pins on the other side. In this research, a version 3.0 of the Arduino Nano equipped with ATMEGA328 microcontroller was used for establishing communication with various controllers and computer. This communication primarily occurs through the digital pins, with pin 0 (Rx) used for receiving data and pin 1 (Tx) used for data transmission. To facilitate this communication, the Arduino Software includes a serial monitor that enables the exchange of textual data between the board and external devices. Arduino Nano pin configurations are shown in table 3.3.

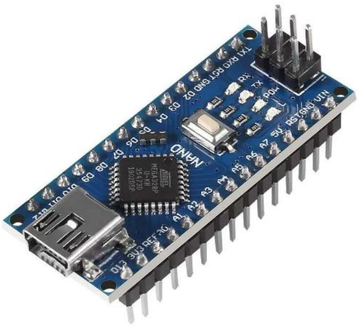


Fig. 3.5 Arduino Nano

Table 3.3 Arduino Nano pin configurations

S. No	**Pin Category**	**Pin Name**	**Details**
1	Power	Vin, 5V, GND	**Vin:** Input voltage to Arduino when using an external power source (6-12V). **5V:** Regulated power supply used to power Arduino Nano and other components on the board. **GND:** Ground pins.
2	Reset	Reset	Resets the Arduino Nano.
3	Analog Pins	A0 – A7	Used to measure analog voltage in the range of 0-5V
4	Input/Output Pins	Digital Pins D0 - D13	Can be used as input or output pins. 0V (low) and 5V (high)
5	Serial	Rx, Tx	Used to receive and transmit TTL serial data.
6	External Interrupts	2, 3	To trigger an interrupt.
7	PWM	3, 5, 6, 9, 11	Provides 8-bit PWM output.

3.9.5.2 Cytron 30 Amp DC Motor Driver

The Cytron 30 Amp DC Motor Driver, known as the MD30C was engineered to handle medium to high-powered brushed DC motors with an impressive current capacity up to 80 A at peak performance and 30 A for continuous operation. Its fully NMOS design not only ensures rapid switching times but also enhances efficiency, eliminating the need for additional heatsinks or fans. Notably, MD30C boasts user-friendly features like reverse polarity protection and an onboard PWM generator, enabling standalone operation without a host controller. Motor control becomes effortless using the built-in switches and speed potentiometer, while external switches and potentiometers can also be seamlessly integrated for added flexibility and control. It was shown in Fig 3.6 and 3.7.

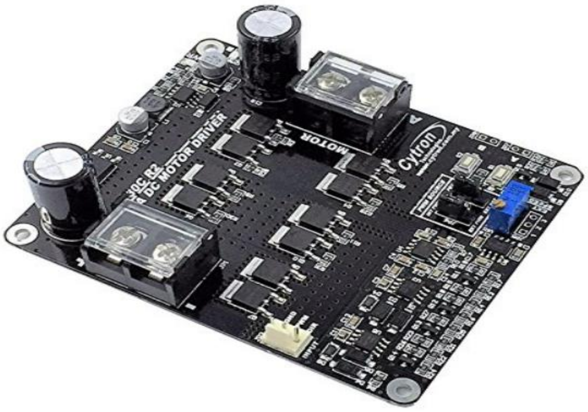


Fig. 3.6 Cytron 30 Amp DC Motor Driver

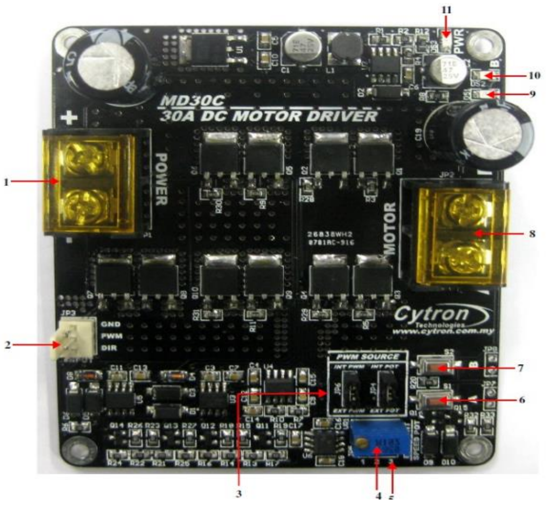


Fig. 3.7 Cytron 30 Amp DC Motor Driver Board layout

3.9.5.2.1 Power terminal block

Attach to a power source by soldering the wire directly into the pad on the bottom layer, especially for high-current applications.

3.9.5.2.2 Input pins of Cytron 30 Amp DC Motor Driver Board layout

The details of input pins of Cytron 30 Amp DC Motor Driver Board layout are given below.

Pin No	Pin Name	Description
1	GND	Ground
2	PWM	PWM input for speed control
3	DIR	Direction input

3.9.5.2.3 PWM Source selector

The details of PWM Source selector of Cytron 30 Amp DC Motor Driver Board layout are given below.

PWM Source	JP4	JP6
Internal potentiometer	INT POT	INT PWM
External Potentiometer	EXT POT	INT PWM
External PWM signal	X	EXT PWM

3.9.5.2.4 Internal PWM potentiometer

It is used to control the motor speed when PWM source is internal potentiometer.

3.9.5.2.5 External potentiometer port

It is used to connect with the external potentiometer (10K Ohm) to control the motor speed when PWM source is external potentiometer.

3.9.5.2.6 Test button – A

When this button is pressed, current flows from output A to B and motor will turn CW (or CCW depending on the connection). External switch can also be connected for the ease of access.

3.9.5.2.7 Test button – B

When this button is pressed, current flows from output B to A and motor will turn CCW (or CW depending on the connection). External switch can also be connected for the ease of access.

3.9.5.2.8 Motor terminal block

It connects to motor. For high current application, soldering of the wire directly to the pad at bottom layer.

3.9.5.2.9 RED led – A

Turns ON when the output B is low and output A is high. Indicates the current flows from output A to B.

3.9.5.2.10 RED led – B

Turns ON when the output A is low and output B is high. Indicates the current flows from output B to A.

3.9.5.2.11 Green power LED

It turn on when the MD30C is powered up.

3.9.6 LCD display

An LCD, which stands for Liquid Crystal Display, is an electronic display module that utilizes the light-modulating characteristics of liquid crystals to create a flat-panel display and other electronically controlled optical devices. LCD modules are used to convey textual information to the user.

LCDs provide users with exceptional flexibility, allowing them to display the necessary data. A 16 × 2 LCD module is a fundamental component commonly employed in numerous devices and circuits. They are the preferred choice over seven-segment and other multi-segment LEDs. However, an LCD alone, without a driver, cannot display data received from an Arduino Nano. In this context, the LCD is equipped with a dedicated LCD driver, serving as a crucial intermediary between the Arduino Nano and the LCD module. This driver features an 8-bit data interface and control pins.

The LCD provides a convenient means to monitor crop spacing during both laboratory and field operations. When the switching regulator is adjusted to a range of 15-20 cm, as dictated by the Arduino program, the entire system is finely tuned to achieve the desired spacing. The LCD display is shown in Fig. 3.8.

Fig. 3.8 LCD display

3.9.7. Variable frequency drive (VFD)

A variable frequency drive (VFD), also known as a variable speed drive (VSD), is a type of motor controller that adjusts frequency and voltage supplied to an electric motor. This control allows for the precise regulation of the motor's speed and torque, enabling efficient operation across a wide range of speeds. VFDs are commonly used in industrial and commercial applications to optimize energy usage, enhance process control, and extend the lifespan of machinery by reducing wear and tear associated with frequent starts and stops. They are particularly beneficial in systems where the load demand fluctuates or where precise control over motor speed is required.

3.9.8 Drive wheel

The wheel features with number of spokes made up of stainless steel. The spokes are attached to the rim and drive wheel hub at the center of wheel. The diameter of wheel is 400 mm. the drive wheel securely attached to the main frame of the rhizome hopper with the necessary supporting frame works. Rotary shaft encoder was fixed at the drive wheel shaft, it gives the pulse count (one revolution of ground wheel equal to 400 pulse count) to the Arduino Nano. An Arduino board is programmed to regulate crop spacing by calculating the drive wheel distance per revolution.

3.9.8.1 Rotary encoder

A rotary encoder, sometimes referred to as a shaft encoder, is an electro-mechanical apparatus designed to transform the angular position or movement of a shaft or axle into analog or digital output signals. The output generated by an incremental encoder offers valuable insights into the shaft's motion and this data is typically processed elsewhere to extract information regarding factors like position, velocity and distance. When it comes to measuring speed, a rotary encoder proves to be the most effective method. In the context of this study, a rotary encoder operating within the voltage range of 5-24 VDC was employed to gauge the speed of the ground wheel.

A forward speed sensor, which is essentially an encoder, plays a crucial role in establishing a relationship between the rotational speed of the rhizome metering and the ground wheel. The encoder and decoder (DC motor drive) are both situated within the electronic control unit. The encoder was affixed to the ground wheel, as illustrated in Fig. 3.9. This rotary encoder is linked to the Electronic Control Unit (ECU) via a cable connection.

The Arduino Nano effectively collected a stream of pulses generated by the sensor and these pulses were processed to determine both the total distance travelled and the current travel speed. Leveraging this travel speed data, the motor responsible for driving the seed metering mechanism was synchronized to dispense rhizomes at the appropriate intervals, maintaining the desired spacing between rhizomes. This precise seed synchronization was achieved by regulating the input to the high-current driver circuits through the PWM channel of the Arduino Nano.

Fig. 3.9 Rotary Encoder

3.9.8.2 Amaron 12 V DC Battery

A battery is a power source that gives electric power supply to Cytron 30 Amp DC Motor Driver. It connects to DC motor, Arduino Nano, rotary shaft encoder and LCD display. For this study we used two 12 volts (Fig. 10) DC batteries connected through series to get 24 V DC supply to DC geared motor (24V, 30 Amp, 430 RPM and 450 W).

Fig. 3.10 Amaron 12 V DC Battery

3.9.9 Electric motor

The electric motor was placed at the bottom part of frame. The drive to the conveyor belt was obtained with the help of 1 hp AC motor with a 70 mm diameter roller shaft connected through chain and sprockets.

3.10 PROGRAMMING SOFTWARE

The Arduino Integrated Development Environment, commonly known as the Arduino Software (IDE), comprises a comprehensive set of tools. These include a text editor for code creation, a message area, a text console, a functional toolbar with commonly used operation buttons and various menus. The IDE acts as the interface facilitating communication with Arduino hardware for program uploads. Within the IDE, code is written in the form of "sketches" and saved with specific file extensions. The text editor provides tools for editing, such as cutting, pasting and text searching/replacing. The message area offers real-time feedback during various actions, including error notifications. The console displays textual output, including detailed error messages and other relevant information. In the lower right corner, essential details like the configured board and serial port are available. The toolbar includes buttons that streamline tasks such as code verification, program uploads, sketch management and access to the serial monitor. Schematic diagram for electronic circuit for sensor based tractor drawn ginger planter was shown in Fig 3.11. The program data for the Arduino Nano board used in the laboratory test is provided in appendix-I, while the program for field evaluation is detailed in Appendix-II.

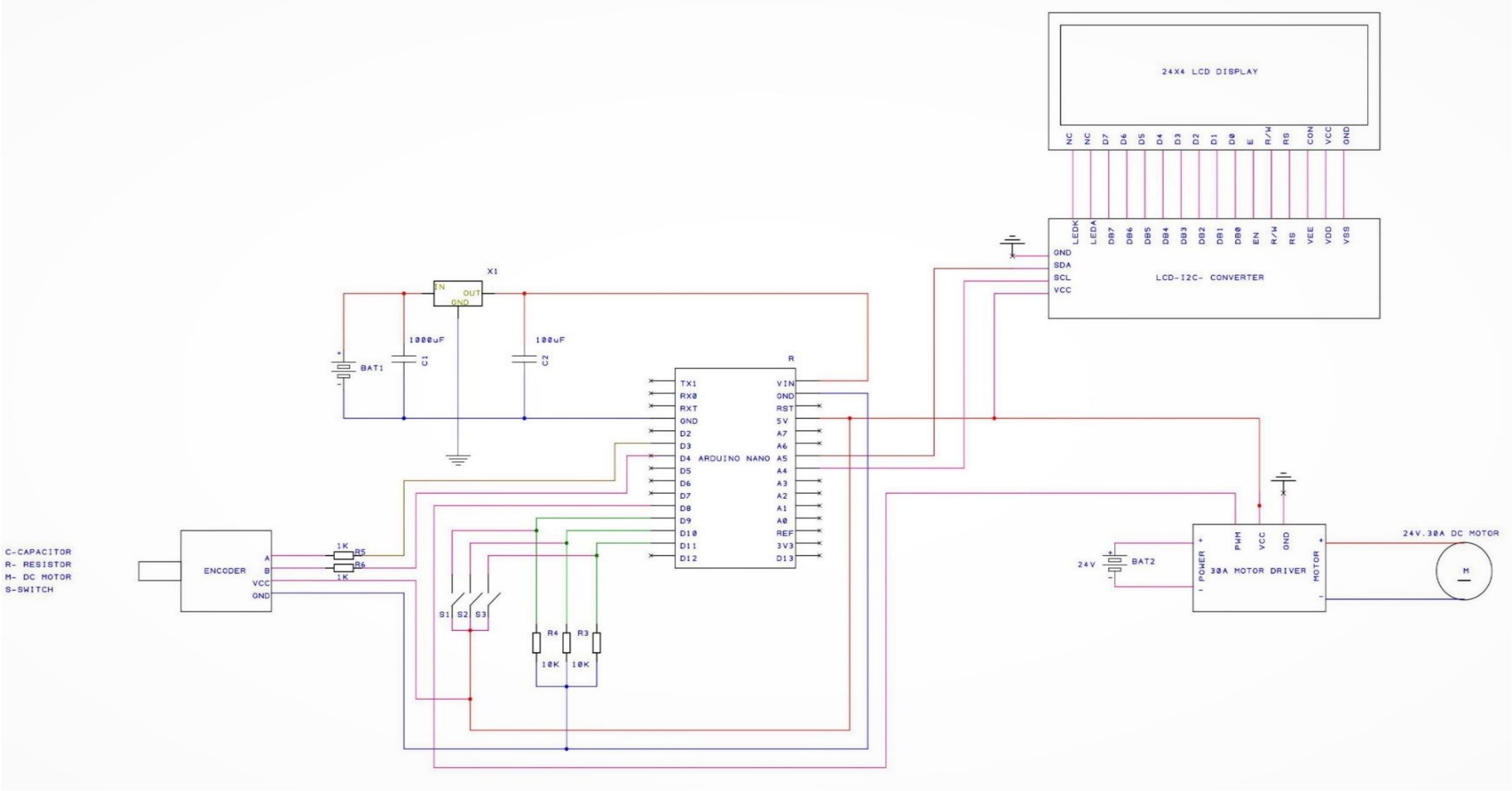


Fig. 3.11 Schematic diagram of electronic circuit for a sensor-based tractor drawn ginger planter

3.11 SELECTION AND TEST PERFORMANCE OF GINGER PLANTER

Independent variables

i. Forward speed of tractor S_1 S_2 S_3
ii. Speed of chain V_1 V_2 V_3
iii. Cell sizes C_1 C_2 C_3

Dependent variables

i. Missing index, (per cent)
ii. Multiple index, (per cent)
iii. Quality of feed index, (per cent)
iv. Cell fill efficiency (per cent)
v. Hill to hill distance, (cm)

3.11.1 Selection of test parameters

Laboratory tests using sticky belt was conducted to test the performance of sensor-based cup feed type metering mechanism. The belt linear speed and speed of chain was varied during the laboratory tests for different cell sizes.

3.11.1.1. Independent variable

Sensor based planting is the proper placement of seeds in a row at a uniform depth and recommended seed spacing without seed damage and seed missing index. The performance of the planters depends on the cell size, the rotational speed of the DC motor and belt speed. The parameters viz., belt linear speed, the speed of metering disc and cell size had a large effect on the accuracy of longitudinal seed distribution.

The effect of operational speed of metering mechanism disc and cell geometry have influenced the precision in spacing, miss index, multiple index and quality of feed index (Singh *et al.*, 2005).

3.11.1.2 Forward speed of operation

The performance of a planter depends upon the forward speed of operation which affects the precise planting or seeding parameters like spacing, quality feed index, seed rate and seed damage. The variability in seed spacing increased with an increase in peripheral velocity of the seed metering roller. To determine the optimum forward speed, it is recommended that five levels of forward speed viz., 1, 1.5, 2.0, 2.5 and 3.0 km h^{-1} were given (Moody *et al*., 2003).

Similarly, in this study, the primary focus on evaluating planter performance, specifically in relation to the forward speed of operation. This factor significantly influences performance parameters such as hill to hill distance, miss index, multiple index, quality of feed index, and cell fill efficiency. The aim is to determine the optimal speed and experiments were conducted at speeds of 1, 1.5 and 2 km h^{-1}.

3.11.1.3 Speed of chain

In this study, a 5/8th clipping chain was chosen and cells were fixed to the chain with nut and bolt. This configuration enhances the strength of both the cup and the chain under operational conditions, ensuring robust performance without encountering obstacles (Kumar and Singh 2019).

3.11.1.4 Size of cell

For selecting the size of cells, length, breadth and thickness of the rhizome seed bits were considered. Accordingly, three levels of cells namely 40 (C_1), 50 (C_2) and 60 (C_3) mm were selected. The equivalent diameter was adopted as the cell depth for seed cell design, as per (Leela 2019). The design of the cell size, based on the physical and engineering properties of the seeds, involved a cell diameter approximately 10 per cent greater than the maximum seed dimension and the cell depth was set to the average seed diameter or thickness, following the principles outlined by Kepner *et al*., (1987) and Jayan and Kumar (2004).

3.12 LABORATORY EVALUATION OF A SENSOR-BASED TRACTOR DRAWN GINGER PLANTER

The planter’s performance indices, including hill to hill distance, multiple index, miss index, quality of feed index and cell fill efficiency were calculated with respect to theoretical spacing. The procedure outlined by Kachman and Smith (1995) and Al-Gaadi (2011) as detailed below were adopted for the laboratory evaluation.

3.12.1 Missing index

Missing index (I_{miss}) is an indicator of how often the seed skips the desired spacing. It is the percentage of spacing greater than 1.5 times the theoretical spacing S in mm. The missing index is mathematically as follows.

$$I_{miss} = \frac{n_1}{N} \times 100$$

Where,

n_1 = Number of spacing in the region > 1.5 S

N = Total number of observations

3.12.2 Multiple index

The multiple index (I_{mult}) 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 S in mm. The multiple index is mathematically expressed as follows.

$$I_{mult} = \frac{n_2}{N} \times 100$$

Where,

n_2 = Number of spacing in the region $\leq$ 0.5 S

N = Total number of observations

3.12.3 Quality of feed index

The quality of feed index (I_{fq}) is the measure of how often the spacing were 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 S in mm. The quality of feed index is mathematically expressed as follows.

$$I_{fq} = 100 - (I_{miss} + I_{mult})$$

Where,

I_{miss} - Miss index, per cent

I_{mult} - Multiple index, per cent

3.12.4 Cell fill efficiency

Per cent cell fill efficiency for a given planter is influenced by the diameter of the cell, speed of the metering mechanism and size of seeds picked. Per cent cell fill efficiency is defined as the total number of seeds discharged divided by the total number of cells passing the discharge point. The most uniform seed distribution is obtained with a combination of uniform size of seeds that suits the cell size and cell shaped will give about 100 per cent cell fill.

According to Kepner *et al.*, (1987), the cell diameter or length should be about 10 per cent greater than the maximum seed dimension and the cell depth should be about equal to the average seed minor diameter or thickness.

3.12.5 Mean rhizome spacing

Average rhizome spacing indicates average value of spacing measured between two consecutive seeds in a row. It was measured using a standard measuring scale (Madhukumar, 2017).

$$D = \frac{\Sigma s_a}{N}$$

Where,

S_a = Actual spacing between two consecutive seeds

N = Total number of observations

Laboratory study was carried out for ginger at various levels of cell sizes (3 levels), forward speed (3 levels) and speed of chain (3 levels) and was replicated in three times (3×3×3×3 = 81 treatments). Each trial was studied in detail and the data recorded at various levels of observations are statistically analysed to optimize the parameters for developing ginger planter.

In this study the selected variables were Forward speed (S) 1 (S_1), 1.5 (S_2), 2 (S_3), km h^{-1}, Speed of chain (V) 126±10 (V_1), 136±10 (V_2), 146± 10 (V_3), rpm and Cell size (C), 40 (C_1), 50 (C_2), and 60 (C_3) mm to determine the superior performance of cell size, forward speed and speed of chain. The test was conducted with the 5 cells per chain with the same diameter of the cell size, it was replicated three times to optimizing performance parameters of the planter. Randomly 25 rhizomes each from four varieties were selected and cut with one or two buds and filled in hopper of the test rig. The procedure involved switching on the grease-coated belt for rotation and activating the seed metering mechanism. Rhizomes were permitted to drop directly onto the rotating grease-coated belt. After one complete rotation of the belt, both the grease-coated belt and the metering mechanism were halted. The hill-to-hill distance on the grease coated belt was measured in each treatment and the procedure was continued up to 81 treatments. Metering mechanism performance was statistically analysed for hill-to-hill distance, miss index, multiple index, cell fill efficiency and feed quality index. The developed laboratory set up was shown in plate. 3.9. The experiment was conducted in the laboratory of the Department of Farm Machinery and Power Engineering, KCAEFT, Tavanur.

Plate 3.9 Developed laboratory set up for the sensor-based tractor drawn ginger planter

3.13 CALIBRATION UNIT

The performance of the tractor operated rhizome planter was tested in the laboratory. The calibration is done to get a predetermined rhizome rate of the planter. The following procedure was followed for calibration of the sensor-based tractor drawn ginger planter.

1. Determine the nominal width of the planter

   $$W = M \times S$$

   Where,

   M = Number of furrow openers

   S = Spacing between the furrow openers, m

2. Find the length of the strip (L) having nominal width W necessary to cover

   1/ 25th of a hectare

   $$= \frac{10000}{w} \times \frac{1}{25}$$

3. Determine the number of revolutions (N) the ground wheel has to rotate to cover the length of strip (L)

   Where,

   D = diameter of the ground wheel, m

   $$N = \frac{10000}{\pi \times D \times w} \times \frac{1}{25}$$

   $$N = \frac{400}{\pi \times D \times w}$$

4. Jack up the planter so that the ground wheels rotate freely. Make a mark on the drive wheel and make another mark at a convenient place on the body of the planter to count the number of revolutions of the drive wheel
5. Put the selected seed in the seed box. Place a sack or a container under each boot for seed tube for collecting the dropped rhizomes.
6. Rotate the drive wheel for N revolutions.
7. Weigh the quantity of seed dropped from each boot
8. Calculate the seed dropped and collected in kg ha^{-1}.

3.14 MECHANICAL DAMAGE OF RHIZOME

To assess the impact of mechanical damage on rhizome germination, it is essential to determine the percentage of mechanical damage. To conduct the experiments, only injury free rhizome was chosen and used. After the test, weight the damaged rhizomes within a two-kilogram sample and calculate the percentage of damaged rhizomes.

3.15 PRECISION PLANTING

Precision planting involves the precise placement of individual seeds in a row, maintaining specific spacing and planting depth, particularly for vegetable crops. This approach aims to establish an optimal environment for uniform germination. In precision seed planting for spices, vegetables, pulses and other crops, the main goal is to minimize the thinning. This is achieved by strategically placing more seeds than required for the recommended plant population, thereby reducing the costs associated with thinning.

3.15.1 The principal requirements for precision planting with a cup feed type metering mechanism are

1. Average size of ginger rhizome is 50 mm after cutting with a one or two buds.
2. The seeds must have an adequate opportunity to pick the single seed from rhizome hopper.
3. There is no chance to pick multiples because cell size is 50 mm.
4. Unloading the seeds from cells must be positive.
5. Seeds should not get damaged to affect the germination.
6. The conveyance of seeds from the metering unit to the bottom of the furrow boot should ensure spacing pattern generated by the metering mechanism.
7. Seeds need to be positioned at the correct depth within furrows, minimizing any bouncing or rolling in the furrow.
8. The seeds should be uniformly covered with the soil and compact to the proper degree to achieve a favourable environment for germination.

3.16 THEORETICAL CONSIDERATION

Based on literature review and laboratory studies, the following theoretical design considerations have been considered and discussed under following sub-sections.

3.16.1 Design considerations for the development of a sensor based tractor drawn ginger planter

The following design requirements were envisaged for the development of proposed rhizome planter. The developed planter will have a sensor based vertical cup feed type metering mechanism to achieve desired seed rate.

i. It should open furrows, meter and drop rhizomes in the furrows and cover with the soil in single pass.
ii. The rhizome dropped in the furrows should be covered with soil and compacted
iii. The total power rquirement should not exceed the horse power capacity available in the tractors.
iv. The hill to hill distance should be at 15-20 cm.
v. The depth of placement of rhizomes should be at 4-10 cm.
vi. The operating width of implement should cover the wheel track of the tractor.
vii. The implement should not cause soil compaction which inhibit plant growth.
viii. The implement should be simple in operaton and ease to manufacture at cheap cost.

3.16.2 Functional design of rhizome planter components

The design calculations of functional components of rhizome planter are given below.

3.16.2.1 Design of rhizome hopper

The rhizome hopper is made of GP sheet. The length of rhizome hopper is given by

Length of seed hopper (L) = Working width of planter- 2b

Where, b = distance between the rhizome hopper wall to outer end of the frame (15 cm)

So, working width of the planter = Number of ridger bottoms × Row spacing

= 4 × 45 = 180 cm

Therefore,

Length of rhizome box (L) = 180 – 2 (15)

= 150 cm

Now, the recommended seed rate of ginger = 1500-1800 kg ha^{-1}

Let us assume, speed of planter is 1.5 km h^{-1} and field capacity 60 per cent

Actual capacity of planter =

$$\frac{\text{Speed }((\text{km } h^{-1}) \times (\text{Working width of planter, m}) \times \text{Field capacity}}{10}$$

$$= \frac{1.5 \times 1.8\ \times 0.6}{10} = 0.162\ ha\ h^{-1}$$

Let us design a rhizome box for such a capacity, assuming that it requires refilling of rhizomes after 0.5 hour

Therefore,

Weight of rhizomes to be used in 0.5 h

= Seed rate (kg ha^{-1}) × Area covered per hr × Time (h)

= 1500 × 0.162 × 0.5

= 121.5 kg

$$\text{Volume of rhizome hopper} = \frac{\text{Weight of rhizomes, (kg)}}{\text{Bulk density kg m}^{-3}}$$

= Bulk density of ginger = 429.44 kg m^{-3}

Therefore,

Volume of rhizome hopper (V_s) $= \frac{121.5}{429.44} = 0.28$ m^3

Volume of rhizome hopper (V_s) $= 0.28$ m^3

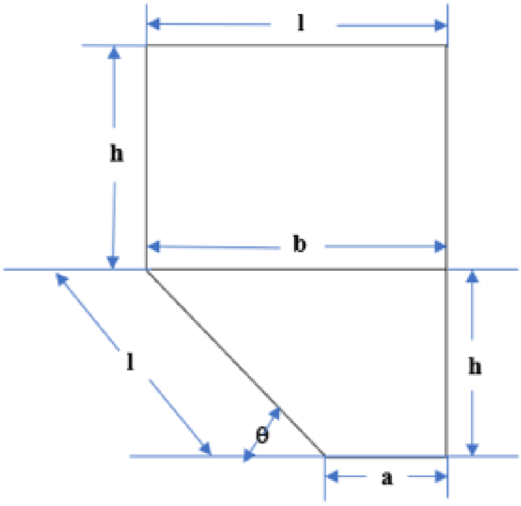


Fig. 3.12 Cross sectional view of rhizome hopper

From the above fig,

L= 0.5 m b = 0.4 m h= 0.3 m,

Volume of cuboid (A) = l × b × h = 0.5 × 0.4 × 0.3

= 0.06 m^3

Trapezoidal portion, $= \frac{1}{2}(a + b) \times l \times h$

a = 0.09 m,   h = 0.25

b = 0.5 m,   l = 0.8 m

Volume of trapezoidal portion (B) $= \frac{1}{2}(0.09 + 0.5) \times 0.25 \times 0.8 = 0.059$ m^3

Total volume of 1 hopper = A+ B = 0.06 + 0.059 = 0.119 m^3

Volume of 3 hoppers = 0.119 × 3 = 0.35 m^3

Hence, the specifications of rhizome seed hopper are,

Length of rhizome hopper = 150 cm

Top width of rhizome hopper = 40 cm

Bottom width of rhizome hopper = 20 cm

Height of the rhizome hopper = 55 cm

Angle of repose = 40^0

3.16.2.2 Design of ground wheel

Diameter of ground wheel = 57 cm = 0.57 m

Circumference of ground wheel = π × D = 3.14 × 0.57 = 1.79 m

Say, 1.80 m

Area covered for one revolution = Circumference of ground wheel × width of planter

= 0.57 × 1.8

= 1.02 m^2

Number of revolutions, ha^{-1} = $\frac{10000}{1.02}$ = 9803 revolutions

The range of hill to hill distance = 15 to 20 cm

3.16.2.2.1 Speed ratio

Assuming no of cells per chain = 9

The Length of chain is = 1.90 m

Diameter of ground wheel = 57 cm = 0.57 m

Distance travelled by ground wheel in 1 revolution = π × 57 = 179.07 cm

Number of seeds dropped for a spacing of 15 cm $= \frac{179.07}{15} = 11.938$ seeds

Length of travel of chain for dropping = 11.938 = $\frac{11.938}{9} = 1.326$ m

length travelled by sprocket in one revolution = 0.194 m

Therefore, Revolution sprocket for covering 1.326 m = $\frac{1.3264}{0.194}$ = 6.80 revolutions

Number of rhizomes per revolution of ground wheel

$$= \frac{\text{Distance travelled per revolution, m}}{\text{Hill to hill distance, m}} = \frac{1.79}{0.20} = 8.95 \approx 9\ cells$$

For ginger = 1:68 (96±10 rpm)

3.16.2.3 Kinematics of chain drive

Let, N_1 = Number of teeth on drive sprocket = 13

N_2 = Number of teeth on driven sprocket = 13

T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8 = Number of teeth on the driven between rhizome metering shaft, in rpm

At rhizome metering shaft

For 1:1 gear ratio

$T_1 = 13$, $T_2 = 13$, $T_3 = 13$, $T_4 = 13$, $T_5 = 13$, $T_6 = 13$, $T_7 = 13$ and $T_8 = 13$

$$\frac{T_1}{T_2} = \frac{T_3}{T4} = \frac{T_5}{T_6} = \frac{T_7}{T8} = 1$$

3.17 TORQUE REQUIREMENT

The force applied at any point to cause a turning effect is called torque. The torque (T) is the product of force (F) and distance (r) of force from centre of shaft. (Sahay., 2009).

Torque = Force × Radial distance

= (ginger weight (g) + cup weight (g)+ shaft weight (g)) × 0.035 (m)

= (540 + 2970 + 8400) × 0.035

= 11910 × 0.035 = 416.85 gm

$$= \frac{416.85}{10000} = 0.41685 \times 9.81$$

= 4.089 Nm

3.18 POWER REQUIREMENT

The term "power requirement" refers to the amount of electrical power or energy needed to operate a particular device or system. It is a quantitative measure of the rate at which energy is consumed or utilized to perform specific tasks or functions.

Power requirement is typically expressed units of watts (W) or kilowatts (kW), where 1 kilowatt is equal to 1000 watts. It can also be expressed in terms of horsepower (hp) for certain mechanical systems. (Sahay, 2009).

$$P = \frac{2\pi NT}{60}$$

$$= \frac{2 \times 3.14 \times 108 \times 4.089}{60}$$

$$= 46.22 \text{ watts}$$

Here, including the mechanical losses, frictional losses and transmission losses etc.

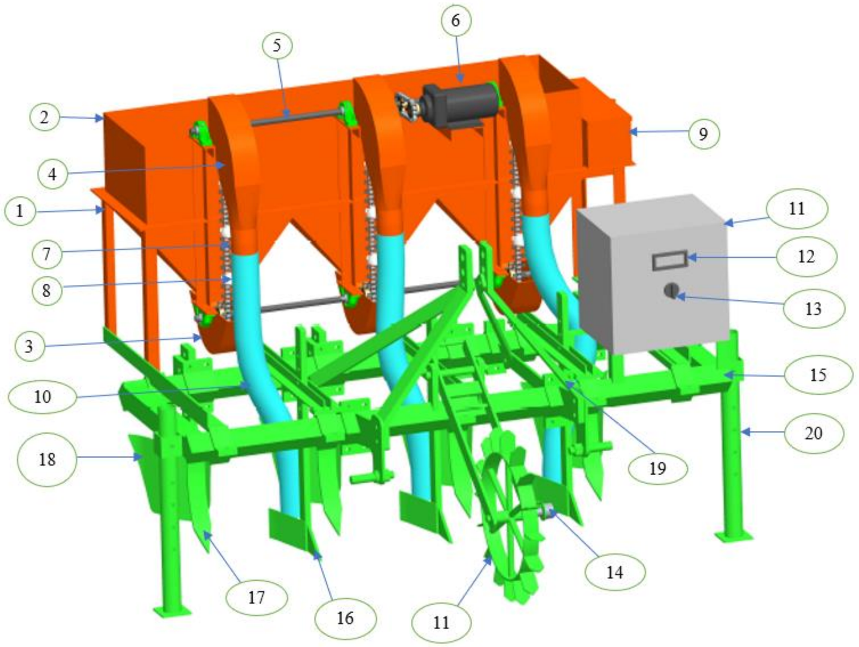
$$= \frac{46.22}{0.92 \times 0.97 \times 0.85}$$

$$= 60.932 \times 3$$

$$= 182.796 \text{ watts}$$

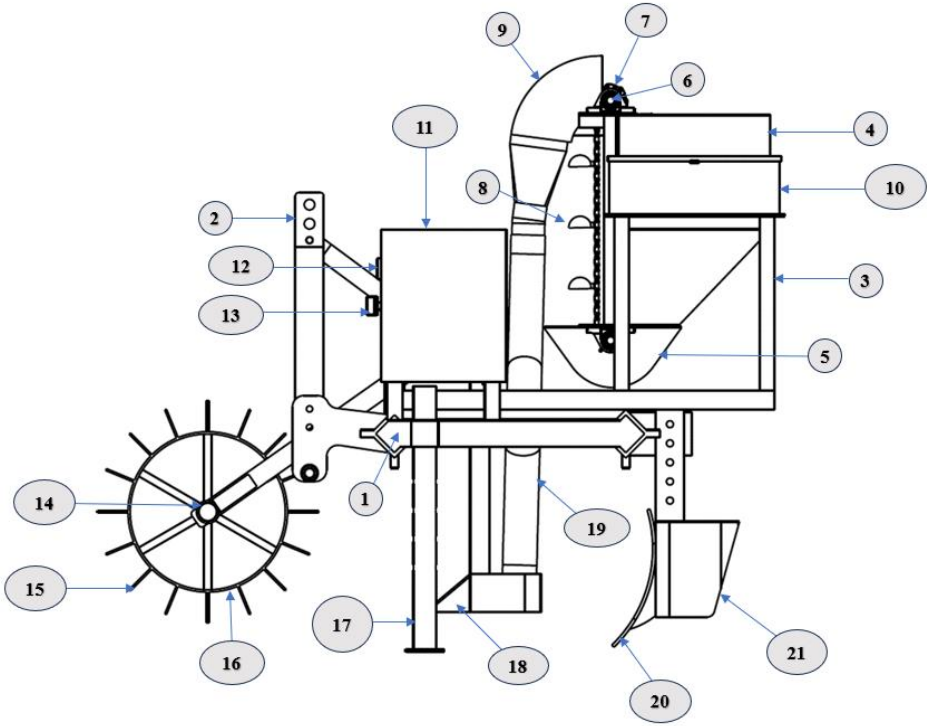
3.19 DEVELOPMENT OF A SENSOR-BASED TRACTOR DRAWN GINGER PLANTER

A prototype of sensor-based rhizome planter as an attachment to existing tractor drawn ginger planter was designed and developed with optimised levels of variables. The prototype of sensor-based rhizome planter consists of rhizome hopper frame, rhizome hopper, seed delivery hopper, seed delivery tube, rhizome collecting device, power transmission system, main frame, ridger bottom, shoe type furrow opener and ground wheel. The isometric and orthographic views of developed rhizome planter was shown below. The constructional details of the rhizome planter were shown from Fig. 3.13 to Fig. 3.18. and Plates from 3.10 to 3.16.



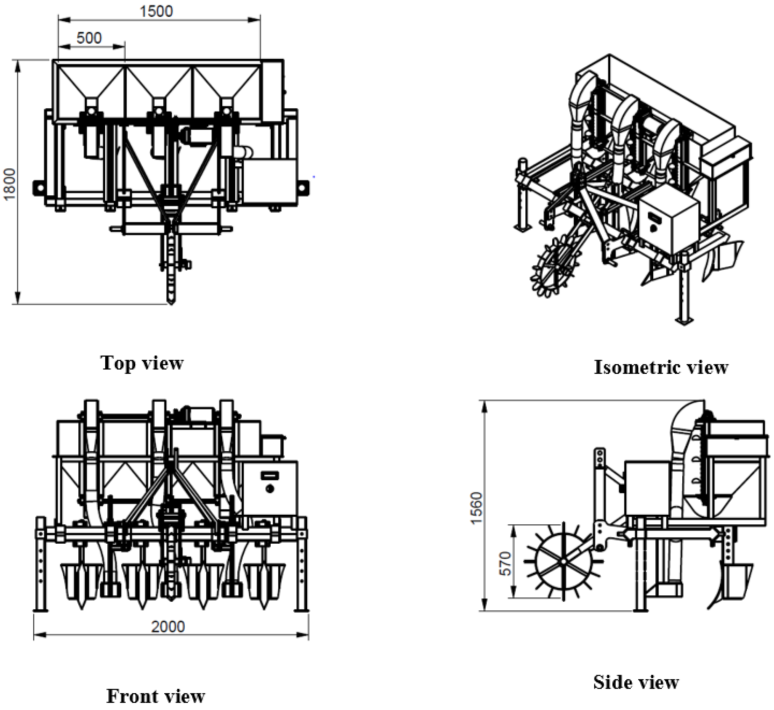
No.	Description
1	Ginger hopper Frame
2	Ginger hopper
3	Seed collecting device
4	Ginger delivery hopper
5	Ginger metering shaft
6	DC motor
7	Chain
8	Cell size
9	Tool box
10	Seed delivery tube
11	Electronic control box
12	LCD
13	Switch
14	Rotary encoder
15	Main frame
16	Shoe type furrow opener
17	Shovel
18	Ridger
19	Hitch point
20	Supporting stands

Fig. 3.13 Schematic view of a sensor-based tractor drawn ginger planter



No.	Description
1	Main Frame
2	Hitch
3	Main frame of ginger hopper
4	Ginger hopper
5	Seed collector
6	Ginger metering shaft
7	Sprocket
8	Cell size
9	Seed delivery hopper
10	Tool box
11	Electronic control box
12	LCD
13	Switch
14	Rotary encoder
15	Lugs
16	Ground wheel
17	Supporting stands
18	Shoe type furrow opener
19	Seed delivery tube
20	Shovel
21	Ridger

Fig. 3.14 Side view of a sensor-based tractor drawn ginger planter



Top view

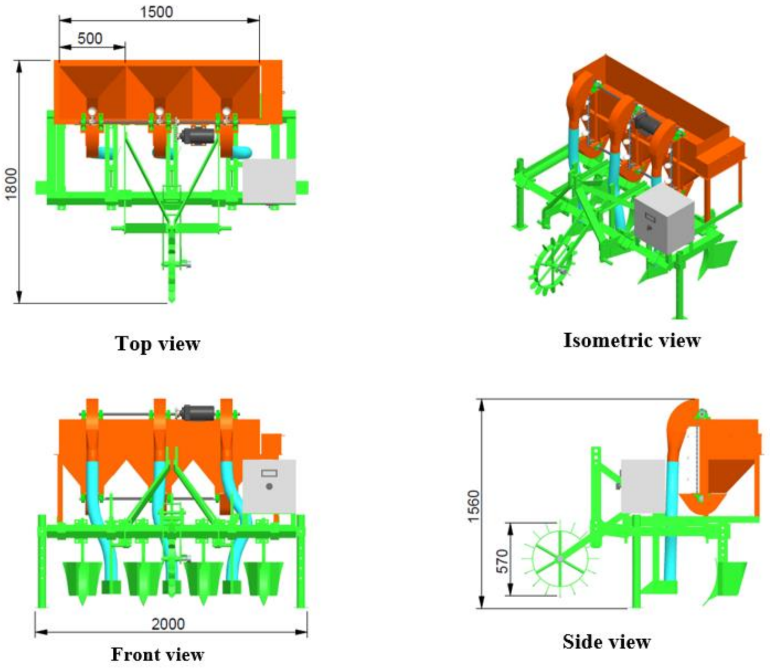
Isometric view

Front view

Side view

All dimensions are in mm

Fig. 3.15 Orthographic views of sensor-based tractor drawn ginger planter



Top view

Isometric view

Front view

Side view

All dimensions are in mm

Fig. 3.16 Detailed views of sensor-based tractor drawn ginger planter

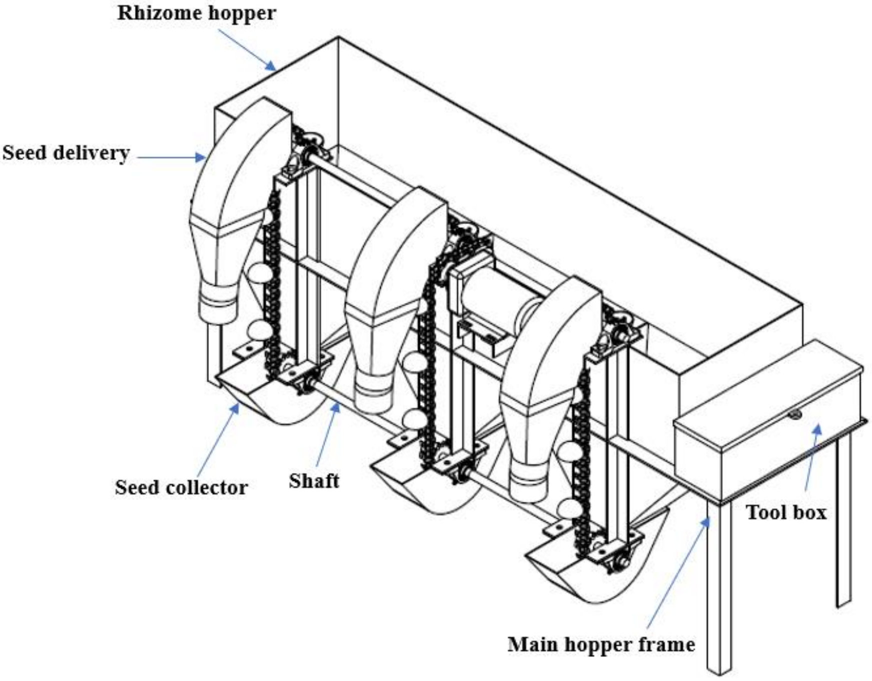


Fig. 3.17 Schematic view of the main hopper, seed metering, seed delivery tube, seed collector, frame, tool box and chain with cups

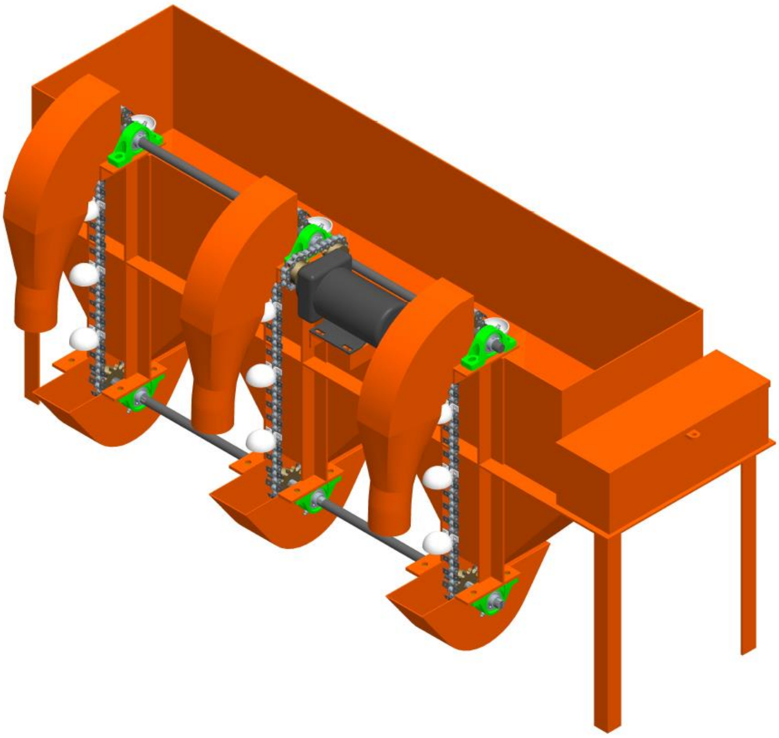
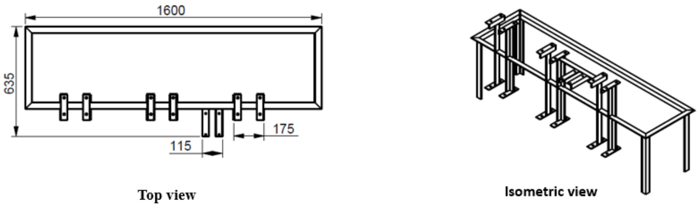


Fig. 3.18 Isometric view of the main hopper, seed metering, seed delivery tube, seed collector, frame, tool box, chain with cups and tool box

Plate 3.10 Top view of the sensor based ginger hopper

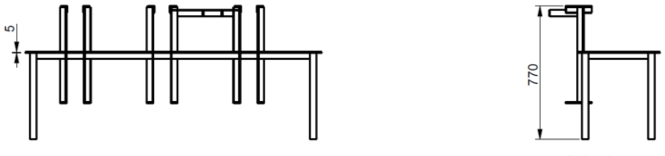
3.19.1 Rhizome hopper frame

The rhizome hopper frame exhibits a vertical rectangular configuration with dimensions of 770 mm in height, 1600 mm in length and a width of 635 mm extending from the edge to the angle iron housing the DC motor. The frame boasts a thickness of 5 mm, and there is a 115 mm gap between the DC motor angle iron frames. This angle iron framework is securely attached to the rhizome hopper using nut and bolt and welding has been done to reinforce the connection between the frame and the hopper edges as shown Fig. 3.19.



Top view

Isometric view



Front view

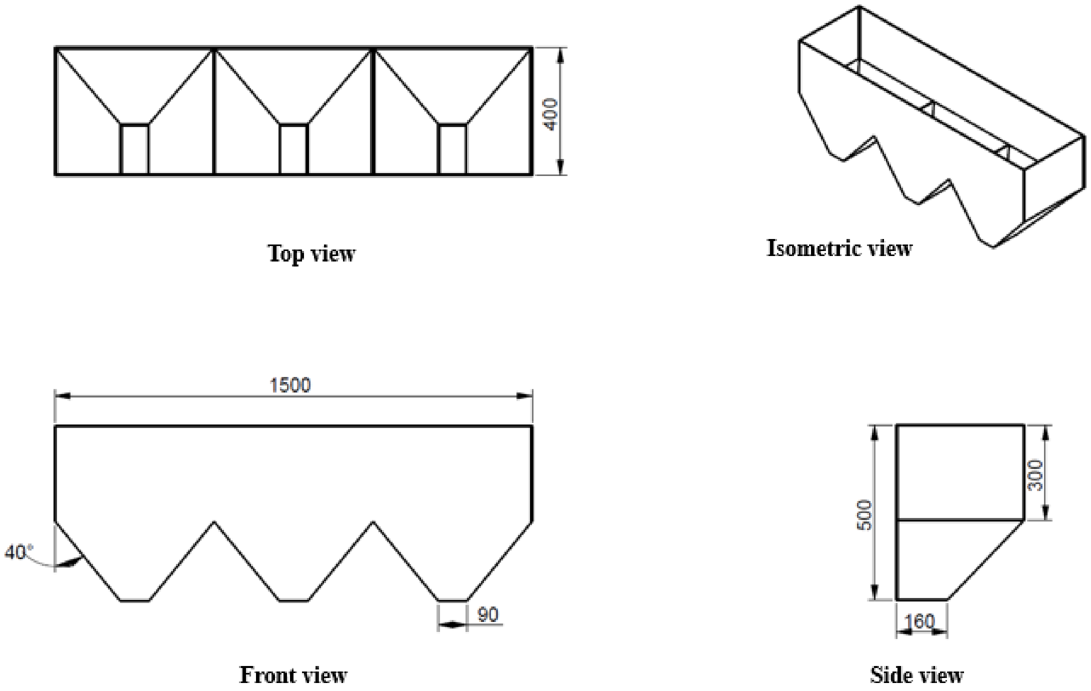
Side view

Fig. 3.19 Orthographic views of the rhizome hopper supporting frame

3.19.2 Rhizome hopper

The rhizome hopper is designed to accommodate a sufficient quantity of rhizomes, minimizing the need for frequent refilling during operation. It was constructed with 2 mm thickness of GP sheet metal, the hopper serves the dual purpose of storing rhizomes and feeding them to the metering devices. Its design takes into account the required volumetric capacity, angle of repose, and bulk density of the rhizomes.

The trapezoidal-shaped hopper is oriented vertically, featuring a rectangular width of 400 mm at the top and a length of 1500 mm. The total height of the rhizome hopper is 500 mm, with a height of 300 mm above the frame as illustrated in Fig. 3.20. A slope of 40° to the horizontal was chosen to ensure the free flow of all rhizomes within the hopper.


Top view

Isometric view

Front view

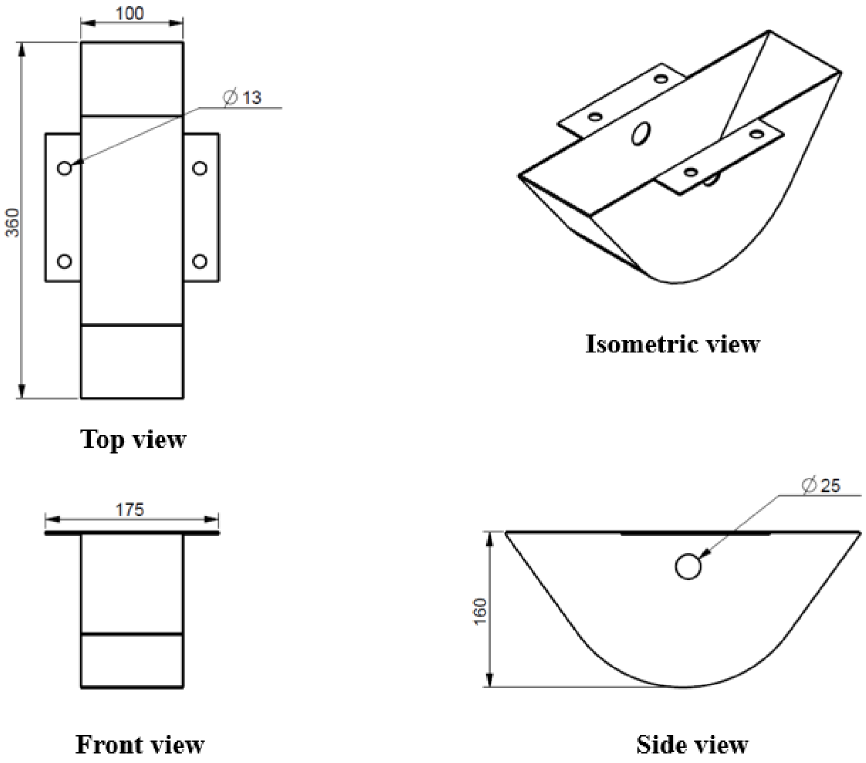
Side view

All dimensions are in mm

Fig. 3.20 Orthographic views of the rhizome hopper

3.19.3 Seed collector

The seed collector was attached to the lower part of the main rhizome hopper using a nut and bolt arrangement. After loading the rhizomes into the hopper, they are transferred to the seed collector. The seed metering system then retrieves the rhizomes from this collector. The seed collector is made of 16-gauge GP sheet metal, with dimensions of 360 mm in length, 2 mm in thickness, 100 mm in width, and 160 mm in height, as depicted in Fig. 3.21.



Top view

Isometric view

Front view

Side view

All dimensions are in mm

Fig. 3.21 Orthographic view of rhizome collecting device

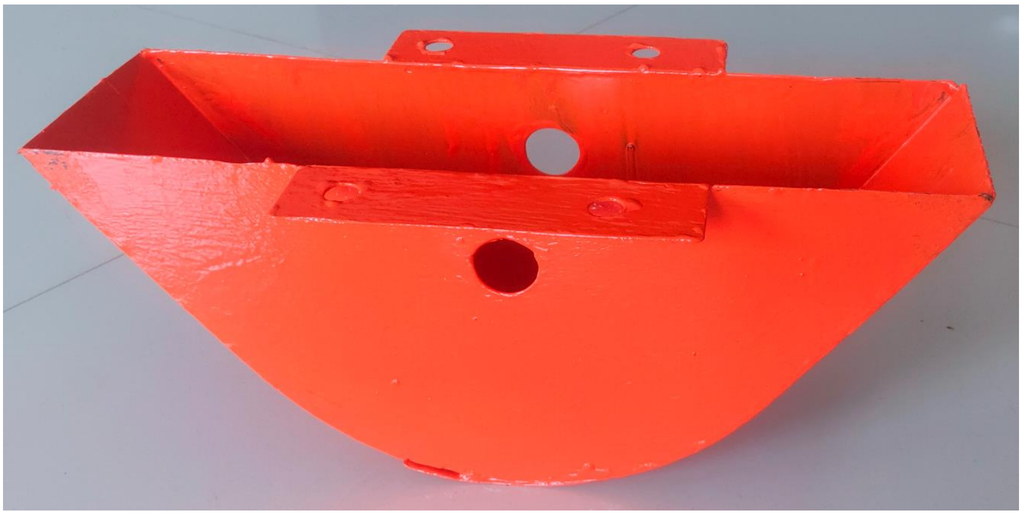
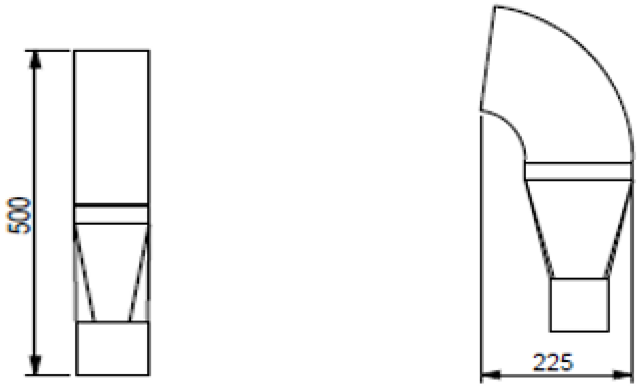


Plate 3.11 Isometric view of the developed rhizome collecting device

3.19.4 Seed delivery hopper

Seeds were flow freely into the delivery tube from the rhizome hopper, facilitated by chain and sprockets. To ensure uniform seed spacing, a flexible pipe is connected from the bottom portion of the delivery tube to the furrow boot. In sensor-based rhizome planters, seed tubes guide the seeds to different furrows. The inclination of these tubes from the vertical is maintained at less than 20^0 (Kepner *et al.*, 1987). The seed delivery hopper is made from GP sheet and the shape, inclination, and height of seed release significantly impact the timing of seed descent as shown below Fig. 3.22. Consequently, achieving proper seed distribution along the row was crucial for optimal performance.

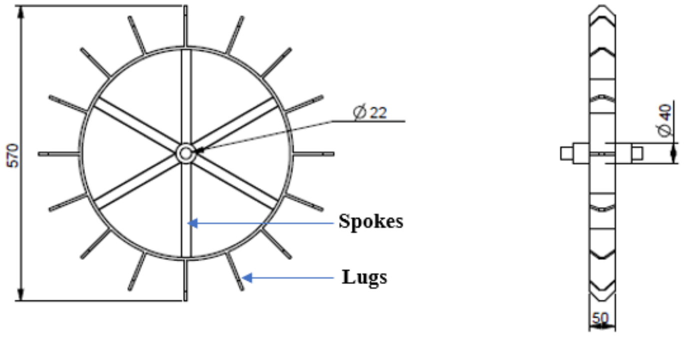


All dimensions are in mm

Fig. 3.22 Seed deliver hopper

3.19.5 Ground wheel

A spike-lugged ground wheel with a diameter of 570 mm, was fabricated using 63 mm mild steel flat as illustrated in Fig. 3.23. The wheel rim is constructed from mild steel flat, measuring 63 mm wide and 6 mm thick. Sixteen lugs, each one made of 6 mm thick MS flat, are welded equidistantly onto the round rim of the ground wheel. These lugs serve to drive the metering devices for rhizome without slippage during forward travel. The wheel features six spokes, crafted from mild steel rods with a diameter of 20 mm and a length of 560 mm. These spokes are welded to both the rim and the hub at the center of the wheel, which acts as a bushing or shaft bearing. The ground wheel is securely attached to the mainframe with the necessary supporting frameworks. The driven shaft was fitted on the rhizome hopper using bearings to facilitate the provision to fit the encoder for speed synchronization between the ground wheel and metering shaft. Rotary shaft encoder gives the pulse count (one revolution of ground wheel equal to 400 pulse count) to the Arduino Nano. An Arduino board is programmed to regulate crop spacing by calculating the ground wheel distance coverage per revolution. This information was used to generate output signals for a DC motor, which in turn adjusts the speed of the seed metering shaft. By controlling the motor speed, the Arduino Nano effectively manages the seed metering shafts rotation rate, compensating for any slippage that may occur with the ground wheel. This integrated system ensures precise control over crop spacing and optimizes seed distribution.



Front view

Side view

All dimensions are in mm

Fig. 3.23 Ground wheel

3.19.6 Power transmission and speed synchronization technique between the ground wheel and metering shaft

Speed synchronization was achieved through an electronic speed control unit, utilizing a rotary shaft encoder to monitor the movement of the ground wheel. The encoder sensor generates a series of pulses, which are captured by the Arduino Nano. These pulses are processed to calculate the total distance covered and provide travel speed information. The DC motor, connected to the rhizome metering shafts attached to the rhizome hopper, is driven based on this travel speed information. This speed regulation ensures precise seed dropping and maintains the desired seed spacing between seeds. The rotary shaft encoder, installed on the driven shaft (ground wheel) of the mainframe, transmits signals to the decoder integrated into the DC motor drive.

3.19.7 Power transmission system

The Power transmission occurs from the rotary encoder attached to the ground wheel shaft. The encoder provides pulse counts to an Arduino Nano for each revolution. The Arduino Nano board is programmed using the Arduino IDE software in the C++ language. The program is designed to consider the speed and desired spacing for ginger crop planting. The Arduino Nano effectively regulates the speed of the DC motor in accordance with the desired seed spacing. This control mechanism extends to the speed regulation of the rhizome metering mechanism, which is driven by the DC motor, as depicted in Fig. 3.24.

3.19.8 Length of the chain

The length of chain was calculated between the two rhizome metering shafts. The diameter of shaft was 20 mm and fitted on the main frame of rhizome hopper by using two pillow block bearings of size UCP -207. The length of chain between two metering shafts calculated by using following equation. (Khurmi and Gupta, 2011).

$$\mathrm{L} = \mathrm{M} \times \mathrm{P}$$

$$\mathrm{M} = \frac{2C}{P} + \frac{(N_1 + N_2)}{2} + \frac{\mathrm{p}\,(N_2 - N_1)^2}{4\,\pi^2 \times C}$$

$$= \frac{2 \times 850}{15.88} + \frac{(13 + 13)}{2} + \frac{15.88\,(13-13)^2}{4\,\pi^2 \times 850}$$

$$= 120.052$$

$$L_C = 120.052 \times 15.88$$

$$L_C = 1906 \text{ mm} = 1.90 \text{ m}$$

Where,

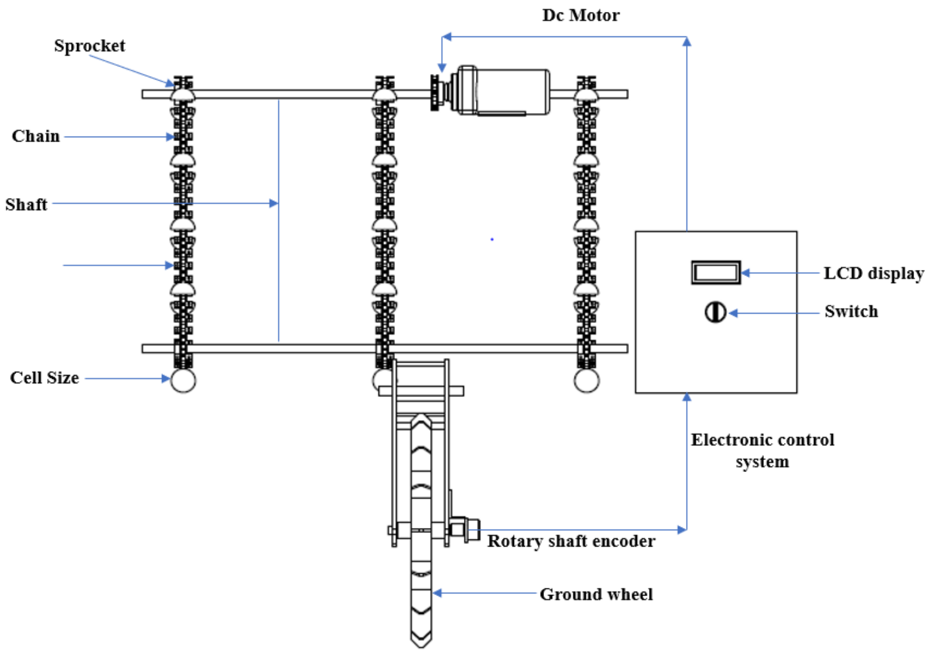
M = Numbers of links

T_1 = Number of teeth on drive the sprocket = 13

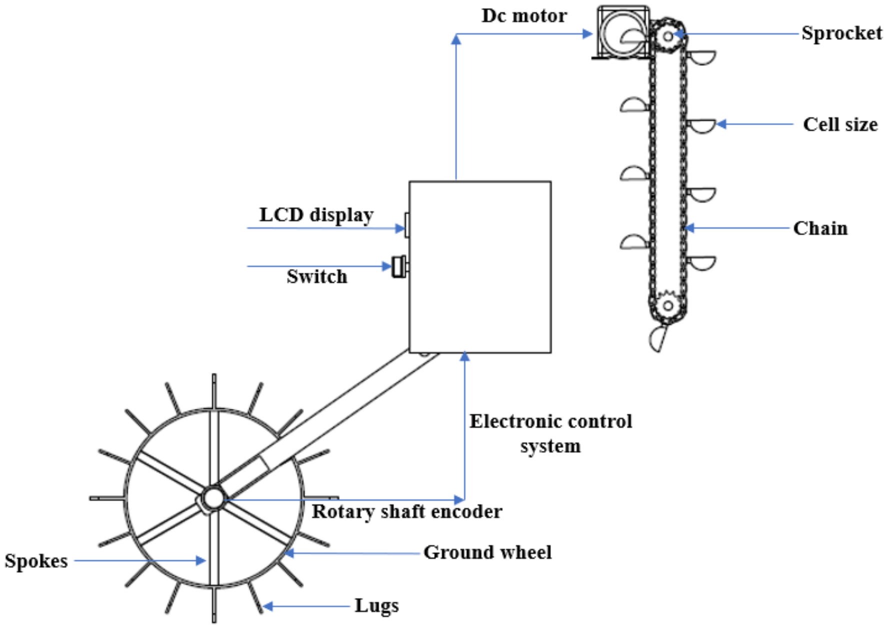
T_2 = Number of teeth on the driven sprocket = 13

C = Centre to center distance = 850 mm

P = Pitch of the chain = 15.88 mm



a) Front view



b) Side view

Fig. 3.24 Schematic view of power transmission system

3.19.9 Main frame

The primary structural framework of the planter, responsible for supporting all other planter components were fabricated using mild steel tubular sections measuring 76 mm × 76 mm × 6 mm. This choice of material and dimensions ensures the necessary strength and rigidity, allowing the planter to withstand various loads during its operation. Additionally, a three-point hitch assembly is incorporated at the front of the main frame, facilitating the attachment of the planter to the tractor.

Frame of the planter is connected to its various components using square clamps, bolts, and nuts of suitable sizes. In the process of designing and fabricating the frame, considerations were taken to allow flexibility in adjusting row spacing and furrow opener positions as needed. The dimensions of the frame were determined based on the anticipated design loads of the components to be mounted on it.

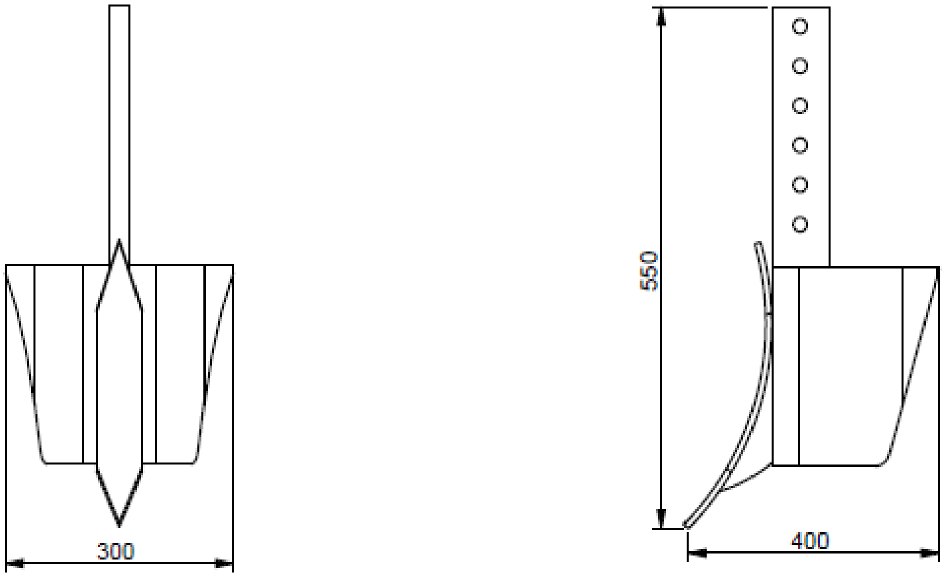
3.19.10 Ridger bottom

The rhizome planter frame was attached to a ridger bottom to make uniform sized ridges during a single pass of the machine after planting ginger rhizome seeds.

This ridger bottom features adjustable curved wings in a mould board shape. The wings are attached to the shank using clamps and the shank, fabricated from a 76 mm × 25 mm mild steel flat bar with a height of 650 mm, serves as the base for both the wings and fixed tyne as illustrated in Fig. 3.25. The wings constructed from 6 mm M.S. plate, are forged to provide the desired curvature. The overall dimensions of the ridger bottom are 400 mm × 300 mm × 550 mm.

3.19.11 Shoe type furrow opener

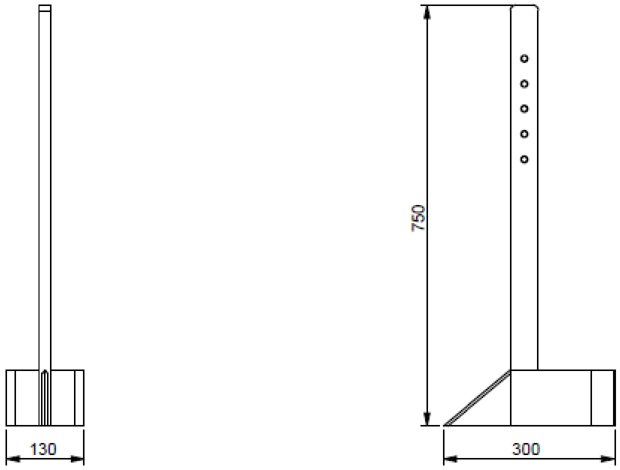
A shoe-type furrow opener with wings is affixed to the main frame beneath the rhizome hopper, positioned at a distance of 40 cm from the ridge share point. The shoe itself was constructed from a triangular-shaped, 10 mm thick plate with sides measuring 110 mm, 100 mm, and 150 mm. This plate was welded to a shank made of a 50 mm × 19 mm mild steel flat bar, having a height of 500 mm. The wings, crafted from 4 mm thick mild steel sheet metal, are also welded to the mild steel shank. This assembly is securely fixed to the planter frame using appropriate clamps, bolts and nuts, ensuring that furrows are created and rhizome seeds were deposited at the bottom of the furrow, as depicted in Fig. 3.26.



Front view **Side view**

All dimensions are in mm

Fig. 3.25 Orthographic view of ridger bottom



Front view **Side view**

All dimensions are in mm

Fig. 3.26 Orthographic view of shoe type furrow opener

3.20 WORKING PRINCIPLE OF A SENSOR-BASED TRACTOR DRAWN GINGER PLANTER

The electronic metered ginger rhizome planter was affixed to the tractor's hitch point, where it was ready for testing. Graded seed is loaded into the seed hopper and in the field, the planter was set into motion at forward speeds of 1, 1.5 and 2.0 km h^{-1}. As the ground wheel turns, an encoder placed at ground wheel shaft and it calculates the travel distance covered in the form of electrical pulses. These pulses are then relayed to a DC motor drive, which converts them into a signal. This signal in turn, instructs the DC motor to rotate in sync with the ground wheel's speed, as depicted in the accompanying diagram. The DC motor plays a crucial role in driving the rhizome metering mechanism, which connects between two shafts via chain and sprockets. This mechanism effectively meters the rhizomes from the hopper and delivers them to the seed delivery hopper.

3.20.1 Testing of a sensor-based ginger planter

Performance evaluation was conducted for 9 combinations of forward speed and speed of chain. Experimental design with 3 forward speed and speed of chain was given in table 3.4.

Table 3.4 Experimental design of rhizome planter testing for forward speeds and speed of chain

SI. No.	Experiment runs	Forward speed, S km h^{-1}	Speed of chain, V rpm
1	S_1R_1	1	86±10
2	S_2R_1	1.5	96±10
3	S_3R_1	2	106±10
4	S_1R_2	1	86±10
5	S_2R_2	1.5	96±10
6	S_3R_2	2	106±10
7	S_1R_3	1	86±10
8	S_2R_3	1.5	96±10
9	S_3R_3	2	106±10

3.21 FIELD TESTING OF A SENSOR-BASED GINGER PLANTER

The developed prototype of rhizome planter was tested in the field. The tests were conducted at Kelappaji College of Agricultural Engineering and Food Technology (KCAEFT), Tavanur campus. The selected plot was prepared by rotavator and operated twice in experimental plots to obtain a fine seed bed for rhizome planting. The John Deere tractor 5065E (65 hp) was used for field test. The tractor driver was required for regulating speeds and employed for the test. The following parameters were observed during the field test.

3.21.1 Hill to hill distance

During the field trials, the hill-to-hill distance (cm) was measured with the help of steel scale (RNAM, 1991) as shown in Plate 3.12. The rhizome-to-rhizome distance was measured in the field at five different locations randomly (Madhu Kumar, 2017).

Plate 3.12 Measurement of hill-to-hill distance

3.21.2 Row to row spacing

While conducting the field trials of the rhizome planter, the spacing between two adjacent rows (cm) was measured with the help of steel tape as shown in Plate 3.13. The row to row spacing was measured in the field at five different locations randomly (Madhu Kumar, 2017).

Plate 3.13 Row to row spacing measurement

3.21.3 Width of operation

During the field trials of the rhizome planter, the width of operation (cm) of entire machine was measured with the help of steel scale. The width of operation was measured in the field at five different locations randomly.

3.21.4 Wheel slippage

The wheel slippage of tractor was measured by marking the sides of rear tyre lugs by numbers for a distance of 20 m in planting condition was recorded to determine wheel slip (Bjerkan., 1947). The wheel slippage was computed in percentage and measured by using the formula**.**

$$\text{Wheel slippage (per cent)} = \frac{N_1 - N_2}{N_1}$$

Where,

N_1 = No. of rotation of rear wheel of tractor in 20 m distance at load condition.

N_2 = No. of rotation of rear wheel of tractor in 20 m distance at no load condition

3.21.5 Fuel consumption

An external portable fuel tank was fitted on the tractor. Fuel tank was filled to full capacity before and after the field test. Amount of refilling after the test was recorded and the fuel consumption for the test was worked out. When filling up the tank, careful attention was paid to keep the tank horizontal and not to leave empty air space in the tank. The fuel consumption was expressed in *l* h^{-1}.

Plate 3.14 Developed sensor-based tractor drawn ginger planter

Plate 3.15 Working of a developed sensor-based tractor drawn ginger planter

3.21.6 Draft

The load cell dynamometer was attached at the front of the tractor on which the implement was mounted as shown in Plate 3.16. Another auxiliary tractor was used to pull the tractor mounted with implement through the load cell dynamometer. The auxiliary tractor pulled the tractor mounted with implement, latter tractor in neutral gear but with implement in the operating position. The pull was recorded in the dial gauge of load cell dynamometer. The draft in the measured distance of 20 m was recorded. On the same field, the draft in the same distance was recorded while the implement is lifted above the ground. The difference gives the draft of the implement.

Plate 3.16 Draft measurement in field

3.21.7 Theoretical field capacity

Theoretical field capacity was measured by considering the width of operation and travel speed of the tractor. The theoretical field capacity was expressed in ha h^{-1} and measured by using the following formula (Kepner *et al.*, 1987).

$$\text{Theoretical field capacity} = \frac{Width\ of\ operation\ (m) \times Travel\ speed\ (km\ h^{-1})}{10} \times 100$$

3.21.8 Effective field capacity

During field tests, time losses for every event such as refilling of seeds in the planter and turning losses were recorded. However, in calculating the effective field capacity (ha h^{-1}), the time consumed for effective work and the time losses for other activities such as turning, and refilling of rhizomes were recorded (Kepner *et al.*, 1987).

$$M = \frac{A}{T_P + T_p}$$

Where,

M = Effective field capacity, ha h^{-1}

A = Area covered, ha

T_p = Productive time, hr

T_n = Non-productive time, hr

3.21.9 Field efficiency

Field efficiency (Ef) was expressed as percentage and measured by using following formula (Kepner *et al.*, 1987)

$$\text{Field efficiency} = \frac{EFC}{\text{TFC}} \times 100$$

Where,

EFC = Effective field capacity, ha h^{-1}

TFC = Theoretical field capacity, ha h^{-1}

3.21.10 Depth of rhizome placement

The depth of rhizome placement was assessed by excavating the soil that had accumulated around the rhizome due to the ridging process. The measurement involved determining the depth at which the rhizome was situated.

3.22 STATISTICAL ANALYSIS

The data obtained were statistically analysed by 2 Factorial Completely Randomized Design (FCRD) using Design Expert (V_{13}) software. The analysis of variance (ANOVA) and mean table for different parameters were tabulated and the level of significance was reported.

3.23 COST OF OPERATION

Following the guidelines outlined in IS: 9164-1979, the fixed cost and variable cost of the rhizome planter unit were computed based on the materials utilized and the labour involved in its fabrication. Subsequently, using the field capacity of the planter, the operational cost per hectare was determined as detailed in Appendix -XV.

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, the soil, crop and machine parameters influencing the sensor-based tractor drawn ginger planter were determined and analysed. The results pertaining to the testing and evaluation of a sensor-based tractor drawn ginger planter having cup-feed type metering mechanism with single seed metering device coupled to an electronic speed control DC motor, desired spacing, depth and engineering properties of ginger were investigated for designing the rhizome planter components. The rhizome planter was tested for rhizome missing index, (I_{miss}), rhizome multiple index (I_{multi}), quality of feed index (I_{qf}), hill to hill distance and cell fill efficiency to evaluate the planting performance.

4.1 DATA COLLECTION ON PRACTICES IN GINGER CULTIVATION

4.1.1 Planting season and Planting method

In this study, four varieties of ginger viz., Athira, Chithra, Aswathy and Karthika were selected and studied as detailed in section 3.1.1. The obtained results are presented in Appendix IV, V, VI, VII. The average plant population of ginger planted by tractor drawn sensor based ginger planter was 13 plants m^{-2}. The row to row spacing and hill to hill distance for this study was selected as 45 and 15-20 cm respectively.

Plate 4.1 Plant population

4.2 SOIL PARAMETERS

At the time of sowing, soil parameters including soil consistency, moisture content, bulk density, and cone index were identified. The determination of these soil properties was elaborated in section 3.2. The collected data underwent statistical analysis, and the outcomes are detailed in Table 4.2.

The field was prepared by rotavator, so that furrows can be easily formed during planting operation. The latitude and longitude coordinates of the field location is 10^0 51^1 10.49^{11} N, 075^0 59^1 20.72^{11} E. Soil was worked at optimum soil moisture to obtain a good tilth for planting seeds at proper depth. The soil samples were taken from the cultivated test areas of ginger experimental plots were analysed to finding the textural composition. The percentage of different soil textures ranged between 60 per cent sand, 10 per cent silt and 30 per cent clay respectively. Hence, it is concluded that the type of soil is laterite loam.

4.2.1 Soil consistency

Soil samples were collected from different locations of the field and soil consistency limits were studied in the laboratory. Finally, the observed values are 37 per cent for liquid limit, 25.49, 20.58 and 27.87 per cent for plastic limits and 21.78, 12.72 and 24.68 per cent for shrinkage limits are shown in below Table 4.1.

Table 4.1 Determination of soil consistency limits

SI. No	Liquid limit	Plastic limit	Shrinkage limit
1	-	25.49	21.78
2	37	20.58	12.72
3	-	27.87	24.68

4.2.2 Moisture content

The soil moisture content was measured at different places of the experimental trial plot at the time of sowing. The moisture content of the soil was determined and statistically analysed. The moisture content varied from 12.73 to 15.55 per cent with mean of 14.45 per cent and a coefficient of variation of 8.90 per cent with standard deviation of 1.286. A favourable moisture level was chosen where the required draft and the soil penetration resistance were moderate and within the working limits for obtaining maximum sowing efficiency. Therefore, sowing at 15 per cent soil moisture content in laterite soil is satisfactory. So, the field condition was suitable for getting maximum sowing efficiency by sensor-based rhizome planters. Hence, the experiments on the performance study of tractor drawn ginger planter was conducted at this soil moisture content level. The data obtained are presented in Appendix - IX.

4.2.3 Bulk density

The soil bulk density was measured at different places of the experimental trial plot at the time of sowing. Soil samples were collected for analysis. The bulk density of soil was determined and statistically analysed. The bulk density of the soil ranged from 1.79 to 1.84 g cm^{-3} with an average mean of 1.80 g cm^{-3}. The coefficient of variation was found out as 1.19 per cent and standard deviation of 0.021. It shows the variations in soil bulk density at respective soil moisture. The data obtained are presented in Appendix - X.

4.2.4 Cone index

The cone index of soil was determined and statistically analysed. The cone index varied from 887.09 to 1968.02 kg m^{-2}. The highest value of the cone index was 1968.02 kg m^{-2} at 14.45 per cent soil moisture content. The cone penetration resistance values varied from 887.09 to 1968.02 kg m^{-2} and cone index increased as the depth increased from the soil surface, due to the increase in penetration resistance. The data obtained are presented in Appendix – XI.

Table. 4.2 Properties of soil parameters at the time of sowing

Sl. No.	Moisture content, (db) Per cent	Bulk density, g cm^{-3}	Cone index, kg m^{-2}
1	13.80	1.82	887.09
2	15.87	1.80	1288.9
3	12.73	1.79	1968.02
4	14.32	1.84	--
5	15.55	1.79	--
Range	3.14	0.05	1080.93
Mean	14.45	1.808	1381.337
S.D	1.286868	0.021679	546.3614
C.V	8.903198	1.199086	39.5531

4.4 PHYSICAL PROPERTIES OF GINGER RHIZOMES

4.4.1 Physical properties of rhizomes

The physical properties of seeds *viz*., size, sphericity, bulk density, surface area and moisture content were determined and analysed statistically. The results obtained are discussed in the following sections for the selected crops and data is given in Appendix – IV, V, VI, VII.

4.4.1.1 Weight of ginger rhizomes

Three samples were randomly selected for weighing with electronic balance with accuracy of 0.01g, and the mean value was calculated. The weight of the ginger rhizomes after cutting with one or two buds rhizomes was 20 g.

4.4.1.2 Size of ginger rhizomes

The investigation focused on evaluating the effectiveness of a cup-feed-type metering mechanism by examining rhizome sizes among various varieties are Athira, Aswathy, Chithra and Karthika have at least 1-2 buds with required weight. The primary and secondary were separated from rhizome clump and different size dimensions were measured (Mishra and Kulkarni, 2009). The length, width and thickness of rhizome setts were measured. The average linear dimensions of two budded rhizome setts measured in natural rest position as well as under different moisture conditions. The outcomes of this study are outlined in Table 4.3.

Table 4.3 Linear dimensions

SI.No.	**Different varieties of ginger**	**Moisture content, Mean ± SD, per cent (Wb)**	**Size (mm)**		
			Length (*l*)	**breadth (b)**	**Thickness (t)**
1	Athira	71.71±1.97	46.95±1.78	33.37±1.41	18.84±2.45
2	Aswathy	74.53±1.0	7.02±2.15	1.22±2.03	16.37±2.92
3	Chithra	72.45±2.34	7.33±2.04	32.29±1.82	17.21±2.47
4	Karthika	76.01±0.83	46.26±2.70	33.19±2.19	17.2±2.02

The obtained results from measuring the mean linear dimensions of ginger rhizomes, which belonged to different varieties and had varying moisture contents, are presented in Table 4.3. These findings revealed that rhizome setts of ginger exhibited an irregular and oblong shape. Consequently, a decision was made to opt for a round-shaped cell for the cup feed type metering. This selected cell had a length corresponding to the major axis and a depth equivalent to the thickness of the rhizome setts. Specifically, for ginger rhizome setts with 1-2 buds, the length of linear dimension chosen was in the range of 40-50 mm. In general, the dimensions of metering device cells depend upon the length and thickness of ginger rhizome setts.

4.4.1.3 Moisture content

The moisture content of selected varieties of ginger rhizomes viz., Athira, Aswathy, Chithra and Karthika were determined as described in section 3.4.3 and results are presented in Table 4.4. The average moisture content of Athira variety of ginger rhizome is 71.71±1.97 per cent. Similarly, the average moisture content of Aswathy, Chithra and Karthika were found to be 74.53±1.0 per cent, 72.45±2.34 per cent and 76.01±0.83 per cent respectively. The standard deviations in moisture content of different rhizomes are given in the Table 4.4. Athmaselvi and Varadharaju (2002) reported that the moisture content of BSR-2 variety was 86 per cent (wb) immediately after harvest. In the present study, the moisture content of rhizome setts was less due to two months storage after harvest.

Table 4.4 Moisture content

SI. No.	Different varieties of ginger	Moisture content, Mean ± SD, per cent (Wb)
1	Athira	71.71±1.97
2	Aswathy	74.53±1.0
3	Chithra	72.45±2.34
4	Karthika	76.01±0.83

4.4.1.4 Sphericity

The sphericity of different varieties of ginger rhizomes was determined as described in section. 3.4.4. Athira variety of ginger rhizome about 71.71 per cent of moisture content has a sphericity of 0.63±0.03 and coefficient of variance observed was 1.75 per cent presented in Table 4.5.

The sphericity of different varieties of ginger rhizomes was determined as described in section 3.4.4. Aswathy variety of ginger rhizome with 74.53 per cent of moisture content has a sphericity of 0.17±0.03 and coefficient of variance observed was 5.96 per cent and presented in Table 4.5.

The sphericity of different varieties of ginger rhizomes was determined as described in section 3.4.4. Chithra variety of ginger rhizome with 72.45 per cent of moisture content has a sphericity of 0.61±0.03 and coefficient of variance observed was 5.77 per cent and presented in Table 4.5.

The sphericity of different varieties of ginger rhizomes was determined as described in section 3.4.4. Karthika variety of ginger rhizome with 76.01 per cent of moisture content has a sphericity of 0.60±0.03 and coefficient of variance observed was 3.06 per cent and presented in Table 4.5.

Table 4.5 Sphericity

SI. No	Different varieties of ginger	Moisture content, Mean ± SD, per cent (Wb)	Sphericity Mean ± SD,	CV (per cent)
1	Athira	71.71±1.97	0.63±0.03	4.9
2	Aswathy	74.53±1.0	0.17±0.03	6.53
3	Chithra	72.45±2.34	0.61±0.03	5.69
4	Karthika	76.01±0.83	0.60±0.03	4.77

4.4.1.5 Bulk density

The bulk density of selected varieties of ginger rhizomes viz., Athira, Aswathy, Chithra and Karthika with two budded rhizome setts were determined as explained in section 3.4.5, and presented in Table 4.6. The average bulk density of Athira variety of ginger rhizome is 429.44 ± 7.55 kg m^{-3}. Similarly, the average bulk density of Aswathy, Chithra and Karthika were found to be 375.6 ± 22.04 kg m^{-3}, 429 ± 24.78 kg m^{-3} and 377 ± 11.55 kg m^{-3} respectively. The coefficient of variance was found for different varieties of ginger rhizomes. The hopper capacity was computed using the measured values of bulk density were 0.28 m^3 respectively. The storage capacity of rhizome hopper depends upon on the bulk density of rhizomes and its packing nature in the container. It was observed that increase in finger length of rhizome setts resulted decrease in bulk density of ginger.

Table 4.6 Bulk density

SI. No	Different varieties of ginger	Moisture content, Mean ± SD, per cent (Wb)	Bulk density ($kg\ m^{-3}$) Mean ± SD, (Wb)	C V (per cent)
1	Athira	71.71±1.97	429.44±7.55	1.75
2	Aswathy	74.53±1.0	375.6±22.04	5.96
3	Chithra	72.45±2.34	429±24.78	5.77
4	Karthika	76.01±0.83	377±11.55	3.06

4.4.1.6 True density

The true density of selected varieties of ginger rhizomes viz., Athira, Aswathy, Chithra and Karthika with two budded rhizome setts were determined as explained in section 3.4.6, and results are presented in Table 4.7. The average true density of Athira variety of ginger is 1.02 ± 0.07 g cc^{-1}. Similarly, the average bulk density of Aswathy, Chithra and Karthika were found to be 1.03 ± 0.10 g cc^{-1}, 0.97 ± 0.18 g cc^{-1} and 1.06 ± 0.28 g cc^{-1} respectively. The coefficient of variance was found for different varieties of ginger.

Table 4.7 True density

SI. No	Different varieties of ginger	Moisture content, Mean ± SD, per cent (Wb)	True density, g cc^{-1} Mean ± SD,	CV (per cent)
1	Athira	71.71±1.97	1.02±0.07	7.61
2	Aswathy	74.53±1.0	1.03 ±0.10	9.95
3	Chithra	72.45±2.34	0.97±0.18	19.55
4	Karthika	76.01±0.83	1.06± 0.28	26.82

4.5 FRICTIONAL PROPERTIES

Rhizome hopper design relies on assessing the frictional characteristics of seeds, as measured by the coefficient of friction and the angle of repose. These parameters, namely the coefficient of friction and angle of repose, play a pivotal role in the formulation of effective rhizome hopper designs.

4.5.1 Angle of repose

The angle of repose of different varieties of ginger rhizomes viz., Athira, Aswathy, Chithra and Karthika with two budded setts were determined as explained in section 3.5.1, and results are given in Table 4.8. The angle of repose of ginger rhizome setts was experimentally determined as 34.43±3.93, 36.87±3.5, 36.54±1.11 and 40.08±2.36 respectively. The angle of repose values mentioned above served as crucial input for the construction of the rhizome hopper. Specifically, the lower section of the rhizome hopper was inclined at 40°, surpassing the experimentally determined angle of repose values. This design choice was implemented to enhance the smooth flow of rhizome setts towards the hopper's lower outlets and subsequently to the metering units.

Table 4.8 Angle of repose

SI. No	Different varieties of ginger	Angle of repose, Mean ± SD, (Degrees)
1	Athira	34.43±3.93
2	Aswathy	36.87±3.58
3	Chithra	36.54±1.11
4	Karthika	40.08±2.36

4.5.2. Coefficient of friction

The coefficient of friction of different varieties of ginger rhizomes are Athira, Aswathy, Chithra and Kartika with two budded ginger rhizome setts were determined as explained in sections 3.5.2, and results are presented in Table 4.9. The coefficient of friction values of rhizome setts on wood, stainless steel and mild steel were measured to select the material for rhizome hopper. It was observed that the coefficient of friction was highest on wood and least on stainless steel. The strength, cost and fabrication easiness of material were main criteria for the selection. The mild steel was selected considering all these factors, being cheaper for fabrication of rhizome hoppers.

Table 4.9 Coefficient of friction

SI. No	Material surface	Athira	Aswathy	Chithra	Karthika
1	wood	0.576±0.06	0.603±0.03	0.536±0.06	0.593±0.06
2	Mild steel	0.523±0.02	0.583±0.07	0.51±0.05	0.53±0.03
3	Stainless steel	0.48±0.04	0.496±0.05	0.463±0.15	0.446±0.06

4.6 DESIGN OF RHIZOME HOPPER FOR LABORATORY SET UP

The laboratory set up of rhizome hopper was made up of GP sheet. The total height of rhizome hopper was 375 mm, width 200 mm and length 250 mm and thickness of 2 mm was designed for the laboratory set up.

4.7 POWER TRANSMISSION

The length of chain between two rhizome metering shafts were calculated. The obtained length of chain is 1.0 m as described in the section 3.7.

4.8 SPEED RATIO OF LABORATORY SET UP

The speed ratio of laboratory set up was obtained from the section 3.8. The obtained value is 136±10 rpm. Here decrease in DC motor speed from optimized value and increase in DC motor speed from optimized value to find the spacing between the rhizomes. The obtained values are 126±10 rpm ± 146±10 rpm. So, 126±10 rpm, 136±10 rpm and 146±10 rpm, the optimized value is 136±10 rpm.

4.9 THE DEVELOPMENT OF LABORATORY SET UP

A laboratory study was conducted to assess the performance of a metering device, focusing on key performance parameters such as miss index, multiple index, quality of feed, hill to hill distance and the cell fill efficiency, with a specific emphasis on precision in seed spacing compared to the recommended seed distances. The evaluation of the metering device involved determining the optimal belt linear speed, metering speed of chain and cell size particularly for ginger rhizomes, as detailed in section 3.9.

The optimization process considered various factors, including type of cell sizes such as 40 mm, 50 mm, 60 mm, metering speed of chain (126 ±10 rpm, 136 ±10 rpm and 146 ±10 rpm) and belt linear speeds 1.0 km h^{-1}, 1.5 km h^{-1} and 2.0 km h^{-1} respectively, tailored for ginger crop. The experiments aimed to fine-tune the metering device performance for ginger crops, employing the 2 Factorial Completely Randomized Design (FCRD) using Design Expert (V_{13}) software. The assessment involved measuring the hill-to-hill distance of ginger rhizomes, accounting for misses, multiples, quality of feed and the cell fill efficiency on a greased belt. The laboratory tests adhered to the standards outlined in the BIS code of IS: 6316, 1993, using a sticky belt. The collected data underwent statistical analysis to discern the impact of belt linear speed, electronic cup feed type metering device and speed of chain for different cell sizes on performance indices. These indices encompassed hill to hill distance, miss index, multiple index, quality of feed index and cell fill efficiency, each one evaluated separately with ginger rhizomes. The subsequent discussion delves into the outcomes of these laboratory experiments.

4.10 LABORATORY EVALUATION OF SENSOR-BASED CUP FEED-TYPE METERING MECHANISM FOR GINGER

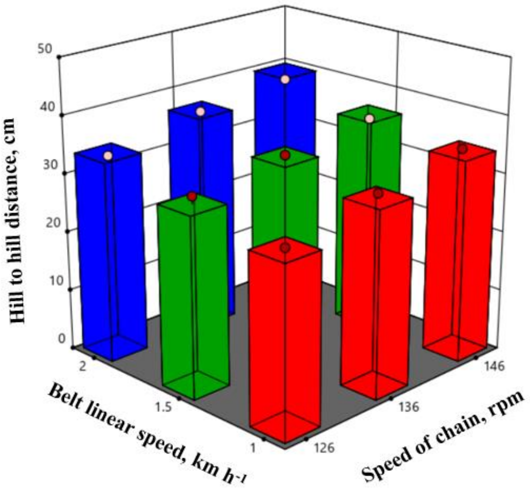
The performance of the sensor-based cup feed type metering mechanism on grease coated belt test set up is given in Appendix – II. The test results were analysed statistically to determine the effect of belt linear speed, metering speed of chain and different cell sizes on the performance of cup feed type metering device for ginger rhizomes.

4.10.1 Effect of belt linear speed and speed of chain on hill-to-hill distance for ginger by using different cell sizes

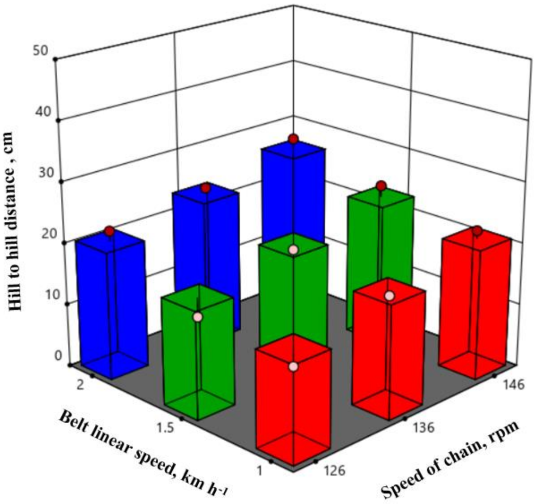
The effect of belt linear speed and speed of chain on hill-to-hill distance was studied. From Fig. 4.1, it was observed that mean spacing between rhizomes increased with increase in forward speed and speed of chain during planting. Testing for the mean spacing of ginger rhizomes with 40 mm, 50 mm and 60 mm cell sizes. By using 40 mm and 60 mm cell sizes are given more missing index between rhizomes and less mean spacing as well as multiples than required, because the average size of ginger rhizome is 50 mm after cutting with two budded rhizomes. The laboratory set up tested with the three forward speeds, three metering speed of chains and different cell sizes are 1 km h^{-1}, 1.5 km h^{-1} and 2 km h^{-1}, 126 ±10 rpm, 136 ±10 rpm and 146 ±10 rpm and 40 mm, 50 mm and 60 mm. From this study the obtained results are forward speed 1 km h^{-1}, speed of chain 136 ±10 rpm and 50 mm cell size are giving superior performance in terms of hill-to-hill distance, missing index, multiple index, quality of feed index and cell fill efficiency.

Statistical analysis was conducted to assess the effect of belt linear speed and speed of chain on various cell sizes and the findings are detailed in ANOVA Table 4.10.

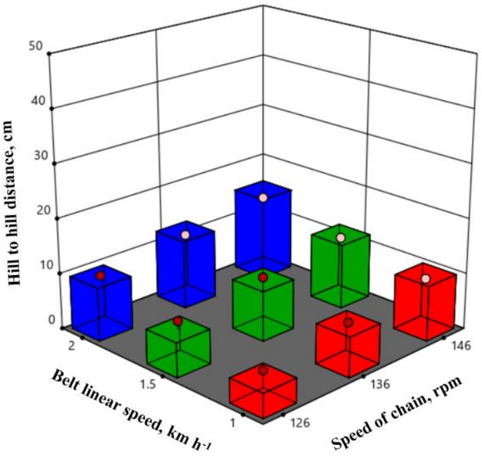
The results revealed that the primary factors, namely belt linear speed (S) and speed of chain (V), demonstrated significance, along with the cell sizes (C), all at a significance level of $p < 0.05$. Notably, the interactions of S × V and S × C were found to be non-significant, while the interaction of V × C achieved significance at a p value < 0.05. similar results are outlined by (Madhu Kumar., 2017).



(a) 40 mm



(b) 50 mm



(C) 60 mm

Fig. 4.1 Effect of belt linear speed and speed of chain on hill to hill distance for different cell sizes (a) 40 mm, (b) 50 mm, (c) 60 mm

Table 4.10 Analysis of variance on hill to hill distance for ginger

Source of variances	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**p-value**	
Model	6964.52	2	267.87	22.24	< 0.0001	significant
Belt linear speed (S)	61.76	2	30.88	2.56	0.0867	
Cell Size (C)	6517.91	2	3258.95	270.56	< 0.0001	
Speed of chain (V)	66.86	2	33.43	2.78	0.0716	
S × V	25.15	4	6.29	0.5221	0.7199	
S × C	104.17	4	26.04	2.16	0.0862	
V × C	123.24	4	30.81	2.56	0.0494	
Residual	626.34	52	12.05			
Lack of Fit	52	626.34	12.045			
Cor Total	7620.28	80				
Std. Dev.	3.47		R-Squared		0.9175	
Mean	20.92		Adj R-Squared		0.8762	
C.V. per cent	16.59		Pred R-Squared		0.7998	
			Adeq Precision		13.0009	

$P_{value} < 0.05$ is significant

4.10.2 Effect of belt linear speed and speed of chain on missing index for different cell sizes

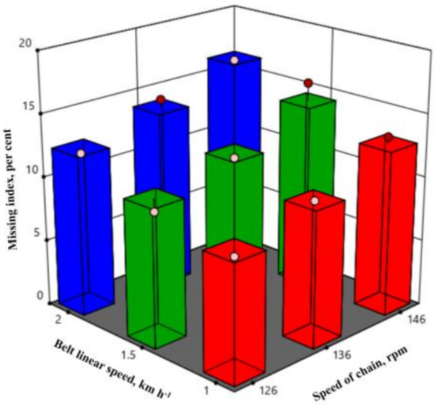
The effect of belt linear speed and speed of chain on missing index was investigated using different cell sizes of 40 mm, 50 mm and 60 mm. This study observed that increasing the forward speed from 1 km h^{-1}, 1.5 km h^{-1} and 2 km h^{-1} along with increasing the speed chain from 126±10 rpm to 136±10 rpm and then 146 ±10 rpm led to a rise in missing index.

The results, indicate that using the 50 mm cell size offers superior performance compared to 40 mm and 60 mm cell size because of average length of ginger rhizome is 30-50 mm after cutting with two budded rhizomes. By reducing the missing index and increasing the multiples because of lowest speed of chain collecting the higher multiples rhizome, the accuracy and efficiency of data collection have been improved especially in capturing data related to ginger rhizomes. These findings suggest that adopting 50 mm cell size configuration is a viable option for obtaining satisfactory results while optimizing data collection efforts during the study of ginger rhizomes.

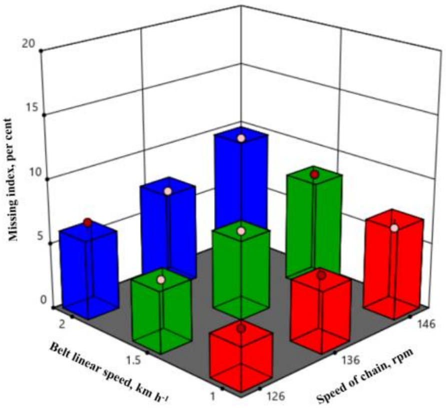
However, it was found that a favourable spacing between rhizomes was achieved when maintaining a forward speed of 1 km h^{-1} and speed of chain of 136±10 rpm by using a cell size of 50 mm and missing index was observed from the study is 5.25 per cent. At these specific conditions, the spacing between rhizomes was suitable for this combination.

In summary, highest level of forward speeds and highest level of speed of chain are generally resulted in increased missing index because of poor picking efficiency. But specific combinations, such as forward speed is 1 km h^{-1} and speed of chain is 136±10 rpm with a 50 mm cell size were able to maintain an appropriate spacing between rhizomes. The result on the missing index was shown in below Fig. 4.2.

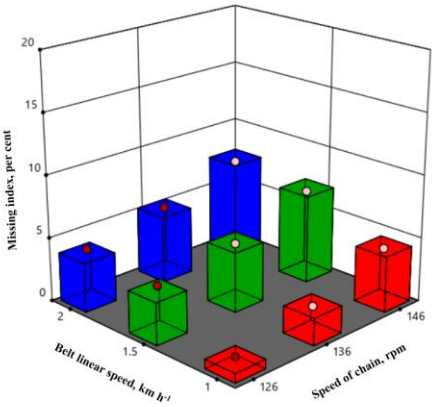
The effect of belt linear speed and speed of chain for different size of cells were analysed statistically and results are presented in ANOVA table 4.11. It is observed from table 4.11 that main factors belt linear speed (S), speed of chain (V) were significant and cell sizes (C) were significant at $p < 0.05$. The interactions S × V, S × C and V × C were significant at p value < 0.05. Similar results were reported by Kumar and Singh (2019).



(a) 40 mm



(b) 50 mm



(C) 60 mm

Fig. 4.2 Effect of belt linear speed and speed of chain on missing index for different cell sizes (a) 40 mm, (b) 50 mm, (c) 60 mm

Table 4.11 Analysis of variance on missing index for ginger

Source of variances	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**p-value**	
Model	1311.58	18	72.87	856.74	< 0.0001	significant
Belt linear speed (S)	139.82	2	69.91	821.99	< 0.0001	
Cell Size (C)	955.01	2	477.50	5614.46	< 0.0001	
Speed of chain (V)	198.10	2	99.05	1164.65	< 0.0001	
S × V	5.61	4	1.40	16.49	< 0.0001	
S × C	3.34	4	0.8344	9.81	< 0.0001	
V × C	9.70	4	2.42	28.50	0.0001	
Residual	5.10	60	0.0850			
Lack of Fit	0.2921	52	0.0056			
Cor Total	1319.26	80				
Std. Dev.	0.2916		R-Squared		0.9961	
Mean	7.87		Adj R-Squared		0.9950	
C.V. per cent	3.71		Pred R-Squared		0.9929	
			Adeq Precision		108.109	

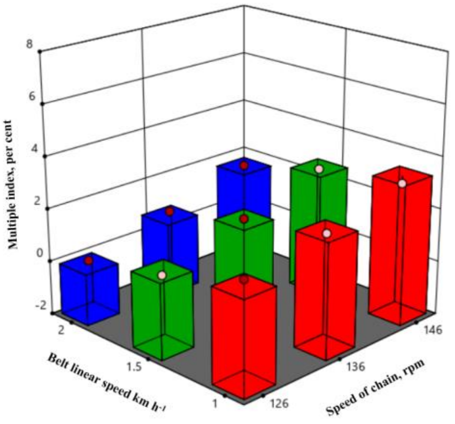
$P_{value} < 0.05$ is significant

4.10.3 Effect of belt linear speed and speed of chain on multiple index for different cell sizes

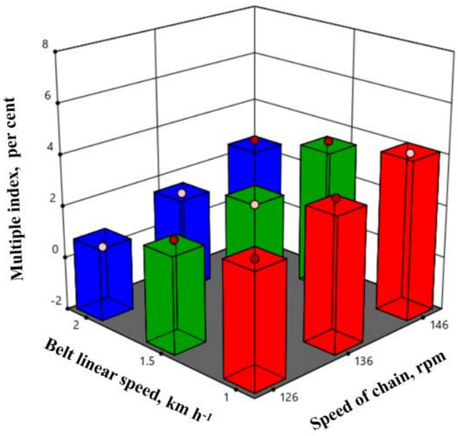
The influence of forward speed, cell size and speed of chain on multiple index was examined in the study. When using 50 mm cell size, it was observed that decreasing the missing index and maintaining multiple rhizomes was achievable with a forward speed of 1 km h^{-1} and speed of chain of 136±10 rpm. On the other hand, when using a 60 mm cell size, the missing index decreased, but the number of multiples increased. Interestingly, the performance of the 50 mm cell size was found to be acceptable when compared to 40 mm and 60 mm cell sizes. Fig. 4.3. displays the results of the multiple indices on ginger rhizome obtained from the study.

The multiple index obtained from the study is 3.54 per cent. From Fig. 4.3, it is observed that as belt linear speed increases with increase in speed of chain, there was decrease in multiple index. However, there is increase in multiple index as cell size increases of from 50 mm to 60 mm, but multiple index decreased at lowest belt linear speed with speed of chain is 136±10 rpm by using 50 mm cell size this was due to picking efficiency gives the acceptable performance compared to highest level of speed of chain is 146±10 rpm as well as less time to pick the rhizome into the cell when using highest speed of chain and it gives the subpar performance of quality of feed and cell fill efficiency.

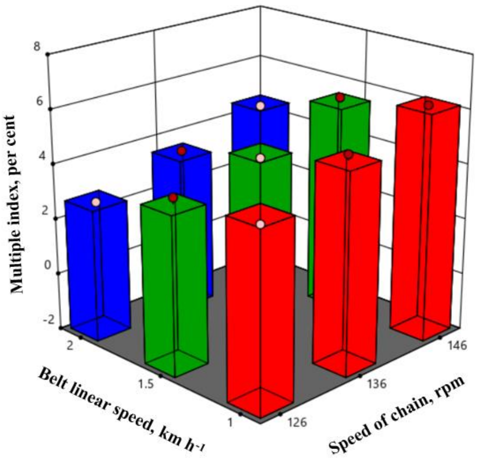
The effect of belt linear speed, metering speed of chain for different size of cells were analysed statistically and presented in ANOVA table 4.12. It is observed from that main factors, belt linear speed (S), speed of chain (V) and (C) cell sizes were significant at $p < 0.05$. The interactions S × V and V × C were non-significant. While S × C at p value < 0.05. Similar results were outlined by Kumar and Singh (2019).



(a) 40 mm



(b) 50 mm



(c) 60 mm

Fig. 4.3 Effect of belt linear speed and speed of chain on multiple index for different size of cells (a) 40 mm, (b) 50 mm and (c) 60 mm

Table 4.12 Analysis of variance on multiple index for ginger

Source of variances	Sum of Squares	DF	Mean Square	F Value	p-value	
Model	194.08	18	10.78	157.45	< 0.0001	significant
Belt linear speed (S)	34.84	2	17.42	254.42	< 0.0001	
Cell size (C)	112.98	2	56.49	824.95	< 0.0001	
Speed of chain (V)	44.93	2	22.46	328.05	< 0.0001	
S × V	0.2627	4	0.0674	0.9845	< 0.4229	
S × C	0.7630	4	0.1907	2.79	< 0.0344	
V × C	0.2915	4	0.0729	1.06	0.3821	
Residual	4.11	60	0.0685			
Lack of Fit	2.7790	52	0.0534			
Cor Total	210.28	80				
Std. Dev.	0.2617		R-Squared		0.9793	
Mean	2.93		Adj R-Squared		0.9730	
C.V. per cent	8.92		Pred R-Squared		0.9622	
			Adeq Precision		48.8055	

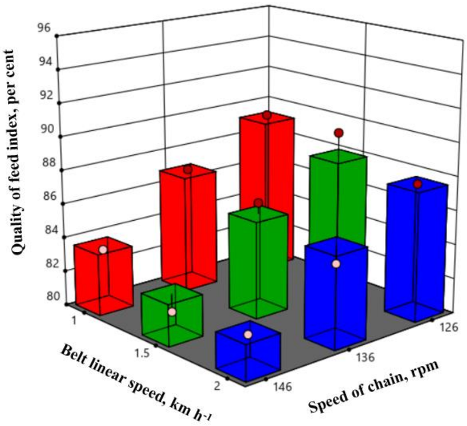
$P_{value} < 0.05$ is significant

4.10.4 Effect of belt linear speed and speed of chain on quality of feed index for different cell sizes

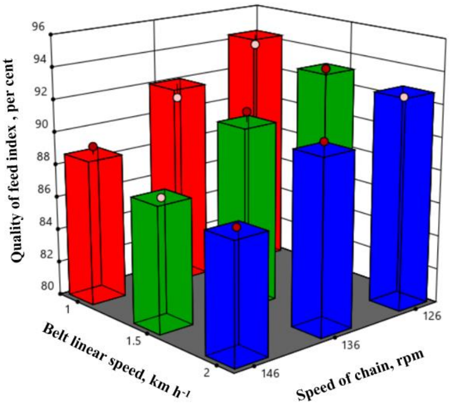
The effect of belt linear speed, cell size and speed of chain on the quality of feed index was investigated and the results are depicted in Fig. 4.4. It was evident from the findings that the highest quality of feed index reaching 91.21 per cent was achieved when using a 50 mm cell size with a forward speed of 1 km h^{-1} and speed of chain of 136±10 rpm. In comparison, both 40 mm and 60 mm cell sizes led to an increase in missing and multiple rhizomes, indicating inferior performance. Based on the laboratory study, the optimized parameters were determined to be a cell size of 50 mm, forward speed is 1 km h^{-1} and speed of chain is 136±10 rpm.

The average quality of feed index obtained from the study was 91.21 per cent as given table 4.13. From Fig. 4.4, it was observed that as belt linear speed increased with increase in metering speed of chain, there was decrease in quality of feed index by using 40 mm cell size and increasing the quality of feed index by using 60 mm cell size with highest level of speed of chain of 146±10 rpm.

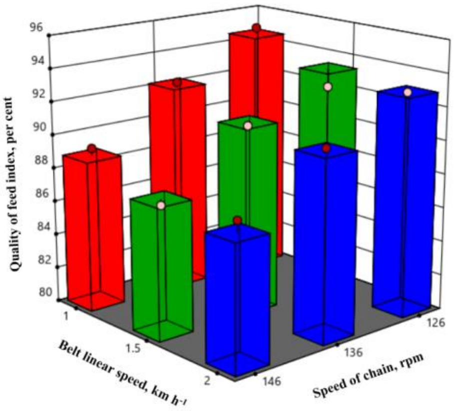
The effect of belt linear speed, speed of chain and different sizes of cell were analysed statistically and presented in ANOVA table 4.13, it is observed from that main factors belt linear speed (S), speed of chain (V) was significant at $p < 0.05$. However, the effect of cell size (C) was significant for the quality of feed index. The interactions S × V, V × C were non-significant and S × C were significant at p value < 0.05. It is revealed from the study that the cell size affects the picking of seeds from the picking chamber during singulation of seeds. The singulation also depends upon the sphericity and roundness characterisation of the seeds. Similar results are reported by (Madhu Kumar., 2017) and Kumar and Singh (2019).



(a) 40 mm



(b) 50 mm



(c) 60 mm

Fig. 4.4 Effect of belt linear speed and speed of chain on quality of feed index for different size of cells (a) 40 mm, (b) 50 mm, and (c) 60 mm.

Table 4.13 Analysis of variance of quality of feed index for ginger

Source of variances	Sum of Squares	DF	Mean Square	F Value	p-value	
Model	979.31	18	54.41	282.31	< 0.0001	significant
Belt linear speed (S)	37.89	2	18.94	98.30	< 0.0001	
Cell size (C)	490.52	2	245.26	1272.64	< 0.0001	
Speed of chain (V)	430.83	2	2415.42	1117.79	< 0.0001	
S × V	7.92	4	1.98	10.27	< 0.4229	
S × C	4.92	4	1.23	6.39	< 0.0344	
V × C	7.4	4	1.81	9.39	0.3821	
Residual	11.56	60	0.1927			
Lack of Fit	4.6038	52	0.0088			
Cor Total	994.29	80				
Std. Dev.	0.4390		R-Squared		0.9883	
Mean	89.20		Adj R-Squared		0.9848	
C.V. per cent	0.4921		Pred R-Squared		0.9787	
			Adeq Precision		60.9874	

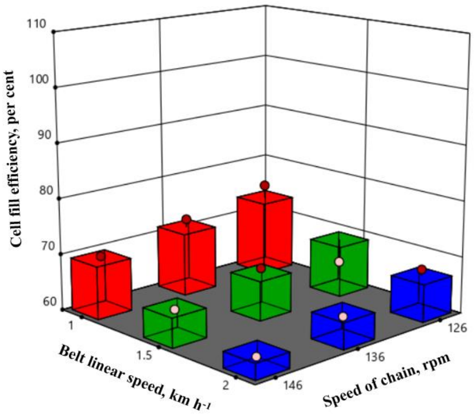
$P_{value} < 0.05$ is significant

4.10.5 Effect of belt linear speed and speed of chain on cell fill efficiency for different cell sizes

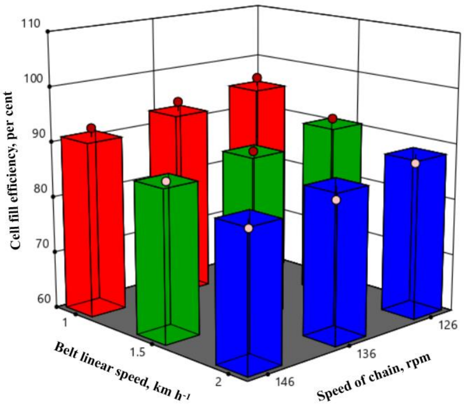
The impact of forward speed, cell size and speed of chain on cell fill efficiency was investigated. The experiment involved varying the forward speed between 1 km h^{-1} to 2 km h^{-1}, the cell sizes are 40 mm to 60 mm and the speed of chain is 126±10 rpm to 146±10 rpm. Surprisingly, the lower level of forward speed is 1.5 km h^{-1}, the highest level of forward speed is 2 km h^{-1} and the cell sizes are 40 mm and 60 mm exhibited poor picking efficiency. Similarly, the speed of chain is 126±10 rpm and 146±10 rpm also resulted in subpar performance.

In contrast, the best cell fill efficiency was observed 95 per cent at a forward speed of 1km h^{-1}, cell size of 50 mm and a speed of chain is 136±10 rpm. These parameters outperformed the other configurations and showed better results, particularly when picking rhizomes, as illustrated in Fig. 4.5. This suggests that a combination of moderately higher forward speed, smaller cell size and optimal speed of chain is essential for achieving superior cell fill efficiency in this particular context.

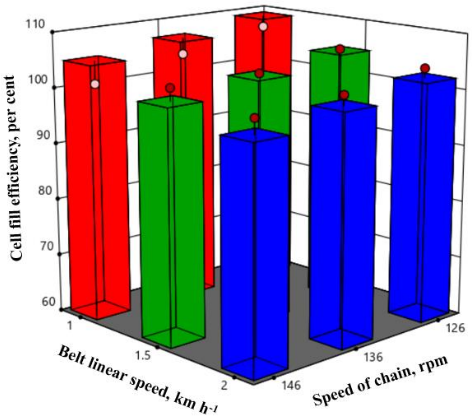
The effect of belt linear speed and metering speed of chain for different sizes of cells were analysed statistically and presented in ANOVA table 4.14, it is observed from that main factors belt linear speed (S), Speed of chain (V) was significant at $p < 0.05$. However, the effect of cell size (C) was significant for the quality of feed index. The interactions S × V significant. while V × C and S × C were not significant at p value < 0.05. The cell fill efficiency depends on medium cell size to get the desired cell fill efficiency. It is revealed from the study the cell size affects the picking of rhizomes from the picking chamber during singulation of seeds. The singulation also depends upon the sphericity and roundness characteristics of the seeds. This was justified by Kepner *et al,.*(1987).



(a) 40 mm



(b) 50 mm



(c) 60 mm

Fig. 4.5 Effect of belt linear speed and speed of chain on cell fill efficiency with different cell sizes (a) 40 mm, (b) 50 mm, (c) 60 mm.

Table 4.14 Analysis of variance on Cell fill efficiency

Source of variances	Sum of Squares	DF	Mean Square	F Value	p-value	
Model	2362.16	18	131.23	77.97	< 0.0001	significant
Belt linear speed (S)	86.08	2	43.04	25.57	< 0.0003	
Cell size (C)	2086.74	2	1043.37	619.93	< 0.0001	
Speed of chain (V)	70.75	2	35.37	21.02	< 0.0007	
S × V	112.35	4	28.09	16.69	< 0.0006	
S × C	1.50	4	0.3739	0.2221	< 0.9186	
V × C	4.74	4	1.19	0.7047	0.6106	
Residual	13.46	8	1.68			
Lack of Fit	2.7790	52	0.0534			
Cor Total	2375.63	26				
Std. Dev.	1.30		R-Squared		0.9943	
Mean	93.98		Adj R-Squared		0.9816	
C.V. per cent	1.39		Pred R-Squared		0.9354	
			Adeq Precision		30.0165	

$P_{value} < 0.05$ is significant

4.11 CALIBRATION TEST

The rhizome planter was calibrated in the laboratory to determine the rhizome seed rate, mechanical damage of rhizomes rate for a particular area. The calibration of rhizome planter was conducted to test and adjust the planter to obtain desired plant population. The calibrations test results are discussed in the following sections.

4.11.1 Calibration test for a sensor-based tractor drawn ginger planter for seed rate

The rhizome seed requirement per unit area was determined by calibrating the sensor-based rhizome planter in the laboratory for ginger. The rhizome planter was calibrated to determine the rhizome seed rate per hectare as described in section 3.13. The ground wheel was rotated for 20 revolutions and metered rhizomes were collected from all the three furrow openers and rhizome seed rate was calculated and the results are given in table 4.15.

Table 4.15 Calibration results for a sensor-based tractor drawn ginger planter

Sl. No.	Description	Value
1	Number of furrow openers	3
2	Spacing between the furrow openers, m	0.45
3	Diameter of ground wheel, m	0.57
4	Number of revolutions	20
5	Ginger rhizomes collected, kg	5.0

The recommended rhizome seed rate of ginger is 1500-2000 kg ha^{-1}, as per the Package of Practices (KAU, 2016). However, the developed rhizome planter was calibrated to achieve a rhizome seed rate of 1378.86 kg ha^{-1}, 1034.145 kg ha^{-1} and 827.316 kg ha^{-1}, for different spacing of rhizome to rhizome.

4.11.2 Calibration test of metering mechanism for cell fill efficiency

The per cent cell fill efficiency for the planter was influenced by factors such as the average seed size concerning cell size, the range of seed sizes, the shape of seeds, the shape of cells and exposure time of a cell inside seed pool of the hopper and the linear speed of the cell as described in the section 3.13. The results obtained was given in Appendix - VIII.

4.11.3 Mechanical damage of rhizome sett

During the calibration process, rhizome setts were randomly gathered from a two-kilogram lot, as outlined in section 3.14. The collected setts were examined for any damage, and the percentage of damaged rhizomes was subsequently calculated.

4.11.3.1 Ginger

Weight of damaged rhizome after test = 120g

$$\text{Rhizome rate required for 4136.58 revolutions} = \frac{120}{2000} \times 100 = 6 \text{ per cent}$$

4.12 PRECISION PLANTING

Precision planting is a cutting-edge agricultural technique revolutionizing modern farming practices. It involves precise placement of seeds and other inputs at optimal depths and spacing within the soil. This method minimizes the potential of each seed while minimizing environmental impacts make it an indispensable tool in modern sustainable agriculture as described in section 3.15.

4.13 THEORETICAL CONSIDERATIONS

4.13.1 Design of rhizome planter

A prototype of sensor-based rhizome planter as an attachment to existing tractor drawn ginger rhizome planter was designed and developed with optimized levels of variables. The planter unit was fabricated as explained in section 3.16.1.

4.13.1.1 Design features and specifications

The sensor-based rhizome planter was developed to suit ginger crops and to work in various types of soil and their conditions. The rhizome planter performs several functions during planting operation are (1) Opens the soil and forms furrows (2) Electronically control rhizomes setts (3) Delivers the rhizomes into seed delivery hopper through the electronic cup feed type metering mechanism with 50 mm cell size

(4) Deposits rhizome setts in the furrows (5) Covers and compacts rhizome setts with soil, forming a ridge in single pass.

Provisions were made to adjust or alter row to row spacing, plant to plant distance and depth of rhizome placement to suit the ginger crops. The row spacing was altered by changing the positions of mounting clamps along the main frame. While the depth of working of furrow opener or ridger can be adjusted by raising or lowering the standard through a rectangular hollow bracket on mounting clamp. The rhizome to rhizome spacing was varied by changing the forward speed as well as speed of chain. Also, this can be achieved by changing the number of cells on the rhizome metering chain. The general specifications of the rhizome planter are given in table 4.16.

Table 4.16 Specifications of the sensor based ginger planter

Sl. No.	Particulars	Values
1	Over all dimensions	
	Length × width ×height, mm	2000 × 1800 × 1560
2	Specifications of tractor	
	i. Make and model	John Deere 6510
	ii. Power source, hp	65
3	Type of implement	Mounted
4	Number of rows	3
5	Row spacing, mm	450 (Adjustable)
6	Hill to hill distance, mm	200 (Adjustable)
7	Nominal working width, mm	1350
8	Depth of planting, mm	70 (Adjustable)
9	Metering mechanism	
	i. Type of rhizome metering mechanism	Sensor based cup feed type metering mechanism
	ii. Source of power for driving metering mechanism	Shaft Encoder was fixed at the Ground wheel shaft
	v. Number of rhizome metering	3
	v. Diameter of metering shaft, mm	200
10	Hoppers	
	a) Rhizome hopper	

	i. Shape	Trapezoidal section
	ii. Capacity, m^3	0.28
11	Ground wheel	
	i. Type	Spike toothed wheel
	ii. Effective diameter of ground wheel, mm	480
	iii. Number of spikes	16
12	Furrow openers	
	i. Number of furrow openers	3
	ii. Type of furrow openers	Shoe type
13	Ridger bottoms	
	i. Number of ridger bottoms	4
	ii. Type of ridger bottom	Wing type (Adjustable)
14	Weight of planter, kg	450
15	Power transmission	
	i. The power from ground wheel to rhizome	i. Rotary shaft encoder was fixed at the ground wheel shaft ii. From rotary encoder output signals sends to Arduino nano iii. From Arduino nano to cytron 30 Amp DC motor driver iv. DC motor rotating the metering mechanism
	ii. Speed ratio	1:1, 1:1, 1:1

4.13.2 Design of rhizome hopper

The rhizome hopper was made up of GP sheet. The rhizome hopper comprises of three units. The volume of each unit is 0.119 m^3 obtained. Then the total volume of the hopper is 0.35 m^3, bulk density of ginger 429.44 kg m^{-3} and the angle of repose is 40^0 was obtained.

4.13.3 Design of ground wheel

Diameter of ground wheel is 570 mm was designed and selected for the rhizome planter to maintain the proper spacing between the rhizome to rhizome.

4.13.4 Speed ratio

The speed ratio of rhizome planter was obtained from the section 3.16.2.2.1. The obtained value is 96±10 rpm. Here decrease in DC motor speed from optimized value and increase in DC motor speed from optimized value to find the spacing between the rhizomes as well as increase the torque then easily can lift load within the hopper. The obtained values are 126±10 rpm ± 146±10 rpm. So, 126±10 rpm, 136±10 rpm and 146±10 rpm, the optimized value is 136±10 rpm.

4.13.5 Kinematics of chain drive

The rhizome metering was consisting of same size of sprockets were used in the unit and gear ratio is 1:1 was maintained in the unit as described in the section 3.16.2.3 respectively.

4.13.6 Torque requirement

In field evaluation is necessary to maintain the torque for lifting the rhizomes inside the hopper. The obtained torque is 4.089 Nm as described in the section 3.17.

4.13.7 Power requirement

The maximum capacity of rated power is 450 W. So, the power requirement of rhizome planter is 182.796 watts was obtained in the section 3.18.

4.14 DEVELOPMENT OF A SENSOR-BASED TRACTOR DRAWN GINGER PLANTER

4.14.1 Rhizome hopper frame

Rhizome hopper frame was made up of mild steel. The angle iron gives the strength of the main rhizome hopper. The height of frame 770 mm, length 1600 mm, width 635 mm and thickness of 5 mm and there is gap between DC motor angle iron frames was 115 mm were choosen for the design.

4.14.2 Rhizome hopper

The length of rhizome hopper is 1500 mm, width of 400 mm and height of 500 mm and thickness of 2 mm. The angle of repose was 40^0 to the horizontal is choosen to ensure the free flow of all rhizomes with in the hopper as well as optimal functionality and efficiency.

4.14.3 Seed collector

The seed collector serves as an integral component fixed to the lower section of the primary rhizome hopper through a nut and bolt arrangement. Its dimensions measure 360 mm in length, 100 mm in width, and 160 mm in height, with a thickness of 2 mm. Once the rhizomes are loaded into the hopper, they are directed into the seed collector. Subsequently, the seed metering system retrieves the rhizomes from this collector, facilitating efficient seed distribution and planting processes.

4.14.4 Seed delivery hopper

The seed delivery hopper's configuration, angle and height of seed release play pivotal roles in determining the timing and trajectory of seed descent. The height and width of the seed delivery hopper was 500 mm and 225 mm were selected. Consequently, ensuring precise seed distribution along the row is paramount for achieving optimal performance in agricultural operations.

4.14.5 Power transmission system

The power transmission system is facilitated by the rotary encoder connected to the ground wheel shaft. This encoder generates pulse counts for each revolution, relaying the information to an Arduino Nano. Programmed using the Arduino IDE software in the C++ language, the Arduino Nano executes a customized program that takes into account both the speed requirement and desired spacing for ginger crop planting. The board effectively governs the speed of the DC motor to align with the specified seed spacing. This control extends to the rhizome metering mechanism, ensuring synchronized regulation driven by the DC motor. In essence, the integrated system leverages precise control to optimize the planting process for ginger crops.

4.14.6 Length of the chain

The length of chain between two rhizome metering shafts were calculated. The obtained length of chain is 1.90 m was obtained as described in the section 3.19.8.

4.14.7 Main frame

The main structural framework of the planter consists of mild steel tubular sections measuring 76×76×6 mm. Various components of the planter frame are interconnected using square clamps along with nuts and bolts of appropriate sizes. During the design phase, careful consideration was given to provide flexibility in adjusting both row spacing and furrow opener positions according to specific requirements and field conditions**.**

4.14.8 Ridger bottom

The ridger bottom plays a vital role in preparing the soil for planting and cultivation, promoting optimal growing conditions, and enhancing overall crop performance in agricultural operations. The overall height is 550 mm, length is 300 mm and width is 400 mm.

4.14.9 Shoe type furrow opener

The shoe-type furrow opener offers a reliable and efficient tool for precision planting, promoting optimal seed placement, soil health, and crop performance across diverse agricultural environments. The overall height is 750 mm, length is 130 mm and width of 300 mm.

4.15 PERFORMANCE EVALUATION OF SENSOR-BASED TRACTOR DRAWN GINGER PLANTER

Field testing and evaluation of the sensor-based tractor drawn ginger planter was conducted in laterite loam soil with ginger rhizome. The moisture content of the soil at the time of sowing 13.80 per cent. The power is transmitted from the rotary shaft encoder, it is attached to the ground wheel shaft, rotary encoder gives the pulse count to an Arduino Nano for every revolution of ground wheel and an Arduino Nano board was programmed from Arduino IDE software C^{++} Language. In Arduino Nano regulates the speed of DC motor based on the required spacing, DC motor shaft was attached to the metering shaft through chain and sprockets. The tractor was operated with ginger rhizomes and different forward speeds of 1 km h^{-1},1.5 km h^{-1} and 2 km h^{-1} as well as speed of chain are 86±10 rpm, 96±10 rpm and 106±rpm and 50 mm cell size were conducted to get the desired plant spacing of 150 mm to 200 mm. In the field evaluation decrease in speed of chain (rpm) compared to laboratory test because increased the torque of the DC motor without clogging or easily pick the load in the rhizome hopper, after planting operation, spacing between plants was recorded randomly within the length of 20 m at three locations by counting the rhizome germination up to 17 days after planting as spacing between seeds was difficult to measure in the furrows (Ozmeri *et al*., 2002). These observations were statistically analysed. Keeping regular two-level factorial design methodology in Design Expert. The test was replicated three times at cell size. The data were statistically analysed to determine the effect of forward speed, speed of chain and cell size on performance indices, namely, plant to plant distance, missing index, multiple index, quality of feed index and cell fill efficiency. The results of the experiments are discussed below.

4.15.1 Field testing of a sensor-based tractor drawn ginger planter

The performance of the sensor-based tractor drawn ginger planter for ginger planting is given in table 4.17. The results were analysed statistically to determine the effect of forward speed, speed of chain and cell size on the planter performance indices for ginger planting.

Table 4.17 Effect of forward speed and speed of chain on ginger planting performance of rhizome planter

Sl. No	Experiment runs	Hill to hill distance, cm	Missing index, Per cent	Multiple index, Per cent	Quality of feed index, Per cent	Cell fill efficiency Per cent
1	S_1R_1	10.5	3.3	1.85	94.85	93.33
2	S_2R_1	14.5	9.28	2.85	87.86	92.78
3	S_3R_1	22.05	14.16	3.45	82.38	89.55
4	S_1R_2	16.7	2.16	1.05	96.73	92.28
5	S_2R_2	20.03	2.05	2.11	95.83	92.56
6	S_3R_2	27.7	9.16	3.13	87.70	89.23
7	S_1R_3	24.03	1.71	0.95	97.34	86.49
8	S_2R_3	28.03	1.5	1.33	97.16	85.32
9	S_3R_3	32.5	4.88	2.2	92.92	82.16

4.15.2 Effect of forward speed and speed of chain on hill-to-hill distance of ginger

The effect of forward speed and speed of chain on hill-to-hill distance is presented in table 4.18. From Fig. 4.6, it is observed that the mean spacing between rhizomes increased with increasing the forward speed and speed of chain during planting. The mean spacing between the rhizomes was observed in between 16.7 to 20.03 cm, while the forward speed ranges from 1 to 1.5 km h^{-1} with speed of chain is 96±10 rpm as given in Table 4.18.

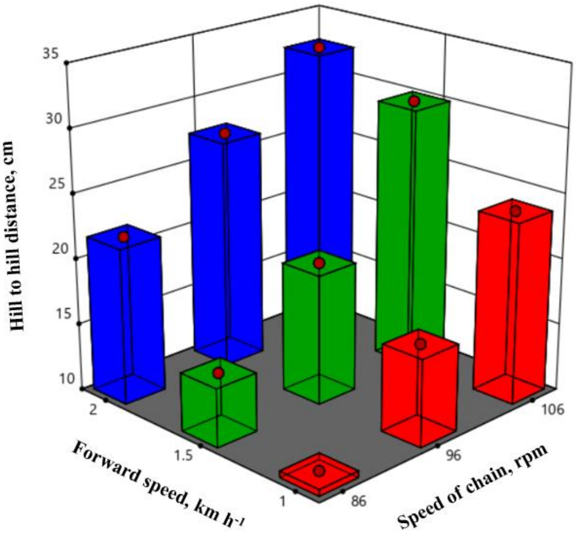


Fig. 4.6 Effect of planter forward speed and speed of chain on hill-to-hill distance of ginger

As shown in table 4.18, it shows the planter forward speed and speed of chain had significant effect ($P<0.001$) on hill-to-hill distance and interactions of S×V between planter forward speed and speed of chain was non-significant effect on hill-to-hill distance ($P>0.005$). Lowest level of speed of chain and highest level of speed of chain are increasing the missing because of less time available to pick the rhizome into the cell. Similar results were reported by Gaadi and Marey (2011) and Madhu Kumara (2017).

Table 4.18 Analysis of variance on hill-to-hill distance for ginger

Source of variances	Sum of Squares	DF	Mean Square	F Value	p-value	
Model	1275.10	4	318.77	245.13	< 0.0001	significant
Forward speed (S)	483.81	2	241.91	186.02	<0.0001	
Speed of chain (V)	791.29	2	395.64	304.24	< 0.0001	
S×V	28.61	4	7.15			
Residual	28.61	22	1.30			
Lack of Fit	28.61	4	7.15			
Cor Total	1303.71	26				
Std. Dev.	1.14		R^2-Squared		0.97	
Mean	22.02		Adj R-Squared		0.97.41	
C.V. per cent	5.18		Pred R-Squared		0.9669	
			Adeq Precision		48.02	

$P_{\text{value}} < 0.05$ is significant

4.15.3 Effect of forward speed and speed of chain on missing index for ginger

The effect of forward speed and speed of chain on missing index is showed in table 4.19. The missing index ranged from 1.5 to 14.16 per cent for different combinations of forward speeds and speed of chains as shown in Fig. 4.7.

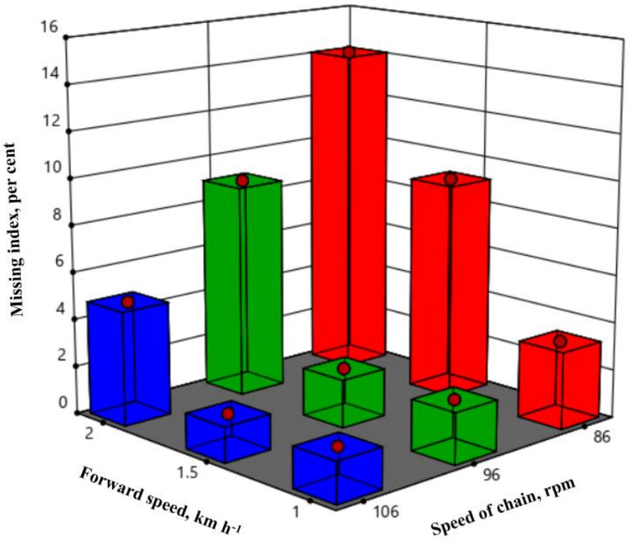


Fig. 4.7 Effect of forward speed and speed of chain on missing index with 50 mm cell size

The highest miss index 14.16 per cent was observed at highest forward speed of 2 km h^{-1} and lowest speed of chain of 86±10 rpm. This was due to decreasing the speed of chain from 96±10 rpm to 86±10 rpm. The lowest missing index 1.5 per cent was observed with a forward speed of 1.5 km h^{-1} due to increasing the speed of chain from 96±10 rpm to 106±10 rpm.

The analysis of variance (ANOVA) in table 4.19 showed the planter forward speed, speed of chain had a significant effect ($p<0.0001$) on missing index and the interactions S×V between planter forward speed and metering speed of chain was non-significant effect on missing index at ($p > 0.05$) probability. With increasing in forward speed from 1 km h^{-1} to 2 km h^{-1} resulting an increase in percentage of missing index. This was due to the decrease in speed of chain to 86±10 rpm from 106±10 rpm. Similar results were reported by Mathanker and Mathew (2002), Singh *et al.*, (2005), Kachman and Smith (1995) and (Madhu Kumara (2017).

Table 4.19 Analysis of variance on missing index for ginger

Source of variances	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**p-value**	
Model	421.66	4	105.42	37.56	< 0.0001	significant
Forward speed (S)	236.84	2	118.42	42.16	< 0.0001	
Speed of chain (V)	184.82	2	92.41	32.92	< 0.0001	
S×V	61.75	4	15.44			
Residual	61.75	22	2.81			
Lack of Fit	61.75	4	15.44			
Cor Total	483.42	26				
Std. Dev.	1.68		R^2-Squared		0.87	
Mean	5.36		Adj R-Squared		0.8490	
C.V. per cent	32.18		Pred R-Squared		0.8076	
			Adeq Precision		18.3457	

$P_{value} < 0.05$ is significant

4.15.4 Effect of forward speed and speed of chain on Multiple index

The influence of the forward speed and speed of chain on multiple index of rhizome planter performance is presented in table 4.20. The number of rhizomes placed less than 50 per cent spacing as per the recommended distance between spacing is indicated as multiple index of planter. The multiple index of ginger ranged from 0.95 per cent to 3.45 per cent for all levels of forward speeds and speed of chain. However, the lowest multiple index is 0.95 per cent was observed at lowest level of forward speed of 1 km h^{-1} and highest level of speed of chain of 106±10 rpm as shown in Fig. 4.8.

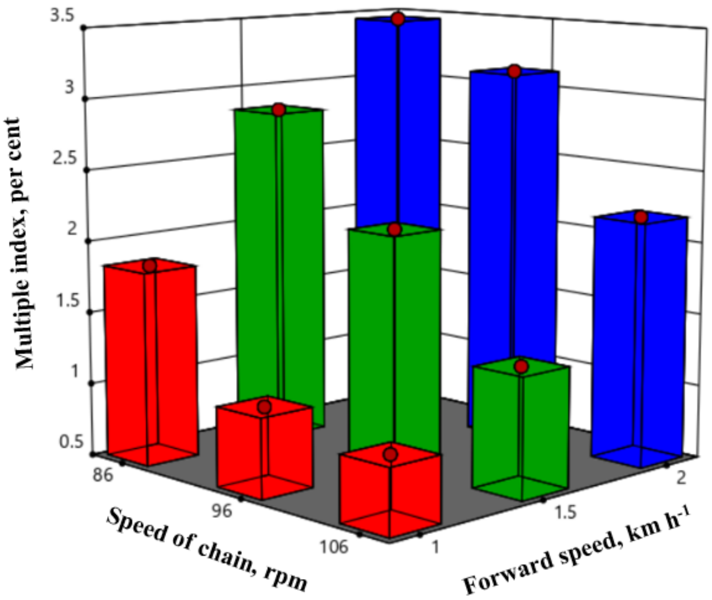


Fig. 4.8 Effect of forward speed and speed of chain on multiple index with 50 mm cell size

The analysis of variance (ANOVA) given in table 4.20, revealed that the planter forward speed (p<0.0001), speed of chain (P<0.0001) had a significant effect on the multiple index of ginger rhizomes and the interactions of S×V non-significant at p value > 0.05. From table 4.20, it was observed that as forward speed increased with decrease in speed of chain, there was increase in multiple index may be attributed to less time available to pick the seed in the cell due to skid. Increase in multiple index as cell size increase from 50 mm to 60 mm. As cell size increased bulk number of seeds picked up by cell, so multiple indices will increase. As the forward speed increases multiple will increases this was due to increasing metering of chain speed from 86±10 rpm to 108±10 rpm. The maximum multiple index obtained from the study was 3.45 per cent. Similar results are reported by Madhu Kumara (2017).

Table 4.20 Analysis of variance on multiple index for ginger

Source of variances	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**p-value**	
Model	18.89	4	4.72	144.01	< 0.0001	significant
Forward speed (S)	12.15	2	6.08	185.33	< 0.0001	
Speed of chain (V)	6.73	2	3.37	102.70	< 0.0001	
Residual	0.7213	22	0.0328			
Lack of Fit	0.7213	4	0.1803			
Cor Total	19.61	26				
Std. Dev.	0.1811		R^2-Squared		0.9632	
Mean	2.10		Adj R-Squared		0.9565	
C.V. per cent	8.61		Pred R-Squared		0.9446	
			Adeq Precision		36.7890	

$P_{value} < 0.05$ is significant

4.15.5 Effect of forward speed and speed of chain on quality of feed index

The results pertaining to quality of feed index is given in table 4.21. From the table 4.21, it is clearly observed that, the quality of feed index of ginger ranged from 82.38 per cent to 97.34 per cent. The highest quality of feed index (97.34 per cent) was observed at a forward speed of 1 km h^{-1} with a speed of chain of 108±10 rpm, whereas lowest quality of feed index, 82.38 was observed at highest forward speed of 2 km h^{-1} and lowest level of speed of chain of 86±10 rpm. The quality of feed index decreased from 97.34 per cent to 82.38 per cent with increase in forward speed as shown in Fig. 4.9. Similar result was observed for potato planter with high quality of feed index at lower forward speed as reported by Gaadi and Marey (2011) and Madhu Kumara (2017).

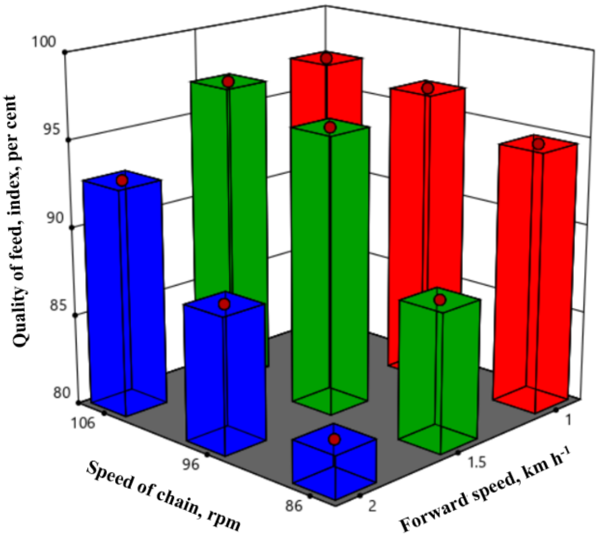


Fig. 4.9 Effect of forward speed and speed of chain on quality of feed index with 50 mm cell size

The analysis of variance (ANOVA) in table 4.21, revealed that the planter forward speed and speed of chain are significant at ($p < 0.0001$). The interaction S×V between planter forward speed and speed of chain had non-significant effect on quality of feed index of ginger rhizome at ($p < 0.05$) probability.

Table 4.21 Analysis of variance on quality of feed index for ginger

Source of variances	Sum of Squares	DF	Mean Square	F Value	p-value	
Model	611.87	4	157.97	49.11	< 0.0001	significant
Forward speed (S)	351.86	2	175.93	56.49	< 0.0001	
Speed of chain (V)	260.01	2	130.00	41.74	< 0.0001	
Residual	68.52	22	3.11			
Lack of Fit	68.52	4	17.13			
Cor Total	680.39	26				
Std. Dev.	1.76		R^2-Squared		0.89	
Mean	92.53		Adj R-Squared		0.8810	
C.V. per cent	1.91		Pred R-Squared		0.8483	
			Adeq Precision		21.1774	

$P_{value} < 0.05$ is significant

4.15.6 Effect of forward speed and speed of chain on Cell fill efficiency

The impact of forward speed, and speed of chain on cell fill efficiency was investigated. The experiment involved varying the forward speed between 1 km h^{-1}, 1.5 km h^{-1} and 2 km h^{-1}, the cell size of 50 mm and the speed of chain 86±10 rpm, 96±10 rpm and 108±10 rpm. At lowest level of forward speed gives the highest level of cell fill efficiency and decreasing cell fill efficiency at highest level of forward speed as depicted in Fig. 4.10.

In contrast, the cell fill efficiency was observed at a forward speed of 1 km h^{-1}, cell size of 50 mm and a speed of chain of 96±10 rpm. These parameters outperformed the other configurations and showed better results, particularly when picking rhizomes. This suggests that a combination of forward speed, medium cell size and optimal speed of chain is essential for achieving superior cell fill efficiency in this particular context.

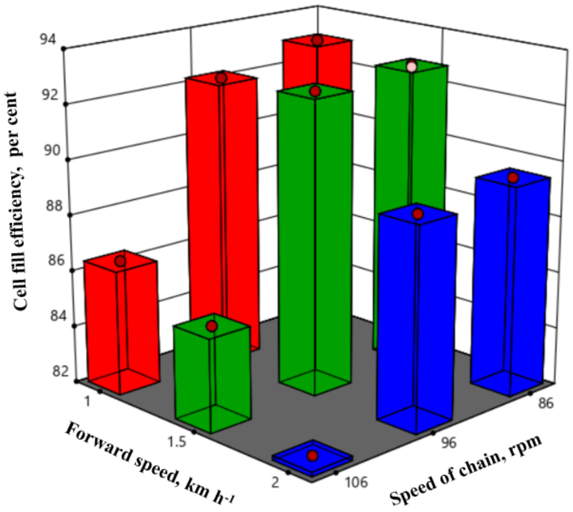


Fig. 4.10 Effect of forward and speed of chain on cell fill efficiency with 50 mm cell size

The effect of forward speed and metering speed of chain for size of cell were analysed statistically and presented in ANOVA table 4.22. It is observed that main factors forward speed (S), speed of chain (V) was significant at $p < 0.05$. However, the effect of cell size (C) was significant for the quality of feed index. The interactions S×V non-significant at p value < 0.05. The cell fill efficiency depends on medium cell size to get the desired cell fill efficiency. It is revealed from the study that the cell size affects the picking of rhizomes from the picking chamber during singulation of rhizomes. The singulation also depends upon the sphericity and roundness characteristics of the rhizomes. Per cent of cell fill efficiency method was followed by (Kepner *et al*,. 1987).

Table 4.22 Analysis of variance on cell fill efficiency for ginger

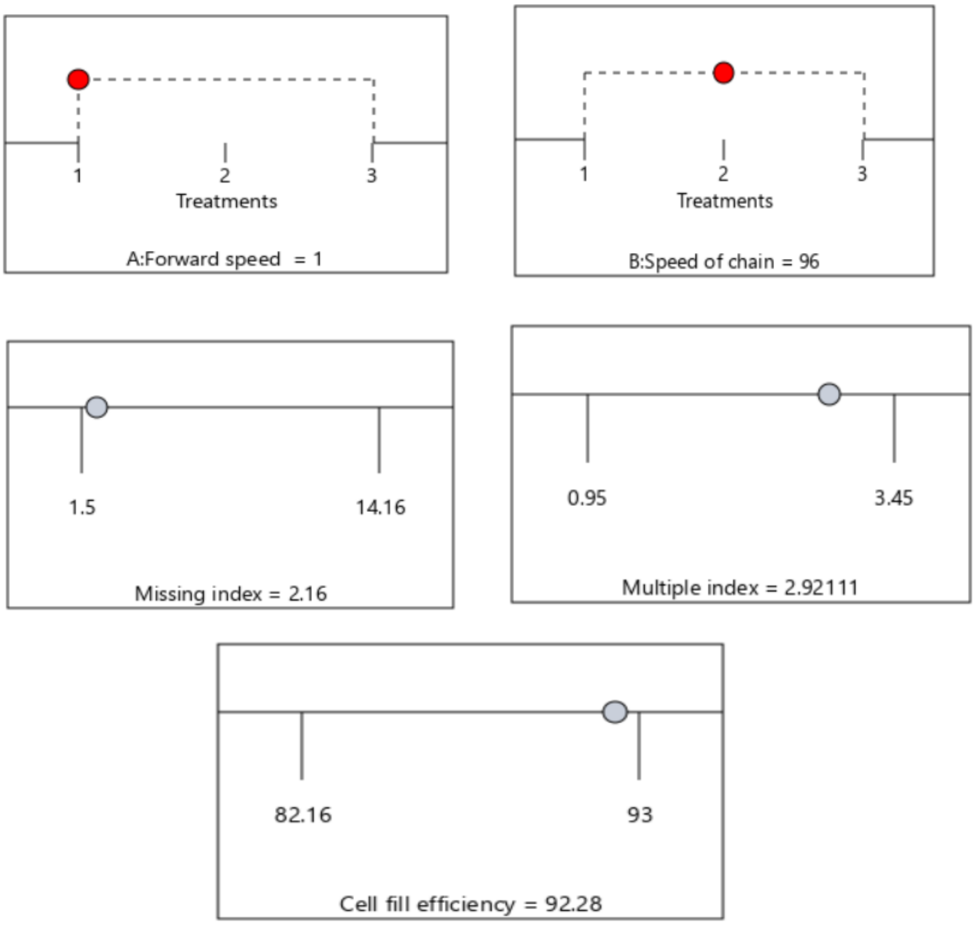
Source of variances	Sum of Squares	DF	Mean Square	F Value	p-value	
Model	703.26	4	175.81	146.46	< 0.0001	significant
Forward speed (S)	136.57	2	68.28	56.88	< 0.0003	
Speed of chain (V)	566.69	2	283.34	236.03	< 0.0001	
Residual	26.41	22	1.20			
Lack of Fit	26.41	4	6.60			
Cor Total	729.67	26				
Std. Dev.	1.10		R^2-Squared		0.9683	
Mean	85.39		Adj R-Squared		0.9572	
C.V. per cent	1.28		Pred R-Squared		0.9455	
			Adeq Precision		34.8681	

$P_{value} < 0.05$ is significant

4.16 OPTIMIZATION OF FIELD PERFORMANCE TEST OF TRACTOR DRAWN SENSOR BASED GINGER PLANTER

4.16.1 Optimization of field performance of sensor based ginger planter

The analysis of results obtained from various treatment combinations of belt linear speed, metering speed of chain and cell size of seed metering unit. Parameter indices studied for the maximum and minimum performance of the metering device is given by the desirability of 0.86 for ginger under field tests. At optimum desirability, the forward speed of 1 km h $^{-1}$ and 1.5 km h^{-1}, metering speed of chain of 96±10 rpm and the cell size 50 mm giving the superior performance during planting. The corresponding optimum values for independent variables and dependent parameters viz., missing index 1.71 per cent, multiple index 0.95 per cent, quality of feed index 97.34 per cent, hill to hill distance was 20 cm and cell fill efficiency 93 per cent respectively as given in Fig. 4.11. For the best performance of the rhizome planter, the machine should be operated at above values of the independent parameters to suit the varying sizes of ginger rhizomes.



Desirability 0.869

Fig. 4.11 Optimum setting of forward speed and speed of chain for minimum missing index, multiple index, cell fill efficiency, hill to hill distance and maximum quality of feed index for ginger.

4.17 FIELD PERFORMANCE TESTS

4.17.1 Draft

The draft developed by tractor for operating the sensor-based tractor drawn ginger planter was measured by rolling method as described in RNAM tests code (1983) mentioned in section 3.21.6. The average draft developed by the tractor mounted rhizome planter at the working test speeds selected for planting operation in the laterite loam soil was 740 Kgf for ginger experiments.

4.17.2 Wheel slippage

The tractor ground wheel slip was measured as described in section 3.21.4 The tractor ground wheel slip measured was 5 per cent which is within the recommended range of 15 per cent (Bjerkan, 1947).

4.17.3 Depth of rhizome placement

The depth of rhizome placement was measured by the procedure as described in section 3.21.10. The average depth of rhizome planting was 6.6 cm to 7.1 cm which was within the recommended value of 5 cm to 10 cm for ginger (Jayashree *et al*., 2014); (Kandiannan *et al*., 2008). The depth of rhizome placement in the furrow by the planter is given in table 4.23. From this table, it was observed that the standard deviation and coefficient of variation of actual field measurements made were computed with respect to the recommended depth. The standard deviation of rhizome depth in the furrow was

1.075 for ginger. Also, the coefficient of variation of depth of rhizome placement was 1.63 ginger.

Table 4.23 Depth of rhizome placement for ginger

Experimental trials	Ginger
1	7
2	6
3	7
4	5
5	7
6	6
7	8
8	5
9	8
10	7
Mean	6.6
Standard deviation	1.075
Coefficient of variation	0.163

4.17.4 Fuel consumption

The procedure was used to measure fuel consumption as described in the section 3.21.5. The planter was operated in an area of 0.75 ha. The time and fuel consumption for the test area was measured. The fuel consumption obtained was 4.1 *l* ha^{-1}.

4.17.5 Field capacity and Field efficiency

The mean field capacity and efficiency of the rhizome planter were 0.11 ha h^{-1} and 84 per cent respectively at a forward speed of 1 km h^{-1}. While field capacity and field efficiency was 0.15 ha h^{-1} and 76.44 per cent respectively at a forward speed of 1.5 km h^{-1}. The maximum field capacity of 0.19 ha h^{-1} observed at a forward speed of 2 km h^{-1} with a field efficiency of 70.85 per cent. Field capacity and field efficiency of tractor drawn sensor-based rhizome planter was given in Appendix XIII. Field efficiency of the rhizome planter was within the acceptable level (Kepner *et al.*,1987) for planters.

4.17.6 Cost of operation

The cost economics of tractor operated rhizome planter was worked out and given in Appendix - XV. Cost of sowing by using sensor-based ginger planter is Rs. 5583.07 ha^{-1} and Rs.1100.26 h^{-1}. The payback period to recover the initial cost of machine is 1.22 years. The cost of sensor-based ginger planter was Rs.80238.18/-. The benefit-cost ratio of the developed machine was 2.87.

Plate 4.2 View of the crop stand on 30 Days after planting

Plate 4.3 View of the crop stand on 60 Days after planting

CHAPTER V

SUMMERY AND CONCLUSIONS

Ginger (Zingiber officinale Roscoe) rhizomes are widely cultivated in India. Ginger is used as spices in cooking for flavour and as a medicine in Indian Ayurvedic treatments due to an oil called “gingerol” in ginger. Ginger is having a lot of uses in the manufacture of medicines and other products used in daily life. Ginger cultivation presents numerous challenges in labour and management for farmers. The crops are raised in beds in which three or four rows are planted at close spacing without much scope for mechanizing other farm operations including harvesting. The planting operation demands approximately 200-250 man-hours per hectare. Also, the harvesting is also done manually which consumes a lot of labour and cost in cultivation.

Mechanization is a gear towards the reduction on the dependence on manual labour and production costs as well as to sustain the productivity. Sowing operation accounts for 18.0 per cent of the total labour utilization which indicates that it is a highly labour-intensive operation. The major constraints in ginger cultivation are non-availability of labour in time, especially during peak periods of sowing. The sowing operation needs a higher degree of precision to increase the efficiency of the inputs and reduce the input losses. The adoption of precision planting techniques ensures consistent plant spacing and depth, facilitating increased mechanization of intercultural farming tasks, ultimately lowering overall production costs. The existing metering mechanisms are mechanical type driven by ground wheel and they are less efficient as there exist a loss of power during transmission through chain, gears and sprockets from the ground wheel. To solve the above problems, an alternative power transmission method by substituting an electronic cup feed type metering mechanism driving through DC motor drive by a speed synchronization mechanism between DC motor and ground wheel is used. Therefore, the present study was undertaken to a sensor-based tractor drawn ginger planter.

Suitable methodologies were adapted for the study. Experiments were conducted in the following aspects.

i. The predominant ginger rhizome varieties are Athira, Aswathy, Chithra and Karthika were selected and their physical properties and mechanical properties were studied and optimized**.**

ii. The sticky belt experimental test rig for testing of electronic cup feed type metering mechanism was developed and evaluated for performance with respect to hill to hill distance, missing index, multiple index, quality of feed index and cell fill efficiency. The levels of variables for the sticky belt laboratory test investigation were metering speed of chain are 126±10 rpm, 136±10 rpm, 146±10 rpm and cell geometry viz., maximum seed dimension, 10 per cent more than the maximum seed dimension and 25 per cent more than the seed dimension. For ginger, belt linear speeds were 1.0, 1.5 and 2.0 km h^{-1} and for the cell sizes 40 mmm, 50 mm and 60 mm respectively.

ii. The electronic cup feed type rhizome metering device driven by the DC motor was conducted to determine the optimum parameters of working for the ginger rhizomes selected for the study. The observed data were statistically analysed and the individual and interactive effect of selected levels of variables on seed rate, hill to hill distance and performance indices were studied.

iii. The combination of variable levels which gave recommended hill to hill distance and seed rate were choosen as the optimum combination of the factors, based on the results from the statistical analysis.

iv. A sensor-based tractor drawn ginger planter was developed based on the agronomic planting considerations, engineering and physical properties of ginger rhizomes. The components of the precision planter were designed based on the materials selected for the functional parts. The furrow openers were mounted on the main frame such that the row spacing and height of furrow opener standard or shank can be adjusted to suit changes in row spacing and depth of sowing for the ginger crop during the sowing operation.

v. Planter performance parameter indices based on ideal spacing viz., the missing index (Imiss), multiple index (Imulti), quality of feed index (Iqf), hill to hill distance and cell fill efficiency were used to evaluate the functional performance of a sensor-based tractor drawn ginger planter.

vi. A prototype of tractor drawn sensor based ginger planter was developed and the effect of a machine and operational parameters was evaluated in terms of forward speed and speed of metering mechanism. The data obtained from the experiments were statistically analysed and optimized to bring out a combination of variables yielding the best performance in terms of maximum planting efficiency and minimum seed damage.

vii. A tractor drawn sensor based ginger planter was evaluated in the field for sowing ginger rhizomes and the field capacity, field efficiency and planting performance were determined.

viii. The cost economics for the developed tractor drawn sensor based ginger planter was carried out.

The following conclusions were drawn from the analysis of the results obtained from the Laboratory study.

i. The average moisture content of Athira variety of ginger rhizome is 71.71±1.97 per cent. Similarly, the average moisture content of Aswathy, Chithra and Karthika were found to be 74.53±1.0 per cent, 72.45±2.34 per cent and 76.01±0.83 per cent respectively.

ii. The average size of different varieties of ginger rhizomes are Athira, Aswathy, Chithra and Karthika having a major axis (length) 46.95±1.78 mm; intermediate axis (width) 33.37±1.41mm; and minor axis (thickness) 18.84±2.45 mm respectively. Similarly, aswathy having a major axis (length) 47.02±2.15 mm; intermediate axis (width) 31.22±2.03 mm and minor axis (thickness) 16.37±2.92 mm, Chithra variety having a major axis (length) 47.33±2.04 mm; intermediate axis (width) 32.29±1.82 mm; and minor axis (thickness) 17.21±2.47 mm and karthika rhizome having a major axis (length) 46.26±2.70 mm; intermediate axis (width) 33.19±2.19; and minor axis (thickness) 17.2±2.02 mm respectively.

iii. The average sphericity determined were 0.63±0.03, 0.17±0.03, 0.61 ± 0.03 and 0.60±0.03 per cent for Athira, Aswathy, Chithra and Karthika respectively.

iv. The average thousand-grain weight determined were 3055, 4570, 4000 and 4899 seeds g for Athira, Aswathy, Chithra and Kartika respectively.

v. The average bulk density determined were 429.44 ± 7.55, 375.6 ± 22.04, 429.00 ± 24.78 and 377 ± 11.55 kg m^{-3} for Athira, Aswathy, Chithra and Karthika respectively.

vi. The highest mean value of friction observed against materials plywood 0.576± 0.06, 0.603 ± 0.03, 0.536 ± 0.06 and 0.593 ± 0.06 for Athira, Aswathy, Chithra and Karthika by mild steel 0.523 ± 0.02, 0.583 ± 0.07, 0.510 ± 0.05 and 0.53±0.03 for Athira, Aswathy, Chithra and Karthika by stainless steel 0.48 ± 0.04, 0.496 ± 0.05, 0.463 ± 0.15 and 0.446 ± 0.06 for Athira, Aswathy, Chithra and Karthika respectively.

vii. The average values of angle repose determined were 34.43±3.93, 36.87±3.58, 36.54 ± 1.11 and 38.24 ± 3.17 degree for Athira, Aswathy, Chithra and Karthika respectively**.**

viii. In the laboratory sticky belt testing, the minimum values of plant-to-plant distance 18.5 cm, miss index 5.25. per cent, multiple index 3.54 per cent, quality of feed index 91.21 per cent and maximum value of cell fill efficiency 95 per cent were observed for ginger rhizome by using the 50 mm cell size and forward speed is 1 km h^{-1} and speed of chain is 136±10 rpm was giving the superior performance compare to 40 mm sell size and 60 mm cell size as well as speed of chains are 126±10 rpm and 146±10 rpm encountered the subpar performance. Lowest level of speed of chain was found that increasing the missing index due to time lagging between collecting and deliver on the grease coated belt. Highest level of speed of chain was found that increasing missing index due to less time to pick the rhizome into the cell. So, here not getting the required spacing between rhizomes were observed from the study.

ix. The plant-to-plant distance increased when the belt linear speed and metering speed of chain were increased and when the cell size was decreased. The mean hill to hill distance of ginger is 18.5 cm was obtained compared to the recommended spacing of 15-25 cm when using 50 cm cell size, metering speed of chain of 136±10 rpm and forward speed is 1 km h^{-1}.

x. The seed rate of laboratory set up by using 40 mm cell size with different spacing of 15 cm, 20 cm and 25 cm are 534.59 kg ha^{-1}, 400.94 kg ha^{-1} and 320.75 kg ha^{-1}.

xi. The seed rate of laboratory set up by using 50 mm cell size with different spacing of 15 cm, 20 cm and 25 cm are 987.42 kg ha^{-1}, 740.56 kg ha^{-1} and 592.45 kg ha^{-1}.

xii. The seed rate of laboratory set up by using 60 mm cell size with different spacing of 15 cm, 20 cm and 25 cm are 2515.72 kg ha^{-1}, 1886.79 kg ha^{-1} and 1509.43 kg ha^{-1}.

xiii. The sticky belt linear speed was optimized as 1 km h^{-1} for ginger rhizome respectively, based on the results of seed rate and uniformity of seeds obtained during the laboratory test in comparison with recommended values**.**

xiv. In the sticky belt laboratory test. The best combination of $S_1C_2V_2$ was selected based on the results of statistical analysis (Design Expert) on the individual and interactive effect of selected levels of variables. The optimized values for ginger rhizome, 50 mm cell size, metering speed of chain is 136±10 rpm and forward speed is 1 km h^{-1}.

The following conclusions were drawn from the analysis of the results obtained from the field study.

i. The optimized cell size tested in the field evaluation. So, here testing with the 27 number of cells including 3 metering mechanisms, each metering fixed with 9 cells. According to 9 cells, speed ratio was decreased compared to laboratory study because in laboratory set up done with one row and 5 number of cells with the speed of chain is 126±10 rpm, 136±10 rpm and 146±10 rpm was observed from the study. In field evaluation speed ratio is 86±10 rpm, 96±10 rpm and 106±10 rpm here decreased the speed ratio because of increased the torque of the DC motor, because without clogging or easily pick the load in the rhizome hopper.

ii. In field testing, the maximum and minimum values of miss index 14.6 per cent to 1.5 per cent, multiple index 3.45 per cent to 0.95 per cent, maximum value of quality of feed index from 82.38 to 97.34 per cent and maximum value of cell fill efficiency from 82.16 per cent to 93 per cent were observed in the filed evaluation. The average hill to hill distance 20.03 cm were observed for ginger.

iii. The average plant population of ginger planted by a sensor-based tractor drawn ginger planter was 13 plants m^{-2}.

iv. The average depth of seed placement was 4.0 to 4.5 cm which is within the recommended value of 10 cm.

v. The recommended rhizome seed rate of ginger per hectare is 1500-2000 kg ha^{-1}, as per the Package of Practices (KAU, 2016). However, the developed rhizome planter was calibrated to achieve a rhizome seed rate of 1378.86 kg ha^{-1}, 1034.145 kg ha^{-1} and 827.316 kg ha^{-1}, for different spacing of rhizome to rhizome.

vi. The field capacity and field efficiency of the precision planter was 0.11 ha h^{-1} and 84 per cent respectively.

vii. In the field test. The best combination of $S_1C_2V_2$ was selected based on the results of statistical analysis (Design Expert) on the individual and interactive effect of selected levels of variables. The optimized values for ginger rhizome, 50 mm cell size, metering speed of chain is 96±10 rpm and forward speed is 1 km h^{-1}.

viii. The cost of planting by using a sensor-based tractor drawn ginger planter is Rs. 5583.07 ha^{-1} and compared with manual planting was Rs.12500 ha^{-1}. The custom hiring cost of a precision planter is Rs. 1100.26 h^{-1}. The payback period to recover the initial cost of the machine is 1.22 years. The cost of a sensor-based tractor drawn ginger planter Rs.80238.18/-. The benefit-cost ratio of the developed machine was 2.87.

ix. The prototype of a sensor-based tractor drawn ginger planter in 89.1 per cent and 98.84 per cent savings in cost and time of operation respectively, when compared to the conventional method of hand dibbling.

x. Based on the economic analysis, it can be concluded that a tractor drawn ginger planter with a cup feed type metering mechanism leads to more precision in planting operation and thus can be recommended for farmers since the metering mechanism is driven and controlled by an electronically driven motor for precision seed metering.

REFERENCES

Abd El-Tawaab, I. M., Badaway, M. E. and El-Khawaga, S. 2007. Development and performance evaluation of a locally fabricated sugar beet planter. *Misr J. Ag. Eng*. 24 (4): 648-665.

Ahmed, A.G., Abbas, Z.K., Akif, K., Sui, Y.K., Michael, N., and Will, G. 2018. Soil bulk density estimation methods. *Pedosphere*. 28(4): 581-596.

Ajav. E. A. and Ogunlade C. A. 2014. Physical properties of ginger (Zingiber Officinale). (*Glob. J. Sci. Frontier Res*). 14(8): 23-29.

Al-Gaadi, K. A. 2011. Performance evaluation of cup-belt potato planter at different operation conditions and tuber shapes. *American-Eurasian*. *J. Agric. Environ. Sci.* 10(5): 821-828.

Al-Gaadi, K. A. and Marey. 2011. Effect of forward speed and tuber characteristics on tuber spacing uniformity for a cup belt potato planter. *Middle E. J. Sci. Res.* 8(4): 753-758.

Anantachar, M., Prasanna GV Kumar, and T. Guruswamy. 2010. Neural network prediction of performance parameters of an inclined plate seed metering device and its reverse mapping for the determination of optimum design and operational parameters. *Comput and Electr in Agric.* 72, no. 2 (2010): 87-98.

Angelis, D. M. 2007. Measurement of soil moisture content by gravimetric method. *Am. Soc. Agro.* Pp: 1-2.

Anonymous. 2010. Report of MPUAT, Udaipur.

ASAE [American Society of Agricultural Engineers]. 1993. S358.2. Moisture Measurement forages. St. Joseph, Mich.

Athmaselvi, K. A. and Varadharaju, N. 2002. Physical and thermal properties of turmeric rhizomes. Madras *Agric. J.* 89(10-12): 666-671.

Atterberg, A. 1911. The relation of clays to water and their plasticity limits and degrees of plasticity. *K. Land no. Handl.And Tskr.* 50: 132-158.

Awady, M.N. and EI-Said, S.A. 1985. Design factors for simple grain drill feeding mechanism. *Misr. J. Ageic. Eng*. 2(2): 33-49.

Aware, V. V. and Aware, S.V. 2014. Development of microprocessor based electronic metering mechanism for seed – an approach. *Eng. Technol. India.* 5(2): 26-31.

Bahnasawy, A. H. 2007. Some physical and mechanical properties of garlic. *Int. J. of Food Eng.* 3(6): 1-18.

Bakhtiari, M. R. and Loghavi, M. 2009. Development and evaluation of innovative garlic clove precision planter. *J. Agric. Sci. Technol.* 11: 125-136.

Balami, A.A., Adebayo, S.E. and Adetoye, E.Y. 2012. Determination of some engineering properties of sweet potato (Ipomoea batatas). *Asian J. of Nat. & Appl. Sci.*1(1): 67-77.

Balasubramanian, S., Mohite, A.M., Singh, K.K., Zachariah, T.J., and Anand, T. 2012. Physical properties of turmeric. *J. of Spi. And Aro. Cr*. 21 (2): 178-181.

Bartley, J. and Jacobs, A. 2000. Effects of drying on flavour compounds in Australian-grown. *J. Sci. Food and Agric*. 80: 209-215.

Bhawna, S., Shirsat, S., Patel, P., Borkar, A., and Bakane, P.H. 2018. Physical properties of fresh ginger (Zingiber Officinale) rhizomes. *Mult. In Sci*. 8(25): 304-307.

Bjerkan, J. A. 1947. The precision planting equipments. *J. Agric. Eng.* 28(4): 54-57.

Bosai, E. S., Verniaev, O. V., Smirnov, I. I., and shakh, S. E. G. 1987. Agricultural machines theory, construction and calculations. Vol. 1, Oxionian press Pvt. Ltd., New Delhi, pp: 237-275.

Boydas, M.G., and Turgut, N. 2007. Effect of vibration, roller design and seed rates on the seed flow evenness of a studded feed roller article. *American Soc. of Agric and Biol. Eng.*

Buitenwerf, H., Hoogmoed, W. B., Lerink, P., and Muller, J. 2006. Assessment of the behavior of potatoes in cup-belt planter. *Biosys. Eng.* 95(1): 35-41.

Celik, A., Ozturk, I., and Way, T. R. 2007. Effects of various planters on emergence and seed distribution uniformity of sunflower. *Appl. Eng. Agric.* 23(1): 57 61.

Chaudari, D.2011. Performance evaluation of various types of furrow openers on seed drills a review. *J. Agric. Eng. Res.* 79: 125-137.

Chhinnan, M. S., Young, J. H., and Rohrbach, R. P. 1975. Accuracy of seed spacing in peanut planting. *Trans of the ASAE,* 18(1): 828-831.

Chowdareddy, M. and Dronachari, M. 2014. Physical and frictional properties of donkeymanure at various depths in compost pit. *J. Academia Ind. Res*. 2(9): 503-506.

Collins, B. A and Fowler, D. B. 1996. Effects of soil characteristics depth, operating speed, and opener design on draft force during direct seeding. *Soil and Tillage Res.* 39:199-211.

Dhinesh Kumar V. and Ananda Kumar S. 2016. Physical and engineering properties of ginger rhizome. *J. of Food Res. and Technol*. 4 (1): 30-34.

Dixit, A., Verma, A., Singh, A., and Manes, G. S. 2015. Performance of tractor mounted vertical belt paired row potato planter. *Agric. Res. J.* 52(1): 59-61.

Dubey, A. K. and Srivastava, N.S.L. 1985. Development of furrow openers for animal drawn seed-cum-fertilizer drill for black soils. *Procedings of the ISAE SJC.* 1: 39-43.

Ebrahim, A. and Hamid, R. 2008. Development of A precision seed drill for oilseed rape. *Turk J. Agric.* 32:451-458.

Gautham, A., khurana R., Manes GS., Dixit A, and Verma A. (2016). Development and Evaluation of Inclined Plate Metering Mechanism for Onion Pelleted Seeds. Vegetos 29:3.

Ghosal, M. K. and Behera, D. 2016. Performance Evaluation and Seed Pattern Characteristics of Manually Operated Cup Feed Metering Seed Drill for Sowing of Groundnut Seeds. *Agric. Eng. Today.* 40(4): 1-6.

Griepentrog, H. W. 1998. Seed distribution over the area. *Eur. Agric. Eng.* 98-A-059: 66-74.

Guo, H., Cao, Y., Song, W., Zhang, J., Wang, C., Wang, C., Yang, F., Zhu, L. Design and Simulation of a Garlic Seed Metering Mechanism. 2021. Agriculture, 11, 1239. https:// doi.org/10.3390/agriculture11121239.

Hadi, K., Hossein, N., Bahram, B., Hossien, B., and Iraj, E. 2017. A practical approach to comparative design of non-contact sensing techniques for seed flow rate detection. *Comput. And Electr in Agric.* 142: 165-172.

Hajahmed. O., Tola, E., Al-Gaadi, K.A., and Kheiralla, A. F.2011. Development of an opto electronic Monitoring System for Crop Planter Seed Metering Unit. *Middle-Est J. of Sci. Res.* 8(4): 732-738.

Hamad, S. A. and Banna, A. B. 1980. The grain drill Cz 3.6 and its viability for sowing different size seeds. *J. Agric. Sci. Mansoura Univ.* 5: 76-85.

Heege, H. J. and Feldhaus, B. 2002. Site specific control of seed numbers per unit area for grain drills. Peer reviewed technical articles (25): *The CIGR J. of Sci. Res an Dev.*

Hummel, J. W., Ahmad, I. S., Newman, S. C., Sudduth, K. A. and Drummond, S.T. 2004. Simultaneous soil moisture and cone index measurement. *Trans of ASAE.* 47(3): 607-618.

Indiastat.2023. www.indiastat.com.

Ismail, Z. E. 1989. Evaluation of some engineering parameters affecting uniformity in row distribution for types of potato planters. *Misr. J. Agric. Eng.* 6 (1): 78 90.

Jafari, M., Hemmat, A. and Sadeghi, M. 2011. Comparison of Coefficient of Variation with Non-Uniformity Coefficient in Evaluation of Grain Drills. *J. of Agric. Sci and Technol.* 13(5): 643-654.

Jayan, P. R. and Kumar, V., 2004. Planter design in relation to the physical properties of seeds. *J. Trop. Agric.* 42 (1&2): 69-71.

Jayashree, E. 2009. Studies on mechanization of field level post-harvest operations in ginger (Zingiber officinale) with reference to washing, peeling and drying.

Unpublished Ph.D. Thesis, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, India.

Jayashree, E., Kandiannan, K., Prasath, D., Pervez, R., Sasikumar, B., Senthil Kumar, C. M., Srinivasan, V., Suseela Bhai, R., and Thankamani, C. K. 2014. Ginger (Extension Pamphlet). Indian Institute of Spice Research. Calicut.

Jiraporn, B., Sakurai, H., and Ito, N. 2010. Design and control of metering system and furrow openers for garlic planter. *Int. Agric. Eng. J.* 19(2): 39-47.

Kachman, S. D. and Smith, J.A. 1995. Alternative measures of accuracy in plant spacing for planters using single seed metering. *Trans. of the ASAE*. 38 (2): 379-387.

Kamgar S, Mohammad Javad Eslami and Mohammad Mehdi M. 2012. Design, development and evaluation of a mechatronic transmission system for upgrading performance of a row crop planter. Conference: Dallas Texas, 29(1): 2012-2016.

Kamgar, S., Noei-Khodabadi. F., and Shafaei, S. M. 2015. Design development and field assessment of a controlled seed metering unit to be used in grain drills for directseeding of wheat. Department of Biosystems Engineering, College of Agriculture, Shiraz University.

Kandiannan, K. and Chandaragiri, K. K. 2008. Monetary and non-monetary inputs on turmeric growth, nutrient uptake, yield and economics under irrigated condition. *Indian J. Hortic.* 65(2): 209-213.

Kandiannan, K., Sasikumar, B., Thankamani, Bhai, S. R., Santhosh, C. K., Eapen, J., Devasahayam. S., and Zachariah, J. T. 2008. Turmeric (Extension Pamphlet). Indian Institute of Spice Research. Calicut.

Kankal, U.S. Karale, D.S., Khambalkar V.P and Thakare S.H. 2016. Performance evaluation of single row manual cotton planter. International *J. of Agric. Eng*. 9(1):1926.

Karayel, D. A. V. U. T., Barut, Z. B., and Ozmerzi, A. 2004. Mathematical modelling of vacuum pressure on a precision seeder. *Biosystems Eng.* 87(4), 437-444.

Karayel, D., Wiesehoff, M., Ozmerzi, A., and Müller, J. 2006. Laboratory measurement of seed drill seed spacing and velocity of fall of seeds using high-speed camera system. *Comput. and Electr. Agric.* 50 (2): 89-96.

Karthick, V., Alagumani, T., and Anbarassan, A. 2015. Growth and export performance of ginger in India- An economic analysis. *J. Food Sci. Technol*. 3(4): 21-29.

KAU. 2016. Package of Practices Recommendations*: Crops.* Kerala Agricultural University, Thrissur.

Kazmeinkhah, K. 2007. Determination of energetic and ergonomic parameters of a semi-automatic sugar-beet steckling transplanter. *J. Agric. Sci. Technol*. 9: 191 198.

Kepner, R.A., Bainer, R., and Barger, E.L. 1987. Principles of farm machinery, CBS Publishers and distributors Pvt. Ltd, New Delhi.

Khurmi, R.S and Gupta, J.K. 2011. A Text book of Machine Design. Eurasia Publishing House Pvt Ltd, India, 762p.

Kocher, M. F., Coleman, J. M., Smith, J. A., and Kachman, S. D. 2011. Corn seed spacing uniformity as affected by seed tube condition. *Appl. Eng. Agric.* 27(2): 177-183.

Koley S. 2012. Design and development of electronic seed metering mechanism for precision planting of seeds. Unpublished M. Tech thesis, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology Udaipur 313001 Rajasthan.

Kual, R. N. and Egbo, C. O. 1985. Introduction to agricultural mechanization. 1st Ed. Macmillan publication Ltd. London and Basintoke. 89p.

Kumar, A. T. M. and Singh, T. P. 2019. Development and Performance Evaluation of Cup Chain type Metering Mechanism for Gladiolus corms in the Soil Bin. *Int. J. Curr. Microbiol. App. Sci.* 8(8): 28132822.doi: https://doi.org/10.20546/ijcmas.2019.88.32.

Kumar, D., kumar., and Kant, K. 2017. Studies and performance of a garlic planter in Utter Pradesh. *Int. J. Agric. Eng.* 10. (1) : 228-233.

Kumari, C. A. 2011. Design and development of a tractor operated onion set planter. Unpublished Ph.D. Thesis, Department of Farm Machinery, Agricultural Engineering College and Research Institute Tamil Nadu Agricultural University, Coimbatore.

Kus, E. 2021. Field scale evaluation of parameters affecting planter vibration in single seed planting. *Measurements*. Vol.184. November 2021, 109959.

Madhu kumar, D. M. 2017. Design, development and testing of a tractor drawn semi-automatic rhizome planter for ginger and turmeric. M.Tech.(Ag. Engg.) thesis, Kerala Agricultural University.

Mahender, B., Reddy., S.P, P., Thanuja, S. G., Balakrishna, M. and Prathap, P. 2013. Effect of seed rhizome size and plant spacing on Growth, yield and quality of ginger (Zingiber officinale Rosc.) Under coconut cropping system. *Plant Arch.* 15(2): 769-774.

Manjunath., Kumar., P Kushwaha., H. L., Sathish, D., Lande, indra mani and roaf ahmad parray. 2019. Performance Evaluation of Sensor Controlled Seed Metering Mechanism for Check Row Planting. *Agric. Eng. Today.* Vol. 43 (3).

Mansuriya, V. 2013. Development and performance evaluation of electronic planter. Unpublished M. Tech thesis, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology Udaipur, Rajasthan.

Marakoglu, T. and Carman, K. 2009. Effects of design parameters of a cultivator share on draft force and soil loosening in a soil bin. *J. Agron.* 8(1): 21-26.

Marey, S. A. 2015. Affecting each of ridger furrow opener parameters and planting methods on water use efficiency and sugar beet yield. *Bulgarian J. Agric. Sci.* 21: 1304-1311.

Mari, G. R., Memon, S. A., Leghari, N., and Brohi, A. D. 2002. Evaluation of tractor operated potato planter. *Pakistan J. Appl. Sci.* 2(9): 889-891.

Mathanker, S. K. and Mathew, M. 2002. Metering mechanisms for ginger planter. *Agric. Eng. J.* 11(1): 31-39.

Mathur, S. M. and Pandey, K. P. 1992. Influence of system parameters on performance of reversible hoe type furrow opener for animal drawn seed and fertilizer drills. Proceeding of the International Agricultural Engineering Conference, November 17-23, 1991, Asian Institute of Technology, Bangkok, Thailand, pp. 143-150.

Mendi, S. D., Nain, C. W., Mfopit, M. Y., Tanya, A., and Mbofung, M. F. 2009. Nutritional merits of a ginger-spiced cheese fed to male wistar rats. *Pak. J. of Nutri.* 8(3): 1415-1421.

Minjin, Yang, He, P., Ling, Y. Qingdong, L., and Zhonghui, C. 2003. Dibble precision seeder for coated rice seeds. *Agric. Mech. Asia. Afr. Latin Am.* 34(4): 9-12.

Misener, G. C. 1979. Relative performance of cup and pick type potato planters. *Canadian Agric. Eng*. 21(2): 131-134.

Mishra. A. K. and Kulkarni, S. D. 2009. Engineering properties of turmeric Rhizome (*Curcuma. Longa L*). *Agric. Eng. Today*. 33(2): 26-31.

Mohsenin, N. N. 1986. Physical Properties of Plant and Animal Materials. 2nd Ed. (revised). Gordon and Breach Science Publishers, New York.

Monnaf, M. A., Rahim, M. A., Hossain, M. M. A., and Alam, M. S. 2010. Effect of planting method and rhizome size on the growth and yield of ginger. *J. Agrofor. Environ. Sci.* 4(2): 73-76.

Moody, F., Henry, John, H.H., and John, B.W. 2003. Evaluating planter performance - cotton seed placement accuracy. ASAE Annual Meeting.

Niu, Kang X. F, Liu, Y. C, Lu, C. X, and Yuan, Y, W. 2017. Optimized performance evaluation of an electronic cup-chain potato metering device. *Int. J. of Agric and Bio. Eng*. 10(2):36-43.

Odigdoh, E. U. and Akubuo, C. O. 1991. A two-row automatic minisett yam planter. *J. Agric. Eng. Res.* 50: 189-196.

Ozmerzi, A., Karayel, D., and Topakci, M. 2002. Effect of Sowing Depth on Precision Seeder Uniformity. *Biosyst. Eng*. 82(2): 227–230.

Pandey, H. S. and C, Sawant. 2023. Design and development of seed metering mechanism for ginger planter. *J. of sci. and industrial Res.* Vol. 82, pp. 1071 1080.

Panning, J. W., Kocher, M. F., Smith, J. A., and Kachman, S. D. 2000. Laboratoryand field testing of seed spacing uniformity for sugar beet planters. *Appl. Eng. Agric.* 16 (1): 7-13.

Pareek, C. M., Tewari, V. K. Machavaram, R. Nare. B. 2023. A mechatronic seed metering control system for improving sowing uniformity of planters. *J. of Eng. Res.* *H*ttps://doi.org/10.1016/j.jer.2023.10.041.

Raghavendra., Veerangouda, M., Prakash, K. V., Vijaykumar, P., Sharankumar, H., and Devanand, M. 2013. Development and evaluation of ridge planter for cotton. *Karnataka J. Agric. Sci.* 26 (1): 88-91.

Raheman, H. and Singh, U. 2002. A Sensor for flow seed metering mechanisms. IE(I). vol: 84:6-8.

Rai, A. K. Sivadasan, K., and Murthy, S. N. 2003. Electronic seed tube blockage detector for tractor drawn seed drill. *J. Agric Eng.* 40 (2): 13-20.

Rajaiah, P., Indra mani, Kumar, A,. Satish, D., Lande, Kumar A S., and Vergese, C 2016. Development and evaluation of electronically controlled precision seed metering device for direct-seeded paddy planter Indian *J. Agric. Sci.* 86 (5): 598–604.

RNAM. 1991. Agricultural Machinery design data handbook, seeders and planter.

Sadhu, R. R. 1982. Development of an onion set planter based on design criteria of plant transplanters. Unpublished M.Sc. (*Agri. Engg.)* Thesis. Texas Tech University, 2500 Broadway, Lubbock, TX 79409.

Sahay, J. 2009. Elements of Agricultural Engineering. Standard Publishers Distributors.

Sahay, K. M. and Singh, K. K. 1994. Unit operations of agricultural processing, Vikas Publishing House Pvt. Ltd, New Delhi.

Sahoo, P. K and Srivastava, A. P. 2000. Development and performance evaluation of okra planter. *J. Agric. Eng.* 37 (2): 15-25.

Santos, Sergio, R., Pedro, H. W., Emerson, F., and Wobeto, C. 2003. Influence of soybean seed size in seeding processes. Revista Brasileira de Engenharia Agricola e Ambiental 7(1): 177-181.

Senthilnathan, N., Gupta, S. Pureha, K and Verma, S. 2018. Fabrication and automation of seed sowing machine using IoT. *Int. J. of Mech. Eng. and Technol.* (IJMET), 9 (4): 903-912.

Shaaf, D. E., Hann, S. A., and Lindwall, C. W. 1981. Performance evaluation of furrow openers, cutting coulters and press wheels for seed drills. *Ln Crop Production with Conservation in the 80's. ASAE Publication* 7-81: 76-84. St. Joseph, MI 49085.

Shouhua, R.E.N., and Shujuan, Y.I. 2022. Control Mechanism and Experimental Study on Electric Drive Seed Metering Device of Air Suction Seeder. *Technical Gazette* 29, (4), 1254-1261.

Simonyan, K. j., Ethiem, J. C., Eke, A. B., Adama, J. C. and Okpara, D. A. 2013. Some physical properties of ginger varieties. *J. Appl. Agric. Res.* 5 (1): 73-79.

Singh, M. K. 2009. Design and fabrication of microcontroller based pneumatic seed metering device. Unpublished M. Tech. thesis, Department of Farm Machinery and Power Engineering, JNKVV, Jabalpur 92(4): 429-438**.**

Singh, R. D. 2004. Tractor mounted semi- automatic two-row belt type potato planter ridger. *Agric. Eng. Today.* 28: 69- 74.

Singh, R.C., Singh, G., and Saraswat, D.C. 2005. Optimization of design and operational parameters of a pneumatic seed metering device for planting cotton seeds. *Int. Agric. Eng. J.* 15(2): 31-41.

Subhashini.S., Anand kumar, S., and Niveadhitha, S. 2015. To study the physical properties of turmeric rhizomes at different moisture content. *Indian J. Appl. Res.* 5 (6): 511-504.

Tarighi, J., Asghar M., and Naser, A. 2011. Some mechanical and physical properties of corn seed. *Afr. J. of Agric. Res.* 6(16): 3691-3699.

Turbatmath, P. A., Bhatt, Y. C., and Kadam, P. B. 2011. Development and field evaluation of tractor operated onion transplanter. *Int. J. Agric. Eng*. 4 (1): 52 55.

Vasuki, G. 2012. Design and development of a tractor operated Turmeric planter. Unpublished M. Tech. (Agri. Eng.) Thesis, department of farm machinery, Agricultural Engineering College and Research Institute Tamil Nadu Agricultural University, Coimbatore.

Verma, A. K. and Dewangan, M. L. 2007. Design, development and evaluation of seed cum fertilizer drill. *AMA.* 38(2): 33-37.

Wang, G, Sun, W zhang, H Liu, X Li, H Yang X., and Zhu, L. 2020. Research on a kind of seeding monitoring and compensating control system for potato planter without additional seed metering channel. *Comput. and Electr. in Agric*. 177: 105681.

Wanzhi, Z Changlong, L Zhaoqin, L Xieteng, Q Haoyu, L and Jialin, H. 2020. Optimised design experiment on novel device for potato planters. Hindawi, Mathematical problems in engineering. https://doi.org/10.1155/2020/1504642.

Wanzhi. Zhang., Chenglong, Liu., Zhaogin, Lu., Xieteng. Qi., Haoyu, Lu., and Jialin, Hou. 2020. Optimized Design and Experiment on Novel Combination Vacuum and Spoon Belt Metering Device for Potato Planters. Mathematical Problems in Engineering Volume 2020, Article ID 1504642, 12 pages. https://doi.org/10.1155/2020/1504642.

Wasiya F., Pricy N.P. and Adu E.A. 2017. Physical properties of raw PTS 10 turmeric variety. *J. of Pharm. And Phyto*. 1(1): 782-786.

Yehuala, T. Z. 2012. Development and evaluation of electro mechanical seed metering device for raised bed planter. Unpublished M. Tech Thesis, College of Agricultural Engineering, University of Agriculture Science, Raichur.

Zamani, D. M. 2014. Development and evaluation of a vegetable transplanter. *Int. J. Tech. Res. App.* 2 (6): 40-46.

Zhang, C. and Araya, K. 2001. A three-stage soil layer mixing plough for the improvement of meadow soil, Part II. Soil bin experiments. *J. Agric. Eng.Res.* 78 (4): 359-367.

Zhang, X.B, Zhao, B. 2008. Automatic reseeding monitoring system of seed. **www.researchgate**. Com.

Appendix-I

Arduino Nano IDE program for a sensor-based tractor drawn ginger planter under Laboratory Conditions

```
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,20,4);

// Motor encoder output pulse per rotation (change as required)
#define ENC_COUNT_REV 400

// Encoder output to Arduino Interrupt pin
#define ENC_IN 3

// MD10C PWM connected to pin 10
#define PWM 10
// MD10C DIR connected to pin 12
#define DIR 7

// Analog pin for potentiometer
int speedcontrol = 0;

// Pulse count from encoder
volatile long encoderValue = 0;

// One-second interval for measurements
int interval = 500;

// Counters for milliseconds during interval
long previousMillis = 0;
long currentMillis = 0;

// Variable for RPM measurement
float rpm = 0;

// Variable for PWM motor speed output 15-20 cm
int motorPwm = 0;
int motorPwm1 =6;
int motorPwm2 =9;
int motorPwm3 = 13;
int motorPwm4 =14;
int motorPwm5 =19;
int motorPwm6 =20;
int motorPwm7=26;
int motorPwm8=29;
int motorPwm9 =32;
```

```
int motorPwm10 =34;
int motorPwm11 =39;
int motorPwm12=42;
int motorPwm13 =46;
int motorPwm14 =49;
int motorPwm15 =52;
int motorPwm16 =55;
int motorPwm17=59;
int motorPwm18=62;
int motorPwm19 =65;
int motorPwm20 =68;
int motorPwm21 =70;
int motorPwm22=74;
int motorPwm23 =77;
int motorPwm24 =80;
int motorPwm25 =85;
int motorPwm26 =87;
int motorPwm27=88;
int motorPwm28=94;
int motorPwm29 =97;
int motorPwm30 =101;
int motorPwm31 =104;
int motorPwm32=107;
int motorPwm33 =111;

void setup()
{
  // Setup Serial Monitor
  Serial.begin(9600);
  lcd.clear();
 lcd.init();
 lcd.backlight();
 lcd.setCursor(3,0);
 lcd.print("A SENSOR BASED");
 lcd.setCursor(3,1);
 lcd.print(" TRACTOR DRAWN ");
  lcd.setCursor(3,2);
 lcd.print("GINGER PLANTER");
 delay(1000);
 lcd.clear();
 // Set encoder as input with internal pullup
 pinMode(ENC_IN, INPUT_PULLUP);

// Set PWM and DIR connections as outputs
pinMode(PWM, OUTPUT);
 pinMode(DIR, OUTPUT);
```

```
 // Attach interrupt
 attachInterrupt(digitalPinToInterrupt(ENC_IN), updateEncoder, RISING);

 // Setup initial values for timer
  previousMillis = millis();
}

void loop()
{

digitalWrite(DIR,LOW);

 currentMillis = millis();
 if (currentMillis - previousMillis > interval) {
  previousMillis = currentMillis;
 rpm = (float)(encoderValue *120  / ENC_COUNT_REV);
if ( rpm > 0) {

 Serial.print("PWM VALUE: ");
 Serial.print(motorPwm);
 Serial.print('\t');
 Serial.print(" PULSES: ");
 Serial.print(encoderValue);
 Serial.print('\t');
Serial.print(" SPEED: ");
 Serial.print(rpm);
 Serial.println(" RPM");
 }

  encoderValue = 0;
 }

 if (rpm >=1)
{
analogWrite(PWM,motorPwm1);
 }
 else
  {
   analogWrite(PWM,motorPwm);
}
  if(rpm>=2)
 {
   analogWrite(PWM,motorPwm2);
  }
 else
```

```
  {
    analogWrite(PWM,motorPwm);
  }

if(rpm>=3)
 {
   analogWrite(PWM,motorPwm3);
 }
else
{
 analogWrite(PWM,motorPwm);
 }
 if(rpm>=4)
 {
  analogWrite(PWM,motorPwm4); }
else
 {
 analogWrite(PWM,motorPwm);
 }

 if(rpm>=5)
  {
   analogWrite(PWM,motorPwm5);
  }
  else
 {
analogWrite(PWM,motorPwm);
}

if(rpm>=6)
{
  analogWrite(PWM,motorPwm6);
}
else
{
  analogWrite(PWM,motorPwm);
}
 if(rpm>=7)
  {
   analogWrite(PWM,motorPwm7);
}
else
{
 analogWrite(PWM,motorPwm);
 }
if(rpm>=8)
```

```
{
  analogWrite(PWM,motorPwm8);
 }
  else
 {
   analogWrite(PWM,motorPwm);
   }
 if(rpm>=9)
 {
  analogWrite(PWM,motorPwm9);
 }
  else
   {
analogWrite(PWM,motorPwm);
 }
 if(rpm>=10)
 {
   analogWrite(PWM,motorPwm10);
 }
 else
{
 analogWrite(PWM,motorPwm);
 }

 if(rpm>=11)
{
  analogWrite(PWM,motorPwm11);
}
else
{
 analogWrite(PWM,motorPwm);
}

if(rpm>=12)
{
 analogWrite(PWM,motorPwm12);
 }
else
{
  analogWrite(PWM,motorPwm);
}
if(rpm>=13)
{
analogWrite(PWM,motorPwm13);
}
else
```

```
 {
 analogWrite(PWM,motorPwm);
 }

if(rpm>=14)
{
 analogWrite(PWM,motorPwm14);
}
else
{
  analogWrite(PWM,motorPwm);
}
if(rpm>=15)
{
 analogWrite(PWM,motorPwm15);
}
 else
{
 analogWrite(PWM,motorPwm);
 }

 if(rpm>=16)
 {
  analogWrite(PWM,motorPwm16);
}
else
 {
  analogWrite(PWM,motorPwm);
}
if(rpm>=17)
{
  analogWrite(PWM,motorPwm17);
}
 else
 {
  analogWrite(PWM,motorPwm);
 }
if (rpm >=18)
 {
  analogWrite(PWM,motorPwm18);
}
else
 {
  analogWrite(PWM,motorPwm);
 }
 if(rpm>=19)
```

```
 {
  analogWrite(PWM,motorPwm19);
 }
 else
 {
  analogWrite(PWM,motorPwm);
 }

 if(rpm>=20)
 {
  analogWrite(PWM,motorPwm20);
 }
else
 {
  analogWrite(PWM,motorPwm);
 }
 if(rpm>=21)
{
 analogWrite(PWM,motorPwm21);
}
else
  {
  analogWrite(PWM,motorPwm);
  }

if(rpm>=22)
{
 analogWrite(PWM,motorPwm22);
  }
else
 {
analogWrite(PWM,motorPwm);
  }

 if(rpm>=23)
{
 analogWrite(PWM,motorPwm23);
  }
 else
 {
  analogWrite(PWM,motorPwm);
  }
  if(rpm>=24)
{
   analogWrite(PWM,motorPwm24);
 }
```

```
  else
 {
   analogWrite(PWM,motorPwm);
 }

if(rpm>=25)
 {
  analogWrite(PWM,motorPwm25);
 }
 else
 {
  analogWrite(PWM,motorPwm);
 }

if(rpm>=26)
 {
   analogWrite(PWM,motorPwm26);
 }
  else
  {
  analogWrite(PWM,motorPwm);
}


 }

void updateEncoder()
{
  // Increment value for each pulse from encoder
  encoderValue++;
}
```

Decreasing the PWM motor speed from optimized above mentioned program to find the spacing between the rhizomes.

```
 #include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,20,4);

// Motor encoder output pulse per rotation (change as required)
#define ENC_COUNT_REV 400

// Encoder output to Arduino Interrupt pin
#define ENC_IN 3

// MD10C PWM connected to pin 10
#define PWM 10
```

```
// MD10C DIR connected to pin 12
#define DIR 7

// Analog pin for potentiometer
int speedcontrol = 0;

// Pulse count from encoder
volatile long encoderValue = 0;

// One-second interval for measurements
int interval = 500;

// Counters for milliseconds during interval
long previousMillis = 0;
long currentMillis = 0;

// Variable for RPM measuerment
float rpm = 0;

// Variable for PWM motor speed output
int motorPwm = 0;
int motorPwm1 =3;
int motorPwm2 =6;
int motorPwm3 = 10;
int motorPwm4 =13;
int motorPwm5 =16;
int motorPwm6 =20;
int motorPwm7=23;
int motorPwm8=26;
int motorPwm9 =29;
int motorPwm10 =33;
int motorPwm11 =36;
int motorPwm12=39;
int motorPwm13 =43;
int motorPwm14 =46;
int motorPwm15 =49;
int motorPwm16 =52;
int motorPwm17=56;
int motorPwm18=59;
int motorPwm19 =62;
int motorPwm20 =65;
int motorPwm21 =68;
int motorPwm22=71;
int motorPwm23 =74;
int motorPwm24 =77;
int motorPwm25 =82;
```

```
int motorPwm26 =84;
int motorPwm27=88;
int motorPwm28=91;
int motorPwm29 =94;
int motorPwm30 =98;
int motorPwm31 =101;
int motorPwm32=104;
int motorPwm33 =108;

void setup()
{
  // Setup Serial Monitor
  Serial.begin(9600);
  lcd.clear();
  lcd.init();
  lcd.backlight();
 lcd.setCursor(3,0);
  lcd.print("A SENSOR BASED");
  lcd.setCursor(3,1);
  lcd.print(" TRACTOR DRAWN ");
 lcd.setCursor(3,2);
 lcd.print("GINGER PLANTER");
 delay(1000);
  lcd.clear();
// Set encoder as input with internal pullup
  pinMode(ENC_IN, INPUT_PULLUP);

 // Set PWM and DIR connections as outputs
 pinMode(PWM, OUTPUT);
  pinMode(DIR, OUTPUT);

  // Attach interrupt
 attachInterrupt(digitalPinToInterrupt(ENC_IN), updateEncoder, RISING);

 // Setup initial values for timer
 previousMillis = millis();
}

void loop()
{

digitalWrite(DIR,LOW);

 currentMillis = millis();
 if (currentMillis - previousMillis > interval) {
 previousMillis = currentMillis;
```

```
 rpm = (float)(encoderValue *120  / ENC_COUNT_REV);
if ( rpm > 0) {

  Serial.print("PWM VALUE: ");
  Serial.print(motorPwm);
 Serial.print('\t');
 Serial.print(" PULSES: ");
 Serial.print(encoderValue);
 Serial.print('\t');
Serial.print(" SPEED: ");
 Serial.print(rpm);
 Serial.println(" RPM");
 }

 encoderValue = 0;
 }

  if (rpm >=1)
  {
   analogWrite(PWM,motorPwm1);
 }
else
 {
  analogWrite(PWM,motorPwm);
}
if(rpm>=2)
{
 analogWrite(PWM,motorPwm2);
 }
 else
 {
   analogWrite(PWM,motorPwm);
 }

if(rpm>=3)
 {
  analogWrite(PWM,motorPwm3);
  }
  else
 {
   analogWrite(PWM,motorPwm);
 }
if(rpm>=4)
{
 analogWrite(PWM,motorPwm4);
}
```

```
else
{
  analogWrite(PWM,motorPwm);
 }

if(rpm>=5)
 {
  analogWrite(PWM,motorPwm5);
}
else
 {
  analogWrite(PWM,motorPwm);
  }

  if(rpm>=6)
 {
  analogWrite(PWM,motorPwm6);
}
 else
{
  analogWrite(PWM,motorPwm);
}
  if(rpm>=7)
  {
  analogWrite(PWM,motorPwm7);
}
else
 {
  analogWrite(PWM,motorPwm);
}
if(rpm>=8)
  {
   analogWrite(PWM,motorPwm8);
  }
  else
 {
   analogWrite(PWM,motorPwm);
}
if(rpm>=9)
{
  analogWrite(PWM,motorPwm9);
  }
 else
 {
   analogWrite(PWM,motorPwm);
 }
```

```
 if(rpm>=10)
 {
   analogWrite(PWM,motorPwm10);
 }
 else
 {
   analogWrite(PWM,motorPwm);
 }

  if(rpm>=11)
 {
   analogWrite(PWM,motorPwm11);
 }
  else
  {
   analogWrite(PWM,motorPwm);
 }

  if(rpm>=12)
 {
   analogWrite(PWM,motorPwm12);
  }
 else
{
  analogWrite(PWM,motorPwm);
 }
 if(rpm>=13)
{
  analogWrite(PWM,motorPwm13);
 }
 else
  {
  analogWrite(PWM,motorPwm);
  }

  if(rpm>=14)
 {
   analogWrite(PWM,motorPwm14);
 }
 else
 {
  analogWrite(PWM,motorPwm);
}
if(rpm>=15)
            {
 analogWrite(PWM,motorPwm15);
```

```
  }
 else
{
 analogWrite(PWM,motorPwm);
}

  if(rpm>=16)
 {
  analogWrite(PWM,motorPwm16);
}
 else
{
 analogWrite(PWM,motorPwm);
 }
if(rpm>=17)
  {
   analogWrite(PWM,motorPwm17);
 }
 else
 {
 analogWrite(PWM,motorPwm);
 }
if (rpm >=18)
  {
   analogWrite(PWM,motorPwm18);
 }
 else
 {
  analogWrite(PWM,motorPwm);
 }
 if(rpm>=19)
 {
  analogWrite(PWM,motorPwm19);
 }
 else
 {
  analogWrite(PWM,motorPwm);
 }

  if(rpm>=20)
 {
  analogWrite(PWM,motorPwm20);
 }
 else
{
  analogWrite(PWM,motorPwm);
```

```
 }
 if(rpm>=21)
 {
 analogWrite(PWM,motorPwm21);
}
else
{
 analogWrite(PWM,motorPwm);
}

 if(rpm>=22)
 {
  analogWrite(PWM,motorPwm22);
}
else
{
 analogWrite(PWM,motorPwm);
}

 if(rpm>=23)
{
 analogWrite(PWM,motorPwm23);
}
else
{
  analogWrite(PWM,motorPwm);
  }
  if(rpm>=24)
 {
 analogWrite(PWM,motorPwm24);
 }
else
{
analogWrite(PWM,motorPwm);
}

if(rpm>=25)
 {
   analogWrite(PWM,motorPwm25);
  }
else
{
  analogWrite(PWM,motorPwm);
}

if(rpm>=26)
```

```
  {
   analogWrite(PWM,motorPwm26);
  }
 else
{
 analogWrite(PWM,motorPwm);
}

 }


void updateEncoder()
{
  // Increment value for each pulse from encoder
  encoderValue++;
}
```

Increasing the PWM motor speed from optimized program to find the spacing between the rhizomes

```
 #include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,20,4);

// Motor encoder output pulse per rotation (change as required)
            #define ENC_COUNT_REV 400

// Encoder output to Arduino Interrupt pin
#define ENC_IN 3

// MD10C PWM connected to pin 10
#define PWM 10
            // MD10C DIR connected to pin 12
#define DIR 7

// Analog pin for potentiometer
int speedcontrol = 0;

// Pulse count from encoder
volatile long encoderValue = 0;

// One-second interval for measurements
int interval = 500;

// Counters for milliseconds during interval
long previousMillis = 0;
long currentMillis = 0;
```

```
// Variable for RPM measuerment
float rpm = 0;

// Variable for PWM motor speed output
int motorPwm = 0;
int motorPwm1 =10;
int motorPwm2 =13;
int motorPwm3 = 17;
int motorPwm4 =18;
int motorPwm5 =22;
int motorPwm6 =24;
int motorPwm7=30;
int motorPwm8=33;
int motorPwm9 =36;
int motorPwm10 =38;
int motorPwm11 =43;
int motorPwm12=46;
int motorPwm13 =50;
int motorPwm14 =54;
int motorPwm15 =56;
int motorPwm16 =59;
int motorPwm17=65;
int motorPwm18=69;
int motorPwm19 =71;
int motorPwm20 =74;
int motorPwm21 =84;
int motorPwm22=89;
int motorPwm23 =91;
int motorPwm24 =92;
int motorPwm25 =98;
int motorPwm26 =101;
int motorPwm27=105;
int motorPwm28=109;
int motorPwm29 =99;
int motorPwm30 =102;
int motorPwm31 =108;
int motorPwm32=111;
int motorPwm33 =114;

void setup()
{
  // Setup Serial Monitor
 Serial.begin(9600);
lcd.clear();
 lcd.init();
```

```
  lcd.backlight();
lcd.setCursor(3,0);
  lcd.print("A SENSOR BASED");
  lcd.setCursor(3,1);
  lcd.print(" TRACTOR DRAWN ");
  lcd.setCursor(3,2);
 lcd.print("GINGER PLANTER");
delay(1000);
 lcd.clear();
 // Set encoder as input with internal pullup
 pinMode(ENC_IN, INPUT_PULLUP);

 // Set PWM and DIR connections as outputs
  pinMode(PWM, OUTPUT);
  pinMode(DIR, OUTPUT);

  // Attach interrupt
 attachInterrupt(digitalPinToInterrupt(ENC_IN), updateEncoder, RISING);

 // Setup initial values for timer
 previousMillis = millis();
}

void loop()
{

 digitalWrite(DIR,LOW);

currentMillis = millis();
 if (currentMillis - previousMillis > interval) {
 previousMillis = currentMillis;
rpm = (float)(encoderValue *120  / ENC_COUNT_REV);
 if (rpm > 0) {

  Serial.print("PWM VALUE: ");
 Serial.print(motorPwm);
  Serial.print('\t');
 Serial.print(" PULSES: ");
 Serial.print(encoderValue);
 Serial.print('\t');
 Serial.print(" SPEED: ");
 Serial.print(rpm);
Serial.println(" RPM");
}

encoderValue = 0;
```

```
 }

if (rpm >=1)
{
  analogWrite(PWM,motorPwm1);
}
else
 {
   analogWrite(PWM,motorPwm);
 }
if(rpm>=2)
 {
 analogWrite(PWM,motorPwm2);
  }
else
{
 analogWrite(PWM,motorPwm);
}

  if(rpm>=3)
  {
  analogWrite(PWM,motorPwm3);
}
else
{
 analogWrite(PWM,motorPwm);
 }
 if(rpm>=4)
{
  analogWrite(PWM,motorPwm4);
}
 else
{
 analogWrite(PWM,motorPwm);
  }

 if(rpm>=5)
 {
 analogWrite(PWM,motorPwm5);
  }
  else
  {
  analogWrite(PWM,motorPwm);
 }

 if(rpm>=6)
```

```
 {
 analogWrite(PWM,motorPwm6);
 }
  else
  {
   analogWrite(PWM,motorPwm);
}
if(rpm>=7)
{
  analogWrite(PWM,motorPwm7);
}
else
{
 analogWrite(PWM,motorPwm);
  }
 if(rpm>=8)
{
  analogWrite(PWM,motorPwm8);
 }
else
{
  analogWrite(PWM,motorPwm);
}
if(rpm>=9)
 {
 analogWrite(PWM,motorPwm9);
  }
else
  {
   analogWrite(PWM,motorPwm);
 }
  if(rpm>=10)
  {
  analogWrite(PWM,motorPwm10);
 }
 else
{
 analogWrite(PWM,motorPwm);
  }

  if(rpm>=11)
 {
  analogWrite(PWM,motorPwm11);
 }
else
{
```

```
 analogWrite(PWM,motorPwm);
}

 if(rpm>=12)
 {
  analogWrite(PWM,motorPwm12);
}
else
  {
   analogWrite(PWM,motorPwm);
 }
 if(rpm>=13)
{
  analogWrite(PWM,motorPwm13);
 }
 else
{
 analogWrite(PWM,motorPwm);
 }

if(rpm>=14)
 {
 analogWrite(PWM,motorPwm14);
 }
 else
{
 analogWrite(PWM,motorPwm);
}
 if(rpm>=15)
 {
  analogWrite(PWM,motorPwm15);
}
 else
 {
 analogWrite(PWM,motorPwm);
}

  if(rpm>=16)
  {
  analogWrite(PWM,motorPwm16);
 }
 else
{
  analogWrite(PWM,motorPwm);
}
if(rpm>=17)
```

```
 {
 analogWrite(PWM,motorPwm17);
  }
 else
{
  analogWrite(PWM,motorPwm);
}
if (rpm >=18)
 {
  analogWrite(PWM,motorPwm18);
}
else
 {
analogWrite(PWM,motorPwm);
 }
 if(rpm>=19)
 {
  analogWrite(PWM,motorPwm19);
 }
 else
{
  analogWrite(PWM,motorPwm);
  }

 if(rpm>=20)
 {
  analogWrite(PWM,motorPwm20);
}
else
 {
  analogWrite(PWM,motorPwm);
 }
 if(rpm>=21)
 {
 analogWrite(PWM,motorPwm21);
 }
 else
{
 analogWrite(PWM,motorPwm);
}

if(rpm>=22)
 {
 analogWrite(PWM,motorPwm22);
  }
 else
```

```
            {
             analogWrite(PWM,motorPwm);
              }

              if(rpm>=23)
             {
              analogWrite(PWM,motorPwm23);
            }
            else
            {
             analogWrite(PWM,motorPwm);
            }
             if(rpm>=24)
            {
              analogWrite(PWM,motorPwm24);
             }
             else
            {
             analogWrite(PWM,motorPwm);
             }

            if(rpm>=25)
             {
             analogWrite(PWM,motorPwm25);
             }
              else
             {
             analogWrite(PWM,motorPwm);
             }

             if(rpm>=26)
            {
             analogWrite(PWM,motorPwm26);
             }
            else
             {
            analogWrite(PWM,motorPwm);
            }
            }

            void updateEncoder()
            {
             // Increment value for each pulse from encoder
  encoderValue++;
}
```

Appendix-II

Distribution of seeds on the row at selected levels of forward speed (S) Speed of chain (V) and cell sizes (C) under laboratory condition

SI. No.		Treatments			Hill to hill distance, cm	Missing index, Per cent	Multiple index, Per cent	Quality of Feed index, Per cent	Cell fill efficiency, Per cent
		Forward Speed (km h^{-1})	Cell Size (mm)	Speed of chain (rpm)					
1	$S_1C_1V_1$	1	40	126	28.5	8.76	1.92	89.33	77.45
2	$S_1C_1V_1$		40	126	28.7	8.8	1.72	89.48	77.83
3	$S_1C_1V_1$		40	126	28.9	8.72	1.64	89.65	78.05
			Mean		**29.03**	**8.76**	**1.76**	**89.48**	**77.77**
4	$S_1C_1V_2$		40	136	32.3	10.52	1.2	88.28	71.25
5	$S_1C_1V_2$		40	136	32.7	10.36	2.12	87.52	71.41
6	$S_1C_1V_2$		40	136	32.9	11.52	4.4	84.08	71.62
			Mean		**33.7**	**10.8**	**2.57**	**86.62**	**71.42**
7	$S_1C_1V_3$		40	146	34.5	13.2	2.88	83.92	66.33
8	$S_1C_1V_3$		40	146	34.9	13.4	3.16	83.44	66.77
9	$S_1C_1V_3$		40	146	35.3	14.12	3.6	82.28	66.89
			Mean		**34.9**	**13.57**	**3.21**	**83.21**	**66.66**
10	$S_1C_2V_1$		50	126	12.6	3.16	1.52	95.32	94.75
11	$S_1C_2V_1$		50	126	12.9	3.56	2.36	94.08	95.05
12	$S_1C_2V_1$		50	126	13.2	4.48	3.25	92.00	95.21
			Mean		**12.9**	**3.73**	**2.46**	**93.8**	**95.00**
13	$S_1C_2V_2$		50	136	17.3	4.68	2.96	92.36	89.22
14	$S_1C_2V_2$		50	136	17.9	5.24	3.64	91.12	90.35
15	$S_1C_2V_2$		50	136	18.2	5.84	4.0	90.16	90.45
			Mean		**17.8**	**5.25**	**3.54**	**91.21**	**90.00**
16	$S_1C_2V_3$		50	146	22.2	5.56	3.56	90.88	88.71
17	$S_1C_2V_3$		50	146	22.8	6.36	4.24	89.4	88.91
18	$S_1C_2V_3$		50	146	23.3	7.6	4.84	87.56	89.03
			Mean		**22.76**	**6.50**	**4.21**	**89.28**	**88.88**
19	$S_1C_3V_1$		60	126	5.5	0.44	3.44	96.12	116.32
20	$S_1C_3V_1$		60	126	5.9	0.92	4.16	94.92	116.73
21	$S_1C_3V_1$		60	126	6.2	1.44	4.88	93.68	116.95
			Mean		**5.86**	**0.93**	**4.16**	**94.91**	**116.66**
22	$S_1C_3V_2$		60	136	7.1	0.88	4.68	94.44	113.98
23	$S_1C_3V_2$		60	136	7.7	2.16	5.4	92.44	114.31
24	$S_1C_3V_2$		60	136	8.1	3.56	6.28	90.16	114.55
			Mean		**7.63**	**2.2**	**5.45**	**92.35**	**114.28**

25	$S_1C_3V_3$		60	146	9.2	3.92	5.08	91.00	108.95
26	$S_1C_3V_3$		60	146	9.5	4.36	6.24	89.4	109.13
27	$S_1C_3V_3$		60	146	9.8	4.92	7.52	89.56	109.20
			Mean		**9.5**	**4.4**	**6.28**	**89.32**	**109.09**

SI. No.		**Treatments**			**Hill to hill distance, cm**	**Missing index, Per cent**	**Multiple index, Per cent**	**Quality of Feed index, Per cent**	**Cell fill efficiency, Per cent**
		Forward Speed (km h^{-1})	**Cell Size (mm)**	**Speed of Chain (rpm)**					
28	$S_2C_1V_1$	1.5	40	126	31.5	9.04	0.36	90.6	69.70
29	$S_2C_1V_1$		40	126	31.8	9.56	0.76	89.68	70.10
30	$S_2C_1V_1$		40	126	32.4	10.6	1.28	88.12	70.22
			Mean		**31.9**	**9.73**	**0.8**	**89.47**	**70.00**
31	$S_2C_1V_2$		40	136	33.5	11.24	1.16	87.6	66.39
32	$S_2C_1V_2$		40	136	33.9	11.8	1.76	86.44	66.71
33	$S_2C_1V_2$		40	136	34.1	12.4	2.44	85.16	68.88
			Mean		**33.83**	**11.81**	**1.78**	**86.41**	**66.66**
34	$S_2C_1V_3$		40	146	35.3	15.12	1.64	83.24	59.65
35	$S_2C_1V_3$		40	146	35.7	15.92	2.72	81.36	60.11
36	$S_2C_1V_3$		40	146	35.9	16.8	3.72	79.48	65.25
			Mean		**35.63**	**15.94**	**2.69**	**81.37**	**60.00**
37	$S_2C_2V_1$		50	126	14.3	3.96	0.92	95.12	91.92
38	$S_2C_2V_1$		50	126	14.7	4.8	1.96	93.24	92.37
39	$S_2C_2V_1$		50	126	14.2	5.72	3.0	91.28	92.63
			Mean		**14.4**	**4.82**	**1.96**	**93.22**	**92.30**
40	$S_2C_2V_2$		50	136	18.9	5.32	1.04	93.64	89.85
41	$S_2C_2V_2$		50	136	19.7	5.96	2.04	92.00	90.01
42	$S_2C_2V_2$		50	136	20.3	7.52	3.56	88.92	90.16
			Mean		**19.63**	**6.26**	**2.22**	**91.52**	**90.00**
43	$S_2C_2V_3$		50	146	24.7	7.96	3.16	88.88	87.98
44	$S_2C_2V_3$		50	146	25.2	8.68	3.8	87.52	88.89
45	$S_2C_2V_3$		50	146	25.8	9.56	4.36	86.08	89.33
			Mean		**25.23**	**8.74**	**3.77**	**87.49**	**88.88**
46	$S_2C_3V_1$		60	126	7.5	3.0	3.0	94.00	107.85
47	$S_2C_3V_1$		60	126	7.9	3.8	4.12	92.08	108.47
48	$S_2C_3V_1$		60	126	8.2	4.68	4.84	90.48	108.69
			Mean		**7.86**	**3.82**	**3.99**	**92.19**	**108.33**
49	$S_2C_3V_2$		60	136	9.9	4.28	3.8	91.92	107.45
50	$S_2C_3V_2$		60	136	9.5	4.84	4.36	90.8	107.69
51	$S_2C_3V_2$		60	136	9.9	5.28	5.04	89.68	107.89
			Mean		**9.76**	**4.8**	**4.4**	**90.8**	**107.67**

52	$S_2C_3V_3$		60	146	11.2	6.2	5.0	88.8	105.73
53	$S_2C_3V_3$		60	146	11.7	7.08	5.8	87.12	105.85
54	$S_2C_3V_3$		60	146	12.1	7.56	6.4	86.04	106.07
			Mean		**11.66**	**6.94**	**5.74**	**87.32**	**105.88**

SI. No.		**Treatments**			**Hill to hill distance, cm**	**Missing index, Per cent**	**Multiple index, Per cent**	**Quality of Feed index, Per cent**	**Cell fill efficiency, Per cent**
		Forward Speed (km h^{-1})	**Cell Size (mm)**	**Speed of Chain (rpm)**					
55	$S_3C_1V_1$	2	40	126	33.3	11.56	0.12	88.32	66.37
56	$S_3C_1V_1$		40	126	33.7	12.16	0.2	87.64	67.65
57	$S_3C_1V_1$		40	126	34.2	12.76	0.12	87.12	66.98
			Mean		**33.73**	**12.16**	**0.14**	**87.7**	**66.66**
58	$S_3C_1V_2$		40	136	36.5	13.56	0.44	86.0	61.96
59	$S_3C_1V_2$		40	136	36.9	14.68	0.84	84.48	62.58
60	$S_3C_1V_2$		40	136	37.2	15.6	1.64	84.76	62.97
			Mean		**36.86**	**14.61**	**0.97**	**84.42**	**62.50**
61	$S_3C_1V_3$		40	146	37.9	15.72	1.16	83.12	59.82
62	$S_3C_1V_3$		40	146	38.7	16.2	1.88	81.92	60.03
63	$S_3C_1V_3$		40	146	38.9	16.76	2.52	80.72	60.15
			Mean		**38.5**	**16.23**	**1.85**	**81.92**	**60.00**
64	$S_3C_2V_1$		50	126	22.3	6.2	0.16	93.64	88.66
65	$S_3C_2V_1$		50	126	22.7	6.92	0.52	92.56	88.91
66	$S_3C_2V_1$		50	126	23.1	7.68	0.92	91.4	89.09
			Mean		**22.7**	**6.94**	**0.53**	**92.53**	**88.88**
67	$S_3C_2V_2$		50	136	24.5	6.84	0.76	92.4	82.93
68	$S_3C_2V_2$		50	136	24.9	7.4	1.56	91.04	83.45
69	$S_3C_2V_2$		50	136	25.2	7.96	2.52	89.52	83.63
			Mean		**24.86**	**7.4**	**1.61**	**90.99**	**83.33**
70	$S_3C_2V_3$		50	146	28.3	8.88	2.2	88.92	81.51
71	$S_3C_2V_3$		50	146	28.7	9.68	2.84	87.48	81.89
72	$S_3C_2V_3$		500	146	29.1	11.2	3.6	85.2	82.05
			Mean		**28.7**	**9.92**	**2.88**	**87.2**	**81.81**
73	$S_3C_3V_1$		60	126	9.7	3.8	2.12	94.08	106.25
74	$S_3C_3V_1$		60	126	10.1	4.28	2.68	93.04	106.63
75	$S_3C_3V_1$		60	126	10.5	4.84	3.48	91.68	107.12
			Mean		**10.1**	**4.30**	**2.76**	**92.94**	**106.66**
76	$S_3C_3V_2$		60	136	11.7	4.88	3.16	91.96	104.46
77	$S_3C_3V_2$		60	136	12.5	5.52	3.68	90.8	104.88
78	$S_3C_3V_2$		60	136	12.3	6.2	4.28	89.52	104.96
			Mean		**12.16**	**5.54**	**3.70**	**90.76**	**104.76**

79	$S_3C_3V_3$		60	146	13.7	6.8	4.12	8908	100.96
80	$S_3C_3V_3$		60	146	14.2	7.44	4.52	88.04	101.35
81	$S_3C_3V_3$		60	146	14.8	8.16	4.96	86.88	101.63
			Mean		**14.23**	**7.46**	**4.54**	**88.00**	**101.31**

Appendix-III

Arduino Nano IDE program for a sensor-based tractor drawn ginger planter under Field evaluation

```
#include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x27,20,4);

// Motor encoder output pulse per rotation (change as required)
#define ENC_COUNT_REV 400

// Encoder output to Arduino Interrupt pin
#define ENC_IN 3

// MD10C PWM connected to pin 10
#define PWM 10
// MD10C DIR connected to pin 12
#define DIR 7

// Analog pin for potentiometer
int speedcontrol = 0;

// Pulse count from encoder
volatile long encoderValue = 0;

// One-second interval for measurements
int interval = 500;

// Counters for milliseconds during interval
long previousMillis = 0;
long currentMillis = 0;

// Variable for RPM measuerment
float rpm = 0;

// Variable for PWM motor speed output
int motorPwm = 0;
int motorPwm1 =9;
int motorPwm2 =13;
int motorPwm3 = 16;
int motorPwm4 =17;
int motorPwm5 =22;
int motorPwm6 =23;
int motorPwm7=29;
int motorPwm8=32;
int motorPwm9 =35;
```

```
int motorPwm10 =37;
int motorPwm11 =42;
int motorPwm12=46;
int motorPwm13 =49;
int motorPwm14 =52;
int motorPwm15 =55;
int motorPwm16 =59;
int motorPwm17=62;
int motorPwm18=65;
int motorPwm19 =68;
int motorPwm20 =70;
int motorPwm21 =74;
int motorPwm22=77;
int motorPwm23 =80;
int motorPwm24 =85;
int motorPwm25 =87;
int motorPwm26 =88;
int motorPwm27=94;
int motorPwm28=97;
int motorPwm29 =101;
int motorPwm30 =104;
int motorPwm31 =107;
int motorPwm32=111;
int motorPwm33 =114;

void setup()
{
// Setup Serial Monitor
 Serial.begin(9600);
 lcd.clear();
 lcd.init();
 lcd.backlight();
 lcd.setCursor(3,0);
 lcd.print("A SENSOR BASED");
 lcd.setCursor(3,1);
 lcd.print(" TRACTOR DRAWN ");
 lcd.setCursor(3,2);
 lcd.print("GINGER PLANTER");
  delay(1000);
  lcd.clear();
 // Set encoder as input with internal pullup
 pinMode(ENC_IN, INPUT_PULLUP);

 // Set PWM and DIR connections as outputs
 pinMode(PWM, OUTPUT);
 pinMode(DIR, OUTPUT);
```

```
  // Attach interrupt
  attachInterrupt(digitalPinToInterrupt(ENC_IN), updateEncoder, RISING);

  // Setup initial values for timer
  previousMillis = millis();
}

void loop()
{

 digitalWrite(DIR,LOW);

  currentMillis = millis();
 if (currentMillis - previousMillis > interval) {
  previousMillis = currentMillis;
  rpm = (float)(encoderValue *120  / ENC_COUNT_REV);
  if (rpm > 0) {

   Serial.print("PWM VALUE: ");
  Serial.print(motorPwm);
  Serial.print('\t');
  Serial.print(" PULSES: ");
  Serial.print(encoderValue);
 Serial.print('\t');
  Serial.print(" SPEED: ");
 Serial.print(rpm);
 Serial.println(" RPM");
  }

  encoderValue = 0;
  }

if (rpm >=1)
 {
  analogWrite(PWM,motorPwm1);
 }
 else
 {
   analogWrite(PWM,motorPwm);
}
 if(rpm>=2)
 {
  analogWrite(PWM,motorPwm2);
 }
 else
```

```
{
  analogWrite(PWM,motorPwm);
}

 if(rpm>=3)
 {
  analogWrite(PWM,motorPwm3);
 }
 else
 {
   analogWrite(PWM,motorPwm);
 }
 if(rpm>=4)
 {
    analogWrite(PWM,motorPwm4);
  }
  else
 {
  analogWrite(PWM,motorPwm);
 }

 if(rpm>=5)
{
  analogWrite(PWM,motorPwm5);
}
else
{
  analogWrite(PWM,motorPwm);
 }

if(rpm>=6)
 {
 analogWrite(PWM,motorPwm6);
}
else
{
  analogWrite(PWM,motorPwm);
  }
  if(rpm>=7)
 {
   analogWrite(PWM,motorPwm7);
}
else
{
analogWrite(PWM,motorPwm);
}
```

```
if(rpm>=8)
 {
  analogWrite(PWM,motorPwm8);
 }
 else
 {
   analogWrite(PWM,motorPwm);
}
if(rpm>=9)
{
 analogWrite(PWM,motorPwm9);
 }
 else
{
  analogWrite(PWM,motorPwm);
}
 if(rpm>=10)
 {
  analogWrite(PWM,motorPwm10);
 }
else
{
analogWrite(PWM,motorPwm);
 }

  if(rpm>=11)
  {
    analogWrite(PWM,motorPwm11);
  }
  else
 {
  analogWrite(PWM,motorPwm);
}

 if(rpm>=12)
 {
   analogWrite(PWM,motorPwm12);
  }
  else
{
  analogWrite(PWM,motorPwm);
 }
 if(rpm>=13)
 {
analogWrite(PWM,motorPwm13);
}
```

```
else
{
 analogWrite(PWM,motorPwm);
 }

  if(rpm>=14)
 {
 analogWrite(PWM,motorPwm14);
 }
 else
{
 analogWrite(PWM,motorPwm);
  }
 if(rpm>=15)
 {
analogWrite(PWM,motorPwm15);
  }
  else
 {
  analogWrite(PWM,motorPwm);
}

 if(rpm>=16)
  {
analogWrite(PWM,motorPwm16);
 }
  else
{
  analogWrite(PWM,motorPwm);
  }
if(rpm>=17)
 {
   analogWrite(PWM,motorPwm17);
  }
  else
 {
  analogWrite(PWM,motorPwm);
 }
if (rpm >=18)
 {
 analogWrite(PWM,motorPwm18);
 }
else
{
 analogWrite(PWM,motorPwm);
}
```

```
  if(rpm>=19)
{
  analogWrite(PWM,motorPwm19);
 }
 else
{
   analogWrite(PWM,motorPwm);
 }

  if(rpm>=20)
 {
analogWrite(PWM,motorPwm20);
 }
 else
  {
  analogWrite(PWM,motorPwm);
}
 if(rpm>=21)
 {
 analogWrite(PWM,motorPwm21);
  }
 else
 {
analogWrite(PWM,motorPwm);
  }

 if(rpm>=22)
  {
   analogWrite(PWM,motorPwm22);
}
 else
 {
  analogWrite(PWM,motorPwm);
}

 if(rpm>=23)
{
  analogWrite(PWM,motorPwm23);
 }
else
 {
 analogWrite(PWM,motorPwm);
 }
 if(rpm>=24)
{
 analogWrite(PWM,motorPwm24);
```

```
 }
 else
 {
  analogWrite(PWM,motorPwm);
 }

if(rpm>=25)
  {
analogWrite(PWM,motorPwm25);
 }
else
 {
 analogWrite(PWM,motorPwm);
 }

 if(rpm>=26)
{
 analogWrite(PWM,motorPwm26);
  }
  else
{
 analogWrite(PWM,motorPwm);
}


}


void updateEncoder()
{
  // Increment value for each pulse from encoder
 encoderValue++;
}
```

Appendix-IV

Physical properties of Athira variety of ginger

Sl. No	Size (mm)			Geometric mean, dia, (mm)	Sphericity	True density (g cc^{-1})
	Length (l)	Breadth (b)	Thickness (t)			
1	51.28	35.03	17.51	30.50	0.59	1.10
2	50.08	35.33	19.01	31.18	0.62	1.03
3	49.13	35.46	17.05	29.92	0.61	0.91
4	49.03	34.19	18.06	30.11	0.61	0.92
5	45.03	34.27	16.21	28.28	0.63	1.11
6	46.07	34.12	21.22	31.09	0.67	1.05
7	47.05	34.05	21.01	31.18	0.66	1.09
8	46.05	33.23	19.34	29.90	0.65	1.12
9	45.34	32.03	17.01	28.16	0.62	0.94
10	45.22	30.07	19.03	28.59	0.63	1.06
11	48.12	32.14	16.05	28.20	0.59	1.04
12	47.24	32.08	18.22	29.21	0.62	0.94
13	49.25	33.01	20.11	30.89	0.63	1.25
14	46.21	33.15	23.01	31.66	0.69	1.05
15	46.41	35.44	18.06	29.92	0.64	0.98
16	45.33	35.05	20.4	30.80	0.68	1.02
17	45.91	34.15	15.06	27.74	0.60	1.09
18	44.09	33.22	13.34	26.06	0.59	0.98
19	45.21	32.06	20.05	29.71	0.66	0.99
20	48.05	32.11	16.04	28.18	0.59	1.01
21	48.07	33.04	19.14	30.15	0.63	0.97
22	45.32	31.33	18.13	28.54	0.63	1.07
23	46.07	31.88	22.01	30.77	0.67	1.03
24	47.09	34.03	21.06	31.21	0.66	0.95
25	47.16	33.99	14.03	27.30	0.58	0.94
Range	**7.19**	**5.39**	**9.67**	**5.60**	**0.63**	**0.34**
Mean	**46.95**	**33.37**	**18.84**	**29.57**	**0.03**	**1.02**
S.D.	**1.78**	**1.41**	**2.45**	**1.46**	**4.93**	**0.07**
CV (per cent)	**3.81**	**4.23**	**13.33**	**4.95**	**0.11**	**7.61**

Appendix-V

Physical properties of Aswathy variety of ginger

Sl. No	**Size (mm)**			**Geometric mean, dia, (mm)**	**Sphericity**	**True density (g cc^{-1})**
	Length (l)	**Breadth (b)**	**Thickness (t)**			
1	50.9	33.2	15.21	28.53	0.56	1.15
2	50.01	33.05	13.02	26.91	0.54	1.13
3	49.93	32.65	17.05	29.28	0.59	1.06
4	49.56	32.45	16.24	28.68	0.58	1.08
5	48.03	32.05	19.22	29.89	0.62	0.93
6	48.09	32.09	22.06	31.30	0.65	1.14
7	48.47	30.05	18.54	29.00	0.60	0.97
8	49.91	30.65	12.01	25.54	0.51	1.10
9	47.06	30.98	14.05	26.47	0.56	1.02
10	47.23	29.98	20.31	29.61	0.63	1.08
11	46.95	29.81	19.25	28.98	0.62	1.15
12	46.81	29.33	18.23	28.28	0.60	1.10
13	46.88	29.04	15.87	26.94	0.57	1.02
14	45.98	28.87	18.02	27.86	0.61	0.91
15	46.05	28.56	15.06	26.18	0.57	1.03
16	45.05	28.06	16.32	26.53	0.59	0.84
17	45.66	28.04	20.12	28.55	0.63	1.10
18	46.79	28.04	16.09	28.28	0.60	0.73
19	44.99	33.25	15.22	27.36	0.61	0.99
20	44.85	33.06	19.36	29.87	0.67	0.93
21	44.79	34.02	10.02	24.15	0.54	1.05
22	44.09	34.56	17.05	28.71	0.65	0.96
23	43.85	34.85	14.66	26.11	0.60	1.04
24	43.75	30.55	12.26	24.61	0.56	1.10
25	50.02	30.62	14.02	26.96	0.54	1.06
Range	**7 .15**	**6.81**	**12.04**	**7.15**	**0.15**	**0.43**
Mean	**47.02**	**31.22**	**16.37**	**27.78**	**0.59**	**1.03**
S.D.	**2.15**	**2.03**	**2.92**	**1.73**	**0.03**	**0.10**
CV (per cent)	**4.58**	**6.51**	**17.85**	**6.24**	**6.53**	**9.95**

Appendix-VI

Physical properties of Chithra variety of ginger

Sl. No	Size (mm)			Geometric mean, dia, (mm)	Sphericity	True density (g cc^{-1})
	Length (l)	Breadth (b)	Thickness (t)			
1	49.26	33.25	17.06	29.33	0.60	1.10
2	48.22	33.08	21.03	31.15	0.65	1.00
3	49.06	34.65	19.54	31.05	0.63	1.01
4	50.03	34.24	16.21	29.27	0.58	0.84
5	50.11	34.05	14.06	27.89	0.56	1.06
6	49.34	35.06	16.44	29.50	0.60	0.98
7	49.56	33.32	20.01	31.00	0.63	1.11
8	48.09	32.06	18.01	29.47	0.60	0.97
9	48.98	32.61	19.22	30.25	0.62	0.98
10	48.88	31.21	15.98	28.04	0.57	1.17
11	47.87	30.11	17.03	28.10	0.59	0.79
12	48.36	34.57	19.06	30.63	0.63	0.99
13	46.33	31.1	16.57	27.84	0.60	0.93
14	46.58	31.05	12.31	25.27	0.54	0.69
15	46.87	31.11	20.01	29.75	0.63	1.35
16	46.07	30.44	18.04	28.38	0.62	1.20
17	47.77	29.56	19.77	29.32	0.61	0.61
18	47.36	28.04	15.24	26.37	0.56	0.81
19	45.84	31.26	17.55	28.32	0.62	1.35
20	45.56	31.07	14.66	26.58	0.58	0.99
21	44.68	32.02	18.09	28.59	0.64	0.71
22	43.22	32.44	20.44	29.57	0.68	0.76
23	42.88	32.08	18.02	28.19	0.66	0.81
24	44.78	34.55	14.05	26.99	0.60	0.97
25	46.78	34.41	12.07	26.01	0.56	0.99
Range	**7.23**	**7.02**	**8.96**	**5.88**	**0.14**	**0.74**
Mean	**47.33**	**32.29**	**17.21**	**28.67**	**0.61**	**0.97**
S.D.	**2.04**	**1.82**	**2.47**	**1.60**	**0.03**	**0.18**
CV (per cent)	**4.32**	**5.63**	**14.38**	**5.58**	**5.69**	**19.55**

Appendix-VII

Physical properties of Karthika variety of ginger

Sl. No	Size (mm)			Geometric mean, dia, (mm)	Sphericity	True density (g cc^{-1})
	Length (l)	breadth (b)	Thickness (t)			
1	51.03	36.05	16.2	29.96	0.59	0.84
2	50.11	35.03	22.03	32.65	0.65	0.97
3	49.37	35.04	18.21	30.51	0.62	1.04
4	49.08	34.36	20.01	31.21	0.64	1.18
5	48.05	35.44	19.32	30.95	0.64	0.85
6	47.42	35.65	16.21	29.14	0.61	0.94
7	47.05	35.78	20.15	31.26	0.66	0.88
8	48.34	36.21	15.00	28.73	0.59	0.95
9	49.77	34.22	14.22	27.97	0.56	2.28
10	47.08	35.32	16.17	28.96	0.62	0.91
11	47.03	34.22	16.25	28.69	0.61	1.11
12	46.57	33.55	16.05	28.30	0.61	1.05
13	44.02	33.63	18.55	29.16	0.66	1.03
14	44.05	33.45	16.37	27.94	0.63	1.07
15	45.78	29.31	16.74	27.29	0.60	1.24
16	45.62	29.04	17.85	27.76	0.61	0.87
17	45.32	31.28	19.34	29.14	0.64	1.08
18	45.01	31.24	16.45	27.55	0.61	1.01
19	45.28	31.66	16.65	27.84	0.61	1.14
20	40.55	32.64	18.25	27.95	0.69	1.29
21	42.11	32.55	18.22	28.26	0.67	0.97
22	40.56	29.87	15.33	25.63	0.63	1.15
23	45.02	30.33	17.34	27.77	0.62	0.95
24	46.07	31.57	18.55	28.99	0.63	0.97
25	46.21	32.47	14.27	26.86	0.58	0.76
Range	**10.48**	**7.17**	**7.81**	**7.02**	**0.63**	**1.52**
Mean	**46.26**	**33.19**	**17.34**	**28.82**	**0.03**	**1.06**
S.D.	**2.70**	**2.19**	**1.92**	**1.57**	**4.93**	**0.28**
CV (per cent)	**5.85**	**6.60**	**11.07**	**5.46**	**0.11**	**26.82**

Appendix-VIII

Calibration test for the developed sensor based ginger planter

A. Calculation of rhizome seed rate for ginger

Width of planter, m = $3 \times 0.45 = 1.35$

Circumference of main drive wheel, m = $\pi \times 0.57 = 1.79$

Area covered per revolution = 1.79×1.35

= 2.41m^2

Number of revolutions per hectare = $\frac{10000}{2.41}$

= 4136.85 revolutions

a) For 15 cm rhizome spacing

Rhizome rate required for 4136.85 revolutions = $\frac{4136.58 \times 5.0}{15}$

Rhizome sett rate = 1378.86 kg ha^{-1}

b) For 20 cm rhizome spacing

Rhizome rate required for 4136.58 revolutions = $\frac{4136.58 \times 5.0}{20}$

Rhizome sett rate = 1034.145 kg ha^{-1}

c) For 25 cm rhizome spacing

Rhizome rate required for 4136.58 revolutions = $\frac{4136.58 \times 5.0}{25}$

Rhizome sett rate = 827.316 kg ha^{-1}

Appendix - IX

Determination of moisture content

Sl.no	Weight of container (w_1)	Weight of container + wet soil (w_2)	Weight of container + dry soil (w_3)	Moisture content ($\frac{w_2 - w_3}{w_3 - w_1}$)	Moisture content (per cent)
1	12.21	69.25	62.33	0.1380	13.80
2	13.54	76.38	67.77	0.1587	15.87
3	12.55	74.50	67.50	0.1273	12.73
4	18.91	76.36	69.16	0.1432	14.32
5	14.28	69.61	62.16	0.1555	15.55

Sample calculations:

Mass of container, w_1 (g) = 12.21

Mass of container + wet soil, w_2 (g) = 69.25

Mass of container + dry soil, w_3 (g) = 62.33

Moisture content, per cent = $[(w_2-w_3) / (w_3-w_1)] \times 100$

= (69.25 – 62.33) / (62.33 – 12.21)

= 7.15 / 50.25

= 0.1380 x 100

Moisture content (per cent) = 13.80

Appendix - X

Determination of bulk density

Mass of core cutter(g)	Mass of core cutter + wet soil(g)	Mass of wet soil (g)	Height of core cutter (cm)	Internal diameter (cm)	Volume (cm^3)	Bulk density (g cm^{-3})
984	2780	1790	12.5	10	981.87	1.82
984	2771	1773	12.5	10	981.87	1.80
984	2760	1762	12.5	10	981.87	1.79
984	2810	1816	12.5	10	981.87	1.84
984	2747	1760	12.5	10	981.87	1.79

Sample calculations:

Mass of core cutter, g = 984

Mass of core cutter + wet soil, g = 2780

Mass of wet soil, g = 1790

Height of core cutter, cm = 12.5

Internal diameter, cm = 10

Volume, cm^3 = 981.87

Bulk density, $g \cdot cm^{-3}$ = Mass/ volume

= 1790 / 981.87

= 1.82 g cm^{-3}

Appendix - XI

Determination of Soil resistance

Sl. no	**Soil depth (cm)**	**Dial readings**						**Penetro meter reading from curve(N)**	**Penetrat ion force (KN)**	**Resistance (KN m^{-2})**
		1	**2**	**3**	**4**	**5**	**mean**			
1	5	67	65	60	64	67	64.6	64	0.627	887.09
2	10	105	85	88	95	92	93	93	0.921	1288.90
3	15	149	137	142	145	141	142.8	142	1.391	1968.02

BA = Base Area = $\pi r^2 = \frac{\pi}{4} \times D^2 = \frac{\pi}{4} \times 3^2 = 7.068\times10^{-4}$ m^2

Sample calculation:

Soil depth = 5

Mean dial gauge reading, PR = 63 N

Penetration force, PF = PR x 0.0098

= 64 x 0.0098

= 0.627 KN

Resistance = PF / BA

= 0.627 / (π/4 x $(3)^2$)

= 0.627 / 7.068×10^{-4}

= 887.09 KN m^{-2}

Appendix – XII

Field testing of cup feed type metering device for ginger

Sl.No.	combination of variable levels			Missing index, per cent	Multiple index, per cent	Quality feed index, per cent	Hill to hill distance, cm	Cell fill efficiency Per cent
	Forward speed (km h^{-1})	Speed of chain (rpm)	Cell size (mm)					
1	1	106	50	1.71	0.95	97.34	24.03	86.49
2	2	86	50	14.16	3.45	82.38	22.05	89.55
3	1.5	106	50	1.5	1.33	97.16	30.2	85.32
4	1.5	106	50	1.5	1.33	97.16	30.2	85.32
5	2	86	50	14.16	3.45	82.38	22.05	89.55
6	1.5	86	50	9.28	2.85	87.86	14.5	92.78
7	1	96	50	2.16	1.05	96.73	16.7	92.28
8	1	86	50	3.3	1.85	94.85	10.5	93.33
9	1.5	86	50	9.28	2.85	87.86	14.5	92.78
10	2	96	50	9.16	3.13	87.70	27.7	89.23
11	1.5	96	50	2.05	2.11	95.83	20.03	92.56
12	1	96	50	2.16	1.05	96.73	16.7	92.28
13	1.5	86	50	9.28	2.85	87.86	14.5	92.78
14	2	106	50	4.88	2.2	92.92	32.5	82.16
15	1.5	106	50	1.5	1.33	97.16	30.2	85.32
16	1	86	50	3.3	1.85	94.85	10.5	93.33
17	1.5	96	50	2.05	2.11	95.83	20.03	92.56
18	2	86	50	14.16	3.45	82.38	22.05	89.55
19	2	96	50	9.16	3.13	87.70	27.7	89.23
20	1	106	50	1.71	0.95	97.34	24.03	86.49
21	1.5	96	50	2.05	2.11	95.83	20.03	92.56
22	1	106	50	1.71	0.95	97.34	24.03	86.49
23	1	96	50	2.16	1.05	96.73	16.7	92.28
24	2	106	50	4.88	2.2	92.92	32.5	82.16
25	1	86	50	3.3	1.85	94.85	10.5	93.33
26	2	96	50	9.16	3.13	87.70	27.7	89.23
27	2	106	50	4.88	2.2	92.92	32.5	82.16

Appendix-XIII

Field capacity and field efficiency

$$\text{Theoritical field capacity} = \frac{Widthe\ of\ operation\ (m) \times Speed\ of\ travel\ (km\ h^{-1}\ )}{10}$$

$$\text{Effective field capacity} = \frac{\text{Area covered ha}^{-1}}{\text{Productive time+Non productive time h}}$$

$$\text{Field efficiency} = \frac{Effective\ field\ capacity}{Theoritical\ field\ capacity} \times 100$$

a) For a Forward speed of 1 km h^{-1}

Theoretical field capacity = $\frac{1.35\times1}{10}$

= 0.135 ha.h^{-1}

Effective field capacity = $\frac{20\times20}{18.3+3.5}\times\frac{60}{10000}$

= 0.11 ha h^{-1}

Field efficiency = $\frac{0.11}{0.13}\times 100$

= 84 per cent

b) For a Forward speed of 1.5 km h^{-1}

Theoretical field capacity = $\frac{1.35\times1.5}{10}$

= 0.2025 ha h^{-1}

Effective field capacity = $\frac{20\times20}{12+3.5}\times\frac{60}{10000}$

= 0.1548 ha h^{-1}

Field efficiency = $\frac{0.1548}{0.2028}\times 100$

= 76.44 per cent

c) For a Forward speed of 2 km h^{-1}

Theoretical field capacity = $\frac{1.35\times2}{10}$

$= 0.27 \text{ ha h}^{-1}$

Effective field capacity $= \frac{20\times20}{9.04+3.5}\times\frac{60}{10000}$

$= 0.1913 \text{ ha h}^{-1}$

Field efficiency $= \frac{0.1913}{0.27}\times 100$

= 70.85 per cent

Appendix - XIV

Estimated cost of the machine

Sl. No.	Material	Qty, nos	Specification, mm	Length, m	Weight, kg m^{-2}	Total weight, kg	Cost, Rs.
I.	**Main frame**						
1.	MS square pipe	1	80×80×4	5.3	8.557	45.35	2231.22
2.	MS iron angle	1	50×50×5	5	3.0	19	934.8
II	**Hitch frame**						
1.	MS Flat	1	75×19	1.6	11.8	18.88	929
2.	MS Flat	1	50×12	2	4.7	9.4	462.50
3.	MS Flat	1	16	0.12	125.6	15	738
4.	Lower hitch pins	2	-	2	-	-	300
III	**Ridger bottom and Furrow opener**						
1.	MS Flat	1	75×25	2.8	14.7	41.16	2025
2.	MS Flat	1	50×19	1.5	7.8	11.77	579
3.	MS Sheet (m^2)	1	5	1	39.2	39.2	1928.64
4.	MS Sheet (m^2)	1	2.8	0.1	22	2.2	108.25
5.	Tynes	4	-	-	-	300 each	1200
IV	**Rhizome hopper sheet**						
1.	GP sheet (feet)	1	16 gauge	8×4	-	32.46	3078
2.	GP sheet (feet)	1	16 gauge	2×2	-	4.90	470.40
V	**Ground wheel**						
1.	MS Flat	1	63×6	4	3	12	590
2.	Spring	1	50 (Dia.)	-	-	-	1500
VI	**Round shafts**						
1.	MS Shaft	1	20	6	-	14.80	1339
VII	**Electronic gadgets**						
1.	Arduino nano	1	-	-	-	530	530
2.	Step down buck convertor	1	-	-	-	170	170
3.	4 pin RMC connection	4	-	-	-	70	280

4.	E bike DC geared motor MY1016Z 24V 530 RPM, 650 w	1	-	-	-	7174	7174
5.	Cytron DC motor driver, 5V-30V 30amp MD30C	1	-	-	-	3044	3044
6.	Wires and cable & other accessories	1	-	-	-	212	212
7.	Amaron 12 V battery	2	-	-	-	3500	3500
8.	Rotary shaft encoder	1	-	-	-	1500	1500
VIII	**Clamps**						
1.	MS hose clips	3	4” NSC-017	-	-	-	114.42
IX	**Sprockets and chain**						
1.	Sprocket	8	13 teeth	-	-	245 each	1960
2.	Chain 5/8th clipping chain	2	5/8th	2	-	4800 each	11328
3.	UCP 204 bearings	12	20	-	-	215 each	2580
X	**MS Metal cups**						
1.	MS metal cups	30		-	-	34 each	1204.00
XI	**PVC pipes**	1	75 mm (Dia.)	4	-	436.44 per meter	1745.76
XII	**Others**						
1.	Nut and bolts (kg)	10	-	-	-	-	1000
2.	Welding rods	-	-	-	-	-	750
3.	Paint	-	-	-	-	-	2000
Total cost						**57505.99**	
		Fabrication				**22732.19**	
Total cost of the planter						**80238.18**	

Appendix-XV

Cost of operation for tractor operated sensor based ginger planter

The following data were considered for determining the cost economics of tractor operated multi crop precision planter. Cost of operation was calculated as given by IS 9164: Guide for estimating cost of farm machinery operation.

Initial cost of tractor : Rs. 8,00,000
Initial cost of precision planter : Rs. 80238.18
Life of a tractor : 10 years
Life precision planter : 10 years
Salvage value : 10 per cent
Interest rate : 12 per cent
Shelter and insurance price : 3 per cent of purchase
Price of diesel : Rs. 95 l^{-1}
Driver charge : Rs. 500 day^{-1}
Annual use of tractor operated precision planter : 250 h
Depreciation method followed : Straight line method

I. Cost of operation of tractor

a. Annual fixed cost

i) Depreciation (D):

The annual depreciation value can be calculated by the following equation

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

Where,

D = Depreciation (Rs. h^{-1})
P = Purchase price (Rs. h^{-1})
S = Salvage value, 10 per cent of purchase price
L = Life of the machine (years)
H = Number of working hours per year

$$D=\frac{8,00,000-80000}{10\times1000} = \text{Rs. } 72\ h^{-1}$$

ii) Interest (I):

Annual interest is calculated by the following expression

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

Where,

I = Annual interest charge (Rs. h^{-1})

i = Interest rate (per cent)

$$I = \frac{8,00,000+80000}{2}\times\frac{0.12}{1,000}= \text{Rs. } 52.8\ h^{-1}$$

iii) Shelter and Insurance:

Insurance and shelter charges taken as 3 per cent of the original cost

$$\text{Shelter \& Insurance} = \frac{3 \text{ per cent of P}}{H}$$

$$\text{Shelter \& Insurance} = \frac{0.03\times 8,00,000}{1000} = \text{Rs. } 24\ h^{-1}$$

Total fixed cost = i + ii + iii

= 72 + 52.8 + 24

= Rs. 148.8 h^{-1} …(a)

b. Operating cost

i. Repair and maintenance costs:

Repairs and maintenance cost was taken 10 per cent of the purchase price of the machine per year.

$$\text{Repair and maintenance costs} = \frac{8,00,000\times0.10}{1000}$$

$$= \text{Rs. } 80\ h^{-1}$$

ii. Fuel cost:

Cost of fuel taken = 95 Rs. l^{-1}

Fuel required for 1 hour = 4 l h^{-1}

Fuel cost = 95 × 4 = 380 Rs. h^{-1}

iii. Lubricants cost:

Charge of lubricant was taken 20 per cent of the total fuel cost.

Lubricating cost = 380 × 0.20 = Rs. 76 h^{-1}

iv. Driver charge:

The cost of the operator was taken based on the labour charge paid per day, Rs. 500 day^{-1} is paid for tractor operator, 8 hours taken for one day

$$\text{Driver charge} = \frac{500}{8}$$

$$= \text{Rs. } 62.5\ h^{-1}$$

$$\text{Total operating cost} = i + ii + iii + iv$$

$$= 80 + 380 + 76 + 62.5$$

$$= \text{Rs. } 598.5\ h^{-1} \qquad \ldots (b)$$

$$\text{The total cost of operating the tractor} = a + b$$

$$= 148.8 + 598.5$$

$$= \text{Rs. } 747.3\ h^{-1}$$

II. Cost of operation of tractor operated sensor-based rhizome planter

a. Annual fixed cost

i) Depreciation

$$D = \frac{80238 - 8023.8}{10 \times 250} = \text{Rs. } 28.88\ h^{-1}$$

ii) Interest

$$I = \frac{80238 + 8023.8}{2} \times \frac{0.12}{250} = \text{Rs. } 21.18\ h^{-1}$$

iii) Shelter and Insurance

Insurance and shelter charges taken as 3 per cent of the original cost

$$\text{Shelter \& Insurance} = \frac{0.03 \times 80238}{250} = \text{Rs. } 9.62\ h^{-1}$$

$$\text{Total fixed cost of rhizome planter} = i + ii + iii$$

$$= 28.88 + 21.18 + 9.62$$

$$= \text{Rs. } 59.68\ h^{-1} \qquad \ldots(c)$$

b. Operating cost

i) Repair and maintenance costs

$$\text{Repair and maintenance} = \frac{80238 \times 0.10}{250}$$

$= \text{Rs. } 32.09 \text{ h}^{-1}$ …(d)

Total cost of precision planter $= c + d$

$= 59.68 + 32.09$

$= \text{Rs. } 91 \text{ h}^{-1}$

Total cost of operating tractor operated sensor-based rhizome planter

= Total cost for operating the tractor + Total cost of rhizome planter

$= 747.3 + 91$

$= \text{Rs. } 838.3 \text{ h}^{-1}$

Theoretical field capacity of planter = 0.20

Actual field capacity of planter = 0.15

Field efficiency of sensor-based rhizome planter = 88 per cent

Time required to cover 1 ha, h $= \frac{1}{\text{AFC}}$

$= \frac{1}{0.15}$

$= 6.66 \text{ hr ha}^{-1}$

Cost of operation of sensor-based rhizome planter $= 6.66 \times 838.3$

$= \text{Rs. } 5583.078 \text{ ha}^{-1}$

III. Over head cost (OHC)

Over head cost (Rs. h^{-1}) = 25 per cent of total cost of operation

$= \frac{25}{100} \times 838.3$

$= \text{Rs. } 209.57 \text{ h}^{-1}$

IV. Custom hiring cost

Custom hiring cost = total cost of operation + Overhead charges + 25 per cent of overhead charges

$$= 838.3 + 209.57 + \left(\frac{25}{100} \times 209.57\right)$$

$= \text{Rs. } 1100.26 \text{ h}^{-1}$

IV. Breakeven point, h annum^{-1}

Breakeven point, h annum^{-1}

$$= \frac{\text{Annual fixed costs, (Rs h}^{-1}\text{)}}{\text{Custom hiring charges,(Rs. h}^{-1}\text{) -Total operating costs, (Rs. h}^{-1}\text{)}}$$

$$= \frac{59.68 \times 250}{1100.26 - 838.3}$$

$= 56.95 \text{ h annum}^{-1}$

V. Payback period

$$\text{Payback period, year} = \frac{\text{Initial cost of machine}}{\text{Average net annual profit}}$$

Average net annual profit

= [Custom hiring charges (Rs. h^{-1}) − Total operating cost (Rs. h^{-1})] × Annual usage

$= (1100.26 – 838.3) \times 250$

$= 261.96 \times 250$

= Rs. 65490

$$\text{Payback period (year)} = \frac{80238}{65490}$$

= 1.22 years

VII. B.C Ratio

B.C ratio is an indicator used in the cost-benefit analysis, to show the relationship between the costs and benefits of a proposed project. It is calculated as following formula.

$$\text{B:C Ratio} = \frac{\text{net annual profit (Rs. h}^{-1}\text{)}}{\text{cost of production (Rs. h}^{-1}\text{)} \times \text{working hours in a year}}$$

$$\text{B:C Ratio} = \frac{65490}{91 \times 250}$$

= 2.87

VIII Cost of planting by traditional method (manual planting)

Labour requirement = 576 man hr ha^{-1}

Cost of planting Rs. 500 per labour $= \frac{576}{8} \times 400$

= Rs. 28800 ha^{-1}

Pair of bullocks required for hectare = 3.5

Cost of pair of bullock = 3.5 × 1000

= Rs. 3500 ha^{-1}

Total amount of manual planting = 28800 + 3500

= Rs. 32300 ha^{-1}

Cost saved over manual planting = 32300 – 5583.07

= 26716.93

Cost saved over manual planting (per cent) = $\frac{28779.4}{32300} \times 100$ = 89.1 per cent

Time saved over manual planting = 576 – 6.66

$$= 569.34 \text{ hr ha}^{-1}$$

Time saved over manual planting (per cent) = $\frac{569.34}{576} \times 100 = 98.84$ per cent

Appendix XVI - Observation table under field evaluation

Sl.No.	**Treatments**			**Missing index, per cent**	**Multiple index, per cent**	**Quality feed index, per cent**	**Hill to hill distance, cm**	**Cell fill efficiency per cent**
	Forward speed (km h^{-1})	**Speed of chain (rpm)**	**Cell size (mm)**					
1	1	86	50	3.9	2.4	93.7	10.8	92.9
2	1	86	50	3.65	1.85	94.5	10.4	93.48
3	1	86	50	2.35	1.3	96.35	10.3	93.68
	Mean			**3.3**	**1.85**	**94.85**	**10.5**	**93.33**
4	1	96	50	1.5	1.25	97.25	17.1	91.77
5	1	96	50	2.25	1.15	96.6	16.7	92.49
6	1	96	50	2.75	0.75	96.5	16.3	91.65
	Mean			**2.16**	**1.05**	**96.78**	**16.7**	**92.30**
7	1	106	50	2.25	1.15	96.6	24.3	86.05
8	1	106	50	1.65	0.95	97.4	24	86.95
9	1	106	50	1.25	0.75	98	23.8	86.99
	Mean			**1.71**	**0.95**	**97.33**	**24.03**	**86.66**
11	1.5	86	50	9.85	3.6	86.55	14.7	92.41
12	1.5	86	50	9.4	2.7	87.9	14.5	92.87
13	1.5	86	50	8.9	2.25	89.15	14.3	93.27
	Mean			**9.28**	**2.85**	**87.86**	**14.5**	**92.85**
14	1.5	96	50	2.45	2.6	94.95	19.2	92.15
15	1.5	96	50	1.95	2.1	95.95	20.2	92.31
16	1.5	96	50	1.75	1.65	96.6	20.7	92.45
	Mean			**2.05**	**2.11**	**95.83**	**20.03**	**92.30**
17	1.5	106	50	1.55	1.15	97.3	29.7	85.39
18	1.5	106	50	1.55	1.2	97.25	30.7	85.83
19	1.5	106	50	1.4	1.65	96.95	30.2	85.93
	Mean			**1.5**	**1.33**	**97.16**	**30.2**	**85.71**
20	2	86	50	14.75	3.75	81.5	21.8	89.25
21	2	86	50	14.15	3.4	82.45	21.6	89.42
22	2	86	50	13.6	3.2	83.2	22.8	89.75
	Mean			**14.16**	**3.45**	**82.38**	**22.05**	**89.47**
23	2	96	50	9.6	3.6	86.8	26.7	84.05
24	2	96	50	9.05	3.15	87.8	27.5	84.23
24	2	96	50	8.85	2.65	88.5	28.9	84.35
	Mean			**9.16**	**3.13**	**87.7**	**27.7**	**84.21**
25	2	106	50	5.25	2.6	92.15	31.6	81.09
26	2	106	50	4.85	2.25	92.9	32.6	81.26
27	2	106	50	4.55	1.75	93.7	33.3	81.42
	Mean			**4.88**	**2.2**	**92.91**	**32.5**	**81.25**

A SENSOR BASED TRACTOR DRAWN GINGER PLANTER

by

T. MAHESH BABU
(2020-28-001)

ABSTRACT

of the thesis submitted in partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

AGRICULTURAL ENGINEERING

(Farm Machinery and Power Engineering)

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY
TAVANUR - 679573
KERALA, INDIA
2024

ABSTRACT

India is the largest producer of spices in the world and ginger contributes 43.00 per cent of world production of ginger. Ginger, turmeric, garlic, clove, etc. are some of the common spice crops. The production of ginger in Kerala was 51.18 million tonnes in an area of 2.58 thousand hectares with the productivity level of 19820 kilogram per hectare in 2022-2023.

The major constrain in raising of ginger crop is the non-availability of labour in time, especially, during peak periods of sowing and harvesting. Traditional methods of growing ginger involve manual planting of excess rhizomes and thinning of the plants is needed to obtain the desired plant population at uniform plant spacing. For obtaining a high yield, it is very essential to drop the desired number of seeds in rows maintaining accurate seed rate and seed spacing during metering. Among the different planting techniques, precision planting is the preferred method, since it provides accurate spacing of single seeds in the row with proper planting depth and creating a uniform germination environment for each seed.

In conventional planters, the metering mechanism is usually driven by a ground wheel while operating with tractor. The speed ratio between the ground wheel and seed metering mechanism could not be maintained due to the power transmission loss, resulting in a reduction in uniformity of seed distribution. To solve the above problem, an alternative method of driving the metering mechanism with a 24 V DC motor was identified in this study. The metering unit was synchronized with the forward speed with the help of an encoder, Arduino Nano and Cytron drive.

The performance of the seed-metering device of a sensor based ginger planter was investigated under laboratory and field conditions to optimize the operating parameters for ginger planting. The effect of operational speed of the metering chain, forward speed and cell size were evaluated by examining the minimum values of mean hill to hill distance 16.0 cm, 0.95 per cent, miss index 1.71 per cent, multiple index 0.95 per cent, and highest quality of feed index 97.54 per cent as well as cell fill efficiency 93.33 per cent. For picking single seed, the planter cell sizes of 40 mm, 50 mm and 60

mm diameter were tested under laboratory. From the laboratory test, optimised cell size of 50 mm was tested in the field condition.

For the field evaluation, forward speeds of 1, 1.5 and 2 km h^{-1} were selected for ginger planting. When the speed of chain was increasing from 86 rpm to 106 rpm, increase in mean hill to hill distance 16.0 cm, missing index 1.7 per cent, multiple index 0.95 per cent and decrease in quality of feed index 97.54 per cent as well as cell fill efficiency 93.33 per cent was observed. However, lower miss index was observed at optimum cell size and lowest speed. Low multiple index was observed at optimum cell size and highest speed.

The maximum field capacity and efficiency of the developed sensor-based tractor drawn ginger planter were found to be 0.11 ha h^{-1} and 84 per cent respectively. Cost of planting with the developed ginger planter is Rs. 5583.07 ha^{-1}. By manual method, it is Rs. 12500 ha^{-1}. The cost and time saving over manual planting was about 89.1 per cent and 98.84 per cent respectively. The cost of rhizome planter was Rs.80238.18. Based on the field performance evaluation, it is concluded that the developed tractor drawn sensor-based planter is economical and efficient for planting ginger.