INVESTIGATIONS ON OPTIMIZATION OF DESIGN AND OPERATIONAL PARAMETERS OF PNEUMATIC SEED PLANTER

BEERGE RAMESH MANOHAR

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING, RAICHUR
UNIVERSITY OF AGRICULTURAL SCIENCES
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By

BEERGE RAMESH MANOHAR

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING, RAICHUR
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DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING, RAICHUR
UNIVERSITY OF AGRICULTURAL SCIENCES, RAICHUR

CERTIFICATE

This is to certify that the thesis entitled **"Investigation on Optimization of Design and Operational Parameters of Pneumatic Seed Planter"** submitted by **Mr. BEERGE RAMESH MANOHAR** for the degree of DOCTOR OF PHILOSOPHY (AGRICULTURAL ENGINEERING) in **FARM MACHINERY AND POWER ENGINEERING** of College of Agricultural Engineering, University of Agricultural Sciences, Raichur, is a record of research work carried out by him during the period of his study in this University, under my guidance and supervision and the thesis has not previously formed the basis of award of any degree, diploma, associateship, fellowship or other similar titles.

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Affectionately Dedicated
To
My Beloved Parents

SMT. RATNAMMA BEERGE AND

SHRI MANOHAR BEERGE

&

MY DEAR BROTHERS

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With ever regardful memories………

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Contd…

LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
CCD	-	Central Composite Design
CFD	-	Computational Fluid Dynamics
cm	-	Centimetre
cm^2	-	Square Centimetre
CMS	-	Computer Measurement System
CNC	-	Computer Numeric Control
d. b.	-	Dry Basis
D	-	Cell Diameter
dpi	-	Dots per inches
Fig	-	Figure
g	-	Gram
$g\ cc^{-1}$	-	Gram per Cubic Centimetre
h	-	Hour
$ha\ h^{-1}$	-	Hectare per Hour
hp	-	Horse Power
IS	-	Indian Standards
ISO	-	International Organization for Standardization
kg	-	Kilogram
$km\ h^{-1}$	-	Kilometre per Hour
k Pa	-	Kilo Pascal
kW	-	kilowatt
L	-	Length
l	-	Litre
$l\ h^{-1}$	-	Litre per Hour

m - Metre

$m\ s^{-1}$ - Meter per Second

min - Minute

MISI - Miss Index

mm - Millimetre

MULI - Multiple Index

PTO Power Transmission Shaft

PREC - Precision Index

P - Vacuum Pressure

QFI - Quality Feed Index

RNAM - Regional Network for Agricultural Machinery

ROI - Region of Interest

rpm - Revolution per Minute

RSM - Response Surface Methodology

s - Seconds

S - Rotor Speed

SRF - Seed Releasing Frequency

.stp - Standard for the Exchange Product Model Data

T - Thickness

W - Width

% - Percentage

₹/h - Rupees per Hour

₹/ha - Rupees per Hectare

₹/l - Rupees per Litre

° - Degree

°C - Degree Centigrade

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I. INTRODUCTION

The increasing population and growing demand for food and fiber in the world is changing the scenario of agriculture. The changing scenario has recorded in agriculture as a more business proposition than merely tradition, in all the progressed nations of the world. Globally it has become challenge to the researchers and farmers to produce more food with a constraint of natural resources. Hence, they started adopting new scientific methods, tools and techniques in agriculture to achieve the goal of production. Indian scenario is not much different from the other part of world. Hence agricultural researchers across the globe brought the concept of precision agriculture. In this concept, researcher were promoting the farmers to adopt high yielding varieties, promoting genetically modified crops and recommending to use sophisticated equipments, tools and technology to perform various agronomic practices for more and assured crop production. As a part of it, growing of two or more crops in a year is one such strategy that is being worked out extensively. This has helped to increase the food grain production from 50.82 million tonnes in 1950 to 264.38 million tonnes in 2014 with little increase in cultivable area in India (Anon., 2014a).

Further increase or sustainability in production can be achieved by adopting modern engineering techniques, which helps to increase productivity of land in India, as of now it is very low as compared to other parts of the world. Similarly, the increased energy input will help to perform agronomic operations at right time and desired rate of application reduces the losses of various inputs at different levels of crop production. The factors responsible for low productivity in agriculture research breakthrough in few crops, growing disparity between potential yields due to improper technology transfer mechanism, low productivity from rainfed crops and lack of farm power availability. Special efforts need to be made to raise the productivity and production of crops and generating surplus for export, keeping in view the fact that India has a great competitive advantage in agricultural export.

The modern agricultural concepts have drastically increased the operational power requirement; hence animal power used in agriculture has thus been slowly replaced by the prime movers like tractor, power tiller and diesel engines *etc.* which can be witnessed from the tractors production and sales during 2013-2014 in the country. Keeping with the demand, the indigenous production increased by many folds and presently India is the world’s largest tractor manufacture with annual production of over 7.08 lakh units of tractors (Anon., 2014b). The production and sales of tractors in the country is increasing steadily and the use of tractors increases at a compound growth rate of more than 20 per cent annually which may be expected to stabilize around 10 per cent by next decade. Hence, suitable matching implements and its standardization for performing various agricultural operations with the tractor is the need of the hour in Indian agriculture.

Among the various farm operations, sowing and planting of seeds is one of the most critical and crucial operation in crop production. The main purpose of planting is to place the seed in soil at specified spacing at desired depth in the soil (Karayel *et al*., 2004). Good crop establishment mainly depends on the quality of seed planting operation and field conditions. Factors that affect seed germination include viability of seed, soil health and several other parameters. Obtaining an early, uniform stand of healthy seedlings is the first and often the most important step in getting desired yield. Plant spacing directly influences soil moisture extraction, light interception, humidity and wind movement. These factors in turn influence other plant growth parameters such as plant height, branch development, pod development and size, crop maturity and ultimately yield. Several technological advances can be used in crop production to help and ensure a good stand of seedlings (Wenshun *et al*., 2013).

The use of seed drills does not maintain intra-row seed spacing, which is essential requirement for row crops to maintain optimum plant density. A uniform distribution of seeds provides optimum space for each plant and increases yield due to the reduction of intra specific competition and weeds are suppressed (Heege, 1993). The conventional practice of sowing high yielding varieties using bullock drawn seed drills may not give desired production due to 20-30 per cent more seed drops than the recommended seed rate, which also increases the input cost and to some extent effects crop yield too. In present farming situation availability of skilled labours and agricultural inputs were costly. In particular, getting quality seed from commercial markets becoming very costly hence, optimum utilization of resources by the farmer is very essential. These factors very well tackled at the initial seed planting stage by adopting well designed seed planters. From the point of view of precision seeding technique and to meet agro-technical needs, seeds should be sown precisely without dropping multiple seeds and misses. Doubling and missing in the row are unwanted, since doubling affects grain yield and dry matter, while missing causes a reduction in yield (Ismett *et al.*, 2012). The importance of plant physiology and agronomic practices of crops is proportional to inter and intra row seed spacing, which is the main reason for planters have been came into existence.

Precision planting is defined as the placement of single seed in the soil at the desired spacing. Usually, farmers and researchers use manual dibbling method to achieve this accuracy. The sowing devices equipped with single seed metering mechanisms are called planters. Planter avoids seed scattering and excessive use of seeds due to uniform distribution of seeds in row by preventing metering of multiple seeds and bouncing in the furrow. Currently in India, various types of planters are in existence and they are having different types of seed metering mechanisms like horizontal plate, vertical plate, inclined plate and cup type are most commonly used models matching to both for animal or tractor power sources. Horizontal plate planters with cells on the periphery were the first precision planters developed (Datta, 1974; Dixit *et al*., 2011). Although, these models are popular and widely used, inherent problems such as seed damage, seed missing and multiple seed drops are very common (Singh *et al*., 2005).

Further research led to the development of the pneumatic precision seed-metering device (Guarella *et al.*, 1996). Pneumatic precision planter places seeds at the specified spacing and provides a desired growing area per plant. There are two common types of precision planter namely belt and vacuum type metering mechanisms. Precision vacuum planter has a metering plate with seed cells on a predetermined radius. A positive or negative pressure is applied to these metering holes by means of a race machined in a backing plate. As the plate rotates, the pressure applied to the metering holes enables them to pick up seeds. Precision pneumatic planter has more advantages over the mechanical type metering devices, in terms of better working quality, more precise seed rates with lower rate of seed damage and also able to handle irregular shape seeds efficiently (Murray *et al*., 2006).

The most commonly adopted pneumatic planters are equipped to release single seeds in furrows as per the desired plant spacing by using a modular rotating seed disc under negative pressure (Singh *et al*., 2005). These planters were more popular in developed countries along with machine vision or opto-electronic sensor system as an on-site performance monitors. The use of pneumatic planters among the Indian farming community was very limited, due to unavailability of suitable multi crop pneumatic planter in the market. Therefore, there is a scope for the design and development of multi crop tractor operated suitable pneumatic planter.

A conveyor belt smeared with grease has generally been used in the laboratory for testing and calibration of seed metering mechanism and these results have been compared with seed distribution in the field. Kocher *et al.* (1998) and Lan *et al.* (1999) developed an opto-electronic seed spacing measurement system that measured time intervals between the seeds and detected front and back seed drop location events to determine the seed spacing uniformity of a planter in the laboratory. A most advanced techniques of computer vision system can also be used for testing of precision planter under simulated laboratory conditions.

Cotton (*Gossypium hisutum* L.) and okra (*Hibiscus esculentus* L.) are tropical to subtropical zone crops, which are widely distributed from Africa to Asia. In India, these crops are grown commercially by selecting suitable potential hybrids, whose seeds are very costly. Hence, single seed planting and its germination matters more for the farmers.

Cotton production in the country touched to all-time high record of 400 lakh bales of 170 kg in the year 2014-15. Cotton advisory board estimated around 3.5 per cent drop in area under cotton from 119.78 to 115.83 lakh ha in 2013-14 as compared to previous year (Anon., 2014a). The decrease in the area of cotton cultivation may be due to high cost of cultivation and shortage of farm labours. Muhammad *et al.* (2002) concluded that, the boll weight decreases by increasing plant population in cotton. Siddiqui *et al*. (2007) reported that the plant height, branches, open and unopened bolls per plant, lint and seed cotton yield were significantly affected by plant spacing and varieties.

Okra is a warm-season crop that is considered to have originated from India (Rao, 1985), which is traditionally grown as commercial vegetable crop in India, Southeast Asia, West Africa, the Southern United States and many other parts of the world (Duzyaman, 1997). Its production is affected by climatic factors and cultural practices, including plant density. When the okra variety Sabzpari was planted at spacing of 60 × 15, 60 × 30 and 60 × 45 cm, Amjad *et al*. (2001) found that the lowest planting (3.7 plants m^{-2}) resulted in the maximum number of 14.43 mature pods per plant and the highest planting density (11.1 plants m^{-2}) had the lowest number of 11.3 pods per plant of okra. This was probably because in the lowest planting density, plants receive more nutrients and lateral growth takes place resulting in increased number of pods per plant.

Hence, there is an urgent need to address these issues by developing the operation specific machinery and equipment for cotton and okra cultivation in the country. Therefore, the present study was attempted to design and develop a multi crop pneumatic planter mainly for cotton and okra seeds, by optimizing the design and operational parameters under simulated conditions. In pneumatic planter, positive and negative air pressures are a critical operational parameters, therefore an advance technique called computational fluid dynamics (CFD) is used for air simulation and optimization (Yu *et al*., 2014). The existing sticky belt method is very cumbersome one which requires more time and labour for testing of seed metering mechanisms under laboratory conditions. Hence, a new concept of 'computer vision system' was used for the laboratory testing of seed metering mechanism under simulated conditions to study its feasibility of testing, which reduces the time required for the calibration in laboratory and which may has potential to replace the conventional testing methods.

Keeping in view of the above facts, the present investigation on 'Optimization of design and operational parameters of multi crop pneumatic planter' has been taken up with the following objectives.

1) Determination of physical and aerodynamic properties of cotton and okra seeds.

2) Design and development of multi crop pneumatic seed metering mechanism.

3) Optimization of design and operational parameters of pneumatic planter using instrumented test rig and computer vision system for cotton and okra seeds.

4) Development and evaluation of the field level pneumatic planter prototype based on optimized design and operational parameters for cotton and okra seeds.

5) To work out the economics of pneumatic planter.

II. REVIEW OF LITERATURE

The primary objective of any planting operation is to establish an optimum plant population at desired plant spacing to obtain maximum net return per hectare. Plant population and spacing requirements are influenced by several factors like type of crop, seed quality, methods of sowing and planting, soil health, moisture content and the effect of plant spacing upon the cost and convenience of operations such as thinning, weed control, inter cultivation and harvesting.

Information on design, development and testing of precision planter in India is scarcely available. The physical properties of cotton and okra seeds relevant to planter design have been rarely studied earlier. Therefore, in this chapter an earlier research findings were concisely reviewed and the available information on planters for precision seeding of various crops, new design and development techniques, methods adopted for testing and evaluation advance techniques of computer vision system and methods used for analysis data are presented below.

2.1 Physical, mechanical and aerodynamic properties

The physical, mechanical and aerodynamic properties of seeds influence on design of various machine components of planter. Therefore, the available information on these properties of the seed for different seeds, relevant to the design of a planter has been reviewed and presented in this section.

Tabak and Wolf (1998) determined the terminal velocity and drag coefficient of cotton seeds as function of moisture content. Terminal velocity of these seed depends on lint content within the range of 0 to 4 per cent, a higher lint content of up to 14 per cent had little effect on terminal velocity. Terminal velocity increased from 5.8 to 10 m s^{-1} as the mass of seeds increased from 0.08 to 0.15 g within the entire range of lint content. Cotton seed terminal velocity increased as moisture content was raised from about 6 to 24 per cent on dry basis where as it was decreased, when the turbulence intensity increased from 3.8 to 14.4 per cent. The drag coefficient of cotton seed was reported in the range of 0.6 to 0.9.

Sahoo and Srivastava (2002) determined the physical properties of okra seed as function of moisture content. As moisture content increased from 8.16 to 87.57 per cent on dry basis, the average length, breadth and thickness of seed varied from 5.92 to 7.30, 4.71 to 5.40 and 4.59 to 5.36 mm, respectively. The increase in moisture content from 8.16 to 19.56 per cent

(d. b.) roundness and sphericity increased from 77.76 to 79.35 and 74.48 to 76.52 per cent respectively and then decreased to 72.39 and 70.63 per cent, with further increase of moisture. At moisture range of 8.16 to 87.57 per cent, the seed volume was increased from 0.067 to 0.124 cm^3, 1000 seed weight varied from 65.78 to 129.75 g and the angle of repose from 27.60 to 39.47°. The bulk density, true density and porosity were decreased from 0.592 to 0.558 g cm^{-3}, 1.107 to 0.986 g $cm^{-3}$and 46.34 to 43.20 per cent, respectively.

Ozarslan (2002) measured the physical properties of delinted and bare cotton seed as function of moisture content. The average length, width and thickness of seeds ranged from 9.02 to 9.19, 4.70 to 4.86 and 4.25 to 4.45 mm respectively as the moisture content increased from 8.33 to 13.78 per cent dry basis. The sphericity of cotton seed increased from 0.626 to 0.635, the seed volume from 95.4 to 109.6 mm^3, thousand seed mass from 104.06 to 109.64 g, projected area from 35.89 to 40.14 mm^2 and the terminal velocity from 8.46 to 8.67 m s^{-1}.The static coefficient of friction of cotton seed also increased linearly on four structural materials, namely, stainless steel (0.27 to 0.35), galvanized iron (0.38 to 0.41), plywood (0.39 to 0.42) and rubber (0.42 to 0.44). The bulk density decreased from 642 to 610 kg m^{-3}, true density from 1091 to 1000 kg m^{-3}porosity from 41.16 to 39.00 per cent and the shelling resistance from 65.0 to 50.2 N.

Jayan and Kumar (2004) studied the physical properties like length, breadth, surface area, roundness, equivalent diameter, sphericity, seed weight, true density, angle of repose and coefficient of restitution for maize, red gram and cotton seeds. The roundness of maize, red gram and cotton were 1.14 ± 0.14, 1.15 ± 0.10 and 1.26 ± 0.10, respectively. While sphericity of these seeds in the natural rest position were 0.621 ± 0.065, 0.750 ± 0.016, 0.550 ± 0.016, respectively. To ensure free flow of seeds, the slope of the seed hopper was fixed at 30°, which is modestly higher than the average angle of repose of seeds. In addition, the inner surfaces of the seed transfer cup was imbedded with 3 mm thick rubber sheet as its coefficient of restitution was lower than mild steel sheet of same thickness.

Bulent *et al*. (2006) studied the physical properties of sweet corn seed as a function of moisture content in the range of 11.54 to 19.74 per cent on dry basis. The average length, width and thickness were 10.56 mm, 7.91 mm and 3.45 mm, respectively. The thousand seed mass increased from 131.2 to 145.5 g, the projected area from 59.72 to 75.57 mm^2, the sphericity from 0.615 to 0.635, the true density from 1133.8 to 1225.5 kg m^{-3}, the porosity from 57.48 to 61.30

per cent and the terminal velocity from 5.56 to 5.79 m s^{-1}. The bulk density decreased from 482.1 to 474.3 kg m^{-3} with increase in the moisture content. The static coefficient of friction of sweet corn seed increased linearly against surfaces of four structural materials, namely, rubber (0.402 – 0.494), aluminium (0.321 – 0.441), stainless steel (0.267 – 0.401) and galvanized iron (0.364 – 0.477) as the moisture content increased from 11.54 to 19.74 per cent on dry basis.

Shahin and Symons (2005) investigated four types of seed differing in size, shape and colour using image analysis technique. The seed sizes determined by image analysis closely matched with those determined by manual sieving both in average seed size and the size distribution for seeds of spherical as well as non spherical shape. The image analysis method was found to be highly repeatable and much faster than the sieving method. Between and within operator's differences were statistically insignificant ($p > 0.05$) for both the methods. The image analysis method took less than 30 seconds to measure one sample as opposed to over 10 min for manual sieving.

Sedat *et al.* (2005) studied selected physical properties of turkey okra seeds at three moisture content levels of 6.35, 9.87 and 15.22 per cent (d. b.). The seed length, width, thickness, mass and geometric diameter increased from 5.178 to 5.507 mm, 4.786 to 4.960 mm, 4.121 to 4.362 mm, 0.059 to 0.067 g and 4.665 to 4.913 mm, respectively. The seed porosity, volume, projected area and terminal velocity increased from 48.92 to 52.08 per cent, 47.38 to 54.68 mm^3, 0.225 to 0.333 cm^2 and 5.2 to 5.68 m s^{-1}, respectively; bulk density from 636.10 to 577.99 kg m^{-3}, sphericity decreased from 0.905 to 0.897. The coefficient of static friction on iron and galvanized iron sheets increased with increase in moisture content.

Refik *et al.* (2006) determined the physical and aerodynamic properties of soybean as a function of moisture content in the range of 6.7 – 15.3 per cent. At moisture content 6.7 per cent the average length, width, thickness, unit mass, geometric mean diameter, arithmetic mean diameter, sphericity, porosity, true and bulk density were 7.41 mm, 5.34 mm, 4.50 mm, 121.76 g, 5.62 mm, 5.75 mm, 75.0, 51.0, 1062.6 and 804.8 kg m^{-3}, respectively. Corresponding values at 15.3 per cent moisture content were 9.57 mm, 6.75 mm, 5.17 mm, 223.65 g, 5.62 mm, 5.75 mm, 72.0 per cent, 44.2 per cent, 1086.4 and 689.3 kg m^{-3}, respectively. The terminal velocity increased from 7.13 to 9.24 m s^{-1} and the coefficient of static friction increased linearly against the moisture content increased.

Karayel *et al.* (2006) reported the means and standard errors of seed linear dimensions for wheat and soybean. The length, width, thickness and 1000 seed weight were 6.9 ± 0.18 mm, 3.3 ± 0.07 mm, 2.3 ± 0.04 mm and 45.4 g for wheat and 7.1 ± 0.12 mm, 5.1 ± 0.08 mm, 4.7 ± 0.06 mm and 187.3 g for soybean, respectively.

Manimehalai *et al.* (2006) determined various dimensions like sphericity, projected area, bulk density, true density and friction coefficient for the well dried fuzzy cotton seeds of MCU 5, LRA 5166 and Rajat 5 varieties at moisture content range of 8.2 to 8.94 per cent on dry basis. The sphericity was not significantly differed with respect to the mass ranges and varied between 0.64 and 0.67. The measured projected area was varied from 24.3 to 38, 25.8 to 40.7 and 21.6 to 40 mm^2. The angle of repose was 38.5, 43.3 and 40.31° for the respective varieties. The coefficient of static friction of fuzzy cottonseeds against the surfaces, galvanised iron, mild steel, card board, aluminium and stainless steel were 0.27, 0.34, 0.47, 0.43 and 0.41, respectively and the coefficient of internal friction is found to be 2.35.

Kilickan and Guner (2006) measured length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, volume, 1000 seed mass, bulk density, true density, porosity, projected area, terminal velocity and drag coefficient of cotton seed ranged from 9.06 to 10.89 mm, 4.73 to 5.88 mm, 4.23 to5.15 mm, 5.74 to 7.31 mm, 5.82 to 6.89 mm, 61.37 to 64.03 per cent, 95.11 to 121.40 mm^3, 106.50 to 126.50 g, 296 to 632.10 kg m^{-3}, 1000 to 1075 kg m^{-3}, 41.20 to 71.59 per cent, 31.90 to 52.70 mm^2, 8.12 to 11.31 m s^{-1}, and 0.462 to 0.684, respectively.

Gupta *et al.* (2007) determined the terminal velocity of sunflower seed of three cultivars as a function of moisture content between 6 and 14 per cent (d. b.). The terminal velocity of NSFH-36, PSF-118 and SH-3322 varieties of sunflower seed increased from 2.93 to 3.28, 2.54 to 3.04 and 2.98 to 3.53 m s^{-1} respectively. The corresponding value of drag coefficient varied from 0.18 to 0.24, 0.20 to 0.31 and 0.17 to 0.40 respectively for moisture range. The moisture content and variety either individually or in combination influenced the terminal velocity and drag coefficient significantly.

Igathinathane *et al.* (2009) developed a machine vision ImageJ Plugin in Java for orthogonal length and width determination of singulated particles from digital images. The pixel-march method, which compared pixel colors to determine object boundaries for dimensional measurements, utilized only the ImageJ fitted-ellipse centroid coordinates and major axis inclination. The pixel-march started from objects centroid and proceeded along the fitted-ellipses major and minor axes for boundary identification. Actual dimensions of selected reference particles measured using digital calipers validated the plugin. The plugin was applied to measure orthogonal dimensions of eight types of food grains. The plugin has overall accuracy greater than 96.6 per cent, computation speed of 254 ± 125 particles per second, handles all shapes and particle orientations, makes repeatable measurements and economical.

Seyed, *et al*. (2010) measured various physical properties of basil seed at moisture content of 5.32 per cent (d. b.) using image processing technique and image processing data result was compared with the experimentally measured one. The average length, width and thickness obtained by image processing and micrometer methods were 3.216 and 3.220, 1.838 and 1.840, 1.363 and 1.374 mm, respectively. The average projected area, sphericity and roundness evaluated by image processing were 4.407 mm^2, 0.95 and 0.54 respectively. Similarly the average geometric mean diameter, arithmetic mean diameter, surface area and sphericity calculated theoretically based on micrometer data were 2.009, 2.145 mm, 12.796 mm^2 and 0.62, respectively. The average 1000 grain mass, volume, true density, bulk density and porosity were measured as 0.0020 and 2.23 g 7.55 mm^3, 1038 kg m^{-3}, 340.24 kg m^{-3} and 67.2 per cent respectively. The filling and falling angles of repose were established as 14.64° and 12.35° respectively. The reported terminal velocity is 4.26 m s^{-1}.

Ebru *et al.* (2010) developed a digital image processing system to determine the geometric features of bean and lentil seeds. The measured features of bean and lentil seeds were projected area, equivalent diameter and thickness. Three approximation models were used to evaluate volume and surface area of lentil and bean seeds of various varieties. The best approximation model was found as the tri axial ellipsoid and the oblate spheroid for bean varieties and two sphere segments for lentil varieties. From the models, the estimated specific surface area were ranged from 5.1 – 5.8 cm^2 g^{-1} for bean varieties and 11.57 – 11.95 cm^2 g^{-1} for lentil varieties. The percentage difference between volume estimated by the psychometric method and triaxial ellipsoid approximation method ranged from 0.49 to 6.14 per cent. Digital image processing approach could potentially be a simple, rapid and non-invasive alternative to the traditional measurement methods.

Polyak and Csizmazia (2010) developed new elutriator to identify the aerodynamic characteristics of corn seeds using image analysis. The average moisture content of the samples was 13.42 per cent. The individual mass of seeds varied between 0.1889 and 0.3758 g. The mass of 1000 seeds used in general practice was 317.562 g. The seed size length, width and thickness, varied in the range of 7.76 to 11.81, 6.77 to 9.99 and 4.41 to 5.85 mm, respectively. The suspension velocity varied between 8.85 and 10 m s^{-1}.

Gursoy and Guzel (2010) experimentally determined the terminal velocity for different seeds, which varied from 7.52 to 8.14 m s^{-1} for wheat varieties, 7.04 to 7.07 m s^{-1} for barley varieties, 7.72 to 7.78 m s^{-1} for lentil varieties and 11.15 to 12.01 m s^{-1} for chickpea varieties. For all the grains, theoretical terminal velocities were lower than the experimental values. The theoretical terminal velocity was calculated by using equation 2.1, corrected with the shape factor while the drag coefficient was calculated by equation 2.2.

$$(V_{krt})^2 = \frac{4gd_e\gamma_t(6Z/\pi)}{3\gamma_a 0.44} \qquad \dots (2.1)$$

$$C = \frac{2\,m_t g}{\gamma_a (V_{krd})^2 A_t} \qquad \dots (2.2)$$

Where V_{krt} is theoretical terminal velocity (m s^{-1}); g is gravitational acceleration (m s^{-2}); γ_a is true density of air (kg m^{-3}); Z is shape factor; C is drag coefficient; m_t is mass of seed (Kg); V_{krd} is terminal velocity experimentally measured (m s^{-1}); A_t is projected area of seed (m^2).

Ghafori *et al*. (2011) determined the physical and aerodynamic properties of corn and barley seeds at seven different air velocities. The geometric and arithmetic mean diameters and sphericity of corn seeds were 80 mm, 63 mm and 20 per cent, respectively, more than the barley seeds. Pressure drop increased nonlinearly and linearly with an increase in air velocity for corn and barley seeds, respectively. However, power consumption was nonlinearly increased with air velocity for both seeds. Mechanical damage of both seeds increased linearly as the air velocity was increased. There was a turning point at which the pressure drop increased rapidly with an increase in air velocity. The lowest pressure drop for corn and barley occurred at the air velocity of 20 and 15 m s^{-1}, respectively. Therefore, for reducing the specific energy consumption and mechanical damage to corn and barley seeds at the conveying capacity of 15 tonne h^{-1}, the air velocity in pneumatic conveying must be decreased below 20 and 15 m s^{-1}, respectively.

Salah *et al.* (2011) the terminal velocity of chickpea, rice and lentil seeds has been experimentally measured by suspending the seeds in an air stream and studied the effects of seed size and moisture content on terminal velocity. The results showed that size and moisture content have significant effect ($p < 0.01$) on terminal velocity in all three crops. Terminal velocity of chickpea, rice and lentil seeds varied within the range of 11.13 - 15.08, 4.25 - 5.01 and 5.08 - 6.41 m s^{-1}, respectively.

Ismett *et al*. (2012) measured the physical properties of delinted cotton (Deltapine 388) and hybrid maize (AG 9241) seeds. The average length, width and thickness were 8.5 ± 0.11, 4.9 ± 0.11 and 4.3 ± 0.07 for cotton and 11.5 ± 0.18, 8.6 ± 0.18 and 6.9 ± 0.15 for maize respectively. The sphericity and 1000 seed weight of cotton and maize seed were 66.1 per cent and 76.6 per cent and 74.2 g and 437.0 g, respectively.

Satti *et al*. (2012) studied the physical properties of 50 randomly selected samples of wheat kernels. Reported that the mean average length, width, thickness, sphericity, 1000 seed mass, projected area, geometric mean diameter and volume were 6.57 mm, 3.63 mm, 3.23 mm, 0.63 per cent, 44.17 g, 13.88 mm^2, 4.19 and 40.33 cm^3, respectively.

Davinder (2013), used image processing methodology for identifying different varieties of paddy seeds using morphological features of image processing. These features were powerful tool which could separate the different varieties of seeds. Three varieties of paddy seeds are taken that are classified according to their morphological feature range. Image of paddy seeds was acquired by a canon digital IXUS 132 camera. The contour based feature extraction and traversal of seeds are carried out. This methodology consist of several steps image acquisition, segmentation using mean shift segmentation that is based on color merge over the space, binarization using otus's threasholding method, feature extraction and classification. Six morphological features were extracted from paddy seed images and they are area, diameter, major axis, minor axis, compactness, roundness.

Sunanda and Kakatkar (2013) developed seed analyzer setup using two CCD cameras one for top view and another for side view and 3D image were constructed from these two images. The 3D image was built from these images using image processing algorithms and the parameters like seed length, width, surface area, volume, shape factor, roundness are computed. The volume of seed was calculated using disk technique, the volume of each cylindrical disk (Vi) is equal to cross sectional area of each ellipse (Ai) times the length of the disk (Pixel) given by equation 2.3.

$$\text{Elliptical disc area (Ai)} = \frac{\pi ab}{4} \qquad \ldots (2.3)$$

$$Vi = Ai\Delta x \qquad \ldots (2.4)$$

Where, i is each elliptical disc; a is major axis diameter at the disc position; b is minor axis diameter at the disc position.

2.2 Design, development and testing of seed metering mechanisms

Bamgboye and Mofolasayo (2006) developed and evaluated a manually operated two-row okra planter and conducted field and laboratory test. The laboratory investigation included the determination of the variation in weight of seeds discharged from two hoppers, percentage damage of seeds and average intra-row spacing of seeds. The field tests comprised the determination of effective field capacity, average depth of placement of seeds in the furrows and mean spacing of seeds within each row. A difference between the weights of seeds discharged from the two hoppers was 4.97 per cent during tests, while the seed rate was 0.36 kg h^{-1}. Reduction in seed damage 3.51 per cent was observed when spacing varied from 59 cm to 70 cm, and an average depth of planting ranging from 8 mm and 9 mm.

Norman (2006) developed an optical encoder, which consists of a rotating disk, a light source and a photodetector (light sensor). The disk, which is mounted on the rotating shaft, has coded patterns of opaque and transparent sectors. As the disk rotates, these patterns interrupt the light emitted onto the photodetector, generating a digital or pulse signal output. The encoding disk is either made from Glass, for high-resolution applications (11 to 16 bits) or plastic (Mylar) or metal for applications requiring more rugged construction (resolution of 8 to 10 bits).

Sukhbeer *et al.* (2006) developed a test rig for mechanical metering of sunflower seeds. The developed test rig can accommodate various seed metering units for mechanical metering of sunflower. Four types of seed metering rollers were evaluated for optimization of seed spacing for sunflower at four different forward speeds 4.11, 7.97, 11.84 and 16.04 m min^{-1}. A speed of 7.97 m min^{-1} was found suitable for mechanical metering of sunflower seed. The peripheral speed of the metering roller has considerable effect on the uniformity of seed metering. The uniformity of seed metering in terms of seed rate, per cent of cell fill, seed germination and seed damage were compared for each roller.

Abd *et al.* (2007) developed a locally fabricated sugar beet planter and investigated its performance. The planter after developing resulted in more soil loosening and a significantly lower bulk density than the planter before developing at the 0 to 25 cm depth. The soil resistance to penetration was 289.2 and 202.5 N cm^{-2} for planter before developing and after developing respectively. It was noticed that, no significant difference in seedling emergence of planter operating at 2.62 and 3.63 km h^{-1}. It is recommended to operate the developed planter at forward speed of 3.63 km $h^{-1}$and the root and sugar yield increased by 25 and 19 per cent, respectively planted using planter.

Arzu and Adnan (2007) studied the operating variables of a vacuum precision seeder including the vacuum applied to the seed plate, the diameter of seed holes and the peripheral speed of the seed plate. Response surface methodology (RSM) was adopted to optimize seed spacing uniformity performance. The optimum levels of vacuum pressure and the diameter of holes for the precision seeding of cotton seeds was reported to be 5.5 k Pa and 3 mm, respectively. No optimum value was obtained for the peripheral speed of the seed plate. It was found that the lower the peripheral speed of the plate, the higher is the performance.

Helmy (2009) conducted an experiment to assess the effect of physical and engineering properties of some corn seed varieties on pneumatic machine performance. The recommended suitable diameter of seed plate holes were 7, 7 and 5 mm for corn SC10, TC310 and ryana, respectively. The optimum suction air speeds were 12, 14 and 15 m s^{-1} for ryana, SC10 and TC310, respectively. At these determined parameters, highest per cent of seeds holding in seed plate holes were obtained and the appropriate operating speed of tractor was 3 km h^{-1}.

Ismett *et al.* (2012**)** developed a vacuum type precision seeder unit with a ground driven wheel of diameter 0.64 m that transfers the motion to the vertical vacuum plate with combination of gears. The height of seed drop was 0.1 m and the holes size 4.5 and 3.5 mm were used for cotton and maize on a circular 0.19 m diameter vacuum plate. Seeds from the vacuum plate are released at an angle of 60˚ from the horizontal and the vacuum pressure applied was 6.3 k Pa. The peripheral speed of the vacuum plate V_p and the forward speed of the seeder V_f was determined by the following relationship.

$$V_p = \frac{\pi d n_p}{60} \qquad \ldots (2.5)$$

$$V_f = \frac{n_p}{60} K Z_t \qquad \ldots (2.6)$$

Tejminder and Dilip (2013) used proximity sensor technique to quantify seed spacing that measures the time interval between the seeds and transmission ratio between two velocities. The calibration unit includes di-sonic frame light barrier sensor (OGWSD 25 P3K-TSSL) that consists of square cross section window including transmitter and receiver with innovative microcontroller technology in its casing along with the inductive type gear tooth sensor that calculates rpm of roller. Mechanical drive of motor/roller/ SMU was controlled using V/F drive through PC itself. Calibration of whole system is based on ISO defined planter standard parameters that are quality of feed index, multiple index and miss index. Developed calibration unit can be used as alternative to grease belt stand to rapidly obtain quantitative evaluations of planter seed spacing uniformity in the laboratory.

Yasir *et al*. (2013) designed a pneumatic precision metering unit, which had a cylindrical seed plate made up of 2 mm thick and 30 mm wide aluminium sheet of 140 mm diameter with 30 equidistant cylindrical holes. The back side of seed plate was fixed with the main shield of driving shaft and inlet of negative pressure. The main shield of the device was made of steel with 200 mm outside diameter and 26 mm depth with total width of 73 mm. The seed kernels enter through the inlet port provided on cover plate at the bottom of the seed plate simultaneously works as a seed lot. The kernels stir according to the movement of the seed plate and were picked up by the seed holes, held and transported under the influence of negative pressure. At the top of the metering device the negative pressure drops by spring loaded air cut-off device, the kernels then fall down vertically via the outlet to the seed tube by gravity.

2.3 Development and assessment of computer vision system

Alchanatis *et al*. (2002) developed a machine vision system for evaluation of performance parameters of pneumatic planters. The system includes a line scan camera, frame grabber, personal computer and image processing algorithm. The lines acquired by the camera were processed online by windows application package that includes user interface for controlling the camera, online image display of the seeds as they are entering the cameras field of view, on-line image processing algorithms for seeds detection and spacing computation, as well as computation of statistical parameters of the seeds distribution were determined and compared with the with a conventional grease belt method, showed that the seeds location as calculated by the optical system coincided with the seeds location as measured on a grease belt. The location of the seed (X) on a virtual propagating plane was computed by using the following relationship.

$$X = -\frac{(X_1 + X_2)}{2} \times X_{res} + \frac{(Y_1 + Y_2)}{2} \times \mathrm{LineRate} \times \mathrm{Speed} \times C \qquad \ldots (2.7)$$

Where, X_1, X_2, Y_1, Y_3 are distance from reference line to seed; X_{res} is spatial resolution along the direction of the line (mm per pixel); Line Rate is rate of line an acquisition (MHz); Speed is assumed velocity of planter propagation (Km h^{-1}); C is constant factor for matching the units of (Line Rate*Speed) (mm/line).

Karayel *et al.* (2004) developed a seed spacing measurement system of seed drill in laboratory and velocity of fall of seeds using high speed camera system. The performance of the high-speed camera system in terms of seed spacing evaluation was compared with a sticky belt test stand, used as reference. Identical seed patterns were evaluated applying both methods simultaneously using wheat and soybean seeds. The speed of the metering rollers of the seed drill was set at 10, 20, 30 and 40 rpm and that of the seed drill at a simulated travelling speed of 1 m s^{-1}. The high speed camera system performed well in obtaining the seed spacing and velocity of fall of seeds. The camera system detected all the seeds of wheat and soyabean. The sowing uniformity of the seed drill as investigated was affected by the speed of the metering rollers. Coefficient of variation of seed spacing, velocity of fall and coefficient of variation of velocity of fall of seeds decreased as the speed of the metering rollers increased.

Okan and Ismet (2009) examined in row seed spacing accuracy by computerized measurement system (CMS) combined with a sticky belt. The sticky belt test stand had a 15 cm wide and 11 m long leader belt with a horizontal viewing surface. The belt speed was varied from 1.8 to 7.2 Km h^{-1} which was controlled by multi speed drive arrangement. Grease oil was smeared on the top surface of the belt to capture seeds as they were released from the seeder to order to avoid seed rolling and bouncing on the belt surface. The CMS hardware consisted of a high precision (1000 dpi) optical mouse coupled with a laser pointer and a notebook computer. The mouse was placed at 40 cm above the belt so that the laser beam fell perpendicular to the sticky to the sticky belt. The arrangement was made to move the mouse along the sticky belt to fall the beam of light on seed and the operator must click the mouse button to store the coordinates of seed. This method cannot be adopted under direct sun.

Navid *et al.* (2011) applied image processing method for laboratory evaluation of seed metering device in terms of uniformity of distribution. A Nikon D70 camera was installed at 1 m ahead of planter and above belt to acquire video clips of seeds falling from planter. The clips were processed via MATLAB image processing tool box to find seed uniformity. The following formula was used to calculate distance between seeds.

$$\Delta x = V \times \Delta t \qquad \ldots (2.8)$$

Where, V is belt speed; Δt is time elapsed until a seed was displaced at location X_2 after the previous seed that had been displaced at location X_1 was calculated. X_1, X_2, $X_{3,}$ indicate the locations of seeds on the images.

$$\Delta t = \sqrt{\left[\frac{2S}{1000g} \times (x_1 - x_2)\right]} \qquad \ldots (2.9)$$

Where, S is resolution power (0.16 mm/pixel); g = gravity acceleration (9.81 m s^{-2}).

The effect of type of metering device and speed was significant on seed feed index ($P < 0.01$) but their interaction was significant at ($P < 0.05$) in grease belt method and non-significant in image processing method. The linear relationship ($R^2 = 0.97$) was reported between seed spacing values measured from grease belt and values estimated from the related images.

Nie *et al.* (2011) developed a seed detecting method based on machine vision system to test the performance of seed meter with corn and soybean seeds. MATLAB software image processing tool box was used to analyze the image data. The mean value of absolute error of the sowing speed for soybean was 0.004 to 0.68 seeds per second and the mean value of relative error was 6.5 to 13 per cent. There were no significant difference of mean, standard deviation and coefficient of variation of selected seed between manual statistics and MATLAB statistics. The machine vision method was proved to be time and labour saving and requires less human interference for precision detection.

Deyong *et al.* (2011) developed a visual inspection system for precision performance of magnetic type seeder was established based on machine vision and image processing technology. The pretreatment techniques including image binarization and image filtering were used to for quality enhancement. The results of comparison between machine vision and manual detection showed that the relative error of preciseness was less than 3 per cent and coefficient of variation and standard deviation were less than 5 per cent which indicated system of high accuracy when used in real time detection.

2.4 Testing and evaluation of planter

Lan *et al.* (1999) described an opto-electronic sensor system for measuring seed spacing uniformity of different seeds. The system consists of a rectangular photo gate with 24 photo sensors and 24 light emitting devices, a digital input/output board in a personal computer. The system was used to test different types of seeds like sugar beet regular-pelleted (3.8 – 4.5 mm), mini-pelleted (3.2 – 4.0 mm), medium encrusted sugar beet seeds (3.2 – 3.6 mm) and pelleted chicory seeds (2.8 – 3.3 mm). The opto-electronic sensor systems seed spacing were not significantly different from the same seed spacing measured with the grease belt test stand. The developed system worked well to obtain seed spacing with regular-pelleted and mini-pelleted sugar beet seeds.

Panning *et al.* (2000) Evaluated five planter configuration for seed spacing uniformity at three field speeds using opto-electronic sensor system for laboratory and seed location method in the field. Planter uniformity was described using the coefficient of precision (CP3) measure. Seed spacing uniformity determined in the laboratory tests was higher than or equal to seed spacing uniformity determined in the field test. Reported that the laboratory test method were significantly different from those determined using the field test method. The planter metering value of high CP3 from laboratory tests were well singulating seed and dropping it uniformly. The John Deere Max Emerge 2 planter with the metal tube at a travel speed of 3.2 km h^{-1} had as high a CP3 value, or did as good a job of seed metering, as the Franz Kleine Unicorn-3 in the laboratory tests. As travel speed increased, the CP3 values for the Franz Kleine Unicorn-3 did not change significantly, while the CP3 values for the other planters decreased. This indicates the Franz Kleine Unicorn-3 seed metering system worked well at the three travel speeds used in these tests.

Karayel and Ozmerzi (2002) studied on comparison of vertical and lateral seed distribution of furrow openers using a new criterion. The seeder was operated at a speed of 5 km h^{-1}. A field experiment was conducted to determine the effect of furrow opener type (shoe, hoe, single disc and double disc) on sowing uniformity according to conventional and developed evaluation criteria. Distribution area of seeds was calculated by ellipse and integral criteria. Seed distribution areas computed by ellipse criterion were significantly lower than by integral criterion for both maize and watermelon seeds.

Kamble *et al*. (2003) developed power operated planter having inclined plate seed metering mechanism. The speed ratio between seed plate to ground wheel of 1:0.74 was provided. The seed plate was mounted at an angle of 60° with the horizontal in the seed metering mechanism. Power was transmitted from ground wheel to metering mechanism through chain and sprocket. The planter was tested for sowing gram and peanut. The seed spacing in the range of 150 to 200 mm was obtained which was found to be optimum for the test crop.

Raheman and Singh (2003) developed a sensor based on light interference technique for sensing the seed flow from the metering mechanism of seed drill and planter. The performance of the sensor was studied for wheat and maize seeds in a test rig developed for testing different metering mechanism used in seed drills and planters. The developed sensor successfully sensed the seed droppings for maize, wheat and mustard seed from fluted roller metering mechanism with maximum error of 10 per cent for maize and 18 per cent for mustard respectively. The developed sensor has the potential for sensing the seed flow by which the operator can easily know the workability of the metering device.

Dhalin and Divakar (2004) developed an opto-electronic system for assessing seed drop spacing of planters. The assessment of plant spacing as provided by mechanical planters is crucial in analyzing their performance. A computerized opto-electronic seed spacing measurement system was developed to rapidly determine the time intervals between seed drop events. It used a photo detector along with allied circuitry and computer interface. By detecting the seed drop events at the seed tube end, it measured the time interval between seed drops. The time interval multiplied by the planters travel speed gave an estimate of the seed spacing. The seed spacing data was acquired at operating speeds of 1.5, 1.75, 2.0 and 2.25 km h^{-1} for metering groundnut, maize, sorghum, green gram and black gram, respectively.

Staggenborg *et al*. (2004) conducted a study to assess the impact of planter speed equipped with a vacuum metering device on plant establishment. It was reported that the indices and standard deviation in plant spacing decreased as planter speed increased, the primary detriment to higher planter speeds is the risk of reducing stand establishment and final plant stands. The correlation coefficient of 0.64 for plant density and corn yield was reported. It is recommended to focus the planter performance in field should be towards establishing the correct seeding rate and subsequent plant stand and less on absolute plant spacing.

Zeliha and Aziz (2004) developed an electronic counter to determine the number of seeds holding on seed plate, while studying the effect of operating parameters on seed holding in single seed metering unit of pneumatic planter for maize. The developed counter consists of an infrared receiver and transmitter fixed to see the holes of seed plate in the metering unit. The counter was used to determine the wholes without seeds on the seed plate at four peripheral velocities of seed plate's *viz.*, 0.16, 0.24, 0.32, and 0.40 m s^{-1}. The electronic seed counter worked satisfactorily to count the holes without seeds. The most suitable shape of the holes in the seed plate was oblong for maize seeds. The seed holding ratio decreased when the peripheral velocity of the seed plate increased, whereas the seed holding ratio increased parallel to the increase in vacuum pressure.

Ivacan *et at*. (2004) evaluated the effect of precision drill operating speed on the Intra-row seed distribution for parsley an increase of operating speed leads to changes of the values of the drill performance indicators. Thus an increase in operating speed results in a decrease of drilling precision because the intra-row seed spacing becomes larger than the required. The set seed spacing increased from 7.5 to 8.3 cm in parallel with increasing the drilling speed by 1.8 to 5.2 km h^{-1}, respectively.

Karayel *et al.* (2004) developed a mathematical model of vacuum pressure on a precision seeder for maize, cotton, soyabean, watermelon, melon, cucumber, sugarbeet and onion seeds were used in laboratory test. The optimum vacuum pressure was determined as 4 k Pa for maize I and II, 3 k Pa for cotton, soyabean and watermelon I, 2.5 k Pa for watermelon II, melon and cucumber, 2.0 k Pa for sugarbeet and 1.5 k Pa for onion seeds. The final mathematical model satisfactorily predicted the vacuum pressure of the precision vacuum seeder with chi square of 2.51×10^{-3}, root mean square error of 2.74×10^{-2} and reported modeling efficiency of 0.99.

Kathrivel *et al.* (2005) reported that the planting operation with ridger seeder, pneumatic planter and cultivator seeder resulted in cost of 44.00, 42.85 and 41.64 per cent saving in cost, respectively. Among the three implements, the savings in cost was high in the ridger seeder treatment. There was a savings of 96.4, 96.3 and 96.2 per cent in time by the ridger seeder, pneumatic planter and cultivator to manual sowing respectively.

Singh *et al.* (2005) investigated the performance of design and operational parameters of a pneumatic seed metering device for planting cotton seeds under laboratory and field conditions. The spacing of the seeds are affected where the mechanism fails to select or drop a seed resulting in large spacing between seeds; or because the mechanism selects and drops multiple seeds causing small spacing between seeds. To achieve accurate seed spacing, different parameters that affect the placement need to be optimized for a specific size of seed. The effect of operational speed of the disc, vacuum pressure and shape of the entry of seed hole were evaluated by examining the mean seed spacing, precision in seed spacing, miss index and highest quality of feed index. For picking single seeds, the planter disc had a seed hole of 2.5 mm in diameter. The metering system of the planter was set to place the seeds at 250 mm spacing. A mean plant spacing of 298 mm was found in the field with a 19.1 per cent precision. The metering system with a speed of 0.42 m s^{-1}, and a vacuum pressure of 2 k Pa produced the best performance with a quality of feed index of 94.7 per cent and a coefficient of variation in spacing of 8.6 per cent.

Maleki *et al.* (2006) reported that the coefficient of variations (CV) fails in the evaluation of grain drill performance due to the induced variations by random sampling. A new index designated as the coefficient of uniformity (Uc) for the evaluation of seed distribution uniformity was introduced. It was established based on the least absolute deviation criterion rather than on least squares. The aptness of the new index to evaluate the seed distribution uniformity was investigated by comparing its performance with the ubiquitous coefficient of variation. The study proves that the coefficient of uniformity was less sensitive for data outliers than the CV. The results also indicated that a consecutive sampling scheme should be considered during grain drill feeding system evaluation instead of randomly selected samples.

Arzu and Adnan (2007**)** optimized the variables effecting on seed spacing uniformity of a vacuum-type precision seeder of cotton using response surface methodology. The considered variables were the vacuum on the seed plate, the diameter of seed holes and the peripheral speed of the seed plate. The central composite design (CCD) of RMS was adopted for optimization of data obtained in the laboratory experiments. Also developed functions in polynomial form that allowed the calculation of optimum level of each independent variable considered in the study. The optimum levels of vacuum pressure and the diameter of holes for precision seeding of cotton seeds were found to be around 5.5 k Pa and 3 mm, respectively. No optimum value was reported for the peripheral speed of the seed plate but at lower peripheral speed of the plate, the higher is the performance.

Celik *et al.* (2007) evaluated four different type seeders namely no till planter, precision vacuum planter, universal planter and semi-automatic potato planter at forward speed of 3.6, 5.4 and 7.2 km h^{-1} for seed spacing uniformity and emergence. Uniformity of horizontal distribution of seed was described by using the multiple index, the miss index, the quality feed index and precision index. Plant emergence ratios were evaluated by means emergence time, emergence rate indexes and emergence percentage. The best seed spacing uniformity and seed emergence ratio were obtained with the no till planter and the best seed depth uniformity was obtained with the precision vacuum planter.

Ajaykumar *et al*. (2007) designed a furrow openers for seed cum fertilizer drill by considering mechanical aspects for minimum soil disturbance and reduced tendency for clogging. The performance of seed drill with inverted - T type furrow opener performs better than shoe and shovel type furrow openers in both Kharif and Rabi soil condition. Seed emergence percentage (86.66 per cent) per meter of row length was found highest for the inverted - T opener as compared to the shoe (70.90 per cent) and shovel (62 per cent) type furrow opener.

Norremark *et al.* (2007) developed instrumentation system and method for high accuracy geo-referencing of sugar beet plants. The research investigated the technological basis for producing geo-spatial maps of individual sugar beet seeds from data acquired during seeding operations. The instrumentation and methodology consisting of a precision seeder retrofitted with RTK-GPS, a dual axis tilt sensor, seed drop sensors, a data acquisition system and data processing algorithms have been developed and validated.

Karim *et al.* (2007) investigated the performance of the instrumentation sensor network design using a data reconciliation technique based on the unscented kalman filter (UKF) to extend an instrumentation sensor network design approach to non-linear dynamic processes. Moreover an efficient performance measure based on the root mean squared error (RMSE) of the estimated variables has been presented to evaluate each candidate instrumentation sensor network design. A simulated non-linear continuous stirred tank reactor (CSTR) benchmark plant has been utilized to illustrate the effective capabilities of the proposed approach.

Ali (2008) investigated the seeding uniformity for vacuum precision seeder. The performance of three row vacuum precision seeders was studied in field. Seeding uniformity was determined in three different distances of 14, 18 and 21 cm. the seeders were operated at 1.8, 3.6 and 5.6 and 7.2 km h^{-1}. Successive seed spacing along with the row of 3 m was measured in three replications on each row. For evaluating the seeding uniformity of seeders, seed spacing's were analyzed using the standard methods (MISS, MULT, QFI & PREC). The best operating speed was 1.8 km $h^{-1}$with highest QFI value (88.5 per cent). There was no difference between 1.8 and 3.6 km $h^{-1}$where as they differed from of 5.4 and 7.2 km h^{-1} speeds. The best PREC value was obtained for 21 cm within row distance (17.4 per cent). PREC values were acceptable for precision seeding in all trials.

Dae and Slaughter (2008) developed a precise displacement measurement system using a non-contact image-based optical sensor and a hardware-based artificial neural network. Field tests, with the sensors mounted on a tractor-drawn toolbar, were conducted to compare the performance of the image-based displacement system with traditional ground-wheel driven encoder-based and radar-based displacement systems at two different travel speeds (0.45 and 1.36 m s^{-1}). The precision of the three methods, expressed as the standard deviation of spot spray activation at 127 mm intervals, was 7.3 mm, 5.9 mm, and 17.3 mm on a rough soil surface (50 mm to 125 mm sized soil clods) at a 0.45 m s^{-1} travel velocity for the image-based, wheel-based, and radar-based displacement sensors respectively. Compared to the radar-based sensor, the image-based sensor had better accuracy on a rough soil surface than the wheel-based sensor, better accuracy at both speeds, and better precision at the low speed. In addition to being non-contact, the main advantage of the image-based sensor over the wheel-based sensor was that it did not require site specific re-calibration to maintain accuracy.

Searle *et al.* (2008) evaluated the effects of field slope on planter seed spacing uniformity for three different seed metering units (cell plate, finger pick-up, and flat plate) operating with medium round corn seed in a laboratory using the University of Nebraska planter test stand with an opto-electronic seed spacing sensor system. The metering units included a John Deere MaxEmerge™ Plus VacuMeter row unit with the standard cell corn plate, a John Deere MaxEmerge™ Plus VacuMeter row unit with the flat plate, and a John Deere MaxEmerge™ Plus row unit with the finger pick-up metering system. As per ISO planter seed spacing uniformity was measured using three parameters namely miss index, Multiples index, and coefficient of precision (CP3). Six replications for nine field slope treatments were conducted for each metering unit. The field slope treatments included front-up (front of planter unit), front-down, right-up (right side of planter unit), and left-up each at field slope levels of 10 per cent and 20 per cent.

Bakhtiar and Loghavi (2009) developed an innovative garlic clove precision planter capable of planting three rows of garlic. Laboratory evaluation of the planter components, especially the seed metering mechanism revealed a satisfactory performance of the planter components, except a few modifications which were needed before conducting field tests. The performance parameters measured/calculated during the field tests included, seed mass rate, seeding depth, seed spacing, miss index, multiple index and seed damage. The results showed that the new machine is capable of planting 220,000 plants ha^{-1} at the seeding depth and spacing of 12.3 and 22.7 cm, respectively. Also, miss index, multiple index and seed damage were measured as 12.23, 2.43 and 1.41 per cent, respectively.

Okan and Ismet (2009) Evaluated the computer measurement system (CMS) by selecting 8 performance parameters like precision seeding, mean seed spacing, standard deviation, multiple index, miss index, quality feed and precision index, the population index, and the coefficient of precision were combined with grease belt test. The standard deviation of 250 spacings measured in the test by the CMS for 5, 10 and 20 cm spacing varied by 0.11, 0.126 and 0.199 cm, respectively. At higher speeds variation in front to back location of seed drops increased and at a seeder travel speed of 8.05 km h^{-1}, the position of the seed was not detected by the sensors. Reported that the seed spacing measurement obtained using the CMS were strongly correlated ($R^2 = 0.9969$, $P < 0.05$) with the seed measurement obtained using digital caliper and also have higher coefficient of determination.

Ismail and Hanify (2009) constructed a punch planter for testing the seeds which studies the effect of oscillating tube mechanism on the seeds distribution and to determine the factors that realizes the best operation condition. The data were statistically analyzed to determine the effect of the oscillating tube radii and the traveling speed of punch planter under two different connecting rod lengths of 150 mm and 180 mm on performance indices, namely mean seed spacing, miss index, multiples index, and quality of feed index, precisions in spacing and the amount of seed rate. For optimization of factors affecting the performance of investigated punch planter, experiments were conducted with four traveling speeds of 0.28, 0.39, 0.48 and 0.59 m s^{-1} and at 21.4, 29.8, 36.69 and 45.09 rpm on metering disc.

Karayel (2009) examined the performance of modified precision vacuum seeder for no-till sowing of maize and soybean following wheat. Sowing depth uniformity, mean emergence time and per cent emergence of both maize and soybean seeds were decreased and precision of the distribution of the seeds along the length of the row was increased as a result of increasing forward speed. The distribution of the seeds along the length of the row, sowing depth uniformity and per cent emergence of the seeder equipped with the double disc-type opener was better than the seeder equipped with the hoe-type opener. The precision of the distribution of the seeds along the length of the row for forward speeds of 1.0 and 1.5 m s^{-1} experienced in this study was well below 29 per cent and therefore is acceptable for both maize and soybean seeds. The modified precision vacuum seeder generally performed best using the double disc-type furrow opener at the forward speed of 1.0 m s^{-1}, based on the distribution of the seeds along the length of the row, sowing depth uniformity and per cent emergence.

Veeranagouda and Shridhar (2010) conducted study on effect of planter forward speed and depth of operation on draft and ground wheel slip. The test was conducted for the measurement of draft and ground wheel slip in a rectangular soil bin of size 2 × 30 m. The planter under test was attached to one of the ends of the prime mower trolley by the hooks provided for the purpose. The groundnut seeds were filled up to the proper level and the unit was hitched to the prime mover and operated with the ground drive wheel engaged. The number of revolutions made by the ground wheel to travel a fixed distance was recorded. The ground wheel slip in the rectangular soil bin was recorded for four different speeds under test.

El (2010) developed opto-electronic seed counting device based on light reflectance for field detection. The new light reflecting opto-electronic field counter capable of detecting and counting free falling object with equivalent length/diameter $\geq$ 0.5mm in seed delivering tube was developed and tested to evaluate seeding rate. The performance of the device is not affected by the shape and color of the counted objects. This device can count falling with 0.11 sec apart accurately or seeding at speed 7 km h^{-1} within 5 cm diameter of seeds delivering tube.

Xiaoyan *et al.* (2010) investigated a seed sucking process of pneumatic precision metering device for rapeseed and proposed mathematical models on contact force and airflow disturbance of sucking process of seed. The optimal model was developed by minimizing the contact force per point of contact ring while the seed was sucked on the seed nozzle. From this model an optimal relation of the diameter of seed, the cone angle and the diameter of the seed nozzles was obtained. Secondly, an approximate model on the pressure difference of the seed nozzle was introduced. Through model analysis provided some optimal conclusions on the diameter of the nozzle given in equation 2.10. Nozzle number of the metering disc, the radius of orifice and the rotational speed of the metering disc.

$$D = d \cos \frac{\alpha}{2} \qquad \ldots (2.10)$$

Where, D is diameter of nozzle; d is diameter of seed and α is cone angle.

Anantachar *et al.* (2010**)** developed a feed forward artificial neural network (ANN) model for the prediction of performance parameters of an inclined plate seed metering device and its reverse mapping for the determination of optimum design and operational parameters. Conducted laboratory experiments using sticky belt and opto-electronic sensor systems to evaluate the performance of inclined seed plate metering mechanism and data used for model development. The ANN model predicted the performance parameters of the seed metering device better than the statistical model. The optimum forward speed of the planting equipment, peripheral speed of the metering plate and the area of the cells on the plate were determined to obtain the recommended seed rate of 33.33 seeds m^{-2}, seed spacing of 100 mm, per cent seed damage of 0.2 with 100 per cent fill of the cells. The peripheral metering plate speed of 0.237 m s^{-1} was reported as optimum for the size of seeds in the range of 95.42 to 123.01 mm^{2}.

Jafari *et al.* (2010) investigated the design and construction of a closed loop control system to change the seeding rate of a grain drill on the go. The dynamic tests were conducted at low and high application rates of 87.5 and 262.5 kg ha^{-1} respectively. The response times of low - to - high and high - to - low transition rates were 7.4 and 5.2 s, respectively, while the drill operated at a travel speed of 1 m s^{-1}.

Zhao *et al*. (2010) investigated the performance of vacuum cylinder seeder for the precision sowing of rape seeds. The forces acting on the seeds in free flight were calculated using the computational fluid dynamics (CFD) software fluent. Using the differential equation for seed motion, seeds falling trajectories using different working parameters were numerically determined. A high speed camera system mounted on a laboratory seeder test rig was used to record the motion of seeds. A mean shift algorithm for tracking seed was used. The horizontal displacement (x) and the fall time (t_f) of seeds predicted by the numerical analysis and measured by the high speed camera were compared. The relative errors of x and t_f were < 5.5 per cent and 6.5 per cent respectively, indicated good agreement.

Kocher *et al.* (2011) studied the variation in corn seed spacing from a John Deere MaxEmerge^{TM} Plus vacumeter planter was evaluated on test stand in a laboratory setting for two seed tube conditions with two corn seed. Seed spacing uniformity was measured using three seed spacing uniformity parameters, coefficient of precision (CP3), ISO multiples index, and miss index. Differences were detected in all three seed spacing uniformity parameters due to the seed tube condition. The new seed tubes had better seed spacing uniformity than the worn seed tubes, within each example of the seed shapes (round or flat) used in this experiment. For the seed used in this experiment, the round corn seed had better seed spacing uniformity than the flat corn seed, within each of the seed tube conditions.

Singh and Mane (2011) developed an electronically controlled metering mechanism for okra seed under laboratory condition. The performance of developed metering mechanism was evaluated in the laboratory using greased belt technique for okra seed with different levels of seed to seed spacing and forward speed of operation. The developed metering mechanism performed well and delivered the seed very close to the target seed to seed spacing with higher quality of feed index. The miss index and multiple indexes were zero. Seed placement was more accurate at slower speeds and larger seed to seed spacing.

Xu *et al.* (2012) **s**tudied the relationship between vacuity and structural and operational parameters of positive and negative pressure of precision metering device for rapeseed. Mathematical model was established by conducting a dynamic analysis to find out maximum vacuity H_{max} and pressure coefficient K of outlet and interface was put forward.

$$H = -KP \qquad \ldots (2.11)$$

$$H_{max} = -KK_1K_2K_3P \qquad \ldots (2.12)$$

Where, H is vacuity of the outlet (Pa); P is absolute vacuity at the interface of rapeseed and nozzle (Pa); H_{max} is critical vacuum pressure; K is pressure ratio of outlet and interface; K_1 is reliability coefficient of seeds from adsorption zone to unloading zone; K_2 is reliability coefficient of nozzle movement; K_3 is affective coefficient of external conditions.

The influence factors of K were studied through air current simulation of vacuum chamber with ANSYS/CFX. Reported that the cone angle of the nozzle has a very significant effect on K, nozzle numbers of the seed disc and the vacuity have no significant effect on K. K is 2 when the nozzle number of the seed disc and cone angle of the nozzle is 25° and 90° respectively. The H_{max} is - 415 Pa when the speed of the seed disc is 18 rpm. Single factor experimental results were that the miss index is lower than 4.36 per cent when the absolute vacuity is greater than 420 Pa, the eligible index reaches as high as 95.52 per cent and the miss index is 2.25 per cent when vacuity is -500 Pa, which proves that outlet vacuum calculation model is correct.

Ismett *et al.* (2012) performed seed spacing accuracy tests on a sticky belt in the laboratory to find quality feed index, miss and multiple indices and precision index of cotton and maize planter. The regression model was used to assess the results and reported that 16 seeds s^{-1} was the upper limit of seed release frequency (SRF) for cotton and maize seeds at maximum peripheral speed of 0.34 m s^{-1}. The Use of 72 holes instead of 26 holes in the vacuum plate at 6.3 k Pa created a vacuum band in the width of 10 mm around holes and this is increased the multiple index and caused a reduction in seeding performance. It is recommended to use for vacuum plates with 60 or 52 holes at forward speed of either 1 or 1.5 m s^{-1} for the seed spacing of 0.05 and 0.10 m, respectively. The performance indices, namely the quality of feed, miss and multiple indices, reduced significantly for cotton and maize seeding when the precision metering unit was run at 20 per cent (11°) slope to the right as compared to the no slope condition.

Sanjeeva *et al*. (2012) tested different types of seed metering mechanism for castor and maize under simulated conditions. The existing inclined plate metering mechanism and newly developed horizontal metering plate were tested for comparative performance at three speeds at 2.5, 3.5 and 5 km h^{-1} with castor and maize seeds using the test rig. The average number of seeds metered at different forward speeds for selected variety of maize varied from 367.5 to 239 for inclined plate and 308 to 281 for horizontal plate when compared to theoretical metered seed of 270. In horizontal plate, the seed metering was more consistent and did not varied much with respect to speed of rotor and delivered 14.02 to 4.03 per cent higher seed rate for castor. The mean seed spacing ranged from 19.3 to 23.1 cm. The horizontal rotor metered 94 – 98 frequency percentile seeds within 15 – 30 cm spacing intervals at operation speeds of 2.5 to 3.5 km h^{-1}. It is reported that, correct seed rate can be achieved with the selected speed ranges by re-designing the seed cells in horizontal plate rotor.

Satti *et al*. (2012) developed a prototype of the pneumatic precision metering device for wheat and the performance in terms of quality feed index (QFI), multiple index (MULI), miss index (MISI) and seed rate expressed in number of kernels per meter length (KPM) were investigated in laboratory using test stand with camera. The rotating speed and negative pressure and their interactions had a significant effect on these variables. The maximum QFI (92.98 per cent) was reported at rotating speed of 19.0 rpm and negative pressures of 2.5 k Pa with MULI and MISI of 2.01 and 5.09 per cent, respectively. The recommended seed rates estimated at 40 KPM and 53 KPM for 12 and 15 cm row spacing respectively, were achieved at a range of rotating speed and negative pressure with QFI ranging between 84.57 to 89.11 per cent.

Yasir *et al.* (2013) evaluated precision planter performance indices described as quality of feed index (QFI), multiple index and miss index. A 5 × 5 RCB statistical design was applied with five levels of rotational speed 19, 24, 29, 34 and 39 rpm and five levels of the negative pressure of 2.5, 3.0, 3.5, 4.0 and 4.5 k Pa at constant belt speed. It is reported that the negative pressure increased the quality feed index and multiple index increased whereas miss index decreased. The consistency between the results of dynamic analysis and the laboratory testing is that the quality feed index decreased and the miss index increased with increasing the rotating speed.

Yu *et al*. (2014) simulated positive and negative pressure to determine the performance of pneumatic precision metering device for rape seed. Studied the relationship between positive and negative pressure of nozzles, fluid models of chamber were developed to simulate the air flow and the k-ε turbulence model was conducted to capture the pressure and velocity of nozzles. Through these efforts linear models were achieved. A three-factor factorial split-split experiment was designed with negative pressure, positive pressure and the rotating speeds varying from -1000 to - 4500 Pa, 50 to 250 Pa and 10 to 45 rpm, respectively. Models relating ratio coefficient K with positive pressure were fitted in different rotating speeds. The results showed that the ratio coefficient was matched $\in [f1(x), f2(x)]$ from the fitting equations with the rotating speed of 10 - 30 rpm, while the rotating speed has greater influence when it was 35 - 40 rpm and the sets $\in [g1(x), g2(x)]$ were achieved, where $\in [100, 250]$.

2.5 Economics

Kathirvel *et al*. (2001) developed the tractor drawn till planter for cotton and reported that saving in cost, time and energy for planter were 23.65, 90.09 and 18.25 per cent, respectively over the traditional method of planting.

Srivastava *et al.* (2003) tested the inclined plate planter for peanut and chickpea. Planter had a field capacity of 0.46 ha h^{-1} with a field efficiency of 69 per cent. The quality feed index varied between 85.6 to 88.9 per cent at the tractor forward speed of 3.5 km h^{-1}.

Sedat *et al*. (2005) developed a test rig to evaluate the performance of inclined plate planter with parameters like rotor speed, cell area of rotor and forward speed for peanut in the laboratory and reported that the seeding rate increased with increase in rotor speed. Similarly the seed to seed distance reduced with increase in rotor speed.

III. MATERIAL AND METHODS

This chapter describes, the methods adopted to measure the physical and aerodynamic properties of seeds selected under the study. A new pneumatic seed metering mechanism was developed and its performance was evaluated under simulated conditions. The process of development, its functions and testing method under the laboratory conditions with standard experimental procedures are thoroughly discussed in this chapter. The development of an experimental set up to refine the design and operational parameters which are affecting the performance of pneumatic seed metering mechanism is also explained in detail.

The development details of an experimental test rig to optimize the rotational speed of rotor and suction pressure of the pneumatic planter to achieve the required spacing of seeds in a row were explained. The experimental procedure leading to the scientific analysis of the system in terms of the seed spacing uniformity and pressure developed are enumerated. In order to optimize the experimental parameters, response surface methodology (RSM) was used and the procedure followed in setting the rotatable within the set boundary conditions is also described in this chapter. In addition to conventional way of seed space measurement using sticky belt, a novel machine vision technique was also developed for seed space analysis and compared with the traditional method of measurement. The details of hardware and software of machine vision and procedure adopted for the analysis of images were discussed in detail.

This chapter also details other general requirement of the planter and its conceptual design, detailed designs of components for development of field level prototype of pneumatic seed planter. The procedure of field evaluation of the seed planter for planting selected seeds is also discussed in detail. As the soil physical conditions such as, soil moisture, bulk density, soil compaction and soil traction parameters like wheel slip and draft affect, the seed placement by the planter, the methods followed to determine these parameters are also explained.

The methodology followed for the design and development of pneumatic planter and its evaluation in laboratory and field by different technique are narrated. All these details are described under the following headings.

3.1 Seed selection and determination of its physical and aerodynamic properties

3.2 Design and development of pneumatic seed metering mechanism

3.3 Testing and optimization of design and operational parameters under simulated conditions

3.4 Simulation and optimization of air pressure using ANSYS FLUENT software

3.5 Computer vision system for testing of seed metering mechanisms in lab

3.6 Design and development of pneumatic planter prototype from optimized parameters

3.7 Calibration and performance evaluation of developed planter under field conditions

3.8 Economics of developed prototype planter

3.1 Seed selection and determination of its physical and aerodynamic properties

The design of any planter seed metering mechanism mainly depends on its seed properties. In addition to physical and mechanical properties, aerodynamic properties of seed also majorly influence the design and operational parameters of pneumatic planter. The size and shape, frontal area, density, thousand seed weight, angle of repose, coefficient of friction, terminal velocity and drag coefficient of selected seeds were measured using standard methodology described in subsections**.**

3.1.1 Seed selection

Cotton and okra crops are grown commercially in India, whose seed cost is very high and precise planting is required for higher yields. One of the most conspicuous reasons of low productivity in cotton and okra is lack of proper awareness of various agronomic practices, in which spacing between plants is considered to be the most important for improving yield and quality (Bracy and Parish, 1998; Wanjura, 1980). In order to achieve the desired production of cotton and okra crops and partly to reduce the seed cost, farmers are adopting hand dibbling method, which is time consuming and laborious. Hence, development of precise planter with correct seed spacing mechanism is very essential for planting cotton and okra seeds which ultimately reduce the cost of cultivation. To overcome and reduce the influence of seed physical parameters variability on metering performance of seed metering mechanism, three varieties of seed were selected for each test crops. The selected cotton seed varieties were namely Ankur 651(CH1), ATM (CH2) and Jaadoo (CH3). The okra varieties of Kaveri 49 (OH1), Anamika (OH2) and RK 501 (OH3) seeds were procured from commercial seed suppliers.

3.1.2 Linear dimensions of selected seeds

Linear dimensions play vital role in designing the seeds handling machinery and equipment. Based on the seed dimensions, the cell size can be decided. The seed dimensions will give a general idea about the other seed properties which are influencing the design.

3.1.2.1 Experimental method

One of the important properties that influences the holding and conveying of seeds by air is the size and shape of the seed. The selected cotton and okra seeds were fully delinted and cleaned to remove unwanted dust and dirt particles from the seeds. The size of the selected seeds of cotton and okra were determined by image analysis technique as explained in subsection 3.1.2.2 using IMAGEJ software (Igathinathane *et al*., 2009) and compared with conventional measurement technique.

One hundred seeds from each variety were picked randomly. All the properties of the selected seeds were measured at respective natural storage moisture content, which was recommended for safe storage. The dimensions of each seed namely length (L), width (W) and thickness (T) were measured in three directions by using electronic digital caliper with 0.001 mm accuracy (Plate 3.1a). The measurement was repeated for each seed of each variety.

3.1.2.2 Image processing method

The conventional method of measurement of seed linear dimension is very laborious and time consuming process. So, there is a need to test and adopt new methodology using advance electronic devices. Seed linear dimensions will play a major role in agricultural machinery design. The image processing technique is a best alternative to measure multiple seeds dimensions simultaneously within a short period of time with minimum error. It is one of the more accurate and reliable method used to determine the linear and geometrical properties of irregular seeds in recent years. Some of the physical properties of cotton and okra seeds were determined by using an image processing technique as given flow chart (Fig. 3.1). It mainly requires an image acquisition device like camera or scanner.

In this study, a scanner (HP Scanjet G3110) was used to acquire the seed images and they were processed by using the ImageJ software to determine the linear dimension of seeds. This software is Java based free image processing and analysis software, readily available, open source platform independent and public domain software developed at the National Institutes of

Health (NIH), Bethesda, Maryland USA (Rasband, 2008). In order to acquire the images, seeds were spread over the scanner surface without touching to each other and scanned with high resolution to reduce shadow effect. Then the images were imported to a personal computer and each image was analyzed using ImageJ software. The image analysis steps involved in this technique are depicted in figure 3.1 and explained here under.

a) Image acquisition: The image was scanned by spreading seeds over the scanner bed and image was acquired and transferred to the computer.

b) Image adjust: The acquired image was read by IMAGEJ software and processed using adjust function which convert the colour of image to binary image. The threshold intensity optimization of image will be carried automatically, on an analysis of the colour histogram of the image. Create a selection and the entire image will be optimized based on an analysis of the selection.

c) Hole fill or seed identification: From the detected edges, the false objects need to be removed. This step identifies seed objects/edges from all the identified edge objects. Edge sharpness, seed size were some parameters used to filter the false edge objects.

d) Edge detection: To identify seeds boundary in the image, an edge detection algorithm of multiple edge contour or canny edge detector would be used. In an IMAGEJ software this can be performed directly by calling a find edges function option directly.

e) Auto calibration or setting of scale: The setting of scale is an important step in measuring the linear dimensions of seed from image, which converts the pixel value in to the desired units of measurement. For this purpose, a known dimension object was scanned and all the dimensions were calculated using the steps as discussed above. A scale was built form the known dimensions of object by dividing the known dimensions and pixel value and the linear dimensions were measured. This scale was used to determine length, width and projected area of the cotton and okra seeds by multiplying with pixel values.

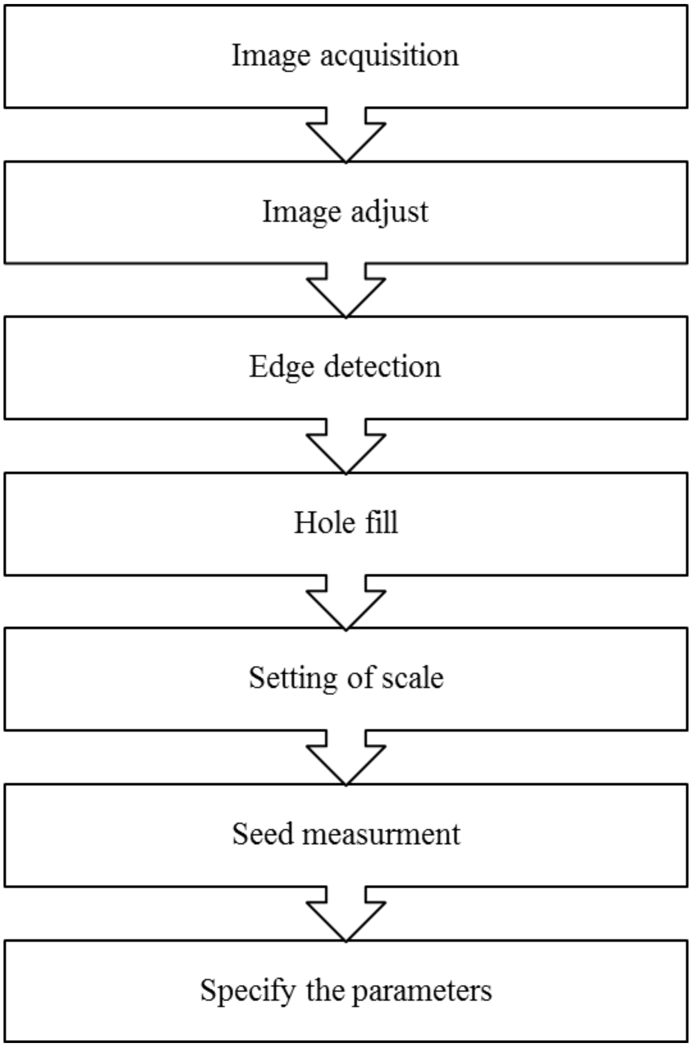


Fig. 3.1 Steps involved in seed image analysis using ImageJ software

3.1.2 Physical and mechanical properties of selected seeds

The basically influencing physical and mechanical properties of selected verities of cotton and okra were studied with standard procedure as explained below.

3.1.2.1 Moisture content

The moisture content of selected seeds was determined by drying the seeds in oven. Seed samples were weighed and then oven dried at 105 ± 5 °C for 24 hours (Ozarslan, 2002). The weight of the dried samples was recorded. The seed moisture content on dry basis (per cent) was calculated using the following expression.

$$Mc = \frac{w_1 - w_2}{w_2} \times 100 \qquad \ldots (3.1)$$

Where, Mc is seed moisture content (d. b.); w_1 is weight of seeds before drying (kg); w_2 is weight of the oven dried seeds (kg).

3.1.2.2 Sphericity

The sphericity of seeds was calculated from the linear dimensions of seed by using the relationship given by Mohsenin (1980).

3.1.2.3 Projected area

The projected area of the seed significantly influences the air stream velocity, when multiple seeds cluster during convey. The projected area of a seed was measured by image processing technique using flatbed scanner to acquire the images and analysis by ImageJ software.

3.1.2.4 One thousand seed mass

Thousand seeds of cotton and okra were selected at random from each variety and weighted in an electronic weighing balance having sensitivity of 0.001 g. The procedure was repeated for all the variety of both the crops.

3.1.2.4 Bulk density

The bulk density of cotton and okra seeds was determined using the standard test weight procedure (Singh and Goswami, 1996) by filling a container of 500 ml with the seed from a height of 150 mm at a constant rate and then weighing the quantity and the procedure was repeated for all the selected varieties.

3.1.2.5 True density

The average true density of cotton and okra seeds was determined using the toluene displacement method. The volume of toluene displaced was found by immersing a weighed quantity of cotton seed in the toluene (Singh and Goswami, 1996). The procedure was repeated for the selected verities of cotton and okra seeds and average value of three replications were reported.

3.1.2.6 Porosity

The porosity of selected cotton and okra seed varieties was calculated from the bulk density and true density using the relationship given by Mohsenin (1980).

3.1.2.7 Angle of repose

Angle of repose of cotton and okra seeds were determined by the method suggested by Waziri and Mittal (1983). Seeds were heaped over a circular shape disc of 200 mm diameter by allowing it to fall from a height of 300 mm until maximum height was reached. The height of the seed heap was recorded. The experiment was replicated five times and the average value was considered for design.

3.1.2.8 Static coefficient of friction

It is the friction experienced between the grains mass and the container. The coefficient of friction apparatus (Plate 3.1b and 3.1c) consists of a horizontal plane and a bottomless open container with a pan. Known weights of grains are taken in the container. The weights are added gradually in the pan and at the instant at which the weight in the pan exceeds grain friction force, the container starts to slide and the coefficient of friction was calculated using equation 3.2. Coefficient of static friction was measured by a frictional device with the mild steel, galvanized iron and nylon sheet surfaces.

$$\mu = \frac{F}{N} \qquad \ldots (3.2)$$

Where, μ is the coefficient of friction; F is the frictional force (force applied); N is the normal force (weight of the grain).

3.1.3 Aerodynamic properties of selected seeds

For the development of equipment such as pneumatic planters, conveyors, separators and aspiration systems it is necessary to study the flow characteristics of seeds in air. Thus the terminal velocity and drag coefficient of cotton and okra seeds were studied in relation with the pneumatic planter design.

3.1.3.1 Terminal velocity

The terminal velocity of the seed was measured using a terminal velocity measuring apparatus (Plate 3.1d) which resembles like a cylindrical air column (Joshi *et al*., 1993). The setup consists of a vertical transparent glass tube air tightly fitted between two flanges. The bottom flange is fixed with air flow control valve to which a blower is attached to pump the air while in operation and a weir mesh was provided just above the air release valve to place seeds on it. The seed was placed on the mesh and blower is switched on, allowed a blower motor pick up full speed, the air flow control valve is slowly released until, the seeds started to float in a high air stream. For each test, a small amount of sample (10 g) was fed over the bottom screen. The air was blown form the bottom the of weir mess in the upward direction to suspend the seeds in the air stream for 30 second. Most of the suspended seeds were carried away and got collected in the collecting interceptor. Some heavier seeds fell in pan below the vertical transparent column after suspension and air velocity was measured directly using anemometer.

3.1.3.2 Drag coefficient

The drag coefficient was calculated from the weight, mass density of seed, projected area, terminal velocity of the seeds and mass density of air (1.293 kg m^{-3}) at standard temperature and pressure using the following equation given by Bilanski *et al*. (1962).

$$C_d = \frac{2W\,(\rho_p - \rho_a)}{V_t^2\,\mathrm{A}_\mathrm{p}\rho_p\rho_a} \qquad \ldots (3.3)$$

Where, C_d is drag coefficient; W is weight of seed (kg); ρ_p is mass density of particle (kg s^2 m^{-4}); ρ_a is mass density of air (kg s^2 m^{-4}); V_t is terminal velocity (m s^{-1}); A_p is projected area (m^2).

3.1a Measurment of linear dimesion of seed

3.1b Coefficient of friction measured on MS sheet

3.1c Coefficient of friction measurment between seeds

3.1d View of suspended seeds while mesuring terminal velocity

Plate 3.1 Measurement of seed properties by using different instruments

3.2 Design and development of pneumatic seed metering mechanism

The function of a seed metering mechanism is to pick up individual seed by vacuum and release it at the desired place in the field, irrespective of the forward speed of the planter. The pneumatic seed metering mechanism is intended to plant the seed with recommended seed spacing for each test crops. The seed metering unit was developed and tested under simulated conditions to optimize the structural and operational parameters of planter for cotton and okra seeds. The development and fabrication work of seed metering unit was carried out at farm machinery research workshop of Hayatnagar Research Farm, ICAR - Central Research Institute for Dryland Agriculture, Hyderabad. The components of newly designed and developed pneumatic seed metering unit mainly consists of a seed hopper, main shield with a seed rotor, drive shaft, vacuum chamber, removable steel cover and seed tube. The step wise development procedure of the seed metering unit was discussed with following subtitle.

3.2.1 Study of agronomic and machine operational parameters

To design any agricultural machinery and equipment, agronomic and machine operational parameter need to be studied thoroughly. The plant and machine parameters were taken into consideration from previous studies and recommendations. A proper consideration of these factors will allow the equipment to perform efficiently in the operation *viz.,* process, treatment and system as a whole. Keeping these points in view, the following factors were studied and considered for the design.

3.2.1.1 Agronomic factors

The performance of pneumatic seed planter depends on several parameters, hence they were identified and considered for the design. The recommended row to row and plant to plant spacing for both the selected crops will vary based on the several factors like soil, variety, agro-ecological zone and agronomic practices of the crop. In India, major portion of the cotton and okra growing area falls in medium to deep black cotton soils and red sandy loam of tropical and sub-tropical zone (Murlidhar *et al.,* 2010). The recommended row to row and plant to plant spacing for cotton were 60 - 120 and 30 - 60 cm, respectively at recommended seed rate of 3 to 4 kg h^{-1} for American varieties (Anon., 2005). Whereas, the seed rate for the okra crop for kharif cultivation was 8 to 12.5 kg h^{-1} with recommended plant to plant and row to row spacing of 60 × 30 or 45 × 30 cm (Anon., 2013).

3.2.1.2 Machine parameters

In pneumatic seed planter design, the machine parameters like forward speed and suction pressure in seed pickup device play a major role for uniform placement of seed to obtain optimum plant stand. The maximum forward speed of planter under Indian field condition was considered to be 3 km h^{-1} as recommended by Singh *et al.* (2005). However, the seed metering mechanism has to operate at its optimum level irrespective of the forward speed of the planter. So, the forward speed and suction pressure were optimized under simulated conditions in laboratory for designed pneumatic seed metering mechanism.

3.2.2 Conceptual design of pneumatic seed metering mechanism

In order to improve the planting performance or to overcome the drawbacks of the existing planters, a new seed metering mechanism was designed and developed. Due to advancement of the industrial sector, many new design techniques and materials have come into existence with an affordable price. Hence, an attempt was made to design a new pneumatic seed metering device which can overcome all the lacunas of existing mechanical planters.

The function of any planter is to pick up and drop a single seed without missing besides avoiding simultaneous multiple seed drop. A pneumatic seed metering mechanism works on the principle of pressure difference before the seed pickup point and seed drop position. The pressure difference may be a positive or negative one, which depends on the model designed and its requirement. Majority of the existing planters works under negative pressure difference which can be created by using a vacuum pump or an exhaust blower. By keeping this fundamental concept in view, a pneumatic seed metering mechanism design was conceptualized, whose description is given below.

The new seed metering mechanism consists of an air tight circular chamber of suitable size in which a roller type rotor with seed cells rotates. The roller width, cell spacing and size depend on the seeds to be tested. Provisions will be made on the cover plate of the chamber for seed to enter into the chamber at bottom portion and picked up seed collection at the top portion. A vent pipe fitted on the periphery of the chamber, when connected to an exhaust blower aid in creating sufficient vacuum in the seed cells to cling on. A small orifice provided at 90° to vent pipe induces positive pressure aiding the seed to be relived from cells and dropped into seed tube spout. The various forces acting on the seed while at pickup and drop positions in the mechanism are described in later sections of this chapter. The conceptual design isometric view is depicted in figure 3.2. The components of fabrication details of conceptualized pneumatic seed metering mechanism unit are described below.

3.2.2.1 Design and development of seed rotor

The axis of rotation of the seed rotor is perpendicular to the direction of travel. While in operation, it lifts the seed from reservoir and drop in to seed tube spout. The design requirement of seed rotor was considered for cotton and okra based on the previous studies and agronomist recommendations as follows.

Recommended seed to seed spacing in a row for cotton and okra (T_s) = 450 mm

Considered forward speed of the planter (F_s) = 3.0 km h^{-1}

Therefore, the number of seed cells in roller can be calculated using equation 3.4.

$$N_C = \frac{F_s \times 1000000}{60 \times R_s \times T_S} \qquad \ldots (3.4)$$

Where, N_c is number of cells; T_s is theoretical seed to seed spacing in row (mm); F_s is forward speed of planter (km h^{-1}); R_s is seed rotor speed (rpm).

$$N_c = \frac{3.0 \times 1000000}{60 \times 55 \times 450} = 2.02 \cong 2$$

Seed releasing frequency (*SRF*) is the number of seeds released from the metering unit in 1 s. At specific theoretical seed spacing, relationship between *SRF* and the forward speed is given by Ismett *et al*. (2012).

$$SRF = \frac{F_s}{T_s} \qquad \ldots (3.5)$$

$$SRF = \frac{0.834}{0.45} = 1.85 \sec$$

Where, F_s is forward speed of rotor (m s^{-1}); T_s is theoretical seed spacing (mm).

The diameter of seed rotor was given by below equation

$$D_r = \frac{F_s}{\pi n} \qquad \ldots (3.6)$$

$$= \frac{0.834 \times 60}{3.14 \times 55} = 0.29m = 29cm$$

Therefore, the designed diameter of the seed rotor is taken as 290 mm.

It acts as heart of the developed metering unit, made up of nylon material which is easily machinable, less in weight and free from corrosion. A solid cylindrical pipe was machined to fabricate the desired rotor housing structure as shown in figure 3.3. The seed rotor was made 300 mm in outer diameter and 70 mm in thick. One side face of solid cylinder was machined to develop hallow circular section of 290 mm diameter with 50 mm depth. The inner hollow circular section of rotor acts as mini seed reservoir and seeds stir according to the movement of the rotor when it was fixed in the main shield.

On circumference of the inner surface of the rotor, circular hole of 3 mm diameter were drilled which exposes to a vacuum. The vacuum chamber of 10 × 10 mm size slot was made on the outer periphery of seed rotor. The slot was made such that, it matches with the air suction outlet provided on the main shield frame of rotor and vacuum cut off. In order to reduce the contact area between rear shield and seed rotor a 3 mm step was provided on the rear side of the rotor which helps in free rotation by reducing the friction between the rear shield surface and the rotor. The rotor has a 50 mm solid knob at the center of the rotor, through which a 20 mm diameter power transmitting shaft was rigidly fixed to rotor.

The drive shaft was made from MS (45C8) cylindrical rod having a 20 mm diameter and 250 mm length. A 50 mm diameter and 5 mm thick circular hub was created at one end of the shaft, which fits over the seed rotor knob. Such an arrangement on a shaft can balance the load of rotor and helps to rotate in angular path. The shaft was supported with a pedestal bearing, which intern fixed at rear side of the main shield to rotate freely and transmits the drive to the seed rotor. On other side of shaft, a sprocket was fitted to get drive from main shaft.

3.2.2.2 Development of main shield chamber

The main shield frame is made out of mild steel sheet (F2), square in section of 350 × 350 × 5 mm size and a circular hole drilled at the center as shown in figure 3.4. A cylindrical hallow ring of 320 mm inner diameter and 70 mm width was rigidly welded on square plate such that, marked center is also the locus of center of the ring. On the circumference of cylindrical ring, two rectangular openings of 25 × 10 mm size were provided, which acts as negative pressure outlet and positive pressure inlet to the pressure chamber. At the center of the ring a 20 mm diameter hole was provided to fix the seed rotor drive shaft. This main shield helps to fix the metering unit on the planter; the cover plate provided to main shield keep the chamber air tight and other provisions made aid in allowing the seed in and out from chamber as required by the unit.

3.2.2.3 Removable shield cover

A removable cover of 350 × 350 × 5 mm was made up of MS (F2) sheet of square section (Fig. 3.5) and fitted over the main shield frame of the seed rotor through 8mm bolt and nut fasteners.

The removable cover was fitted to main shield in such a way that, the axis of rotor matches the center of the plate, so that seed inlet and out lets provided over the cover can occupy the annular space of the seed rotor. A 30 × 30 mm seed inlet opening was provided over cover plate at the bottom center of rotor to store small quantity of seed at bottom annular space of rotor and 30×40 mm seed outlet was provided at top center of rotor exactly below the vacuum cutoff device. The seed out let was an extended portion inside the seed rotor, where seed cell passes over this space, here in called seed delivery spout which was connected to boot of furrow opener through a flexible PVC pipe. A seed hopper was fixed to cover plate and hopper outlet was inserted into seed inlet spout provided over shield cover.

In order to optimize the design and operational parameters of pneumatic seed metering mechanism a three different size of vacuum of chamber and atmospheric openings of metering mechanisms models were developed similar design concept with different dimensions are presented in Table 3.1.

3.2.3 Design and development of seed hopper

The shape of the box was designed so as to retain the seed at the bottom of the seed box which facilitate easy flow of seeds from the hopper to seed metering mechanism. Individual hopper was designed for each seed metering unit. The bulk density of test crops (cotton and okra) varied from 480 to 590 kg m^{-3}. The seed hopper was designed by taking value of bulk density of 600 kg m^{-3}.

Table 3.1 Dimensions of developed pneumatic seed metering mechanism

Parameter	**SMM1**	**SMM2**	**SMM3**
Vacuum chamber size, mm	10 × 15	15 ×10	10 × 10
Width of annular space, mm	40	60	50
Atmospheric opening size, mm	10 × 15	15 × 10	10 × 20

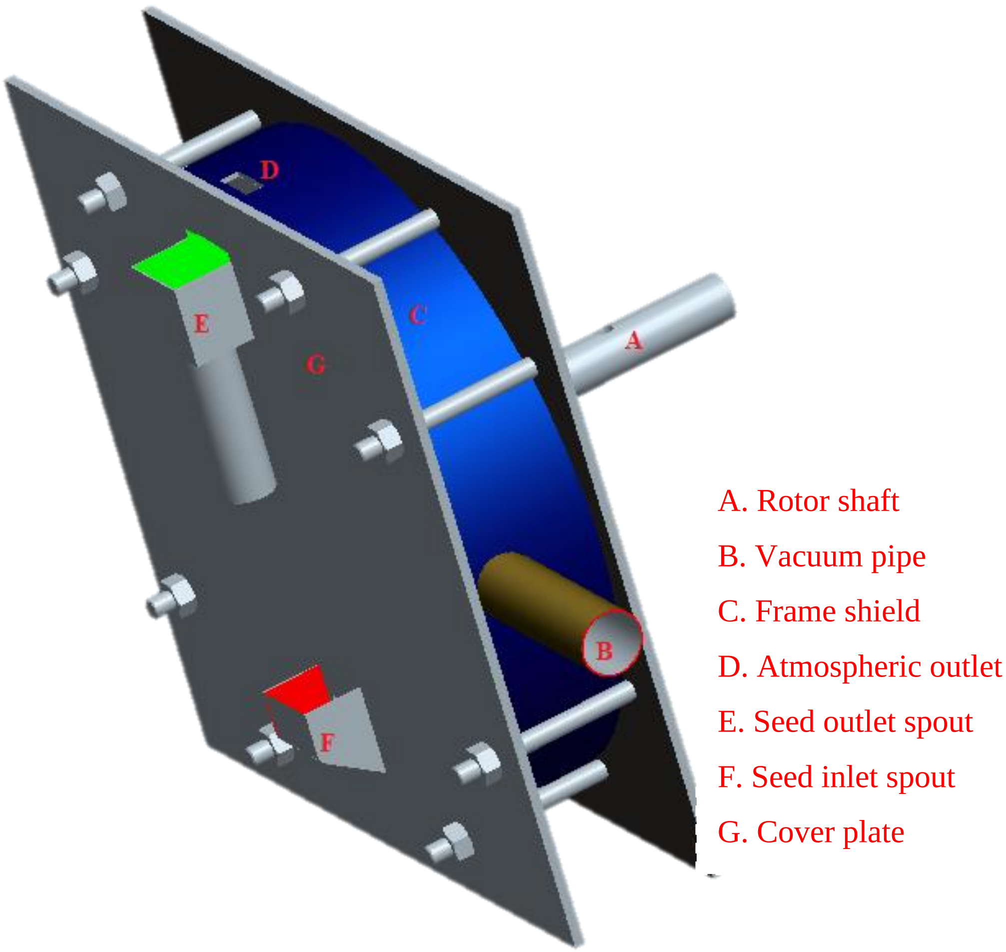


Fig. 3.2 Conceptual 3D model of pneumatic seed metering mechanism

The volume of hopper was calculated using equation.

$$V = \frac{Q}{\rho} \qquad \dots (3.7)$$

Where, ρ is bulk density of seeds (kg m^{-3}); Q is capacity of hopper (kg); V is volume of each seed hopper (m^3).

Considering each box contains maximum of 2.5 kg of seeds. Seed volume in each hopper

$$V = \frac{2.5}{600} = 0.04\,\mathrm{m}^3$$

Therefore, Number of seed hoppers on pneumatic seed planter is given by the equation 3.8.

$$n = \frac{V_t}{V} \qquad \dots (3.8)$$

Where, n is number of seed hoppers on the planter; V_t is total hopper capacity (m^3); V is volume of each seed hopper (m^3).

$$n = \frac{0.12}{0.04} = 3$$

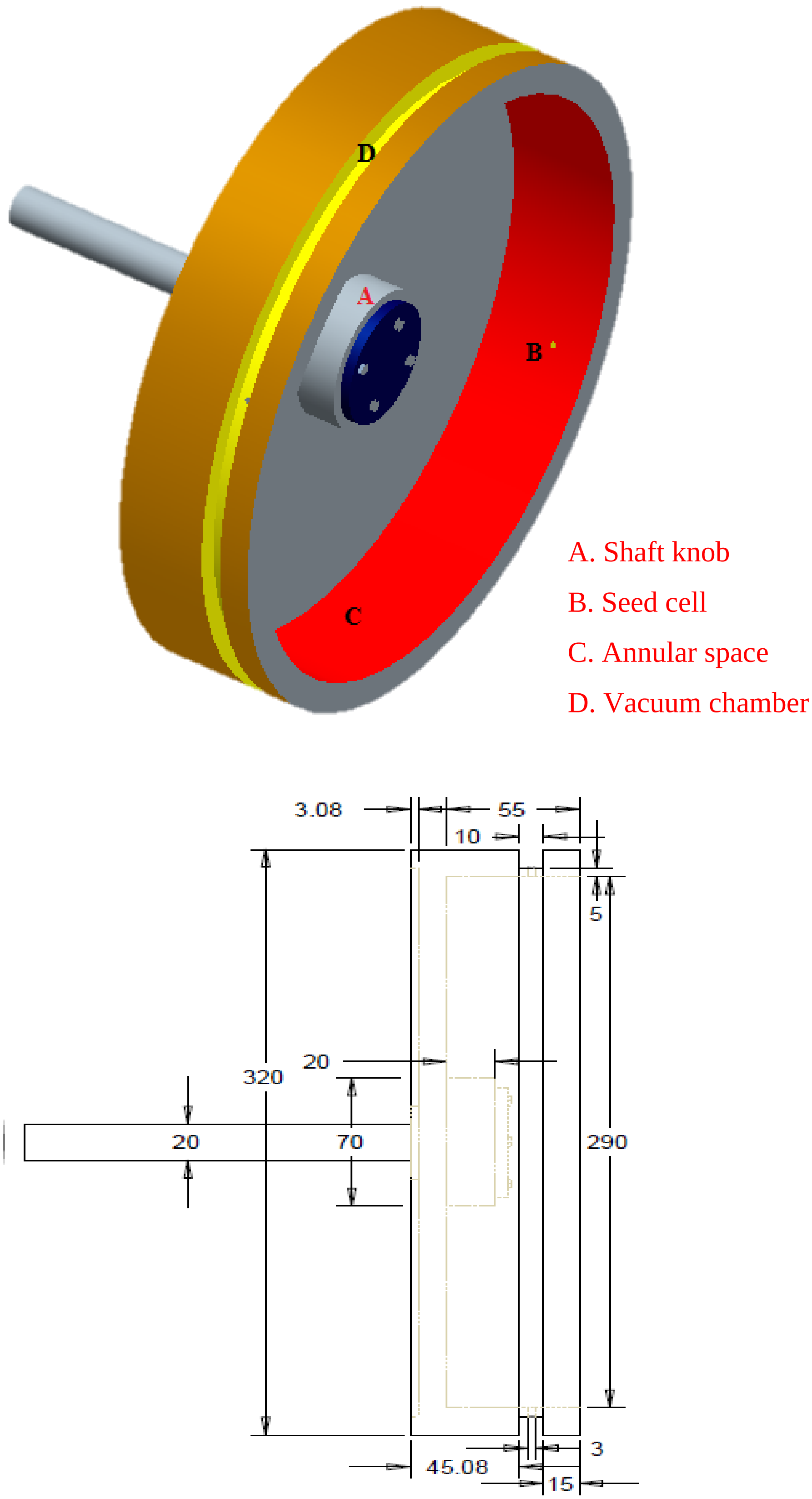


Fig. 3.3 Seed rotor 3D model and its line diagram (all dimensions are in mm)

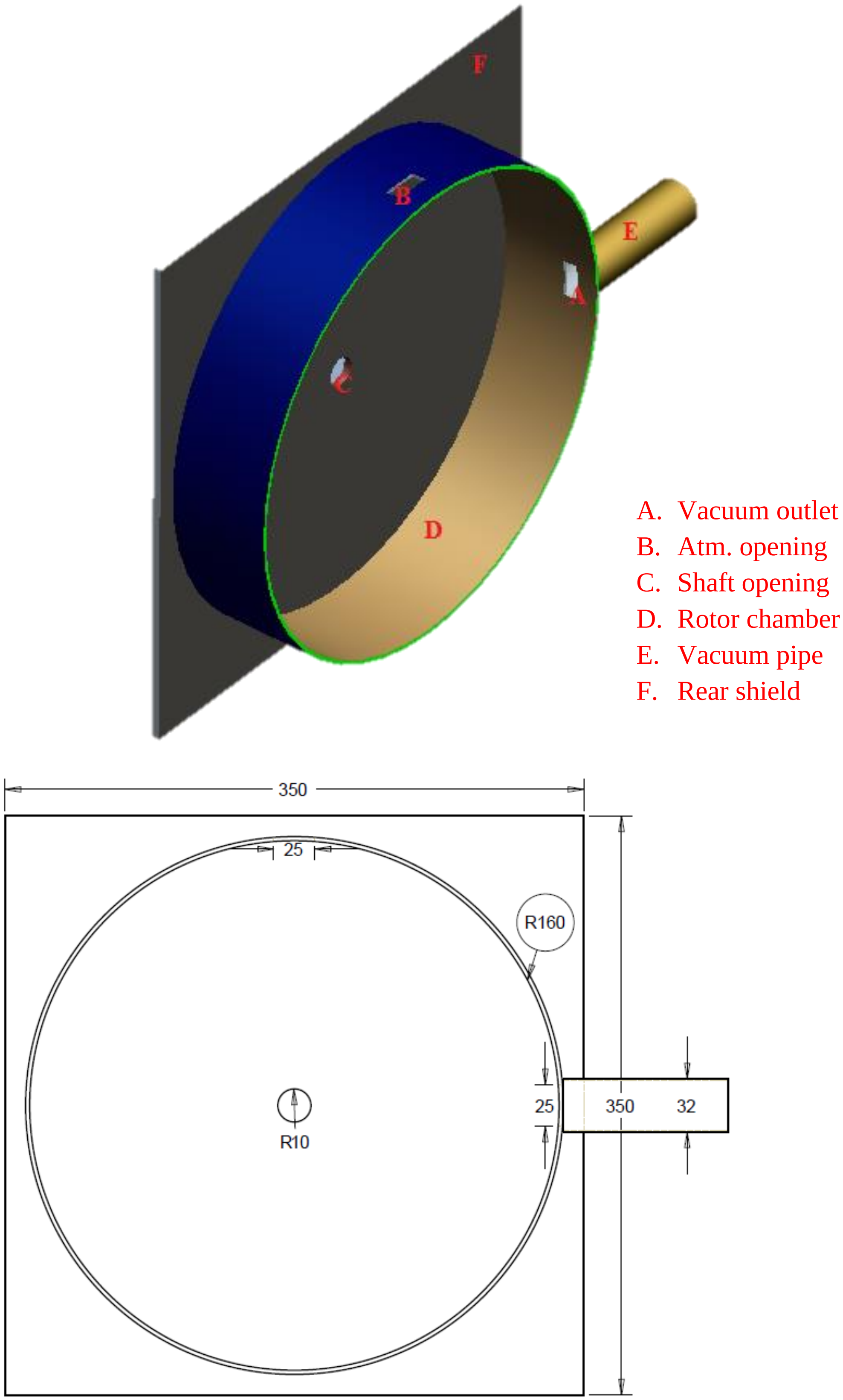


Fig. 3.4 Back cover 3D model and its line diagram (all dimensions are in mm)

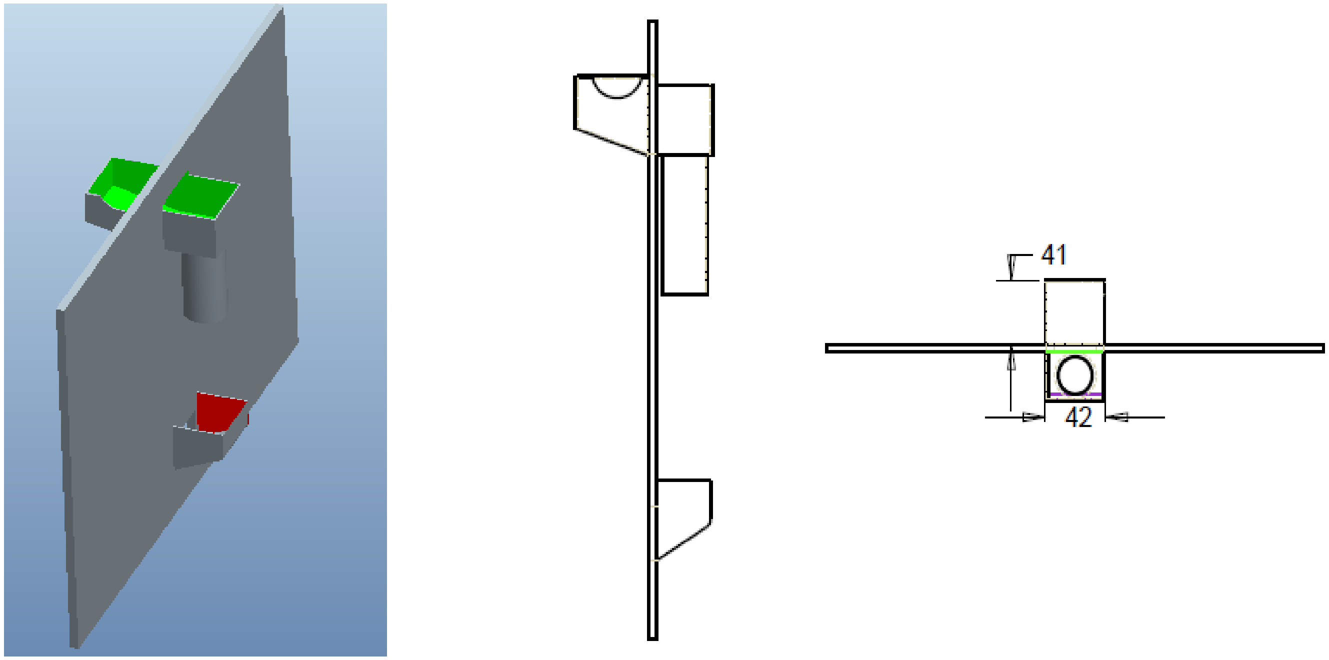


Fig. 3.5 Removable shield cover 3D model and its line diagram (Dimensions are in mm)

3.3 Testing and optimization of design and operational parameters under simulated conditions

Uniform seed spacing is important for majority of row crops, because plant spacing uniformity has been demonstrated to be significant factor in affecting agronomic practices as well as crop productivity. With uniform spacing, the root and shoot systems can grow to optimum level and fill the row space without overlapping.

3.3.1 Dynamic force analysis theory for developed seed metering mechanism

The seeds stir according to the rotation of the seed rotor and they were picked and transported by the seed cell provided on seed rotor. Under the influence of vacuum pressure chamber, a seed cell will pickup seed and held tightly against the rotor surface and due to rotor rotation it will be transported to rotor top. At the top, a seed cell exposes to the atmosphere pressure through cutoff provided over the main frame shield. The influence of negative pressure on rotating seed is more at pick up stage and transporting stage, so these two stages were analyzed.

3.3.1.1 Force analysis on seed during pick up process

The seed pickup stage using the device, various forces acting on a single seed are depicted in figure 3.6 and (*G*) can be denoted as gravity force due to seed weight, friction force caused by seed rotor (F_{fg}), normal force from seed plate (F_{Ng}), force of the negative pressure (F_Q) caused by sucking air out from chamber by blower and centrifugal force (F_c) possess by seed due to rotary motion. As for the analogy given by Yasir *et al.* (2013) in working of rotary type pneumatic device, the various forces act in equilibrium.

The summation of all the forces acting on the seed in X and Y direction are given below

$$\sum F_X = F_{fg} - G\sin\theta = 0 \qquad \text{… (3.9)}$$

$$\sum F_Y = F_{Ng} - G\cos\theta - F_Q - F_c = 0 \qquad \text{… (3.10)}$$

The relationship between friction forces F_{fg} and supporting normal force F_{Ng} can be given as

$$F_{fg} = F_{Ng}\tan\alpha_g \qquad \text{... (3.11)}$$

Where, α_g is the friction angle between the seed and seed rotor surface.

Substituting F_{fg} from equation 3.11 in equation 3.9.

$$\sum F_X = F_{Ng} \tan \alpha_g - G \sin\theta = 0 \qquad \text{… (3.12)}$$

$$\sum F_Y = F_{Ng} - G \cos\theta - F_Q - F_c = 0 \qquad \text{… (3.13)}$$

From equation 3.12, a relationship was derived

$$F_{Ng} = \frac{G \sin\theta}{\tan \alpha_g} \qquad \text{… (3.14)}$$

Substituting F_{Ng} from equation 3.14 in equation 3.13.

$$F_Q = G \frac{\sin\theta}{\tan \alpha_g} - G \cos\theta - F_c \qquad \text{… (3.15)}$$

The force of the negative pressure F_Q either to be greater than or equal to the forces to pick up seeds so,

$$F_Q \geq G \frac{\sin\theta}{\tan \alpha_g} - G \cos\theta - F_c \qquad \text{… (3.16)}$$

If

$$F_Q = G \frac{\cos\alpha_g \sin\theta}{\sin \alpha_g} - G \cos\theta - F_c \qquad \text{… (3.17)}$$

Thus,

$$F_Q = G \frac{\sin(\theta - \alpha_g)}{\sin \alpha_g} - F_c \qquad \text{… (3.18)}$$

Theoretical force required for seed pickup is given by

$$F_Q = C_d \, S \, \frac{\rho V_o^2}{2} \qquad \text{... (3.19)}$$

Where, C_d is drag coefficient; S is projected area (m^2); ρ is air density (kg m^{-3}); V_o is air velocity (m s^{-1}).

Air velocity required to pick and held the seed against the seed cell can be calculated from the following equation

$$V_0 = \frac{Q}{2\pi R^2} \qquad \text{… (3.20)}$$

$$S = \frac{\pi d_s^2}{4} \qquad \text{… (3.21)}$$

$$G = \frac{\pi \rho_s g d_s^3}{32} \qquad \text{… (3.22)}$$

$$\frac{C_d \rho Q^2}{\pi^2 \rho_s d R^4 g} \geq \frac{\cos(\theta - \alpha_g)}{\sin \alpha_g} - F_c \qquad \text{… (3.23)}$$

Where, α_g is friction angle between seed and seed rotor.

3.3.1.2 Force analysis on seed during transport stage

The summation of all the forces acting on the seed in X and Y direction are as given below as shown in figure 3.7.

Subjected to the condition, $0 < \beta \leq 90°$

$$\sum F_X = F_{fg} - G \sin \beta = 0 \qquad \text{… (3.24)}$$

$$\sum F_Y = F_{Ng} - G \cos \beta - F_Q - F_c = 0 \qquad \text{… (3.25)}$$

$$F_{fg} = F_{Ng} \tan \alpha_g \qquad \text{… (3.26)}$$

$$F_c = m \omega^2 R_c \qquad \text{… (3.27)}$$

Where, Fc is the centrifugal force. Thus, equation 3.25 becomes

$$F_{Ng} = \mathrm{G} \frac{\sin \beta}{\tan \alpha_g} \qquad \text{… (3.28)}$$

Substituting F_{Ng} in equation 3.25.

$$G \frac{\sin \beta}{\tan \alpha_g} - G \cos \beta - F_c = F_Q \qquad \text{… (3.29)}$$

$$\text{Put } F_c = \mathrm{m} \omega^2 R_c$$

$$F_Q \geq -m \omega^2 R_c + G \left(\frac{\sin \beta}{\tan \alpha_g} - \cos \beta \right) \qquad \text{… (3.30)}$$

Or

$$F_Q = -m \omega^2 R_c + G \left(\frac{\sin \beta \cos \alpha_g - \cos \beta \sin \alpha_g}{\sin \alpha_g} \right) \qquad \text{… (3.31)}$$

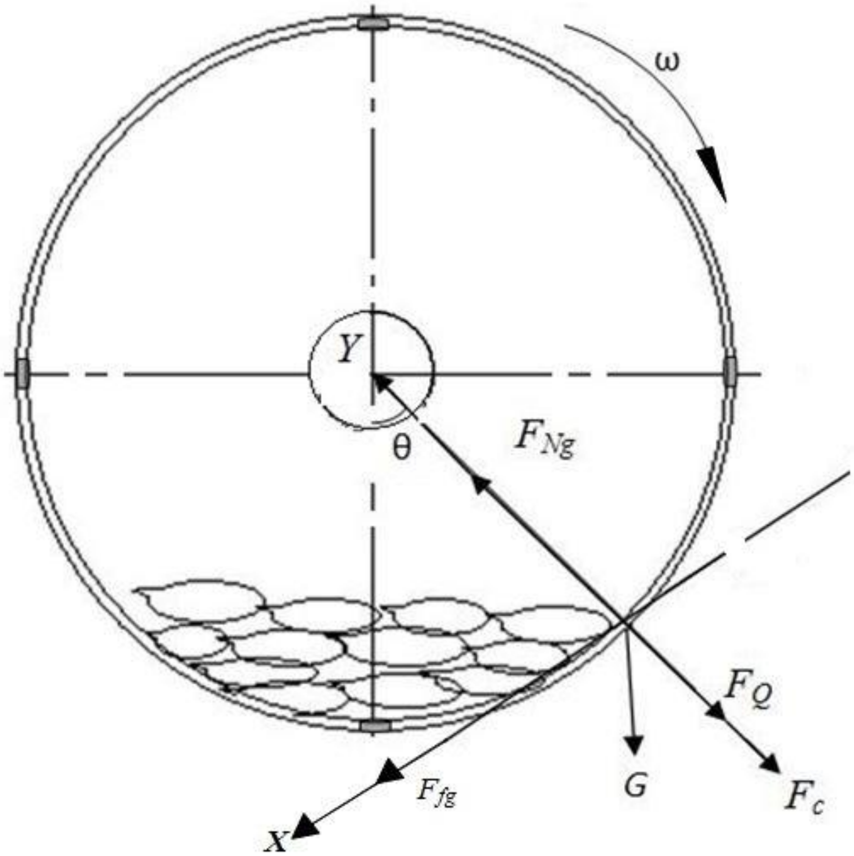


Fig. 3.6 Forces affects seeds during pick up stage

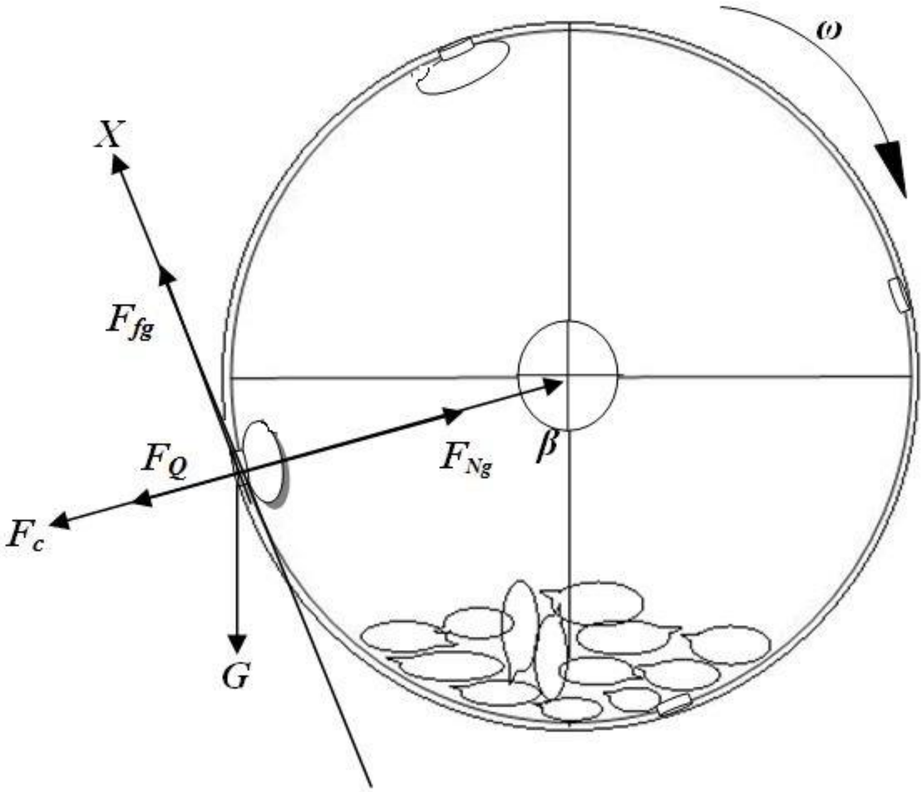


Fig. 3.7 Forces acts on seeds during transporting stage

Put $\beta = 90°$

$$F_Q = G\frac{\cos\alpha_g}{\sin\alpha_g} - m\omega^2 R_c = m\left(\frac{G}{\tan\alpha_g} - \omega^2 R_c\right) \qquad \ldots (3.32)$$

The force of the negative pressure can also be given by the following equation:

$$F_Q = PS = P\frac{\pi d_s^2}{4} \geq m\left(\frac{G}{\tan\alpha_g} - \omega^2 R_c\right) \qquad \ldots (3.33)$$

Where, $\tan\alpha_g$ is the friction index for the friction force F_{fg}.

This indicates that, as the seed picked up and while in transport with the seed rotor, it was influenced by many factors such as cell diameter (d), mass of the kernel (m), the rotational speed of rotor (ω), the radius of the seed rotor (R_c), the negative pressure (P) and the friction index $\tan\alpha_g$.

3.3.1.3 Force analysis on seed during release process

In this stage, the force of gravity (G) and centrifugal force influence more than the force of negative pressure (Fig. 3.8). Due to decreased negative air pressure and self-weight of seed the force of gravity may increase which helps in releasing seed from seed cell and drops in to seed outlet spout. In this design, during seed releasing process if the force of negative air pressure was higher than the self-weight of seed and force of gravity than the seed may not be released from seed cell which may leads to increased miss index and directly influences on the performance of seed metering unit.

3.3.2 Testing of newly developed pneumatic seed metering mechanism

The newly designed and developed pneumatic metering unit was tested for the selected cotton and okra seeds under the simulated conditions. Before developing a field level prototype of pneumatic planter, the design and operational parameters of pneumatic planter were optimized by fixing the levels of different influencing variables in order to analyze the performance of designed pneumatic seed metering unit. It was tested by adopting two methods namely grease belt method and machine vision technique and compared both methods to optimize the design and operational parameters of the pneumatic metering unit for cotton and okra seeds. The parameters optimization methods were discussed in detail below.

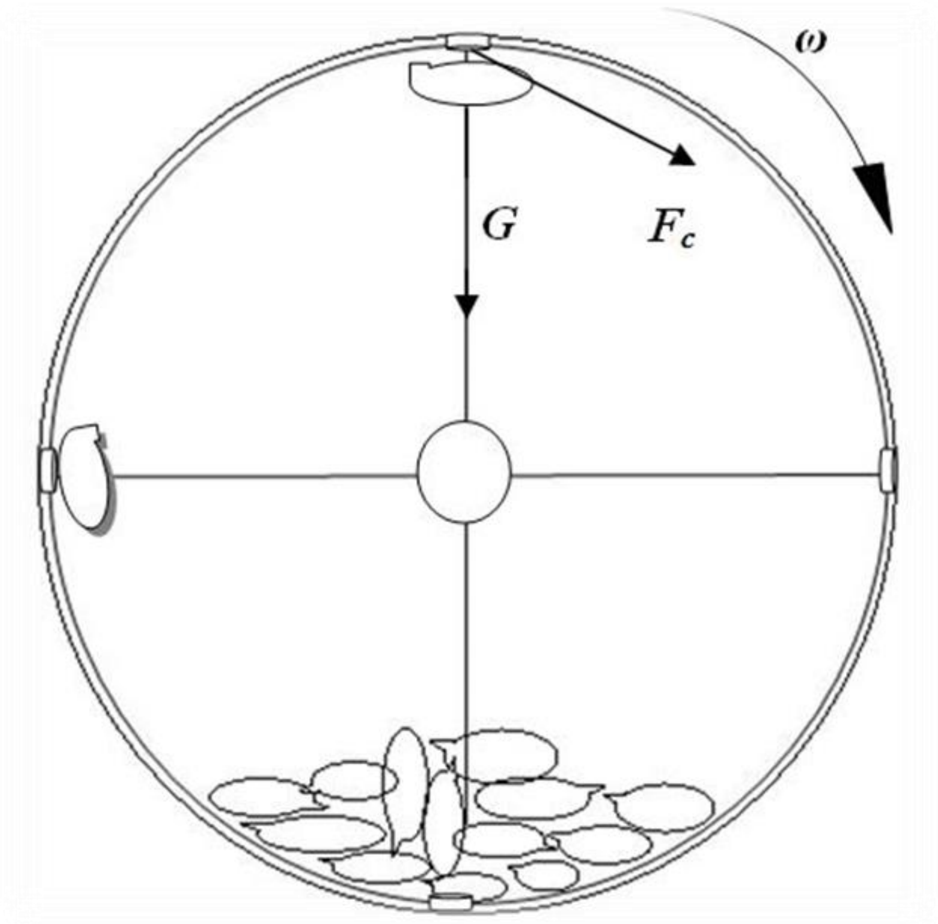


Fig. 3.8 Forces affects seed during seed release process

3.3.2.1 Selection of independent variables

The performance of pneumatic seed metering unit is influenced by several factors as explained in dynamic analysis, but the major factors like air pressure, forward speed and cell diameter were considered as independent variables in this study. The lower and upper levels for each of the variables are fixed as follows within the boundary conditions.

The lower level of air pressure was chosen above the terminal velocity value of the selected seeds when the particular type of seed begins to get conveyed. To arrive at optimum vacuum air pressure of a precision vacuum seeder, a mathematical model was developed by Karayel *et al*. (2004) by using physical properties of seeds. The predicted vacuum pressure values by the models were 3 k Pa for cotton seeds. In another study Singh *et al*. (2005) determined the required minimum pressure difference empirically for holding a seed of 5.3 mm geometric mean diameter and 0.113 g mass would be 0.49 k Pa. In the present study, the seed holding pressures were determined empirically for selected seeds and values ranged from 2 to 3 k Pa. Hence, the levels of air velocity were set with middle value of 2.5 k Pa and upper and lower value were fixed at an interval of 0.5 k Pa and computed through central composite design (Rotatable k<6) of RSM design as presented in Table 3.2.

The seed spacing and seed rate requirements of cotton and okra seeds were discussed in section 3.2.1. The metering mechanism was operated at five different peripheral speeds of seed rotor. These were 0.59, 0.69, 0.83, 0.97 and 1.069 m s^{-1}. The centre point of 0.83 m s^{-1} of peripheral speed of the seed rotor corresponds to 3 km h^{-1} forward travel speed of the planter. The normal sowing speed with mechanical seed metering device is in the range of 1.5 to 2.5 km h^{-1} (Singh *et al*., 2005), but an air seed planter may have to cater the higher forward operating speed and hence, the levels were extended up to 3.5 km h^{-1}. The levels of forward speeds in the study were computed through central composite design (Rotatable k < 6) of RSM design as presented in Table 3.2.

The seed picking and conveying efficiency of pneumatic seed planting unit depends on cell shape and size, which directly influences the planter performance. The shape of the cell usually depends on shape of the seed, however a circular shape cell was reported to be the best compared to other shapes for seed holding and gave the best uniformity of seed distribution for different seed shapes (Zeliha and Aziz, 2004). The diameter of the cell may also directly influence the negative pressure. Hence, diameter of cell was considered as one of the variable parameter in this study. The cell diameter was determined based on the ≤ 50 per cent size of the geometric mean diameter of the selected seeds. To prevent the seed entry deep in to the cell, exact diameter was provided at pickup point, which completely closed with the seed to avoid multiple seeds accommodation and the cell diameter at the suction side was twice the pickup side in order to provide the sufficient pressure to pick the seed. The middle value of cell diameter for cotton was 3 mm whereas 2.5 for okra seeds. Based on the middle value, the upper and lower values for both the seeds were set at 0.5 interval and the five levels were computed through central composite design (Rotatable K < 6) of RSM design as presented in Table 3.2. To maintain desired accuracy of cell diameter, the holes were drilled on the CNC machine.

3.3.3 Optimization of design and operational parameters using RSM

Considering the experimental needs of the newly developed pneumatic seed metering unit, an experiment was designed using mathematical and statistical technique called response surface methodology (RSM) to optimize design and operational parameters as discussed above *i.e.* cell diameter, forward speed and vacuum pressure under simulated conditions.

The RSM designs are not primarily used for understanding the mechanism of the underlying system and assessing treatment main effects and interactions, but to determine within some limits the optimum operating conditions of a system (Myers, 1971). It is very laborious and time consuming to go in for the conventional way of one variable at a time experimentation approach and use statistical analysis designs. The RSM is an effective technique for optimizing complex processes, since it reduces the number of experiments needed to evaluate multiple parameters and their interactions (Lee *et al*., 2006).

The response surface problem usually center on an interest in some response Y, which is a function of k independent variables. In this particular case forward speeds (S), air pressure (*P*) and cell diameter (*D*), that is,

$$Y = f\left(S, P, D\right) \qquad \dots (3.34)$$

And response surface can take the different forms according to the function types of response and usually response function is defined in the quadratic polynomial form as follows

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum \beta_{\mathrm{ii}} X_i^2 + \overset{k}{\underset{i=1}{\sum_{\mathrm{i}}\sum_{j}}} \beta_{ij} X_i X_j + \varepsilon, \qquad i \le j, \qquad \textbf{… (3.35)}$$

Table 3.2 Actual and coded levels of independent variables used in developing response functions

Variables	**Unit**	**Cotton**					**Okra**				
		-1.68 (-α)	-1	0	1	1.68 (α)	-1.68 (-α)	-1	0	1	1.68 (α)
Vacuum pressure (P)	k Pa	1.65 (P_1)	2.0 (P_2)	2.5 (P_3)	3.0 (P_4)	3.34 (P_5)	1.65 (P_1)	2.0 (P_2)	2.5 (P_3)	3.0 (P_4)	3.34 (P_5)
Rotor velocity (V)	rpm	0.59 (S_1)	0.69 (S_2)	0.83 (S_3)	0.97 (S_4)	1.07 (S_5)	0.59 (S_1)	0.69 (S_2)	0.83 (S_3)	0.97 (S_4)	1.07 (S_5)
Cell diameter (D)	mm	2.14 (D_1)	2.5 (D_2)	3.0 (D_3)	3.5 (D_4)	3.84 (D_5)	1.65 (D_1)	2 (D_2)	2.5 (D_3)	3 (D_4)	3.34 (D_5)

Where, Y is the response; β_0 is the intercept β_i, β_{ii}, β_{ij} are the regression coefficients; X_i X_j are the coded variables and ε is the error.

The coding of independent variable into X_i is expressed by the following equation

$$X_i = \frac{S_i - S^*}{S_v} \quad \text{… (3.36)}$$

Where, S_i is the actual value in original units, S^* is the mean value (center point) and S_v is the step value.

The determination of center point for each independent variable was based on field conditions and the physical properties of the selected seeds used, since for the design of such experiments special care has to be given for the selection of center point as explained in section 3.3.2.1, as well as the minimum and maximum levels of the independent variables were to be calculated. The design used in this study is a rotatable central composite design (CCD), which requires minimum five levels for each independent variable. A second order model can be constructed efficiently with CCD (Arzu, 2007). The CCD first order (2^N) designs augmented by additional center and axial points to allow estimation of the tuning parameters of a second order model. These levels were coded, respectively.

Each operating condition was established carefully and the vacuum level was measured using a manometer. Each test was replicated three times. The performance data were then transferred into a design expert statistical package program for further analysis.

All the replications were used for the development of response surface functions. The response surface functions were developed for each performance criteria. The functions developed were defined as full quadratic polynomials in design expert, a statistical package program and stepwise procedure used for the selection of variables as they enter the model in linear, interaction and quadratic form.

The newly developed seed metering mechanism was then tested for treatment combinations (run) designed by RSM given in Table 3.4. Some additional validation tests were also made at different operating conditions for further verification of the model. In addition to normal way of interpretation of data, an ISO standard methodology as described by Katchman and Smith (1995) planter performance parameters also interpreted in terms of derived parameters namely quality feed index, miss index, multiple index and precision index as dependent variables.

Table.3.3 Speed of seed metering rotor and drive roller with respect to forward speed

Forward speed (km h^{-1})	Seed rotor velocity (m s^{-1})	Belt drive roller speed (rpm)
2.15	0.59	103
2.5	0.69	120
3.0	0.83	144
3.5	0.97	169
3.85	1.06	186

The mean comparison results were analysed to arrive at the best treatment combinations, which yielded the recommended seed spacing through analysis of performance indices. This was carried out for all the three selected varieties of cotton and okra seeds. The best performing treatment combination was considered for the design of the field prototype model of planter.

3.3.4 Development and fabrication of test rig

Earlier researchers used variety of measures to quantify planter performance with regard to seed spacing, among them grease belt test is most followed one. An experimental test rig has been developed to examine the performance of the designed pneumatic seed metering mechanism as explained in sections 3.3. Lan *et al*. (1999) evaluated the seed metering mechanism at different operating conditions using a test simulator fitted with instruments under the controlled condition. The optimization of operational parameters was also possible by simulating the seed metering mechanism with test rig, which saves cost and time. Keeping above facts in mind, a controlled simulator was developed to evaluate the performance of seed metering unit at various speeds and pressures for selected crop seeds.

The test rig consists of a rectangular frame of 400 × 60 cm made of 35 × 35 × 5 mm MS angles (Fig. 3.9). Eight legs of 60 cm length welded to the frame to give stability and proper ground clearance to note the observation. Two rollers of 41 cm length and 11 cm diameter is fabricated and fitted over the frame using pedestal bearing at 280 cm apart to run the endless belt. The distance between the two rollers is adjustable in 25 mm increments to tighten the belt when required. The drive transmission from the motor to the drive roller of endless belt is through sprocket and chain at speed ratio of 1:1. A five hp motor was fitted with a speed reduction gear box to the drive roller. To fit different seed planter metering mechanism boxes for testing, a 90 cm height and 60 cm rectangular frame made of 35 × 35 × 5 mm MS angles was fabricated and welded near the drive roller. A Two hp electric motor fitted with speed reducer will drive the seed metering mechanism as shown in Plate 3.2. The drive transmission of seed metering mechanism is provided through chain and sprocket with 1:1 ratio. To obtain different belt speeds and seed metering mechanism a variable speed step up AC motor is used and fitted in a single control panel for both the motors.

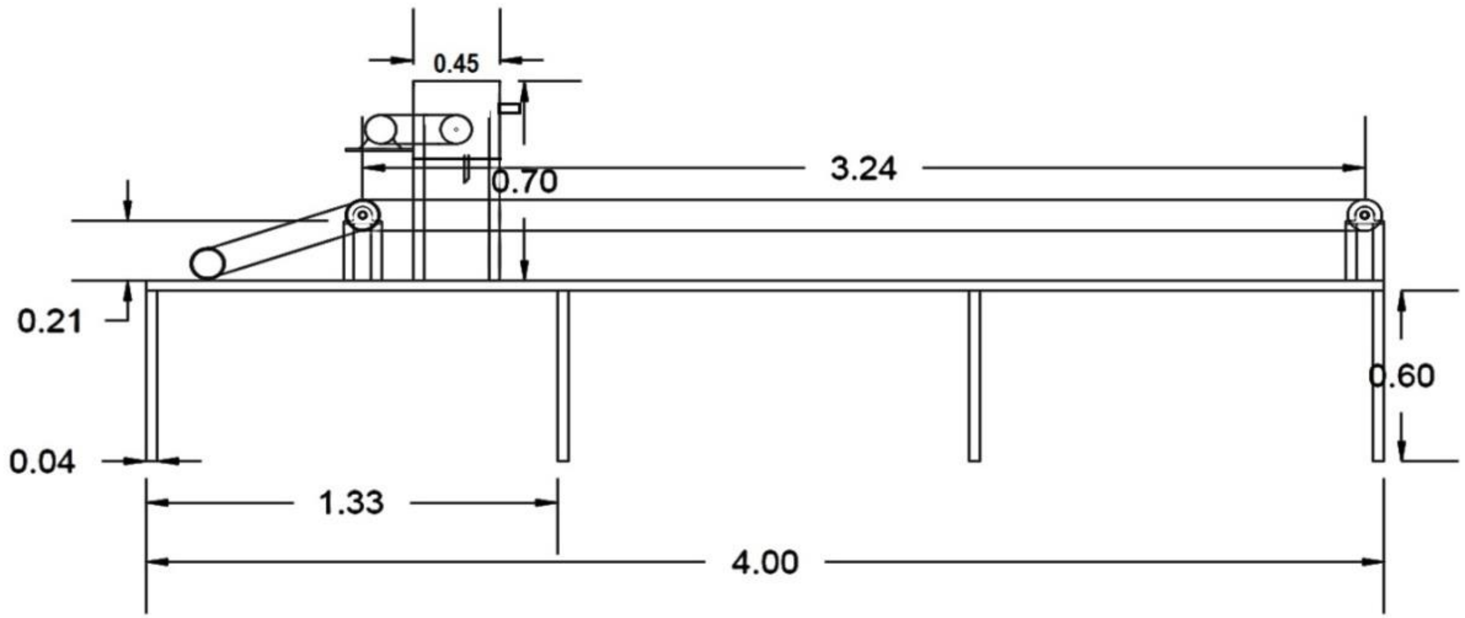


Fig. 3.9 Side view of sticky belt test rig (all dimensions are in meter)

The variable speeds are obtained by variable frequency drive regulator, which in-turn changes the in-put voltage to the motors. The drive can be used both in position and remote position, for which two independent remote points were provided for each motor. Another advantage in this particular drive is, it could also be operated in reverse direction, to clear any jam while in operation. Two in built revolution counters with digital read out greatly help to regulate the shaft out-put rpm with 98 per cent accuracy**.** A specially fabricated 2.5 mm thick poly vinyl chloride impregnated with nylon material non expandable single side grip flexible endless belt was used for the test rig**.**

Suction pressure inside the metering unit was created by using aspirator blower. A suction pipe having inside diameter of 25 mm was connected to suction outlet of the seed metering unit. The blower was operated by a five hp electric motor which was fixed over the separate frame beside the test rig. The variations in pressure were obtained by altering the impeller speed of blower through changing the speed ratios between blower and electric motor. The vacuum pressure is measured at the vacuum outlet of the seed metering device using digital differential manometer (Latron PM - 9100). The air pressure is adjusted by adjusting flow control valve provided at the outlet of the seed metering unit.

3.3.5 Laboratory evaluation of developed seed metering mechanism

The seed metering mechanism was rigidly fixed over the test rig frame (Plate 3.2) and drive was arranged through chain and sprocket from electric step up motor where a provision was made to set the drive RPM. The speed of belt and rotor were directly controlled by changing the voltage supply to the motor and for easy setting of speeds, a speed ratio 1:1 was selected between the motor and drive units. The pressure in the seed metering unit was set by adjusting the impeller speed and valve provided over the metering unit outlet. The hopper was filled with graded seeds and seed outlet is kept open just to allow seeds in regulated manner from hopper to the seed metering mechanism. To test the developed seed metering unit, the belt and rotor RPM were calculated with respect to predefined variables using standard procedure. The drive speeds calculated to run the test rig and seed metering mechanism are presented in Table 3.3.

Plate 3.2 Arrangement of drive for testing of seed metering mechanism on test rig

Before starting the experiment, the belt was smeared with grease to secure the seed to the belt surface, which prevents rolling and bouncing of seed. The entire set up was allowed to run for five minutes in each run to set the pressure and speed of rotor. Air pressure was stabilized by setting the pressure inlet valve and measured at vacuum chamber outlet of seed metering unit as shown in Plate 3.3.

The experiments were conducted with CCD variable parameters combinations given in Table 3.4. The tests were replicated three times for each variety of seed and spacing of 30 seeds with misses and multiples were measured on the greased belt. The data were analyzed to determine the effect of cell diameter, air pressure and forward speed on performance indices, namely, mean seed spacing, miss index, multiple index, quality feed index and precision in spacing.

The International Organization for Standardization (ISO) defined a number of measures based on the theoretical spacing set for a planter. These measures include the multiple index, miss index, quality of feed index and precision index were considered as a dependent variables in this study. The theoretical spacing is not a statistic as much as it is a parameter. The theoretical spacing is the distance between seedlings, assuming that there were no skips, multiples or variability and is based on design specification. It will typically be equal to the mode of the distribution of spacing's (Katchman and Smith, 1995).

In this analysis, a set theoretical spacing forms the basis for calculation of the quality of feed index, multiples index, miss index and precision index. The theoretical spacing is taken as basis to divide the observed spacing into several regions.

3.3.5.1 Miss index

Miss index (I_{miss}) is the percentage of spacing greater than 1.5 times the theoretical spacing.

$$M_{miss} = \frac{n_2}{N} \qquad \dots (3.37)$$

Where: n_2 is number of spacing > 1.5S.

These skips could be due to a number of factors including the failure of the planter to drop a seed or the failure of the seed to germinate or produce a seedling.

Table 3.4 Central composite design (CCD) treatment combinations with uncoded (coded) independent variables.

Cotton				Okra			
Run	***P* (k Pa)**	***V* (m s^{-1})**	***D* (mm)**	**Run**	***P* (k Pa)**	***V* (m s^{-1})**	***D* (mm)**
1	2.50(0)	0.83(0)	3.00(0)	1	2.50(0)	0.83(0)	2.50(0)
2	2.50 (0)	0.83(0)	3.84(1.68)	2	2.50(0)	0.83(0)	2.50(0)
3	3.34(1.68)	0.83(0)	3.00(0)	3	2.00(-1)	0.97(1)	3.00(1)
4	3.00(1)	0.69(-1)	3.50(1)	4	3.00(1)	0.97(1)	3.00(1)
5	2.50(0)	0.83(0)	3.00(0)	5	3.34(1.68)	0.83(0)	2.50(0)
6	2.50(0)	1.07(1.68)	3.00(0)	6	2.50(0)	0.83(0)	2.50(0)
7	2.00(-1)	0.69(-1)	3.50(0)	7	2.50(0)	0.83(0)	2.50(0)
8	2.50(0)	0.83(0)	3.00(0)	8	2.50(0)	0.59(-1.68)	2.50(0)
9	2.50(0)	0.83(0)	3.00(0)	9	3.00(1)	0.69(-1)	3.00(1)
10	3.00(1)	0.97(1)	2.50(-1)	10	2.50(0)	1.07(1.68)	2.50(0)
11	2.00(-1)	0.97(1)	2.50(-1)	11	2.50(0)	0.83(0)	1.66(-1.6)
12	2.50(0)	0.83(0)	3.00(0)	12	2.00(-1)	0.97(1)	2.00(-1)
13	2.50(0)	0.59(-1.68)	3.00(0)	13	3.00(1)	0.97(1)	2.00(-1)
14	2.50(0)	0.83(0)	2.16(-1.6)	14	2.50(0)	0.83(0)	2.50(0)
15	2.00(-1)	0.69(-1)	2.50(-1)	15	2.00(-1)	0.69(-1)	2.00(-1)
16	1.66(-1.68)	0.83(0)	3.00(0)	16	2.50(0)	0.83(0)	2.50(0)
17	3.00(1)	0.69(-1)	2.50(-1)	17	2.50(0)	0.83(0)	3.34(1.68)
18	3.00(1)	0.97(1)	3.50(1)	18	2.00(-1)	0.69(-1)	3.00(1)
19	2.50(0)	0.83(0)	3.00(0)	19	1.66(-1.68)	0.83(0)	2.50(0)
20	2.00(-1)	0.97(1)	3.50	20	3.00(1)	0.69(-1)	2.00(-1)

Plate 3.3 Vacuum pressure measurement by using digital manometer

3.3.5.2 Multiple index

Multiple index (I_{mult}) is the percentage of spacing that are less than or equal to half of the theoretical spacing (S).

$$M_{mult} = \frac{n_1}{N} \quad \text{… (3.38)}$$

Where,

n_1 is number of spacing $\leq 0.5S$, N is total number of measured spacing.

3.3.5.3 Quality feed index

Quality of Feed Index (I_q) is the percentage of spacing that are more than half but not more than 1.5 times the theoretical spacing. The quality of feed index is a measure of how often the spacing was close to the theoretical spacing. There are a number of possible causes for a low quality of feed index including a large number of multiples or misses and a large amount of variability around the drop site. Given that the quality of feed index is 100 per cent minus the miss and multiples indices, the quality of feed index is simply an alternative way of presenting the information contained in the other two indices.

$$I_q = 100 - (I_{miss} - I_{mult}) \quad \textbf{… (3.39)}$$

3.3.5.4 Precision index

Precision index (I_p) is a measure of the variability in spacing between plants after accounting for variability in spacing plants after accounting for variability due to both multiples and skips. The precision is the coefficient of variation of the spacing that is classified as singles. The precision differs from the usual coefficient of variation in that; it uses the theoretical spacing as the denominator in place of the sample mean. While the definition of precision is stated differently by the International Organization for Standardization (1984), both definitions are equivalent.

$$I_p = \frac{S_d}{S} \quad \text{… (3.40)}$$

Where, S_d is standard deviation of the spacing more than half but not more than 1.5 times the set spacing S in mm.

Unlike the sample standard deviation, precision is not affected by outliers. Because, the calculation of precision does not take into account any spacing outside the target range, it will only measure the degradation of performance within the target range.

The theoretical upper limit for precision is 50 per cent. The upper limit of 50 per cent occurs when half the spacing are at the lower limit of the target range. A practical upper limit on the value of precision is 29 per cent. A precision of 29 per cent would be indicated of all the spacing being spread uniformly within the target range. While there is a theoretical upper limit of 50 per cent on precision, values consistently greater than 29 per cent should be viewed with suspicion (Katchman and Smith, 1995). It is important not only to look at the numbers obtained, but to examine the distribution of spacing to make sure our interpretations make sense.

3.3.5.5 Seed breakage

The breakage of seeds was calculated using the formula (Kepner *et al.,* 1987).

$$B_s = \frac{\mathrm{W}_2}{\mathrm{W}_1} \times 100 \qquad \text{… (3.41)}$$

Where, B_s is breakage of seeds (%); W_1 is total weight of seeds collected (g); W_2 is weight of broken seeds (g).

3.4 Simulation of vacuum pressure using ANSYS FLUENT software

It is important and necessary to optimize the negative and positive pressures on the newly designed metering device. The seed pick up, transport and release, completely depends on the influence of the pressure in the vacuum chamber, hence the simulation of air pressure is found necessary to optimize the design and operational parameters of the developed pneumatic planter. The required pressures may change to obtain set seed spacing in tune with the change in machine forward speed or in other terms with the rotor speed and real field condition, which directly reduces the planter performance. It is beneficial to maintain required pressures for the performance of the metering system in the planter and optimize the structural parameters of pneumatic metering device. It is difficult to measure air velocity and corresponding pressure at the seed pickup and drop positions in the chamber to validate the theoretical concepts described in section 3.3.1. So, the computational fluid dynamics (CFD) model (ICEM) was used and analyzed using ANSYS to simulate the air velocity and pressure at seed cell. The assumptions made to simplify the fluid model during the simulation are,

i. The temperature of air considered to be constant at 35℃

ii. The seed rotor and main shield frame contact tightly without any air leakage

iii. A cut off device is considered to completely close the vacuum chamber

3.4.1 Development of model geometry using ICEM-CFD of ANSYS

The fluid surface model of the seed metering unit was built according to the structural parameters with designed dimension in ProE WildFire Version 5 and converted to the STEP format. The model .stp file was imported in the ICEM and the necessary modification was carried in the geometry section as shown in figure 3.10.

A body of volume was created in vacuum chamber, where air flow takes place. The tetrahedral mesh (Fig. 3.11) was created in the model using mesh function and the output file was written in .msh format using ANSYS fluent solver.

3.4.2 Simulation using fluent solver

The MSH file written in ICEM CFD was read by fluent and scale and units of the parameter were set in general section of solution setup. The model was defined as viscous k-epsilon equation of turbulence model of solver. The material is defined as air in solution setup with density of 1.225 kg m^{-3}. In cell zone condition, angular velocity was assigned to the air body by specifying the center of the geometry, direction of rotation and speed of rotation (rpm). The boundary conditions for cutoff and seed space were defined as the inlet vent with an atmospheric pressure and vacuum outlet as pressure outlet with specified negative pressure value. The other components are defined as wall and direction is given to rotor and seed cell as moving wall.

In solution section, the solution methods and solution controls were defined and hybrid initialization was done. The run calculation of solver was started by defining the number of iterations as 1000 and reporting interval as one. The convergence of continuity curve was observed and iterations were stopped. An iso-surface was created on the center plane and viewed the results of pressure and velocity contours and vectors and the reports were generated.

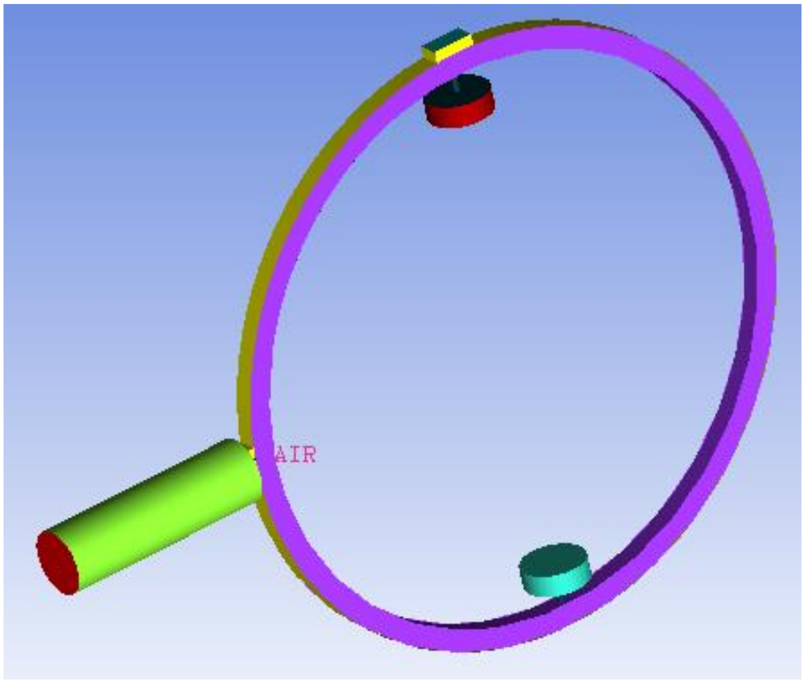


Fig. 3.10: Fluid model geometry of vacuum chamber

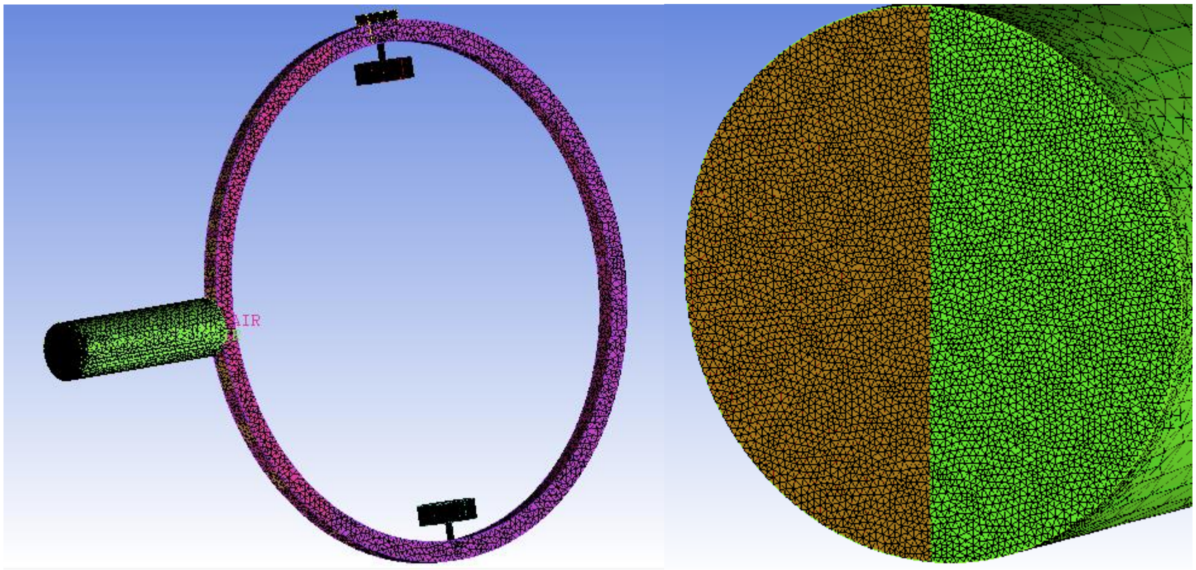


Fig. 3.11: Tetrahedral mesh of fluid model and its mesh intensity

3.5 Computer vision system for measuring seed spacing

The most common method for testing planters in the lab is the grease belt method which needs a setup and manual labour for measuring seed space. So, many researchers attempted alternate evaluation techniques using electronic sensor and other instruments. Opto-electronic sensors have been used at least from last 15 years for measuring the spacing distribution of seeds, instead of the adhesive belt. Most of the systems reported in literature are based on light emitting diodes and photo-detectors in order to create a photoelectric sensing system that senses the seeds as they pass through seed tube (Lan *et al*., 1999; Kocher *et al*., 1998). The main limiting factors in these systems are, that they cannot be used for small sized seeds due to their poor spatial resolution (4 mm or more) and inability to reliably sense multiple seeds when they are in the same line. In addition to that, the measurement is based only on sensing seed presence and it lack capability of determining the seed's geometrical features like area, center *etc*. In a recent works, scientists using kinetic image processing technique to measure seed distribution (Hu *et al*., 2000). Hence, in the present study an attempt was made to develop an alternate technique of evaluation using computer vision system and demonstrated how the obtained data can be used to evaluate the planter's performance. The details of methodology adopted, hardware and software used for the vision based planter evaluation is discussed in detail under following sub headings.

3.5.1 Computer vision setup

The vision system was developed using semi-professional digital camera (Nikon D70) which was installed at one m ahead of the planter and above the belt (Fig. 3.12). The settings were made in the camera to capture the region of interest (ROI). In order to avoid lighting effect during video clips acquisition, a uniform illumination was provided by infrared lamp. Cotton and okra seeds of natural colour were used during experiments with white background for clear detection of seeds. A video of two min duration was captured during each test run experiment in the lab. The test rig experimental procedure was already discussed in section 3.4. For each replication, the planter was started and allowed to run for three minutes until it reached to its steady state condition and there after video acquisition was started. The captured images were transferred to personal computer and processed using MATLAB software using computer vision and image analysis tools. Simultaneously seed spacing was measured over the grease belt and compared with values of video analysis technique. Detailed description of video processing for seed detection, tracking and spacing was disused below.

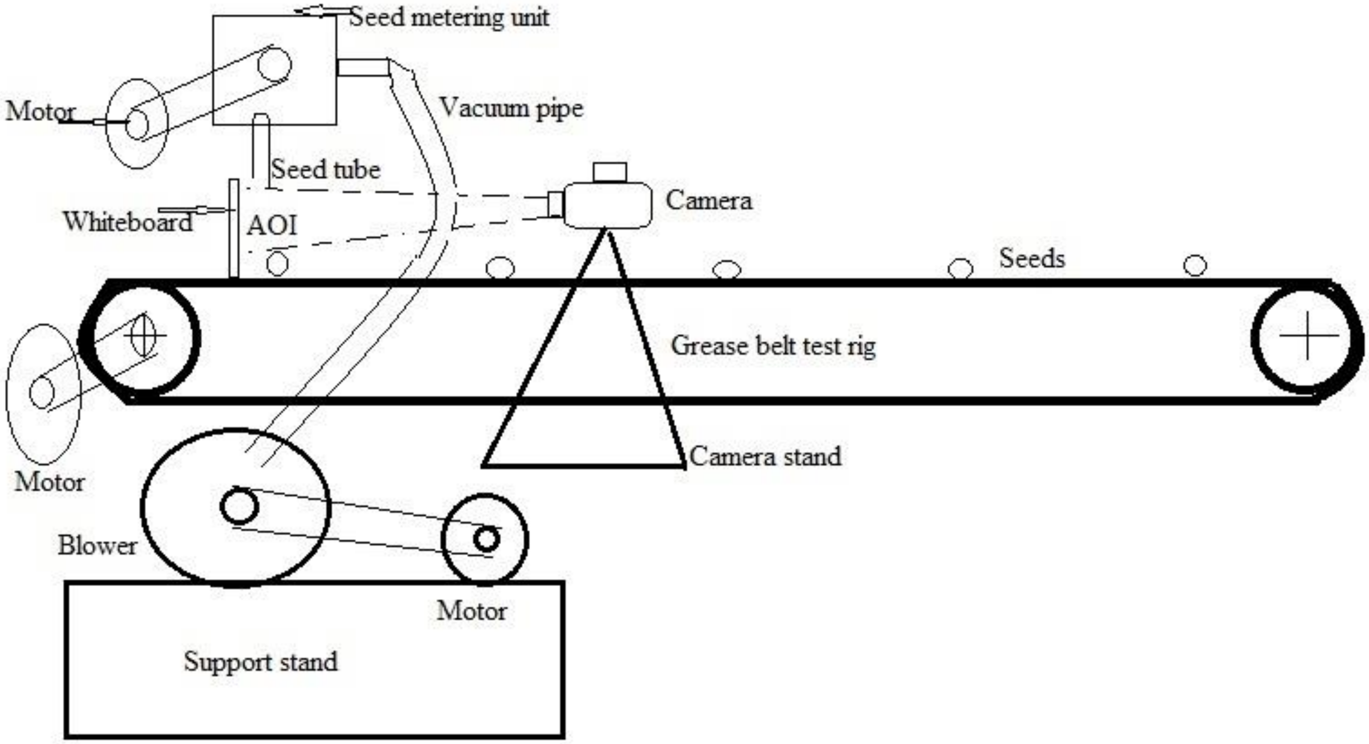


Fig. 3.12 Setup for video acquisition of computer vision system

3.5.2 Determination of seed spacing from captured videos

Video films image analysis were performed by a specific programming language of MATLAB using computer vision tool and image processing tool to get seed to seed spacing. Captured video clip was read in MATLAB platform and the first frame of each clip in which first seed appeared was considered as reference frame. All the frames of the video clip were subtracted to reference frame, then difference greater than the threshold of the object was detected. For tracking side used region props command of MATLAB with properties of centroid, bounding box and area of white pixels. So, the bounding box was tracked of moving object. A problem was formulated in sequential manner and planned different step with different set of operation (Fig. 3.13). The formulations of steps were defined as follows.

1. Import the captured video clip to MATLAB platform
2. Read first object frame of video, considered as an reference image
3. Read other frames of the video clip in sequence
4. Took subtraction of them and set thresholding
5. Applied Gaussian filter to remove noise
6. Applied morphological operation like dilation and erosion to remove small noise
7. Fill hole in resulted image
8. Took label connected component with its properties like bounding box, centroid and area of seed
9. For I = 1:n; % n is no of object move

   ```
       A = (length of object) find (L==1); % find black pixel whose length is A
       If (A>100 & A<8000);
       Then draw rectangle plot centroid of that rectangle end
   ```
10. Measured distance of centroid to reference point
11. Take velocity estimation by ratio of distance to time per frame

$$\text{Elapsed time} = \frac{\text{Frame rate } (fps)}{\text{Grab interval}} \qquad \ldots (3.42)$$

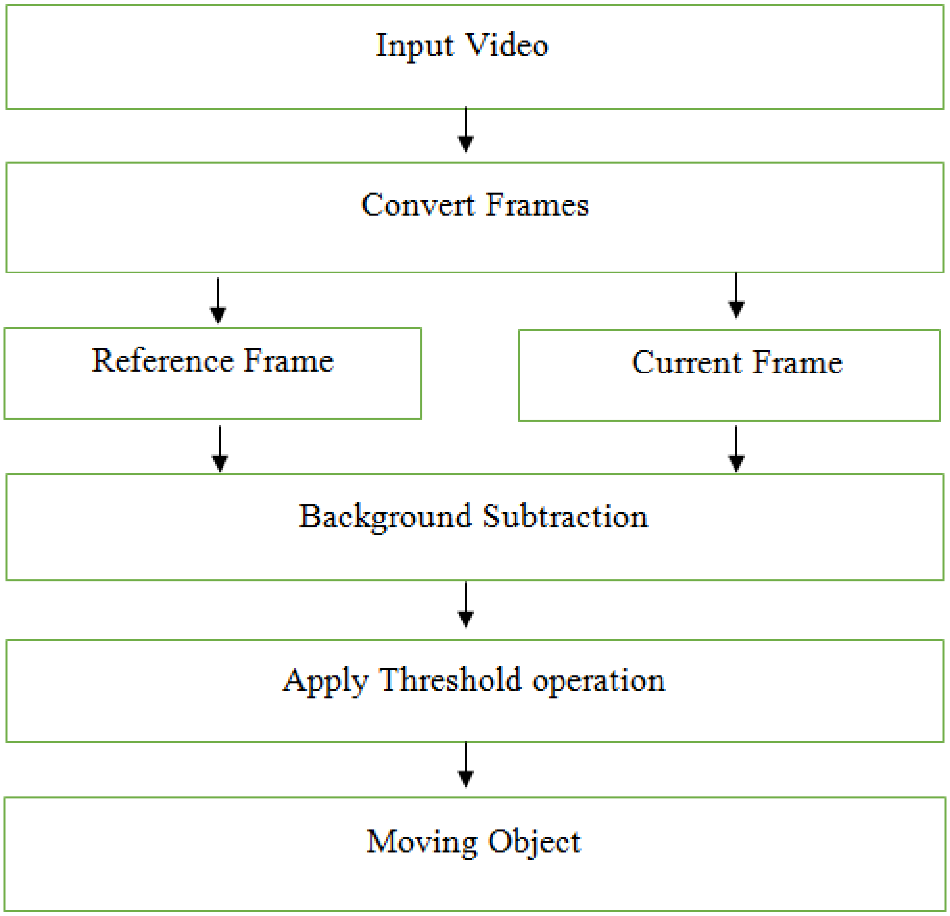


Fig.3.13 Flow chart of image processing by subtraction method using MATLAB

3.6 Design and fabrication of a prototype of multi crop pneumatic planter

A prototype of multi crop pneumatic planter with three furrow openers was designed on the basis of optimized design and operational parameters of newly designed pneumatic seed metering mechanism from the laboratory experiments.

3.6.1 Factors affecting design of pneumatic planter

The design of multi crop pneumatic seed planter is primarily based on agronomic factors and physical properties of seeds, seed rate, depth of seed placement and resultant forces acting on soil contact surfaces of planter components. The integration of analytical design with seed, soil and machine is essential to achieve the recommended seed rate with proper soil environment for good plant establishment. The mechanical components of the pneumatic planter *viz*., ground wheel, ground wheel shaft, drive transmissions, main shaft and bearings were designed based on stresses, twisting and bending moment induced due to the forces acting on the components during the planting operation. The dimensions and the grades of the materials for different machine components were selected considering the respective section modulus and bearing stress induced while in operation. The following agronomic and machine parameters were taken into consideration for the design of filed prototype of pneumatic planter.

3.6.1.1 Agronomic factors

The agronomic parameters like physical properties of selected seeds, recommended seed rate and seed spacing were thoroughly discussed in section 3.2.1. Based on these considerations, design parameters like seed rotor diameter, rotor speed, cell diameter and operating forward speed of planter were optimized to achieve the recommended seed rate for the selected crops. Number of cells on seed rotor, spacing between rotor cells and diameter of the rotor were designed based on the optimum rotor speed obtained from the experiments conducted using instrumented test rig in lab.

3.6.1.2 Row Spacing

The dimensions of the main frame of the planter were designed based on recommended row spacing of test crop. A maximum row spacing of 900 mm was considered for the furrow openers setting. However, a provision is also made to alter the distance between two consecutive furrow openers depending on other crops requirement. The recommended row to row and plant to plant spacing is discussed in section 3.2.1. Plant and row spacing decides the plant population and seed rate requirement of a selected crop.

3.6.1.3 Depth of placement of seed

The shoe type furrow openers with 45° tool angle was designed to ensure the placement of seed at an optimum depth, as the angle of the opener results in placement of seed at uniform depth (Heege, 1993). The cross section of the furrow openers was set minimum to reduce the draft required and to avoid unnecessary soil disturbance while planting operation.

3.6.1.4 Machine factors

Several mechanical components were involved in final prototype design of pneumatic planter. All these components are subjected to certain kind forces and stresses. The strength and durability of any machine component mainly depends of forces acting on it and material properties. The mechanical components of pneumatic seed planter were designed by considering the forces acting on the components, stresses induced and availability of power source. The selection of material and grades for mechanical components of the developed pneumatic planter were selected from the data book for agricultural machinery design (Varshney *et al*., 2004). The details of designs and fabrication procedure of mechanical components of three row pneumatic planter were discussed here under.

3.6.2 Theoretical consideration for design and evaluation of prototype

A three row multi crop pneumatic planter has major components like main frame, metering mechanism, seed hopper, furrow openers, drive transmission and aspirator blower. The furrow opener was designed based on the force analysis, strength and optimized operational parameters of metering mechanism obtained from the experiments conducted using test simulator. This section provides design details of furrow opener, main frame, power transmission system and aspirator blower fabrication and testing of prototype of multi crop pneumatic seed planter. The design considerations followed for mechanical components of prototype of multi crop pneumatic planter are explained under the following headings.

3.6.3 Setting of furrow opener dimensions and working out resultant force

A shoe type of furrow opener was designed to ensure the seed placement at desired depth as shown in figure 3.14. The furrow opener has components *viz.,* inclined share point, shank, boot and seed tube. The furrow openers are fixed to the main frame of the planter with bolts and nuts for easy row spacing adjustment. Each furrow opener is subjected to soil resistance against the pull transferred through the hitch point from the tractor in forward movement. As the furrow opener penetrates into the soil, subjected to force due to weight of segment of soil sliding over its inclined share point as the planter moves in the forward direction. The resultant acceleration force (A_f) is acting at an angle with the forward failure surface on the tool. The shoe type furrow opener having an inclined wedge angle (θ) 45˚, an angle of internal friction 36˚, width of opener 12.5 mm and length of opener 120 mm operating at a minimum depth of 80 mm was considered for the design (Ajaykumar *et al*., 2007). The bulk density of the soil used in the calculation of soil acceleration force was 1180 kg m^{-3} (measured value).

The soil acceleration force (F_s) is calculated using the following equation given by Srivastava *et al*. (2003).

$$F_s = \frac{\rho \times g}{g} b \times d \times {V_0}^2 \frac{\sin\theta}{\sin(\theta+\alpha)} \qquad \text{… (3.43)}$$

Where, F_s is soil acceleration force (N); b is width at penetration of tool (m); d is depth of penetration of tool (m); V_0 is forward speed of planter (m s^{-1}); θ is tool lift angle (degree); α is angle of forward failure surface (degree); ρ is bulk density of soil (kg m^{-3}); g is gravitational force (m s^{-2}).

Angle of forward failure surface is calculated using below relationship

$$\alpha = \frac{1}{2}(90 - \varphi) \qquad \text{… (3.44)}$$

Where, φ is angle of internal friction (degree)

Substituting the values in equation 3.44, the angle of forward failure surface is

$$\alpha = \frac{1}{2}(90° - 36°) = 27°$$

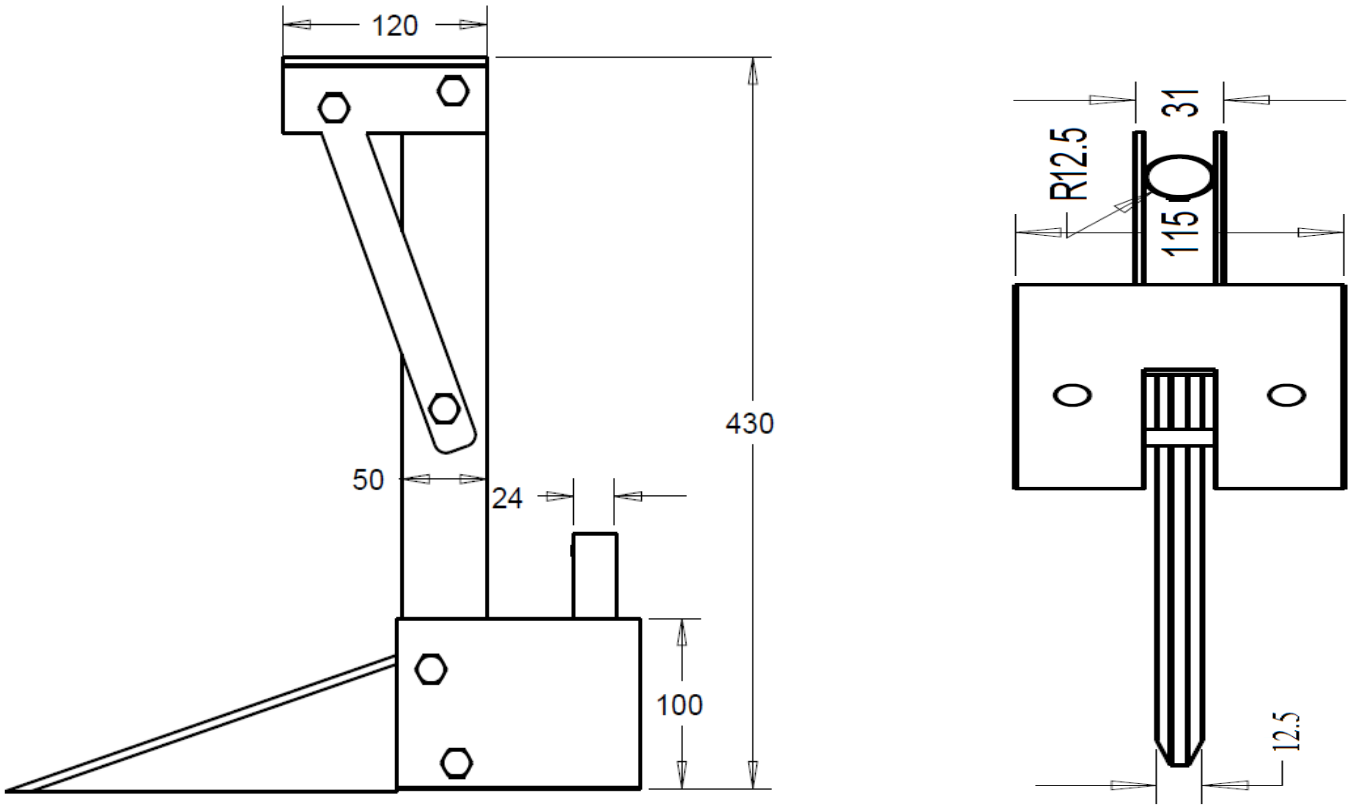


Fig.3.14: Side and top view of furrow opener and boot

Then, substituting the necessary value in equation 3.43.

$$F_s = \frac{1180 \times 9.81}{9.81}\left(0.012 \times 0.12 \times 3^2\right)\frac{\sin(45)}{\sin(45+27)}$$

$$F_s = 1180 \times 0.012 \times 0.12 \times 9 \times 0.7435$$

$$F_s = 11.37 \text{ N}$$

Area of share plane a head of tool (A_1) is calculated by the equation.

$$A_1 = \frac{bd}{\sin\alpha} \qquad \ldots (3.45)$$

Where, b is width at penetration of tool (m); d is depth at penetration of tool (m); α is angle of forward failure surface (degree); A_1 is area of shear plane ahead of tool (m^2).

Substituting the value in Eq. (4.3)

$$A_1 = \frac{0.012 \times 0.12}{\sin(27)}$$

$$A_1 = 0.0031 \text{ m}^2$$

The force due to soil weight (W) is calculated using the equation

$$W = \rho g \times b \times d^* \left(L_0 + \frac{L_1 + L_2}{2}\right) \qquad \ldots (3.46)$$

Where, d^* is height of soil surface (m); L_0 is length of tool (m); L_1 is length of soil surface near tip of tool (m); L_2 is length of soil surface at rear end of tool (m); W is force due to weight of soil (N); ρ is bulk density of soil (kg m^{-3}); g is gravitational force (m s^{-2}).

Substituting the value in the following equation the values of d^* and L_1 are calculated as under

$$d^* = \frac{d[\sin(\theta + \alpha)]}{\sin\alpha} \qquad \ldots (3.47)$$

Where, d is depth at penetration of tool (m); α is angle of forward failure surface (degrees); θ is tool lift angle (degree).

$$d^* = \frac{0.12[\sin(45+27)]}{\sin 27}$$

$$d^* = 0.251 \text{ m}$$

$$L_1 = \frac{\mathrm{d}\left[\cos\left(\theta + \alpha\right)\right]}{\sin\alpha} \qquad \text{… (3.48)}$$

$$L_1 = \frac{0.12\left[\cos\left(45 + 27\right)\right]}{\sin 27}$$

$$L_1 = 0.0814 \text{ m}$$

The length of soil surface at rear end of tool (L_2) is calculated by using the formula

$$L_2 = d^* \tan\theta \qquad \text{… (3.49)}$$

$$L_2 = 0.251 \times \tan 45$$

$$L_2 = 0.251 \text{ m}$$

Then substituting the value in equation (3.46), the value of W is obtained as

$$W = 9.81 \times 1200 \times 0.012 \times 0.251\ \ 0.12 + \left(\frac{0.0814 + 0.251}{2}\right)$$

$$W = 10.14 \text{ N}$$

Considering the geometric factor (Z) as 1.048 and soil cohesion as 0.080 N m^{-2}, the horizontal force, D^* on the tool is calculated by using equation given by Srivastava *et al.* (2003).

$$D^* = \frac{W}{Z} + \frac{CA_1 + F_s}{Z\left(\sin\alpha + \mu\cos\alpha\right)} \qquad \text{… (3.50)}$$

Where, D^* is horizontal force due to soil reaction (N); W is force due to weight of soil supported by tool (N); Z is geometric factor; C is soil cohesion (N m^{-2}); A_1 is area of share plane a head of tool (m^2); α is angle of forward failure surface (degree); F_s is soil acceleration force (N); θ is tool lift angle (degree); μ is coefficient of soil metal friction.

By substituting the value in equation 3.50

$$D^* = 19.53 \text{ N}$$

The vertical force on the tool in equilibrium can be represented by the equation

$$V = \frac{\mathrm{D}^*\left(\cos\theta - \mu'\sin\theta\right)}{\sin\theta + \mu'\cos\theta} \qquad \text{… (3.51)}$$

Where, V is vertical force of soil on tool (N); θ is tool lift angle (degree); μ' is coefficient of soil metal friction

By substituting the values of D^* and μ' in equation 3.51

$$V = \frac{19.53\left(\cos 45 - 0.3\sin 45\right)}{\sin 45 + 0.3\cos 45}$$

$$V = 5.27 \text{ N}$$

Resolving the total soil reaction (P) in horizontal and vertical directions are computed as follows.

$$P_h = D^* = 19.53 \text{ N}$$

$$P_v = V = 2.57 \text{ N}$$

Therefore, force exerted on the opener is given by

$$D = k_o \times b \times d \qquad \dots (3.52)$$

Where, D (F) is draft force (kgf); k_0 is specific soil resistance, (kg cm^{-2});

$$D = 0.75 \times 1.2 \times 12 = 10.8 \text{ kgf}$$

Now taking a factor of safety, the draft force on each tine was considered as 15 kgf. Therefore, total draft from the three furrow openers is 45 kgf. Since, the shank is rigidly fixed to the main frame at top end, so it can be considered as a cantilever beam, whose maximum bending moment for a length of 430 cm be given by

$$M = D \times L_s \qquad \dots (3.53)$$

Where, M is bending moment (kgf cm); L is length of shank (cm).

$$M = 45 \times 430 = 1935 \text{ kgf cm}$$

The section modulus of the shank was computed from the classical flexural formula (Seely and Smith, 1952) as given by equation 3.54.

$$\delta = \frac{MC}{I} \qquad \dots (3.54)$$

Where, δ is bending stress (kgf cm^{-2}); M is bending moment (kgf cm); C is distance from the natural axis to the point at which stress is determined (cm); I is moment of inertia of the rectangular section (cm^4).

The section modulus was computed by using the formula,

$$z = \frac{I}{C} \qquad \dots (3.55)$$

From equation 3.54 and 3.55,

$$z = \frac{M}{\delta} \qquad \dots (3.56)$$

Assuming bending stress equal to 1000 kgf cm^{-2} (Sengar, 2002).

$$Z = 1.95\ \text{cm}^3$$

The section modulus of the furrow openers is

$$z = \frac{bh^2}{6} \qquad \ldots (3.57)$$

The most commonly assumed ratio of thickness to width of tine b : w = 1:3 to 1:4. Assuming b: w, as 1:4, *i.e.* w = 4b

From equation 3.57

$$z = \frac{b \times (4b)^2}{6}$$

$$1.95 = \frac{b^3 \times 16}{6}$$

$$b^3 = 0.73, \text{ therefore } b = 0.9 \text{ cm or } 9 \text{ mm}$$

Considering factor of safety as 1.4 and availability of material of standard size, the thickness of shank was selected as 12.5 mm. Therefore, the width of the shank, w = 4b.

$$W = 4 \times 12.5 = 50 \text{ mm}$$

Therefore, the cross section area of the shank was 12.5 mm × 50 mm. Deflection of this section would be determined using the following equation.

$$Y_{\max} = \frac{DL_s^{\ 3}}{3EI} \qquad \ldots (3.58)$$

Where, Y_{max} is deflection produced due to loading (mm); D is draft force (kgf); Ls is length of the shank (mm); E is modulus of elasticity (kg mm^{-2}); I is area moment of inertia (mm^4).

Area moment of inertia of shank section was calculated by the following formula.

$$I = \frac{bh^3}{12} \qquad \ldots (3.59)$$

$$I = \frac{12.5 \times 430^3}{12}$$

$$I = 82.81 \times 10^6\ \text{mm}^4$$

Therefore,

$$Y_{\max} = \frac{45 \times (430)^3}{3 \times 2 \times 10^4 \times 82.81 \times 10^6} = 0.7 \times 10^{-4} \text{ mm}$$

The deflection of the shank is negligible, hence a rectangular section shank of size 430 × 50 × 12.5 mm (L_s × w × b) made from St 42 - S material was selected (Varshney *et al.*, 2004).

3.6.4 Design of main frame

The main frame of the planter is subjected to torsion and bending due to induced force by the furrow openers of three numbers fitted on front and rear tool bars at 900 mm apart. The frame setting and forces acting on is shown in figure 3.15 and figure 3.16, respectively.

The total force acting on each furrow opener is 108 N as obtained from equation 4.11. Considering the main frame has a clearance of 430 mm from the ground as set in furrow opener design calculations, the torque produced on each furrow opener is given by the equation.

$$T = \mathrm{F} \times \mathrm{R_g} \qquad \ldots (3.60)$$

Where, T is torque (N mm); F is total force on each furrow opener (N); R_g is ground clearance (mm).

Substituting the values in equation 3.60, the value of torque is

$$T = 108 \times 430 = 46440 \text{ N mm}$$

Total torque acting on the tool bar is given by multiplying torque of each furrow opener and the number of furrow openers on the tool bar *i.e.*

$$46440 \times 3 = 139320 \text{ N mm}$$

In addition to the torque, bending moment is also produced in the tool bar. Considering the toolbar as simply supported beam and the force due to individual furrow opener is concentrated load as shown in figure 3.16. The maximum bending moment will be at the center of the bar (C). Considering the reactions forces acting on the tool frame at points A and B as R_A and R_B, respectively.

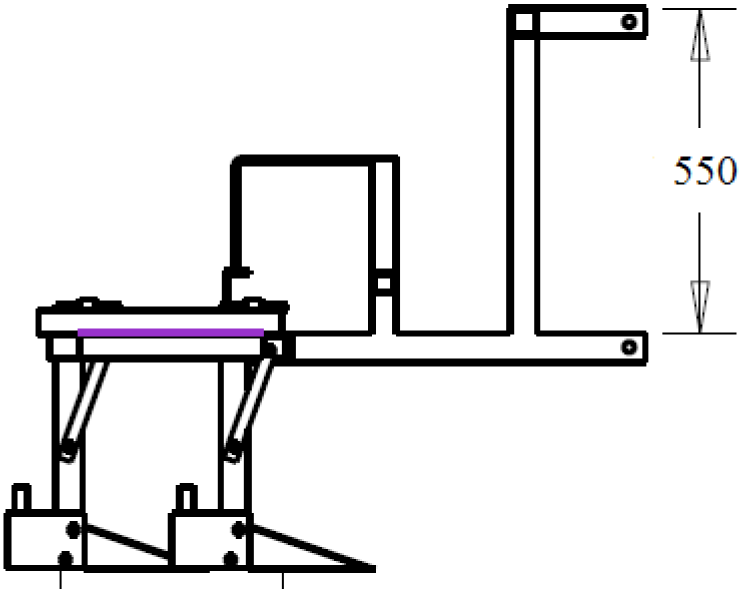


Fig. 3.15 Side view of frame and furrow opener arrangement

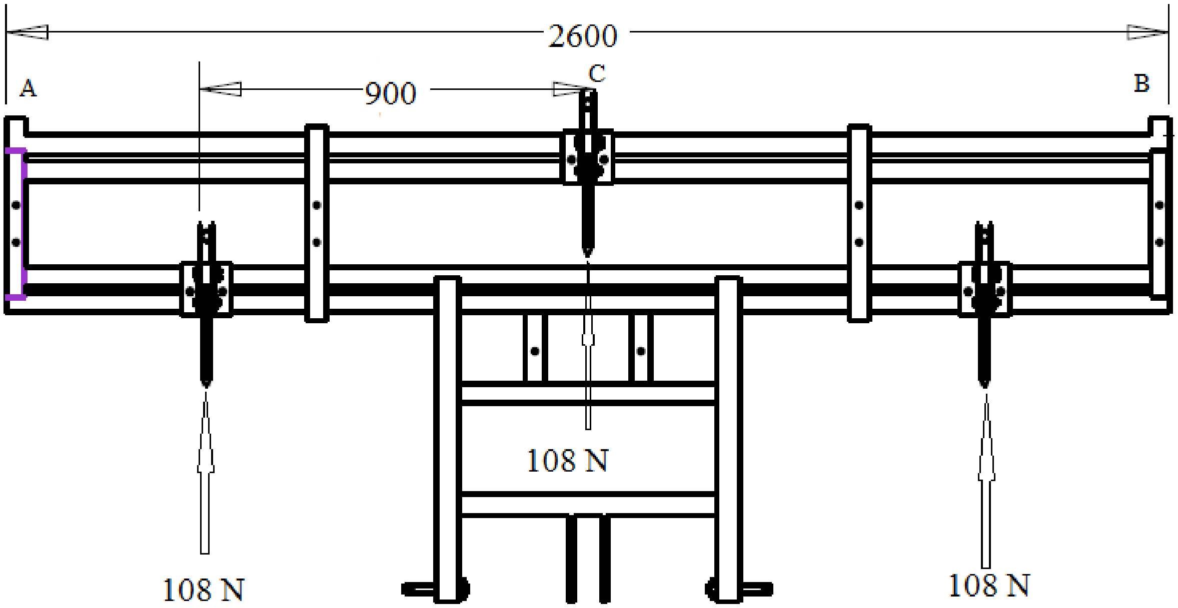


Fig. 3.16 Forces acting on main frame from furrow openers

The forces acting on frame is symmetrical on the span, each vertical reaction equal to half of the total on the span (Khurmi and Gupta, 2003). The reaction at support is calculated using equations.

$$R_A = R_B = \frac{\mathrm{F} \times \mathrm{N}}{2} \qquad \dots (3.61)$$

Where, *F* is total force on each furrow opener (N); *N* is number of furrow openers.

Substituting 'F' from equation 3.52 in the equation 3.61, reaction at each support is calculated as

$$R_A = R_B = \frac{108 \times 3}{2} = 162\,\mathrm{N}$$

The maximum bending moment is at the center of the tool bar AB. Taking moment about the center (C), the maximum bending moment on the tool bar M is given by the summation of bending moments of different forces taken from the center.

Thus,

$$\mathrm{M} = 162 \times 1300 - 108 \times 900 = 210600 - 97200 = 113400 \text{ N mm}$$

Equivalent torque is given by the equation.

$$T_e = \sqrt{(\mathrm{K_m} T)^2 + (\mathrm{K_1} M)^2} \qquad \dots (3.62)$$

Where, T_e is equivalent torque (N mm); T is maximum torque on tool bar (N mm); M is maximum bending moment on tool bar (N mm); K_m is shock factor; K_t is endurance factor.

Considering the shock factor and endurance factor as 1.5 and 1.25, respectively (Khurmi and Gupta, 2003) and substituting the value in equation 3.62, equivalent torque is calculated as

$$T_e = \sqrt{(1.5 \times 46440)^2 + (1.25 \times 113400)^2}$$

$$T_e = 157941.69 \text{ N mm}$$

A hollow square section of IS SQ40 with 6 mm thick wall selected conforming to IS: 808 – 1964 having section modulus of 8105.6 mm^3 (Bajaj, 1993).

$$Z_1 = 8105.6 \text{ mm}^3$$

The bending stress in the material of the frame is given by equation 3.63.

$$\therefore\ f_b = \frac{M}{Z_1} \qquad \ldots (3.63)$$

Where, f_b is bending stress (N mm^{-2}); M is maximum bending moment (N mm); Z_1 is section modulus (mm^3).

Substituting the values in the above equation, the value of f_b is

$$f_b = 13.99 \text{ N mm}^{-2}$$

As specified in the last paragraph of section 3.6.3, hollow square material made of St 42–S having ultimate bending stress of 420 N mm^{-2} selected and assuming the factor of safety as 6, whose allowable bending stress is 70 N mm^{-2} (Khurmi and Gupta, 2003).

The actual bending stress produced in the frame section (13. 99 N mm^{-2}) is less than the allowable stress (70 N mm^{-2}), hence the main frame design is safe.

3.6.5 Design of power transmission system

The transmission system is provided to transmit the power from the ground wheel to the seed metering mechanism (Fig. 3.17a and 3.17b). The mechanical components of transmission system, like ground wheel, ground wheel shaft, chain and sprocket, main shaft, bearing were designed based on the material properties considerations using standard calculations for respective components.

3.6.5.1 Design of ground wheel

The ground wheel support frame was fixed to the mainframe with a free movement to the counter shaft in a plane to allow the ground wheel to traverse depending on soil undulations. A bush bearing was provided to support the counter shaft which intern fitted to square plate to be attached to main frame with clamps. Due to pull of tractor, planter moves forward and required traction was obtained by the lugs provided on the circumference of the ground wheel. The power is transmitted from the ground wheel to the main shaft through the counter shaft, sprockets and chain arrangement. From the optimization studies conducted under laboratory, the following basic parameters were considered for design of ground wheel.

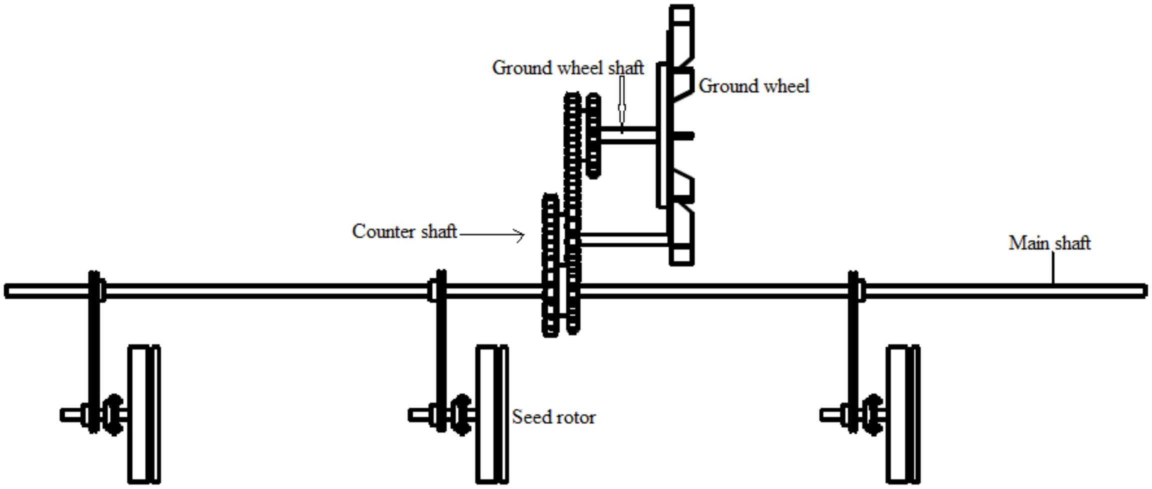


Fig. 3.17 (a) Power transmission system in prototype pneumatic seed planter (top view)

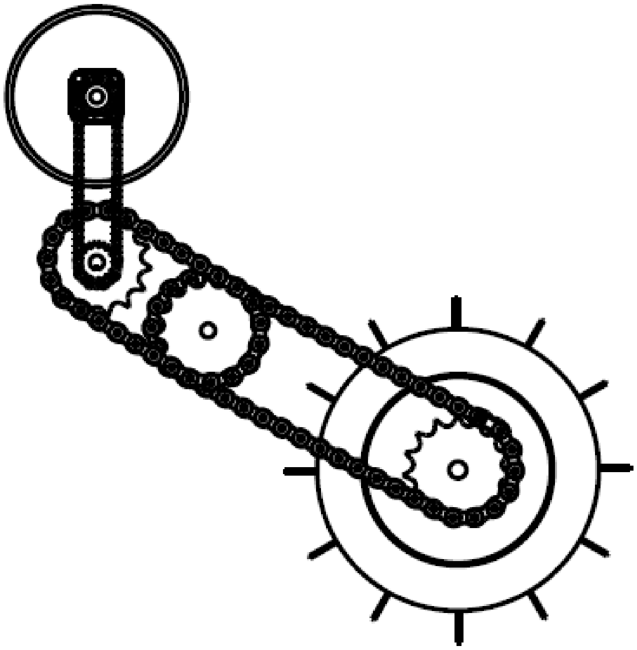


Fig. 3.17 (b) Power transmission system in prototype pneumatic seed planter (Side view)

Seed to seed spacing = 450 mm

Number of cells on the seed rotor (N_1) = 2

Transmission ratio between ground wheel and rotor = 0.636

The sprocket mounted on ground wheel has 11 teeth. Then the number of teeth of sprocket mounted on counter shaft is calculated by the following equation.

$$T_c = \frac{T_g}{T_r} \qquad \text{… (3.64)}$$

Where, T_r is transmission ratio; T_g is number of teeth on sprocket of ground wheel; T_c is number of teeth on sprocket of main shaft.

Substituting the value in equation 3.64, the number of teeth on sprocket mounted on counter shaft is calculated as,

$$T_c = \frac{11}{0.636}$$

$$T_c = 17$$

Number of revolution required by the ground wheel to drop one seed is given by the equation.

$$N_g = \frac{T_c \times N_p}{T_g} \qquad \text{… (3.65)}$$

Where, N_g is number of revolution made by the ground wheel to drop one seed; T_p is number of revolution made by seed rotor to drop one seed

The value of N_p obtained from

$$N_p = \frac{\mathrm{N}_0}{\mathrm{n}_1} \qquad \text{… (3.66)}$$

Where, N_p is number of revolution made by the rotor (rpm); N_0 is number of seeds dropped; n_1 is number of cells on seed rotor

Substituting values in above equation

$$N_p = \frac{1}{2} = 0.5$$

Substituting the value of N_p in equation 3.65, the number of revolution to drop one seed is given by

$$N_g = \frac{11}{17} \times \frac{1}{2} = 0.33$$

The diameter of ground wheel is calculated using the following equation.

$$D_g = \frac{S}{\pi N_g} \qquad \text{… (3.67)}$$

Where, D_g is diameter of ground wheel (mm); F_s seed spacing of planter (mm); N_g is number of revolutions made by ground wheel to drop one seed. Substituting the values of N_g from equation 3.67, diameter of ground wheel is obtained as,

$$D_g = \frac{450}{3.14 \times 0.33}$$

D_g = 436.8 mm (Diameter of ground wheel selected as 450 mm).

The ground wheel was cut from a 6 mm thick MS sheet (Fe-410) of diameter 450 mm.

3.6.5.2 Design of lugs

The lugs are provided on the circumference of the ground wheel to obtain proper traction. Lugs provided on the ground wheel are subjected to force due to weight of ground wheel and acceleration force (F_a) due to forward movement of planter (Fig. 3.18).

The soil acceleration force is calculated using the equation 3.50, as given by Srivastava *et al*. (2003).

The size 50 IS F6 flat was selected for lug of length 75 mm, made of Fe - 410 (Khurmi and Gupta, 2003), half of the lug (35 mm) projected outside the disc to penetrate into soil. The lugs are welded on the outer face perpendicular to ground wheel with 90° to soil surface. The bulk density of the soil was measured as 1180 kg m^{-3}. It is assumed that, the angle of internal friction as 36°, maximum forward speed as 9.6 km h^{-1} (Kepner *et al*., 1987).

Angle of forward failure (α) was taken as 27° from equation 3.43.

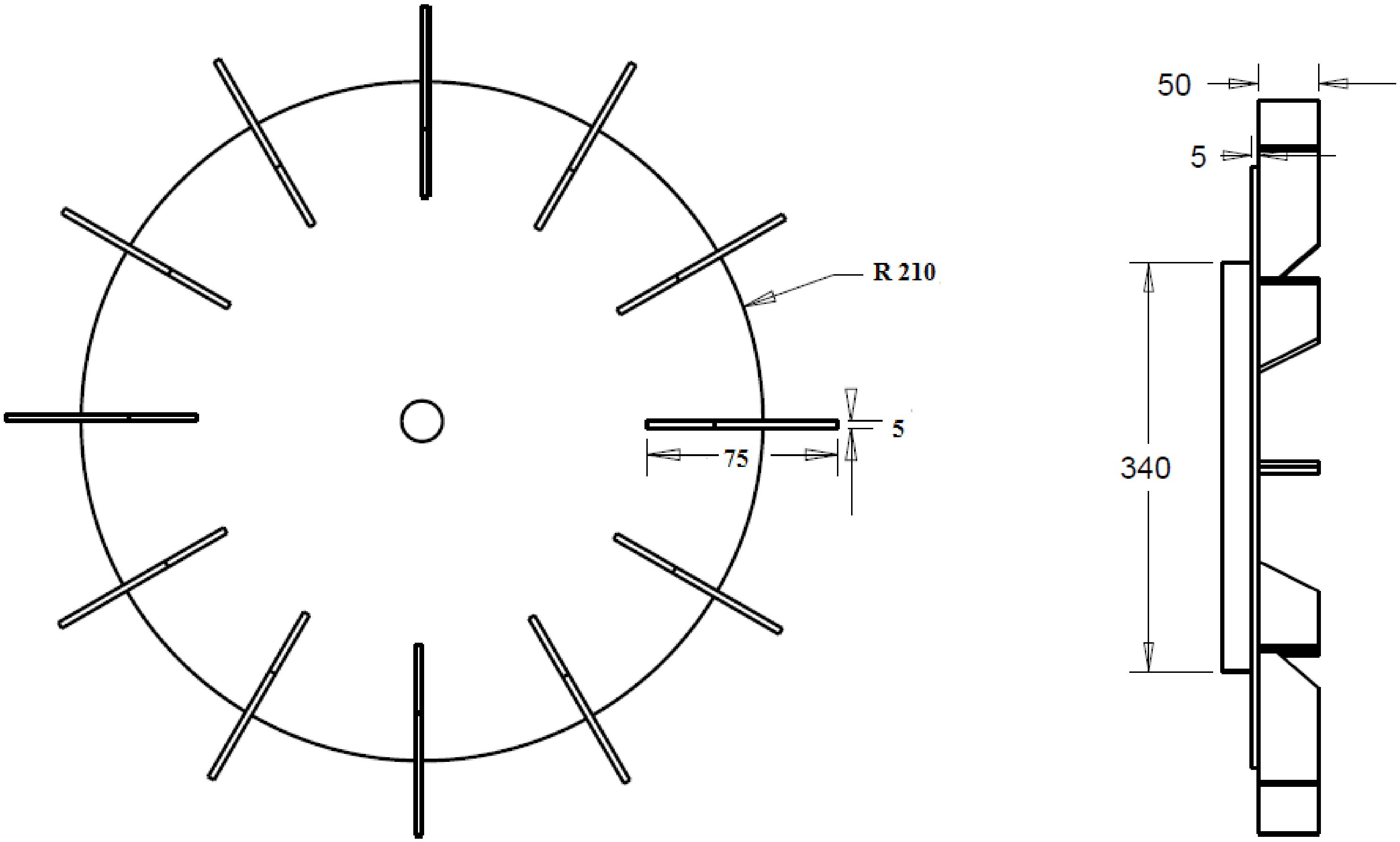


Fig. 3.18 Ground wheel and force acting on ground wheel lug

Soil acceleration force acting on each lug is given by equation 3.44.

$$\therefore\ F_a = 1180 \times 0.05 \times 0.035 \times (3)^2 \frac{\sin 90^\circ}{\sin\left(90^\circ - 27^\circ\right)} = 99.2\ \text{N}$$

Considering three lugs are in contact with the soil at any given moment while working, total soil acceleration force is given by

$$B_0 = 3 \times F_a = 3 \times 99.2 = 297.8\ \text{N}$$

Where, B_0 is total soil acceleration force on ground wheel (N); F_a is total soil acceleration force on single lug (N).

The total soil acceleration force act at the center of projected length of lug and hence, the maximum bending moment will be acting at this point. The maximum bending moment is given by equation.

$$M = B_0 \times L \qquad \dots (3.68)$$

Where, M is maximum bending moment (N mm); L is distance between point of action of soil resistance and top edge of lug (mm). Substituting the value in equation 3.68.

$$M = 50.40 \times 17.5$$

$$= 11168\ \text{N mm}$$

The bending stress induced in the material of the lug is calculated using equation 3.69 (Khurmi and Gupta, 2003).

$$f_b = \frac{\mathrm{M}}{\mathrm{Z}_2} \qquad \dots (3.69)$$

Where, M is maximum bending moment on lug (N mm); f_b is stress induced in material of lug (N) mm^{-2}; Z_2 is section modulus of ground wheel lugs, mm^3.

Section modulus for rectangular section is given by Varshney *et al*. (2004).

$$Z_2 = \frac{1}{6} b t^2 \qquad \dots (3.70)$$

Where, Z_2 is section modulus (mm^3); t is thickness of lug (mm); b is width of lug (mm).

Substituting the value in equation (3.70).

$$Z_2 = 300 \text{ mm}^3$$

Substituting the value of Z_2 from equation 3.70, the bending stress produced in the material f_b equation 3.69.

$$f_b = \frac{11168}{300}$$

$$f_b = 37.22 \text{ N mm}^{-2}$$

The selected lug is made of St-42 S having ultimate bending stress of 420 mm^2, the factor of safety is taken as 2 and the allowable bending stress in the material is 70 N mm^{-2} (Khurmi and Gupta, 2003).

Bending stress produced (37.22 N mm^{-2}) is less than allowable bending stress (70 N mm^{-2}), hence the design is safe. Considering the spacing between lugs as 100 mm and number of lugs ground wheel is obtained as

$$N = \frac{\pi Dg}{S_1} \qquad \dots (3.71)$$

Where, D_g is diameter of ground wheel (mm); S_1 is spacing between lug (mm); N is number of lugs.

$$N = \frac{3.14 \times 450}{110} = 12.84 = 12$$

Hence, twelve lugs have been provided on the ground wheel.

3.6.5.3 Design of ground wheel shaft

A shaft is fitted with ground wheel at one end and a sprocket on other end. The power transmitted by the ground wheel shaft is given by an equation 3.72.

$$P = B_0 \times S_g \qquad \dots (3.72)$$

Where, P is power transmitted (W); B_0 is total soil acceleration force (N); S_g is speed of ground wheel (m s^{-1}).

Speed of ground wheel is given by

$$S_g = \frac{\pi D_g N}{60} \qquad \dots (3.73)$$

Where, V_g is forward speed of ground wheel (m s^{-1}); D_g is diameter of ground wheel (m); N is rotary speed of ground wheel (rpm).

Considering the designed transmission ratio of 1:0.636. Therefore, rotary speed of ground wheel is calculated by given equation.

$$N = \frac{N_r \times T_r}{(1 - S_1)} \qquad \ldots (3.74)$$

Where, N is rotary speed of ground wheel (rpm); S_l is ground wheel slip (percent), N_r is speed of rotor (rpm); T_r is transmission ratio.

Maximum travel speed of tractor is taken as 3 km h^{-1} for which the ground wheel rotates at 35 rpm and the ground wheel slip is measured as per cent, substituting the values in equation 3.74.

$$N = \frac{35 \times 1}{(1 - 0.1) \times 0.636}$$

$$N = 61 \text{ rpm}$$

Substituting the value of D_g from equation 3.67 and N from equation 3.74, the value of ground wheel forward speed obtained.

$$S_g = \frac{3.14 \times 450 \times 61}{1000 \times 60}$$

$$S_g = 1.436 \text{ m s}^{-1}$$

Substituting S_g from equation 3.73 in equation 3.72, power transmitted by the ground wheel is obtained as

$$P = 50.40 \times 1.436$$

$$P = 72.37 \text{ W}$$

The ground wheel shaft is subjected to combined torsion and bending. The torque transmitted by the shaft is given by.

$$T = \frac{P \times 60}{2\pi N} \qquad \ldots (3.75)$$

Where, T is torque transmitted by the ground wheel (N m); P is power transmitted by the ground wheel (W); N is speed of ground wheel (rpm).

Substituting the value of P from equation 3.72 and N from equation 3.74, the value of torque transmitted, T is obtained as

$$T = \frac{72.37 \times 60}{2 \times 3.14 \times 61} = 11.33 \text{ N m}$$

The ground wheel is subjected to bending moment of the force due to its own weight acting perpendicular to the axis of the shaft. Soil acceleration force is acting on the lug parallel to the axis of the shaft. The bending moment due to force acting parallel to the shaft on the lug of the ground wheel is calculated by,

$$M_1 = B_0 \times L \qquad \dots (3.76)$$

Where, M_1 is maximum bending moment (N mm); B_0 is total soil acceleration force (N); L is center distance between shaft and lug (mm)

Substituting the value of B_0 in equation 3.76, bending moment is obtained as

$$M_1 = 50.40 \times 227.5 = 11466 \text{ N mm}$$

The bending moment force due to weight of ground wheel is given by the equation 3.77.

$$M_2 = Fg \times L_1 \qquad \dots (3.77)$$

Where, F_g is force due to ground wheel weight (65) (N); L_1 is distance of ground wheel from center of the bearing (mm).

Considering the force due to ground wheel weight and substituting the values in equation 3.77.

$$M_2 = 65.19 \times 50 = 3259.5 \text{ N mm}$$

Resultant bending moment on the ground wheel shaft is given in following relationship (Khurmi and Gupta, 2003).

$$M_g = \sqrt{\left((M_1)^2 + (M_2)^2\right)} \qquad \dots (3.78)$$

Where, M_g is resultant bending moment (N mm); M_1 is bending moment acting parallel to shaft (N mm); M_2 is bending moment acting perpendicular to shaft (N mm).

Substituting the value in equation 3.78.

$$M_g = 11920.30 \text{ N-mm}$$

The ground wheel shaft is subjected to twisting moment (T) and resultant bending moment (M). Therefore equivalent twisting is calculated by the equation 3.79.

$$T_e = \sqrt{\left(T^2 + M^2\right)} \qquad \dots (3.79)$$

Where, T_e is equivalent twisting moment (N mm); T is twisting moment (N mm); M is resultant bending moment (N mm).

Substituting value in equation 3.79,

$$T_e = \sqrt{(11330)^2 + (11920)^2}$$

$$T_e = 16445.52 \text{ N mm}$$

The ground wheel shaft is subjected to combined bending and tensional load. The ground wheel is supported by a bush bearing of length 900 mm. One end of the shaft is fitted with a rigid support and other end ground wheel fitted with sprocket to transmit the power to the main shaft of seed metering unit through a counter shaft. The selected shaft is made of 45C8 mild steel having ultimate tensile stress of 450 N mm^{-2} and the factor of safety is taken as 9. Allowable shear stress in the shaft material is 50 N mm^{-2} (Khurmi and Gupta, 2003). The diameter of the shaft is obtained by the equation.

$$d^3 = \frac{l \times T_e}{\pi \times \tau} \qquad \dots (3.80)$$

Where, l is length of key *(mm);* T_e is equivalent torque (N mm); τ is allowable shear stress (N mm^{-2}); d is diameter of the shaft (mm).

$$= \frac{16 \times 16445}{\pi \times 50} \; = 1675.92$$

$$\text{d} = 11.87 \text{ mm} = 12 \text{ mm}$$

Considering factor of safety and load fluctuated load over ground wheel shaft diameter is taken as 25 mm.

3.6.5.4 Design of chain drive

Power from the ground wheel is transmitted to the seed metering rotor through chain drive. The chain drive was selected to have combined effect of versatility of belt drive and positiveness of gear drive. The requirement of power transmission by chain drive is as follows,

i. Power transmission ratio : 1 : 0.636
ii. Speed of seed rotor (rpm) : 55
iii. Center distance between the ground wheel shaft and counter shaft (mm) : 360
iv. Torque produced by the ground wheel shaft N mm (Eq. 3.79) : 16445.52 N m
v. Ground wheel slip : 10 per cent
vi. Number of teeth on sprocket of ground wheel shaft : 11

Design power is calculated using the formula given by

$$P_d = P \times K_s \qquad \dots (3.81)$$

Where, P_d is design power (W); P is rated power transmitted by the ground wheel sprocket (W); Ks is service factor.

Service factor is calculated by the equation.

$$K_s = K_1 \times K_2 \times K_3 \qquad \dots (3.82)$$

Where, K_s is service factor; K_1 is load factor; K_2 is lubrication factor; K_3 is rating factor.

Considering load factor, lubrication factor and rating factor as 1.5, 1.35 and 1.25 respectively service factor is calculated by substituting the value in equation 3.82 (Khurmi and Gupta, 2003).

$$K_s = 1.5 \times 1.35 \times 1.25 = 2.53$$

Power transmitted by the ground wheel is 72.37 W (Eq. 3.72). The design power is obtained from equation 3.81.

$$P_d = 72.37 \times 2.53$$

$$= 183.09 = 183 \text{ W}$$

Number of teeth on counter shaft sprocket is calculated by the equation.

$$N_1 T_1 = N_2 T_2 \qquad \dots (3.83)$$

$$T_2 = \frac{N_1}{N_2} \times T_1$$

Where, N_1 is speed of ground wheel (rpm); T_1 is number of teeth on ground wheel sprocket; N_2 is speed of counter shaft sprocket (rpm); T_2 is number of teeth on sprocket mounted on counter shaft.

$$T_2 = \frac{55}{35} \times 11 = 17.28$$

The center distance between ground wheel shaft and counter shaft is 360 mm.

The chain pitch can be calculated by using the formula,

$$P = \left(\frac{X}{30} \right) \qquad \dots (3.84)$$

Where, P is pitch (mm); X is center distance between two sprockets (mm).

$$P = \frac{360}{30} = 12.00$$

Roller chain of standard pitch of 12.7 mm is selected and the corresponding transfer pitch is 13.92 mm, roller diameter is 8.51 mm, width between inner plates is 7.75 mm and breaking load is 17.8 KN (Varshney *et al*., 2004). Pitch circle diameter of sprocket on ground wheel is calculated by the equation (Khurmi and Gupta, 2003).

$$d_1 = P \operatorname{cosec} \frac{180}{T_1} \qquad \dots (3.85)$$

Where, d_1 is pitch circle diameter of sprocket on ground wheel (mm); P is pitch (mm); T_1 is number of teeth of sprocket on ground wheel.

$$d_1 = 12.7 \operatorname{cosec} \left(\frac{180}{11} \right) = 45 \text{ mm}$$

Pitch circle diameter of the sprocket mounted on counter shaft

$$d_2 = P \operatorname{cosec} \left(\frac{180}{T_2} \right) \qquad \dots (3.86)$$

Where, d_2 is pitch circle diameter of sprocket on counter shaft (mm); P is pitch (mm); T_2 is number of teeth of sprocket on counter shaft

$$T_2 = 17$$

$$P = 12.7 \text{ mm}$$

$$d_2 = 12.7 \times \operatorname{cos}ec\left(\frac{180}{19}\right)$$

$$d_2 = 77.18 \text{ mm} = 80 \text{ mm}$$

Pitch line velocity of the sprocket mounted on the ground wheel is given by equation (Khurmi and Gupta, 2003).

$$V_1 = \frac{\pi d_1 N_1}{60} \qquad \ldots (3.87)$$

Where, V_1 is pitch line velocity of smaller sprocket, MS-1 speed of ground wheel; d_1 is pitch circle diameter of sprocket mounted on ground wheel (mm); N is speed of ground wheel (rpm).

$$V_1 = \frac{\pi \times 45 \times 35}{60 \times 1000} = 0.0824 \text{ m s}^{-1}$$

Force due to chain pull is given by formula.

$$F_0 = \frac{P_r}{V_1} \qquad \ldots (3.88)$$

Where, F_0 is force due to chain pull (N); P_r is rated power (W); V_1 is pitch line velocity (m s^{-1}).

Submitted the value of V_1 from equation 3.87 and design power from equation 3.88, the forced due chain pull is obtained as

$$F_0 = \frac{183}{0.0824} = 2220.8 \text{ N}$$

The force due to pull exerted (2220.8 N) is less than breaking load of chain (17800 N) (Khurmi and Gupta, 2003). Hence the design is safe.

3.6.6 Design of aspirator blower

The blower converts mechanical energy into kinetic energy of a fluid flow (in this case air) by accelerating it to the outer rim of a revolving device known as an impeller. The principle involved in the design of a blower is virtually similar in every important aspect as that of a centrifugal pump, except for the fact that the term “centrifugal pump” is often associated with liquid (water) as its working fluid, while the blower is meant to work on air (Edward, 1995).

The effect of centrifugal force acting upon the spinning air within the confined housing (technically called as Volute), the impeller creates the suction. As the impeller rotates, spinning air moves outward away from the hub, creating a partial vacuum which causes more air to flow into the impeller. Fluid enters the inlet port at the center of the rotating impeller or the suction eye. As the impeller spins in a counter clockwise direction, it thrusts the fluid outward radially, causing centrifugal acceleration. As it does this, it creates a vacuum in its wake, drawing even more fluid into the housing through inlet. Centrifugal acceleration creates energy proportional to the speed of the impeller (Adekunle *et al*., 2008). The faster impeller rotates, the faster the fluid movement and the stronger its force. Impellers are the rotating blades that actually move the fluid imparting kinetic energy from the mechanical energy it gets. The impeller is mounted on a shaft, which connected to the drive shaft that rotates within the blower casing.

In case of blower, entering air flow is in radial direction, hence the radial component V_r of the absolute velocity is the same as the inlet velocity V_i.

$$\text{That is, } V_r = V_i$$

It is assumed that, the flow is completely guided by the blades and the fluid flow angles coincide with the blade angles. With the following dimension, a blower was designed.

Inlet vane angle, $\beta_1 = 29°$

Outlet vane angle, $\beta_1 = 31°$

Volute inside radius, $r_1 = 0.08$ m

Volute outside radius, $r_2 = 0.335$ m

Vane width at the suction eye, $b_1 = 0.0355$ m

Vane width at the tapered end, $b_2 = 0.024$ m

Blower was operated through V belt and pulley driven by tractor PTO shaft. Generally the rpm of tractor PTO shaft was 540 ± 10. It is easy to connect the PTO shaft of tractor to the drive shaft directly using standard PTO connector, hence the input rpm for the driver shaft was considered as 500 rpm. A 400 mm diameter pulley was mounted on driver shaft and the pulley diameter on the blower shaft was calculated using relationship given below.

$$N_1 D_1 = N_2 D_2 \qquad \ldots (3.89)$$

Where, N_p is rpm of the PTO shaft; D_P is pulley diameter (mm) on drive shaft; D_b is diameter of blower pulley; N_b is rpm of blower shaft.

$$D_b = \frac{N_p D_p}{N_b} = \frac{500 \times 400}{3430}$$

$$D_b = 58.3 \text{ mm} = 60 \text{ mm}$$

The linear speed of vane at the inlet is given by the relation

$$U_1 = r_1 \omega \qquad \ldots (3.90)$$

$$U_1 = \frac{2\pi \times 3430 \times 0.08}{60} = 28.74 \, \text{m s}^{-1}$$

$$V_I = V_r = U_1 \tan \beta_1 = 2874 \tan 29 = 15.93 \text{ m s}^{-1}$$

The expected theoretical flow rate for the set dimensions of the blower is

$$Q = 2\pi r_1 b_1 V_r \qquad \ldots (3.91)$$

$$= 2 \times 3.14 \times 0.08 \times 0.0355 \times 15.93 = 0.2842 \text{ m}^3 \text{ s}^{-1}$$

Applying continuity concept at the blower discharge,

$$V_3 = \frac{Q}{A_3} = \frac{0.2842}{0.134 \times 0.134} = 15.83 \, \text{m s}^{-1}$$

Applying Bernoullis equation between the room and blower discharge point,

$$\frac{P_{atm}}{\rho g} + \left(\Delta h_t\right)_{1 \to 2} = \frac{P_{atm}}{\rho g} + \frac{V_3^2}{2g} \qquad \ldots (3.92)$$

Where, V_3 is discharge velocity; Q is fluid flow rate; A_3 is cross sectional area at the discharge end; P_{atm} is atmospheric pressure; $(\Delta ht)_{1\rightarrow 2}$ is the total head change; ρ is air density; g is acceleration due to gravity.

The total head change imparted to the flow by the blower is then

$$(\Delta h_t)_{1\rightarrow 2} = \frac{V_3^2}{2g} = \frac{15.83^2}{2\times 9.81} = 12.77m$$

The power input to the blower is determined by substituting the value of Q from equation 3.91 in equation 3.93.

$$P = \rho Qgh \qquad \dots (3.93)$$

$$= 1.239\times 0.2842\times 9.81\times 12.77 = 44.11\ W$$

3.6.7 Development of prototype multi crop pneumatic seed planter

A pneumatic seed planter prototype was fabricated based on the dimensions obtained from the designs of various components. The detailed drawing of prototype was shown in figure 3.19. The planter has three furrow openers and seed metering boxes having adjustable row spacing. The specification of components and material used for the fabrication of prototype is presented in Table 4.1. The overall dimensions of the planter was found to be 2.6 × 1.6 × 0.98 m in length, width and height. A prototype planter was fabricated with standard production techniques discussed in further sections at research workshop of ICAR - Central Research Institute for Dryland Agriculture, Hyderabad.

3.6.7.1 Seed metering mechanism

The fabricated seed metering mechanism consisted of seed metering unit, seed hopper and seed tube. A seed metering unit design details and fabrication was discussed in details in section 3.3.

Three units of seed hopper were fabricated using material F2 confirming having thickness of 1.5 mm. Overall dimensions of the hopper is 300 mm in length, 150mm in breath and 250 mm in height. The hopper unit bottom surface was inclined at 60° to facilitate easy flow of seeds towards the seed outlet and the designed capacity is 2.5 kg of cotton seeds. A provision was made to control the seed flow through outlet funnel by opening and closing the shutter.

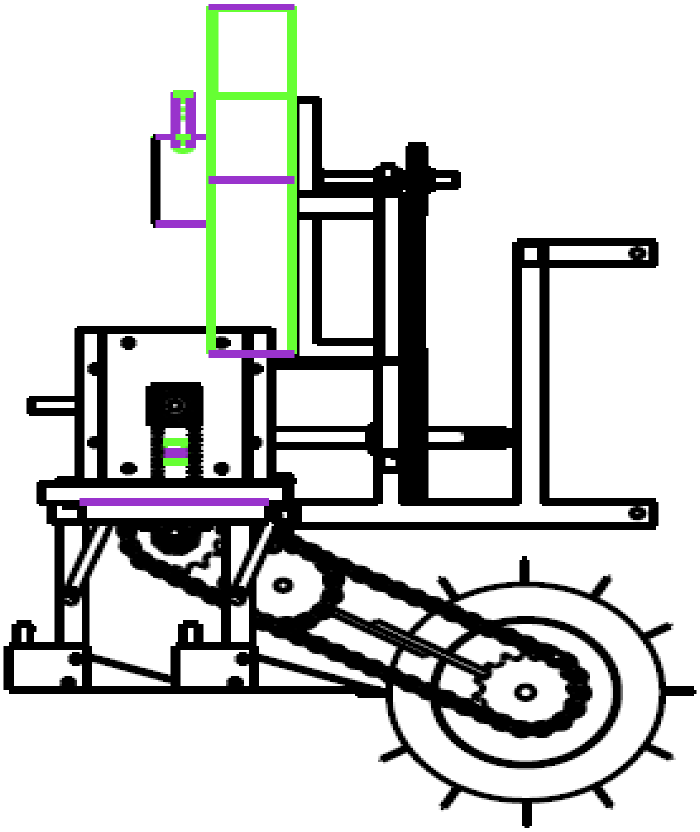


Fig. 3.19 Complete assembly drawing of prototype pneumatic planter side view

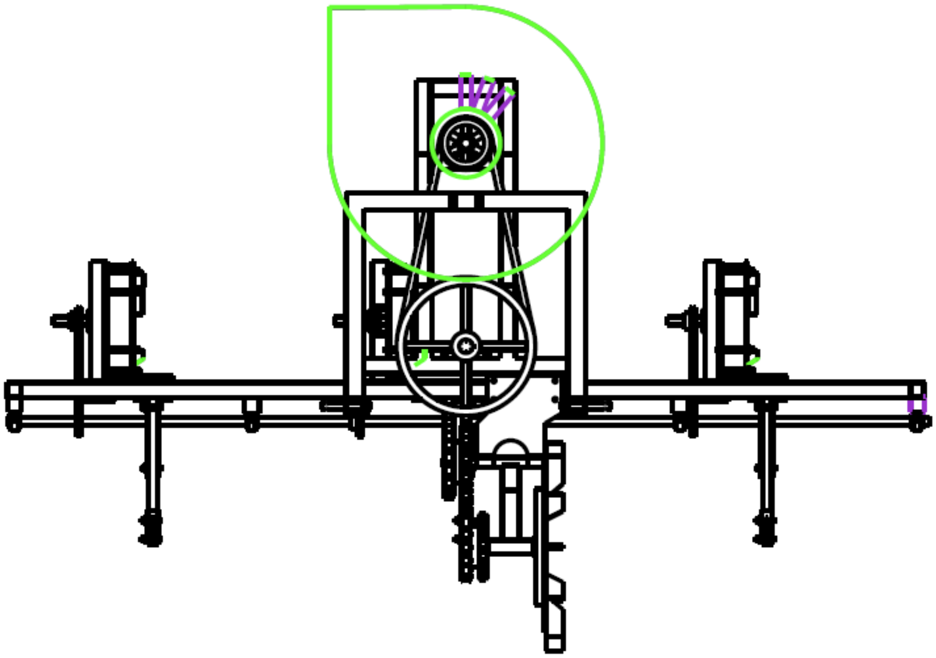


Fig. 3.20 Complete assembly drawing of prototype pneumatic planter front view

The seed hopper was mounted over metering unit cover plate and outlet tube was positioned in seed inlet of rotor which can be easily removable. The furrow opener was fabricated by taking into account of optimum depth of placement of seed required in the soils. A seed tube was fixed to boot of furrow opener. The 25 mm diameter PVC tube was inserted in to seed delivery spout of seed metering unit and other end was fixed in boot pipe. PVC tubes were selected as they are transparent, reliable and provides easy seed moment with less friction.

3.6.7.2 Main frame

The main frame was made to support the seed metering units and furrow openers to which hitch system and power transmission system provisions fitted. The overall dimension of the main frame was rectangular in shape with 2.6 × 0.9 m in size. It is fabricated with 45 × 45 × 6 mm of ST42S confirm to IS: 808-1964 (Bajaj, 1993). The front tool bar of frame was provided with mountings for fixing three point hitch of category – I. The main tool bar frame was perfectly aligned to obtain line of pull centrally to facilitate the various planter components mounting and to reduce side draft while in operation. A 12 mm gap was provided between two square sections for easy adjustment of furrow openers and seed metering units.

3.6.7.3 Furrow opener

A shoe type furrow opener was fabricated using rectangular flat of size 430 × 50 × 25 mm of C 75, which conforms Bajaj, 1993. It consists of tine (shank), shoe and a boot with tubes. Boot and tube are made from MS sheet metal of 1.8 mm thickness. Shoes are made of carbon steel and get hardened by heat treating. Three number of such furrow openers were fabricated. These are bolted to main frame in zigzag fashion at a recommended row to row spacing for cotton and okra. A 25 mm diameter pipe was welded to boot for fixing the seed tube from seed metering unit.

3.6.7.4 Transmission system

It is provided to transmit the power from the ground wheel to seed metering mechanism and drive train was shown in figure 3.19. The drive for the main shaft was taken from ground wheel assembly (ground wheel arm) fixed to the beam, which is freely suspended on counter shaft. The bush bearing of the counter shaft is fixed to the tool bar of the main frame with U clamp using nut and blots.

A ground wheel of diameter 450 mm was fabricated with 6 mm thick plate made of Fe 410. Twelve number of lugs made of 50 IS F6 of length 75 mm and welded at one side of the ground wheel made of St42S (Bajaj, 1993). The ground wheel shaft of 25 mm diameter and 190 mm length is made of 45C8, which conforms to IS: 919-1993 (Khurmi and Gupta, 2003). A key is provided to the ground wheel shaft on end to hold sprocket. A steel bush of length 90 mm with inner diameter of 16 mm lined with babbit material was fixed to the beam thus provides the bearing surface for ground wheel shaft.

Drive was taken from the ground wheel to the main shaft through chain and sprocket through roller chain of pitch 12.7 mm (Varshney *et al*., 2004). The main shaft supported on four self-aligning ball bearings with bearing block of size 30 mm diameter made of 45C8 conform to IS: 919-1993 (Khurmi and Gupta, 2003). The power form main shaft to the seed rotor was transmitted through roller chain of same pitch.

3.7 Calibration and performance evaluation of developed planter under field conditions

The developed prototype pneumatic planter was studied in terms of row to row variations in planting rate, per cent of cell fill and seed breakage. The viability of the seeds was tested after calibration of the planter to study the internal damage to the seeds during metering operation.

The laboratory testing of planter *viz.*, seed metering and uniformity of seeding tests were carried out as per IS: 6316 (Part I) - 1971. The metering test involves calibration of metering mechanism and seed breakage determination test. The calibration of metering mechanism was conducted to determine the per cent cell fill and seeding rate obtained at full capacity of hopper and variation among furrow openers, when the planter was stationary. The planter was mounted to tractor three point hitch and jacked up to make the ground wheel free. PTO shaft of a tractor was connected to blower shaft by telescopic shaft through which blower was operated. To avoid fluctuation in drive and to get different forward speeds, a two hp variable speed step up AC electric motor was fitted over frame (Plate 3.4). A drive was connected to main shaft through chain. The variable speeds are obtained by variable frequency drive regulator, which in-turn changes the in-put voltage to the motors. The rpm of the motor was set to the ground wheel rpm, hence it was operated in desired forward speeds of planter.

Plate 3.4 Laboratory calibration of developed pneumatic planter

Seed breakage determination test was carried out on one kg of seed for each of the test runs to determine the damage to the seeds during calibration. The seed breakage was computed for each metering mechanism as per procedure explained in section 3.2.3.3. The experiment was replicated for five times. The seed viability test was carried out for the seeds collected at the outlet of each metering mechanism to study the internal damage of seeds during calibration.

The uniformity of seeding test was conducted using sand bed method (IS: 6316 Part I -1971). An artificial leveled sand bed of 5000 × 2000 × 250 mm length, width and depth was prepared. The planter was allowed to travel over this bed with furrow openers lowered to 30 mm from the top surface of the bed. The number of seeds dropped and seed to seed distance for each meter of bed length were recorded.

The viability of seeds was tested before and after calibration of metering mechanism to know the effect of internal breakage to seed which effects germination (Mohsenin, 1980). A sample of seeds was taken in petty dish kept in germination chamber with 25 ± 2 °C temperature and 95 ± 5 per cent relative humidity were maintained. After 7 days the normal seedlings were counted for each sample and expressed as germination percentage.

3.7.1 Pneumatic planter prototype field testing

The performance of developed planter was tested in the field (Plate 3.5a and 3.5b) to determine the seeding rate to check the accuracy of seed placement, draft, speed, field capacity and field efficiency. A test field of 10 × 25 m with fine tilth was selected for sowing each variety of test crops. All the settings were made on the planter to achieve the recommended plant spacing for cotton and okra. The cotton and okra seeds were planted in Brahaman Pally Village near Hytanagar Research Farm of CRIDA using the developed planter.

The experiments were laid out in response surface methodology with 3 replications. The parameters of initial field conditions like moisture content and bulk density were determined using standard procedure (Anon., 1995). The machine parameter *viz*., depth of seed, speed of operation, draft, wheel slip, fuel consumption, field capacity and field efficiency were recorded during the field evaluation. The crop parameter *viz*., planting rate, uniformity of sowing depth, germination count, plant to plant distance and plant population were recorded 21 days after planting. The planter performance was analyzed in terms of plant spacing, missing hills and multiples in fifteen meter length of crop sown.

Plate 3.5(a) Side view of pneumatic planter prototype during field evaluation

Plate 3.5(b) Rear view of pneumatic planter prototype during field evaluation

3.7.1.1 Soil type and field condition

The type of soil and field condition effects on machine performance. The speed of operation and depth of sowing mainly depends on soil type, soil moisture content, bulk density and soil resistance. These soil parameters were determined with standard procedure before field evaluation of the machine based on that the necessary settings are made in the equipment.

3.7.1.2 Soil moisture content

The soil moisture content was determined as suggested by Mohsenin (1980). Core samples of wet soil at three different locations of test plot were randomly selected. Weight of the soil sample was taken using an electronic balance (sensitivity ± 0.01g). The samples were placed in hot air oven maintained at 105 °C for 8 hours. The samples were taken from oven and kept in desiccators. The bone dry weight of samples was recorded by using electronic balance. The soil moisture content on dry basis was calculated using the following formula.

$$S_m = \frac{W_1 - W_2}{W_2} \times 100 \qquad \text{… (3.94)}$$

Where, S_m is soil moisture (per cent); W_1 is initial weight of soil sample (g); W_2 is bone dry weight of soil sample (g).

3.7.1.3 Bulk density of soil

The bulk density of soil was determined by the procedure explained by Mohsenin (1980). Three soil samples were collected at different locations randomly selected in the test plot using cylindrical core soil sampler. The diameter and length of cylindrical soil sampler were measured. The soil samples are kept in hot air oven maintained at 105 °C for 24 hours. After that, sample were taken out and kept in a desiccator. The bone dry weight of soil samples was measured. The bulk density of the soil was calculated by using following formula.

$$\rho = \frac{M}{\pi D^2 L} \qquad \text{… (3.95)}$$

Where, ρ is bulk density (kg m^{-3}); M is bone dry weight of soil sample (kg); D is diameter of cylindrical core sample (m); L is length of cylindrical core sample (m).

3.7.2 Speed

The forward speed of the tractor mounted with planter was measured by marking a distance of 20 m in the field. The time required for the tractor with planter to travel a distance of 20 m was recorded. The speed of the tractor planter system was calculated by using the formula (Anon., 1995).

$$S = \frac{D}{T} \qquad \ldots (3.96)$$

Where, S is speed (ms^{-1}); D is distance travelled by the tractor with planter (m); T is time taken to travel 20 m distance (sec).

3.7.3 Draft

The draft of planter was measured using hydraulic dynamometer (0 to 10000 N). The dynamometer was attached to the front of the tractor to which the planter was attached and another tractor (auxiliary tractor) was used to pull the tractor with the planter. A distance of 20 meter was marked on the field. The auxiliary tractor pulled the tractor with planter in operating condition and the draft readings were recorded the tractor with the planter lifted condition was pulled by the auxiliary tractor attached with dynamometer and the draft at no load condition was also recorded (Anon., 1995).

The draft of the planter was computed using the formula.

$$D = D_1 - D_2 \qquad \ldots (3.97)$$

Where, D is draft of the planter (N); D_1 is draft of the tractor with planter in operating condition (N); D_2 is draft of the tractor with planter at no load condition (N).

3.7.4 Wheel slip

The wheel slip of tractor with planter was determined with the following method as suggested by (Anon., 1995). A mark was made on the tractor drive wheel with colour tape. The distance moved by the tractor in forward direction was measured for 10 revolution under no load. The tractor was run with load under the same surface for 10 revolutions. The distance travelled by the tractor was measured for no load and load condition. Percentage of wheel slip was computed using the following formula.

$$x = \frac{A - B}{A} \times 100 \qquad \ldots (3.98)$$

Where, S is wheel slip (per cent); A is distance covered by the tractor for 10 revolution under no load (m); B is distance covered by the tractor for 10 revolution with load (m).

3.7.5 Fuel consumption

The fuel consumption was measured by filling the tank to full capacity before and after the test. The quantity of refilling of the fuel after the test was the fuel consumed by the tractor for operating planter (Anon., 1995).

3.7.6 Theoretical field capacity

Theoretical field capacity of tractor with planter was calculated by using the formula (Kepner *et al.*, 1987).

$$F_t = \frac{W \times S}{10} \qquad \ldots (3.99)$$

Where, F_t is theoretical field capacity (ha h^{-1}) W is rated width of planter (m); S is speed of tractor with planter (km h^{-1}).

3.7.7 Field efficiency

Field efficiency of tractor with planter was computed using the formula. (Anon., 1995).

$$E_f = \frac{W_e \times V_e \times T_p}{W_t \times V_t \times (T_p + T_1)} \qquad \ldots (3.100)$$

Where, E_f is field efficiency (percent); W_e is effective working width (m); W_t is rated width (m); V_e is effective operation speed (m s^{-1}); V_t is theoretical operation speed (m s^{-1}); T_p is productive time (sec); T_1 is unproductive time (sec).

3.7.8 Effective field capacity

Effective field capacity of tractor with planter was computed by using the formula (kepner *et al.*, 1987).

$$F_c = F_t \times E_f \qquad \ldots (3.101)$$

Where, F_c is effective field capacity (ha h^{-1}); E_f is field efficiency (per cent); F_t is theoretical field capacity (ha h^{-1}).

3.7.9 Seeding rate

The hopper was filled with graded seeds before starting the sowing operation. An area of 10 m^2 at six locations was marked in the field. The sowing operation was carried out using planter in the field. The number of seeds dropped (counter readings) from each furrow opener were recorded. The seeding rate in terms of seeds per square meter was determined for the respective test crops (Raheman and Singh, 2003).

3.7.10 Uniformity of sowing depth

The uniformity of sowing depth for six samples was determined by soil slicing method as suggested by Heege (1993). Plain slice of soil of five mm thickness were cut consecutively from the soil surface using slicing unit at an angle to the direction of travel and the depth. The sample was placed on a sieve which retained the seeds. When most of soil had passed the sieve, the number of seeds was counted. The seeds were collected from each opener. The deviation in the planting depth of adjacent openers were added to deviations from mean sowing depth within the single openers.

3.7.11 Germination count

Six sampling area of 1 × 1 m each were randomly selected in the test plot. The number of seeds germinated in one meter length of each row was counted on 15th day of planting Mohsenin, (1980). The seeds not germinating in the soil were dug and counted. The germination count in the field in terms of percentage was determined for the selected test crops.

3.7.12 Plant to plant distance

The plant to plant distance was measured in a length of 15 m in a row at six randomly selected location. The per cent missing hills, single, double, and triple plant (s) per hill were counted. The percentage deviation from recommended plant to plant spacing was computed. The variation among rows in respect of plant to plant distance was also analyzed by Jasa and Dickey (1982).

3.7.13 Plant population

The plant population in the field for each test crops was recorded using the standard method (IS: 6316-1971). A square ring of 1 × 1 m was used to measure the plant count per unit area. A square ring was placed randomly on number of locations in the field and the number of plants inside the ring was counted. The average plant population per square meter for each variety of test crops was calculated.

3.7.14 Coefficient of precision

The coefficient of precision was determined in a length of 15 m row at six randomly selected location using following formula (Panning *et al*., 2000).

$$C_p = \frac{n_1}{n_2} \quad \dots (3.102)$$

Where, C_p is coefficient of precision (per cent); n_1 number of plants within 15 mm mode range of theoretical plant to plant distance; n_2 is total number of plants in the sample.

3.8 Economics of developed prototype planter

The unit cost of operation of prototype multi crop inclined plate planter was estimated by considering fixed and variable costs (IS: 9164 - 1979). The break - even point of the planter was also calculated. The details of calculation is given in appendix I and II.

IV. EXPERIMENTAL RESULTS

In this chapter, the physical and aerodynamic properties of cotton and okra seeds are summarized. Test results of newly developed pneumatic seed metering mechanism under simulated condition using experimental test rig and computer vision system are presented. The vacuum air pressure simulation with respect to cell diameter and rotor speed was performed using ANSYS CFD software results were also depicted. Laboratory experimental results of seed metering mechanisms are optimized and presented in this chapter. This chapter also includes the results of pneumatic planter prototype calibration; testing and its performance evaluation for planting of cotton and okra seeds are under laboratory and field conditions, respectively. The cost of planter fabrication and operation are estimated and presented in this chapter.

4.1 Physical, mechanical and aerodynamic properties of cotton and okra seeds

All physical, mechanical and aerodynamic properties of three varieties of cotton namely Ankur 651(CH1), ATM (CH2) and Jaadoo (CH3) and okra varieties of Kaveri 49 (OH1), Anamika (OH2) and RK501 (OH3) seeds were procured from commercial seed suppliers. The moisture content of the selected seeds was determined with three replications and results are presented in sub sections. Selected seed linear dimensions were measured manually and using image processing techniques and results are correlated and presented below. The results of important physical and mechanical properties like frontal area, thousand seed mass, true density, bulk density and porosity were presented here under. Aerodynamic properties like terminal velocity and drag coefficient were also determined experimentally as explained in section 3.1.12 and results summarized in this section.

4.1.1 Linear dimensions of seeds

The average length of cotton seed were found to be 9.086, 9.197 and 8.263 mm by experimental method whereas, 8.902, 9.038 and 8.095 mm was obtained by image analysis technique for CH1, CH2 and CH3, respectively. The mean reduction in length of cotton seed in image processing technique was found to be 2.07 per cent and processed and resulted images of seed were shown in figure 4.1. The measured width of cotton seed varied within the range from 3.944 to 5.816 mm for selected varieties with mean value of 4.815, 5.068 and 4.734 mm. Width determined from image analysis technique was 4.623, 4.895 and 4.626 mm for CH1, CH2 and CH3, respectively.

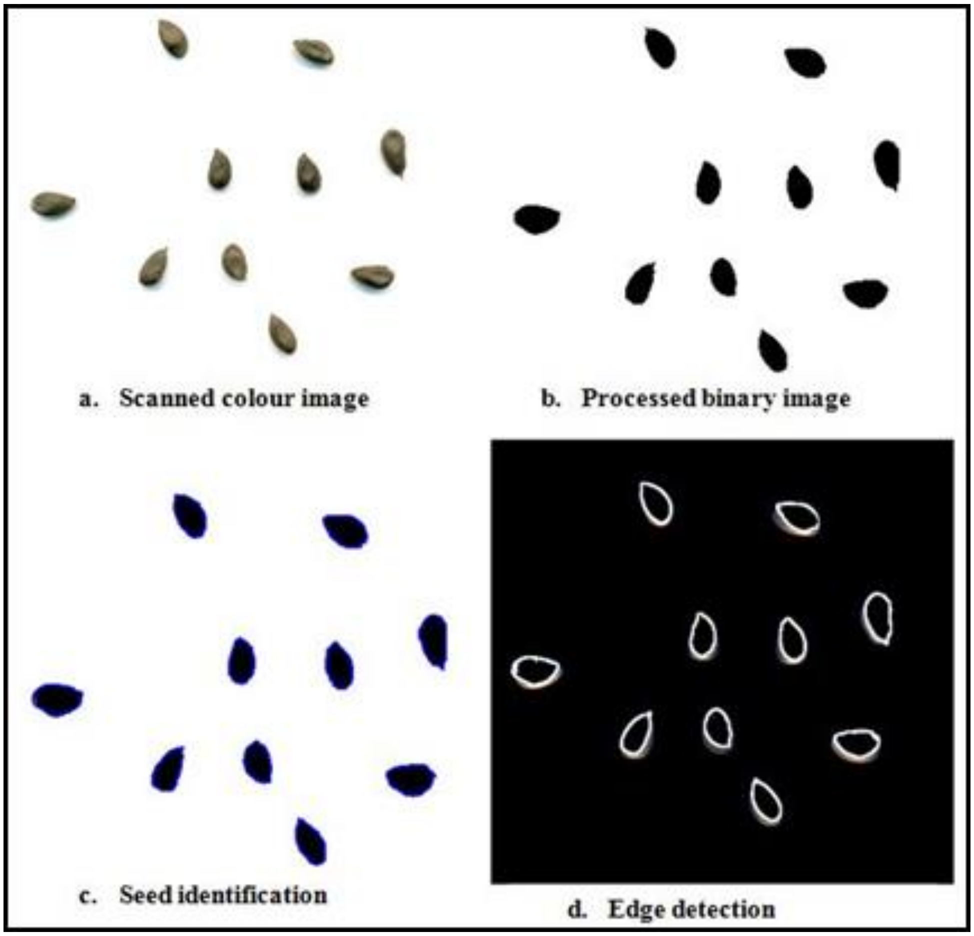


Fig. 4.1 Cotton seed image at different steps during image processing

The linear dimensions mean values and standard deviations of cotton seeds were tabulated in Table 4.1 and its regression equation and R^2 value were presented in Table 4.2. The thickness of selected cotton seeds are varied between 3.573 to 5.098 mm with mean value of 4.316, 4.983 and 4.183 for CH1, CH2 and CH3, respectively.

A strong linear relationship was found between values of experimental method and image analysis technique in length and width of selected cotton seeds. The determined linear regression coefficient for length of CH1, CH2 and CH3 were 0.889, 0.932 and 0.914, respectively. Regression coefficient between both determination methods for width was found to be 0.919, 0.924 and 0.945 for CH1, CH2 and CH3, respectively from Table 4.2.

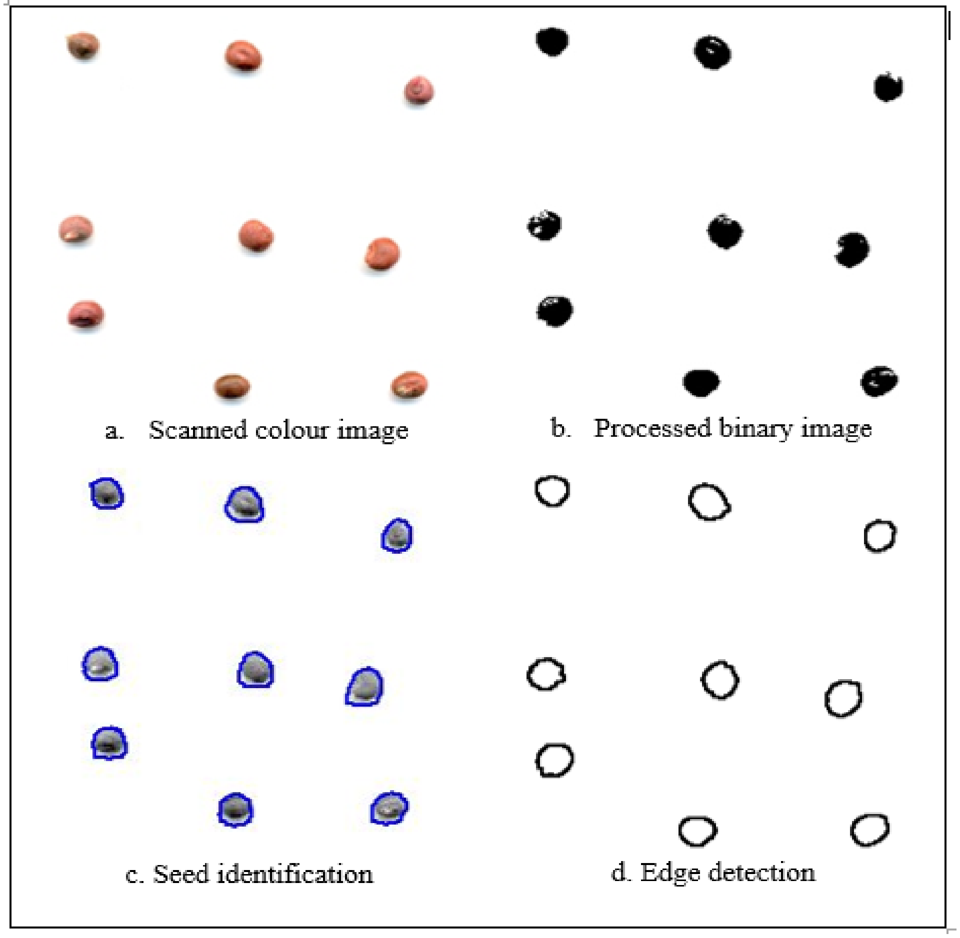
Seed linear dimensions like length and width of okra varieties were also studied using both methods and average values are presented in Table 4.3. The resulted images after processing were depicted in figure 4.2. Measured length of okra seeds was varied from 4.86 to 5.99 mm while the width from 4.09 to 4.86 mm, irrespective of method of determination. Average thickness of selected seed was found to be 4.36, 4.60 and 4.68 mm for OH1, OH2 and OH3, respectively.

Liner relationships between two methods of measurements are expressed in terms of equation with coefficient of determination (R^2) for okra seed length and width are presented in Table 4.4. A highest R^2 value was found to be 0.905 (OH1) for length and 0.926 (OH2) for width.

4.1.2 Physical and mechanical properties of cotton and okra

Physical properties like moisture content, projected area, sphericity, unit mass, volume, thousand seed mass, true density, bulk density and porosity were determined experimentally for all the selected varieties of cotton as depicted in Table 4.5. Among the selected varieties, the projected area was higher for CH2 (39.86 mm^2) followed by CH1 (36.173 mm^2) and CH3 (29.73 mm^2). The computed mean sphericity values were 0.608, 0.636 and 0.669 for CH1, CH2 and CH3, respectively.

It is seen from the results that, the mean mass of 1000 seeds were observed to be 94.68, 83.86 and 89.26 g for CH1, CH2 and CH3, respectively. The average true density and bulk density values were found to be 1107.683, 1285.432 and 1235.896 kg m^{-3} and 589.137, 576.765 and 480.563 kg m^{-3} for CH1, CH2 and CH3 cotton hybrids, respectively.



a. Scanned colour image

b. Processed binary image

c. Seed identification

d. Edge detection

Fig. 4.2 Okra seed image at different steps during image processing

Table 4.1 Linear dimensions of selected varieties of cotton seeds

Linear dimensions of seed	No. of observations	Methods			
		Experimental		Image analysis	
		Mean	SD	Mean	SD
CH1 variety					
Length, *L* (mm)	100	9.086	0.89	8.902	0.93
Width, *W* (mm)	100	4.815	0.51	4.623	0.58
Thickness, *T* (mm)	100	4.316	0.59	--	--
CH2 variety					
Length, *L* (mm)	100	9.197	0.92	9.038	0.87
Width, *W* (mm)	100	5.068	0.61	4.895	0.63
Thickness, *T* (mm)	100	4.983	0.53	--	--
CH3 variety					
Length, *L* (mm)	100	8.263	0.56	8.095	0.62
Width, *W* (mm)	100	4.734	0.43	4.626	0.32
Thickness, *T* (mm)	100	4.183	0.34	--	--

Table 4.2 Regression equation and coefficient of determination between two methods

Varieties	Seed length		Seed width	
	Regression Equation	R^2	Regression Equation	R^2
CH1	$Y = 0.882X + 0.647$	0.889	$Y = 0.986X – 0.315$	0.919
CH2	$Y = 0.938X + 0.053$	0.932	$Y = 0.925X – 0.026$	0.924
CH3	$Y = 1.050X - 0.877$	0.914	$Y = 1.0X – 0.368$	0.945

Where, Y is experimental method; X is image processing method.

Table 4.3 Linear dimensions of selected varieties of okra seeds

Linear dimensions of seed	No. of observations	Methods			
		Experimental		Image analysis	
		Mean	SD	Mean	SD
OH1 variety					
Length, *L* (mm)	100	5.55	0.46	5.39	0.12
Width, *W* (mm)	100	4.49	0.51	4.41	0.15
Thickness, *T* (mm)	100	4.36	0.42	--	--
OH2 variety					
Length, *L* (mm)	100	5.19	0.38	5.06	0.18
Width, *W* (mm)	100	4.72	0.47	4.60	0.17
Thickness, *T* (mm)	100	4.60	0.29	--	--
OH3 variety					
Length, *L* (mm)	100	5.59	0.49	5.47	0.11
Width, *W* (mm)	100	4.58	0.55	4.50	0.14
Thickness, *T* (mm)	100	4.68	0.43	--	--

Table 4.4 Regression equation and coefficient of determination between two methods

Varieties	Seed length		Seed width	
	Regression Equation	R^2	Regression Equation	R^2
OH1	Y = 0.883X + 0.489	0.905	Y = 0.975X – 0.026	0.891
OH2	Y = 1.009X – 0.179	0.881	Y = 0.993X – 0.094	0.926
OH3	Y = 0.975X + 0.026	0.891	Y = 0.907X + 0.348	0.879

Where, Y is experimental method; X is image processing method.

The mechanical properties like angle of repose and friction coefficients were also studied in this experiment for all the three varieties of cotton seeds at respective moisture content and presented in Table 4.5. The measured angle of repose was 39.195º, 35.363º and 38.569º for CH1, CH2 and CH3 seed varieties, respectively. The average lowest coefficient of static friction for the three varieties of cotton seeds against three material surfaces *i.e.* mild steel, card board and nylon sheet were 0.412, 0.382 and 0.296 for CH3, CH2 and CH1 cotton hybrids, respectively. The coefficient of static friction for the cotton seed varieties against each surface is very closer, which indicates that friction property of cotton seed varieties was not much affected by the material surfaces. Among the selected material surfaces, galvanized iron offered the maximum coefficient of static friction followed by mild steel and nylon sheet (Table 4.5).

Physical and mechanical properties of selected varieties of okra seeds were experimentally determined and data was tabulated in Table 4.6. The observed moisture content for the selected OH1, OH2 and OH3 was 9.75, 7.64 and 8.27 per cent on dry basis, respectively. The maximum sphericity was found to be 0.916 for OH3 while the minimum was observed to be 0.881 for OH2 variety. The average volume of a single seed for selected okra varieties was varied from 49.09 to 54.84 mm^3. The thousand seed mass of 94.37 g was found maximum, while minimum was noticed for OH2 (87.16 g) varieties. The porosity was calculated from the bulk density and true density of the seed. It was found 48.26, 52.16 and 53.11 per cent for OH1, OH2 and OH3 varieties, respectively.

Mechanical properties like angle of repose and coefficient of friction were presented in Table 4.6. The maximum angle of repose was observed for OH2 (29.16º) variety, whereas the minimum was found to be 26.13º for OH1 variety of okra seeds. The figures from the Table 4.6 indicates that, the Nylon sheet surface has offered a lowest coefficient of friction (0.24) whereas highest was noticed in galvanized iron surface of 0.43 for OH2.

4.1.3 Aerodynamic properties of selected cotton and okra seeds

The measured average terminal velocity of cotton seeds for selected varieties is tabulated in Table 4.7. It was observed that, terminal velocity of 8.917, 8.792 and 8.818 m s^{-1} were observed for CH1, CH2 and CH3 varieties, respectively. The variation in terminal velocity among selected seed varieties were found very minimum, which may be due to the fact that, the lots were selected from the grain which is under gone processes meant for seed purpose.

Table 4.5 Physical and mechanical properties selected varieties of cotton seeds

Properties	No. of observations	Seed varieties		
		CH1	CH2	CH3
Moisture content (d. b.)	5	9.86	8.63	9.37
Projected area, P_a (mm^2)	100	36.173	39.86	29.73
Sphericity, Ø	100	0.608	0.636	0.669
Unit Mass (g)	100	0.098	0.086	0.089
Mass of 1000 seed (g)	5	94.682	83.857	89.264
Volume, V (mm^3)	10	93.917	89.467	86.633
True density, ρ_t (kg m^{-3})	10	1107.683	1285.432	1235.896
Bulk density , ρ_b (kg m^{-3})	5	589.137	576.765	480.563
Porosity, P_f (%)	5	46.764	53.961	52.638
Angle of repose, θ (°)	5	39.195	35.363	38.569
Coefficient of friction (μ)				
Mild steel	5	0.432	0.415	0.412
Galvanized iron	5	0.441	0.429	0.437
Nylon sheet	5	0.296	0.329	0.308

Table 4.6 Physical and mechanical properties selected varieties of **okra seeds**

Properties	No. of observations	Seed varieties		
		OH1	OH2	OH3
Moisture content (d. b.)	5	9.75	7.64	8.27
Projected area, P_a (mm^2)	100	22.46	20.89	24.09
Sphericity, Ø	100	0.903	0.881	0.916
Unit Mass (g)	100	0.068	0.065	0.73
Mass of 1000 seed (g)	5	93.68	87.16	94.37
Volume, V (mm^3)	10	52.53	54.84	49.09
True density, ρ_t (kg m^{-3})	10	1131.02	1197.05	1279.9
Bulk density , ρ_b (kg m^{-3})	5	588.25	579.19	601.56
Porosity, P_f (%)	5	48.26	52.16	53.11
Angle of repose, θ (°)	5	26.13	29.16	27.97
Coefficient of friction (μ)				
Mild steel	5	0.38	0.41	0.42
Galvanized iron	5	0.40	0.43	0.41
Nylon sheet	5	0.24	0.32	0.29

4.7 Terminal velocity and drag coefficient of selected varieties cotton and okra seeds

Varieties	Terminal velocity (m s^{-1})	S E (m)	Drag coefficient	S E (m)
Cotton seeds				
CH1	8.917	0.059	0.58	0.26
CH2	8.792	0.048	0.61	0.28
CH3	8.818	0.055	0.63	0.25
Okra seeds				
OH1	5.98	0.049	0.45	0.21
OH2	5.47	0.042	0.43	0.25
OH3	5.62	0.039	0.47	0.22

The range of terminal velocity and drag coefficient were determined at respective moisture content of okra seeds are presented in Table 4.7. The average terminal velocity of okra seed is 5.98, 5.47 and 5.62 for OH1, OH2 and OH3 okra seed variety, respectively. The minimum drag coefficient was found to be 0.45 for OH1, whereas maximum of 0.47 was noticed for OH3 Variety. The minute variation terminal velocity and drag coefficient between the seed varieties may due change individual seed mass and projected area.

4.2 Design and development of pneumatic seed metering mechanism

The pneumatic seed metering mechanism was designed and developed based on its fundamental working concept and keeping existing metering device drawbacks in mind. The seed metering mechanism consists of rear frame shield, seed rotor with drive shaft and cover plate. The details of newly developed metering mechanism are discussed in section 3.3. In order to optimize the design parameters of pneumatic seed metering mechanism, a three different dimension vacuum chamber and atmospheric opening seed metering mechanisms models were developed with similar design concept as given in Table 3.1 and its conceptual design details with 3D model was discussed in section 3.3.2.

4.3 Testing and optimization of design and operational parameters under simulated conditions

Three different seed metering mechanisms (Table 3.1) were developed as explained in section 3.3.5 of previous chapter and tested under simulated conditions as described in section 3.4.2 for cotton and okra seeds. Optimization of design and operational parameters of pneumatic planter was performed by analyzing laboratory experimental results using statistical technique called response surface methodology (RSM) using design expert software 7.7.0. Experiments were conducted according to rotatable design sequence and influencing independent parameters were set at five levels as listed in Table 3.2.

For selected three factors, each at five levels with quadratic polynomial model and numerical optimization technique were used to find the optimum value of vacuum pressure (P), rotor speed (S) and cell diameter (D) for testing of developed seed metering performance. In addition to the selected single factors, the interaction effects were also analyzed through cubic model terms and significance of the results were summarized and discussed in this section. The effect of design and operational parameters of pneumatic seed metering for cotton and okra were discussed as here under.

4.3.1 Effect of independent variables (*P*, *S* & *D*) on performance of developed seed metering mechanism models for cotton seeds

The effect of design and operational (Independent variables) parameters were evaluated based on the measures of theoretical seed spacing. According to ISO (1984) defined measures of seed metering mechanism includes miss index, multiple index, quality feed index and precision index were set as dependent variables for the optimization. Quality feed index parameter was neglected while optimization, because it is an alternative way of presenting the information contained in miss and multiple indices (Katchman and Smith, 1995). Numerical optimization technique is used to select the best suitable design model and optimum treatment combination as given in Table 3.4. Experimental results were tabulated with respect to performance indices for individual seed metering model and discussed under the successive sub headings of this section.

4.3.1.1 Miss index for cotton seeds

Miss index for the tested models were computed as per procedure explained in section 3.4.6 and results are tabulated in Table 4.8 with respect to treatment combination and run number.

From Table 4.8 it is observed that miss index was found lowest of 4.06, 2.86 and 3.24 per cent for SMM1, SMM2 and SMM3, respectively at 2.50 k Pa vacuum pressure with 3.84 mm cell diameter at 0.83 m s^{-1} of rotor speed. The highest miss index of 21.26 and 22 per cent for SMM1 and SMM2, respectively observed at run no. 15, but 20.16 of SMM3 model was found at run no. 18 from Table 4.8. To identify significantly effected independent variable and its intensity on individual model performance was computed through statistical analysis and presented in Table 4.9. Quadratic polynomial model was fitted to each designed model with respect to coded independent variable and discussed below.

The effect of vacuum pressure (*P*), rotor speed (*S*) and cell diameter (*D*) significantly influenced the miss index at 5 per cent level of significance and the model F values were 9.44 (SMM1), 8.36 (SMM2) and 5.93 (SMM3) implies that , the model was significant at this level. The interaction effect of variables $P \times S$, $P \times D$, $S \times D$ and $P \times S \times D$ were not significantly influenced the miss index. The fit of model was expressed by the coefficient of determination (R^2), which was found to be 0.9534, indicating that 95.34 per cent of the variability of response could be explained by the model.

Table 4.8 Effect of independent variables (*P*, *S* & *D*) on miss index of cotton seeds

Run	Vacuum Pressure (*P*) k Pa	Forward Speed (*S*) m s^{-1}	Cell Dia. (D) mm	SMM1 model	SMM2 model	SMM3 model
1	2.50	0.83	3.00	7.15	6.02	5.81
2	2.50	0.83	3.00	6.36	5.77	7.79
3	2.50	0.83	3.00	7.71	7.73	8.14
4	2.50	0.83	3.00	6.12	5.99	6.39
5	2.50	0.83	3.00	5.56	6.54	6.89
6	2.50	0.83	3.00	6.23	7.64	7.93
7	2.00	0.69	2.50	10.58	9.88	10.33
8	3.00	0.69	2.50	6.45	7.82	8.03
9	2.00	0.97	2.50	13.63	12.43	13.12
10	3.00	0.97	2.50	8.19	7.97	8.32
11	2.00	0.69	3.50	9.49	10.13	11.42
12	3.00	0.69	3.50	5.88	6.19	4.49
13	2.00	0.97	3.50	13.56	11.56	10.86
14	3.00	0.97	3.50	7.13	5.58	6.59
15	1.66	0.83	3.00	21.26	22	19.33
16	3.34	0.83	3.00	4.23	5.21	6.11
17	2.50	0.59	3.00	8.46	6.43	7.71
18	2.50	1.07	3.00	18.24	16.71	20.16
19	2.50	0.83	2.16	11.42	12.33	12.48
20	2.50	0.83	3.84	4.06	2.86	3.24

Table 4.9 Analysis of variance for response of miss index for cotton seeds

Source	DF	SMM1 MODEL			SMM2 MODEL			SMM3 MODEL		
		Sum of squares	F value	P value	Sum of squares	F value	P value	Sum of squares	F value	P value
Model	13	373.37	9.44	0.0058*	358.21	8.36	0.0079*	339.21	5.93	0.0192*
P	1	143.31	47.10	0.0005*	140.95	42.76	0.0006*	87.38	19.84	0.0043*
S	1	47.82	15.72	0.0074*	52.84	16.03	0.0071*	77.50	17.60	0.0057*
D	1	27.08	8.90	0.0245*	44.84	13.60	0.0102*	42.69	9.69	0.0208*
$P\ S$	1	2.13	0.70	0.4346	2.46	0.75	0.4205	0.00	0.00	0.9794
$P\ D$	1	0.03	0.01	0.9272	1.44	0.44	0.5325	2.10	0.48	0.5155*
$S\ D$	1	0.04	0.01	0.9180	0.44	0.13	0.7269	0.30	0.07	0.8040
P^2	1	42.70	14.03	0.0096*	57.56	17.46	0.0058*	28.76	6.53	0.0432
S^2	1	54.97	18.06	0.0054*	23.22	7.15	0.0368*	48.91	11.11	0.0158
D^2	1	0.01	0.00	0.9493	0.23	0.07	0.8008	1.35	0.31	0.6004
$P\ S\ D$	1	0.29	0.09	0.7699	0.016	0.00	0.9464	3.33	0.76	0.4181
$P^2\ S$	1	8.95	2.94	0.1371	22.68	6.88	0.0394*	32.34	7.34	0.0351*
$P^2\ D$	1	11.21	3.68	0.1033	16.56	5.02	0.0662	12.50	2.84	0.1430
PS^2	1	22.09	7.26	0.0358*	28.58	8.67	0.0258*	8.94	2.03	0.2040
LoF	1	15.25	25.39	0.0040*	16.02	21.31	0.0058*	21.98	24.77	0.0042
		Mean		9.08	Mean		8.84	Mean		9.26
		Std. Dev.		1.74	Std. Dev.		1.82	Std. Dev.		2.10

DF: Degrees of freedom; * Significant at 5 percent level; *LoF*: Lack of Fit;Std. Dev.: Standard deviation

The adjusted R^2 was 0.8524 and adequate precision was 11.71 shows an adequate signal. A ratio greater than four is desirable and hence this model may be used to navigate the design space. Considering all the above criteria, the model (Eq. 4.1) was selected for representing the variation of miss index and for further analysis of the SMM1.

The cubic model obtained from regression analysis for miss index of SMM1 model in terms of coded levels of the variables is as follows,

$$\text{Miss index (SMM1)} = 6.59 - 5.03P + 2.91S - 2.19D - 0.52PS - 0.059PD + 0.066SD + 1.72P^2 + 1.95S^2 - 0.03D^2 - 0.19PSD - 1.64P^2S + 1.84P^2D + 2.58PS^2 \quad \ldots (4.1)$$

Where, P is vacuum pressure (k Pa), S is rotor speed (m s^{-1}) and D is cell diameter (mm).

The miss index of SMM2 model was also expressed by the coefficient of determination (R^2), which was found to be 0.9463, indicating that 94.63 per cent of the variability of the response could be explained by the model. The adjusteduted R^2 was 0.8299 and adequate precision was 12.40 showed an adequate signal. Observed adequate precision ratio was 12.40 which indicate an adequate signal.

Considering all the above criteria, the model (Eq. 4.2) was selected for representing the variation in miss index of SMM2 model and for further analysis. Final equation for miss index for SMM2 model, in terms of coded levels of the independent variables was as follows,

$$\text{Miss index (SMM2)} = 6.69 - 4.99P + 3.06S - 2.82D - 0.56PS - 0.43PD - 0.24SD + 2.02P^2 + 1.30S^2 - 0.11D^2 + 0.045PSD + 2.62P^2S + 2.24P^2D + 2.94PS^2 \quad \ldots (4.2)$$

The miss index model for the SMM3 model was formulated as equation 4.3 from coefficients of coded independent variables. Coefficient of determination was found to 0.9277 where as predicted R^2 is -12.271. The negative predicted R^2 value implies that the overall mean (9.26) is a better predictor of the response.

$$\text{Miss index (SMM3)} = 7.24 - 3.93P + 3.70S - 2.75D - 0.02PS - 0.51PD - 0.19SD + 1.41P^2 + 1.84S^2 - 0.31D^2 + 0.64PSD - 3.12P^2S + 1.94P^2D + 1.64PS^2 \quad \ldots (4.3)$$

The adequate precision ratio for SMM1, SMM2 and SMM3 model were 11.716, 12.6 and 9.637, respectively, it indicates model equation can be used to navigate the design space.

4.3.1.2 Multiple index for cotton seeds

Multiple index for cotton seed was varied from 2.19 to 15.64 per cent for the tested seed metering mechanism models. From Table 4.10, minimum multiple index of 2.19 per cent was observed for treatment $P_3S_3D_1$ *i.e.* 2.5 k Pa vacuum pressure, 0.83 m s^{-1} rotor speed and 2.16 mm cell diameter of SMM2 model whereas, maximum multiple index 15.64 per cent was noticed for treatment $P_5S_3D_3$ of SMM1 model.

Table 4.11 revels statistical attributes of multiple index of cotton seeds for all tested models of the study. Quadratic polynomial model fitted to the experimental results of multiple index shows that model F value for SMM1, SMM2 and SMM3 were 33.15, 34.29 and 19.53 respectively, implies the model is significant at 5 per cent of level of significance whereas, the lack of fit F value was 0.35 (SMM1), 0.01 (SMM2) and 0.01 (SMM3) which implies that it is not significant which seems fitted model is good. The fit of model for SMM1 was also expressed by the coefficient of determination (R^2), which was found to be 0.9841, indicating that 98.41 per cent of the variability of the response could be explained by the model. The adjusteduted R^2 was 0.9497 and adequate precision was 22.93 showed an adequate signal which is desirable.

Considering all the above criteria, the model (Eq. 4.4) was selected for representing the variation of multiple index for SMM1 model and for further analysis. The cubic model for multiple index in terms of coded levels of the variables was as follows,

$$\text{Multiple index (SMM1)} = 8.61 + 3.99P - 1.06S + 2.61D - 0.66PS + 0.76PD - 0.29SD + 0.55P^2 - 0.54S^2 - 0.45D^2 + 0.27PSD + 0.36P^2S - 1P^2D - 3.11PS^2 \quad \ldots (4.4)$$

ANOVA for response surface cubic model of SMM2 model was depicted in Table 4.11. The values of "Prob. > F" less than 0.05 indicates model terms are significant. The coefficient of determination (R^2) of 0.9867, the predicted R^2 of 0.9735 is in agreement with the adjusted R^2 of 0.9579. Adequate precision of 9.736 shows an adequate signal. A ratio greater than 4 adequate precision is desirable and hence this model may be used to navigate the design space.

The quadratic polynomial model obtained from regression analysis for multiple index in terms of coded factors of the variables is as follows,

$$\text{Multiple index (SMM2)} = 7.75 + 3.34P - 1.57S + 3.65D + 0.023PS + 1.05PD + 0.25SD + 0.18P^2 - 0.67S^2 + 0.21D^2 + 0.51PSD - 1.38P^2S - 2.33P^2D - 1.64PS^2 \quad \ldots (4.5)$$

Table 4.10 Effect of independent variables (***P***, ***S*** & ***D***) on multiple index of cotton seeds

Run	Vacuum Pressure (*P*) k Pa	Forward Speed (*S*) m s^{-1}	Cell Dia. (D) mm	SMM1 model	SMM2 model	SMM3 model
1	2.50	0.83	3.00	8.88	7.09	6.81
2	2.50	0.83	3.00	8.11	8.64	9.11
3	2.50	0.83	3.00	8.49	6.77	7.27
4	2.50	0.83	3.00	8.66	7.98	6.97
5	2.50	0.83	3.00	9.88	7.56	7.11
6	2.50	0.83	3.00	7.67	8.48	6.48
7	2.00	0.69	2.50	5.46	5.48	7.46
8	3.00	0.69	2.50	7.55	7.76	6.89
9	2.00	0.97	2.50	6.47	5.58	5.95
10	3.00	0.97	2.50	4.86	5.89	4.12
11	2.00	0.69	3.50	8.06	6.54	7.49
12	3.00	0.69	3.50	12.33	10.96	10.16
13	2.00	0.97	3.50	7.05	5.59	5.89
14	3.00	0.97	3.50	12.97	12.16	14.56
15	1.66	0.83	3.00	2.21	2.63	4.12
16	3.34	0.83	3.00	15.64	13.86	13.82
17	2.50	0.59	3.00	9.04	8.46	7.69
18	2.50	1.07	3.00	4.46	3.19	3.88
19	2.50	0.83	2.16	3.11	2.19	3.83
20	2.50	0.83	3.84	12.88	14.46	13.16

Table 4.11 Analysis of variance for response of multiple index for cotton seeds

Source	DF	SMM1 MODEL			SMM2 MODEL			SMM3 MODEL		
		Sum of squares	**F value**	**P value**	**Sum of squares**	**F value**	**P value**	**Sum of squares**	**F value**	**P value**
Model	13	217.80	33.15	0.0002*	209.28	34.29	0.0002*	183.60	19.53	0.0008*
P	1	90.18	178.45	0.0001*	63.06	134.30	0.0001*	47.05	65.06	0.0002*
S	1	10.49	20.75	0.0039*	13.89	29.58	0.0016*	7.26	10.04	0.0194*
D	1	47.73	94.44	0.0001*	75.28	160.33	0.0001*	43.52	60.19	0.0002*
$P\ S$	1	0.53	1.04	0.3473	0.00	0.01	0.929	2.81	3.88	0.0962*
$P\ D$	1	11.79	23.32	0.0029*	8.82	18.79	0.0049*	23.60	32.64	0.0012*
$S\ D$	1	0.21	0.42	0.5389	0.51	1.09	0.3375	6.27	8.67	0.0258*
P^2	1	0.38	0.75	0.4206	0.49	1.04	0.3477	5.21	7.20	0.0363*
S^2	1	5.31	10.51	0.0176*	6.50	13.85	0.0098	3.97	5.49	0.0576*
D^2	1	0.40	0.79	0.4070	0.65	1.38	0.2844	2.71	3.74	0.1012
$P\ S\ D$	1	3.58	7.08	0.0375*	2.12	4.52	0.0777	6.59	9.11	0.0234*
$P^2\ S$	1	4.05	8.01	0.0299*	6.28	13.38	0.0106*	2.98	4.12	0.0888
$P^2\ D$	1	2.66	5.26	0.0616	18.00	38.33	0.0008*	3.75	5.19	0.0630
PS^2	1	23.43	46.36	0.0005*	8.93	19.01	0.0048*	10.34	14.30	0.0092*
LoF	1	0.20	0.35	0.5822	0.007	0.013	0.0002	0.004	0.005	0.9458
		Mean		8.19	Mean		7.56	Mean		7.64
		Std. Dev.		0.71	Std. Dev.		0.69	Std. Dev.		0.85

DF: Degrees of freedom; * Significant at 5 percent level; *LoF*: Lack of Fit;Std. Dev.: Standard deviation

From Table 4.11, statistical attributes analysis was made for the multiple index of SMM3 model, which shows the model terms was significant at 5 per cent level. The fitted model of multiple index of SMM3 was expressed by the coefficient of determination (R^2), which was found to be 0.9769, indicating that 97.69 per cent of the variability of response could be explained by the model. The adjusted R^2 was 0.9269 and adequate precision was 15.032 shows an adequate signal. A ratio greater than 4 is desirable and hence this model may be used to navigate the design space. Considering all the above criteria, the model (Eq. 4.6) was selected for representing the variation of multiple index and for further analysis.

$$\text{Multiple index (SMM3)} = 7.29 + 2.88P - 1.13S + 2.77D + 0.059PS + 1.72PD + 0.89SD + 0.6P^2 - 0.52S^2 + 0.43D^2 + 0.91PSD - 0.95P^2S - 1.06P^2D - 1.774PS^2 \quad \dots (4.6)$$

The statistical attributes presented in Table 4.11 revels that, linear terms *P, S* and *D* for all models had significant effect on multiple index. Further the linear interaction terms PS, PD, P^2, PSD and PS^2 were also found significant at 5 per cent level of significance. P value greater than 0.1 indicates model terms are not significant.

4.3.1.3 Precision index for cotton seeds

The experimental results carried out in the laboratory based on CCD principle using RSM methodology are presented in Table 4.12. It is observed that, the metering mechanism operated at 0.83 m s^{-1} forward speed, 2.16 mm cell diameter and 2.5 k Pa vacuum pressure (run no. 19 in Table 4.12) gives satisfactory results in terms of precision index (9.76) for all tested seed metering models. Precision is a measure of the variability in spacing between seeds after accounting for variability due to both multiple and skips.

ANOVA for responses of cubic model for precision index was presented in Table 4.13. The model F values were 6.85, 5.094 and 6.03 for SMM1, SMM2 and SMM3 model, respectively, implies the model is significant at 5 per cent level of significance. The p values less than 0.05 indicates model terms are significant, hence P, D, P^2S, P^2D *and* PS^2 variables were found significant model terms of precision index of Table 4.13.

From Table 4.13 revels F value of lack of fit observed to be 1.67, 7.61 and 0.16 implies, the lack of fit is not significant relative to the pure error which is good for the model term. The computed R^2 value is 0.9369 for SMM1, whereas the predicted R^2 (-2.5557) was found negative which implies that, the overall mean is a better predictor of the response.

Table 4.12 Effect of independent variables (*P*, *S* & *D*) on precision index of cotton seeds

Run	Vacuum Pressure (*P*) k Pa	Forward Speed (*S*) m s^{-1}	Cell Dia. (D) mm	SMM1 model	SMM2 model	SMM3 model
1	2.50	0.83	3.00	21.58	19.26	20.09
2	2.50	0.83	3.00	20.06	20.01	22.41
3	2.50	0.83	3.00	19.88	15.4	17.18
4	2.50	0.83	3.00	16.59	18.96	17.24
5	2.50	0.83	3.00	15.26	15.88	16.19
6	2.50	0.83	3.00	16.42	15.44	15.89
7	2.00	0.69	2.50	14.35	10.88	15.12
8	3.00	0.69	2.50	15.02	21.45	14.09
9	2.00	0.97	2.50	19.43	28.48	22.22
10	3.00	0.97	2.50	14.58	19.16	16.58
11	2.00	0.69	3.50	16.64	19.52	17.16
12	3.00	0.69	3.50	28.23	26.34	27.81
13	2.00	0.97	3.50	18.56	31.46	16.91
14	3.00	0.97	3.50	26.48	24.26	23.18
15	1.66	0.83	3.00	15.86	13.16	15.73
16	3.34	0.83	3.00	30.46	27.56	28.16
17	2.50	0.59	3.00	22.16	21.46	18.56
18	2.50	1.07	3.00	14.26	12.2	12.81
19	2.50	0.83	2.16	9.76	13.09	12.99
20	2.50	0.83	3.84	32.54	28.26	29.46

Table 4.13 Analysis of variance for response of precision index for cotton seeds

		SMM1 MODEL			**SMM2 MODEL**			**SMM3 MODEL**		
Source	**DF**	**Sum of squares**	**F value**	**P value**	**Sum of squares**	**F value**	**P value**	**Sum of squares**	**F value**	**P value**
Model	13	635.37	6.85	0.0133*	633.48	5.084	0.0280*	439.99	6.030	0.0184*
P	1	106.58	14.95	0.0083*	103.68	10.817	0.0166*	77.25	13.764	0.0100*
S	1	31.21	4.38	0.0814	42.87	4.473	0.0788	16.53	2.945	0.1369
D	1	259.46	36.39	0.0009*	115.06	12.004	0.0134*	135.63	24.166	0.0027*
P S	1	10.56	1.48	0.2694	143.74	14.996	0.0082	10.10	1.800	0.2283
P D	1	70.15	9.84	0.0202*	0.33	0.035	0.8585	69.56	12.394	0.0125
S D	1	2.50	0.35	0.5756	3.71	0.387	0.5566	26.17	4.663	0.0741
P^2	1	25.57	3.59	0.1071	42.13	4.395	0.0809	21.27	3.791	0.0995
S^2	1	2.52	0.35	0.5740	3.07	0.320	0.5918	14.36	2.559	0.1608
D^2	1	5.57	0.78	0.4110	47.79	4.986	0.0670	13.29	2.369	0.1747
P S D	1	0.43	0.06	0.8147	4.31	0.449	0.5276	0.01	0.001	0.9737
$P^2 S$	1	28.84	4.04	0.0910	115.32	12.031	0.0133*	17.50	3.119	0.1278
$P^2 D$	1	39.59	5.55	0.0566	10.84	1.131	0.3285	25.34	4.515	0.0778
PS^2	1	19.48	2.73	0.1495	57.69	6.018	0.0496*	19.31	3.441	0.1130
LoF	1	10.73	1.67	0.2523	34.70	7.61	0.0399	1.05	0.16	0.7053
		Mean		19.41	Mean		15.39	Mean		18.99
		Std. Dev.		2.67	Std. Dev.		1.27	Std. Dev.		2.37

DF: Degrees of freedom; * Significant at 5 percent level; *LoF*: Lack of Fit;Std. Dev.: Standard deviation

Adequate precision ratio of model 10.196 which is greater than the desirable (4), hence model can be used to navigate the design space.

From coefficient estimate, final model equation for SMM1 model in terms of coded factors can be written as follows.

Precision index (SMM1) = $18.36 - 4.34P + 2.35S + 6.77D - 1.15PS + 2.96PD - 0.56SD + 1.33P^2 - 0.42S^2 + 0.62D^2 + 0.23PSD - 2.95P^2S - 3.46P^2D - 2.42PS^2$ … (4.7)

The statistical attributes presented in the Table 4.13 of SMM2 model indicates that, the model terms P, D, PS, P^2S and PS^2 are significant at 5 per cent level. Values greater than 0.1 indicates the model terms are not significant at this level. The coefficient of determination (R^2) was 0.9168, whereas the adjusted R^2 of 0.7364 implies that the overall mean is a better predictor of response. Adequate precision ratio is greater than 4 (*i.e.*7.945), which is found desirable to navigate the model design space.

Final equation in terms of coded factors for precision index of SMM2 model was written from coefficient of estimation as follows,

Precision index (SMM2) = $17.39 - 4.28P - 2.75S + 4.51D - 4.24PS - 0.2PD - 0.68SD + 1.71P^2 - 0.46S^2 + 1.82D^2 + 0.73PSD + 5.90P^2S - 1.81P^2D - 4.17PS^2$ … (4.8)

The precision index of SMM3 model for cotton seeds was expressed by the coefficient of determination (R^2), which was found to be 0.9289, indicating that 92.89 per cent of the variability of the response could be explained by the model. The adjusteduted R^2 was 0.7749 and adequate precision was 8.40 showed an adequate signal which is greater than desirable, hence model can be used to navigate the design space.

The model was formed from the estimated coefficients and presented in the form of final equation of precision index for cotton seeds in terms of coded level as follows.

Precision index (SMM3) = $18.19 + 3.7P - 1.71S + 4.90D - 1.12PS + 2.95PD - 1.81SD + 1.22P^2 - 1S^2 - 0.96D^2 + 0.029PSD + 2.30P^2S + 2.77P^2D + 2.41PS^2$ … (4.9)

The standard deviation for SMM1, SMM2 and SMM3 models were 2.67, 1.27 and 2.37 respectively for precision index. The coefficient of variation varied from 8.23 to 13.76 per cent (Table 4.13).

4.3.2 Effect of independent variables (*P*, *S* & *D*) on performance of developed seed metering mechanism models for okra seeds

Similarly the developed pneumatic seed metering mechanism models (Table 3.1) were also tested for okra seeds with same experimental setup and procedure as that of cotton by varying independent variables in accordance with seed physical properties. Experimental results were statistically analyzed and numerical optimization technique is also used to select the best suitable design model and optimum treatment combination for okra plantation. Experimental results were tabulated with respect to performance indices for individual seed metering model and discussed here under.

4.3.2.1 Miss index for okra seeds

Miss index for okra seeds for all tested models were computed as per procedure explained in section 3.4.6 and results are tabulated in Table 4.14 with respect to treatment combination and run number.

Table 4.14 revels that, the miss index was found minimum of 2.45, 1.02 and 2.99 per cent for SMM1, SMM2 and SMM3 models, respectively at different treatment combinations. Maximum miss index for SMM1 (14.63 per cent), SMM2 (15.69 per cent) and SMM3 (15.23 per cent) was observed at run no. 9, 15 and 19, respectively. Miss index statistical attributes of okra seed for the tested models are presented in Table 4.15. The effect of vacuum *P*, *S* and *D* are significantly influenced the miss index at 5 per cent level of significance. Similarly the model F values of 26.96 (SMM1), 28.17 (SMM2) and 25.33 (SMM3) were implies, the model was significant.

The adjusted R^2 was found to be 0.9467, 0.9839 and 0.9821 and adequate precision was 16.30, 17.88 and 15.65 for SMM1, SMM2 and SMM3 model, respectively, showed an adequate signal which means model can be used to navigate the design space.

Considering all the above criteria, the model equations 4.10, 4.11 and 4.12 were selected for representing the variation in miss index of SMM1, SMM2 and SMM3 models and coefficients were considered for further optimization analysis.

Model equation for SMM1 model was presented in equation 4.10.

$$\text{Miss index (SMM1)} = 5.33 - 2.88P + 1.98S - 3.08D - 1.14PS - 0.74PD - 0.8SD + 1.09P^2 + 0.14S^2 + 1.21D^2 - 1.18PSD + 0.98P^2S + 3.36P^2D + 0.88PS^2 \quad \ldots (4.10)$$

Table 4.14 Effect of independent variables (*P*, *S* & *D*) on miss index of okra seeds

Run	Vacuum Pressure (*P*) k Pa	Forward Speed (*S*) m s^{-1}	Cell Dia. (D) mm	SMM1 model	SMM2 model	SMM3 model
1	2.50	0.83	2.50	5.79	4.68	6.32
2	3.00	0.69	2.00	3.86	5.45	6.38
3	2.50	1.07	2.50	6.37	5.09	4.93
4	2.50	0.83	2.50	4.99	3.59	5.88
5	2.50	0.83	2.50	4.98	5.56	5.09
6	2.50	0.59	2.50	5.89	4.85	4.26
7	3.00	0.69	3.00	2.45	1.99	3.78
8	3.00	0.97	2.00	4.56	3.31	5.09
9	2.50	0.83	2.50	14.63	13.68	14.98
10	1.66	0.83	2.50	7.45	8.29	8.06
11	2.50	0.83	1.66	8.46	7.86	8.12
12	2.50	0.83	2.50	2.88	1.56	3.21
13	2.00	0.69	3.00	12.69	11.83	13.32
14	2.50	0.83	3.34	7.29	8.94	8.46
15	2.00	0.69	2.00	13.59	15.69	14.53
16	2.00	0.97	3.00	3.89	3.19	4.11
17	3.34	0.83	2.50	2.72	1.02	2.99
18	2.50	0.83	2.50	9.38	10.16	10.91
19	3.00	0.97	3.00	14.23	13.62	15.23
20	2.00	0.97	2.00	3.88	4.31	4.65

Table 4.15 Analysis of variance for response of miss index for okra seeds

Source	DF	SMM1 MODEL			SMM2 MODEL			SMM3 MODEL		
		Sum of squares	**F value**	**P value**	**Sum of squares**	**F value**	**P value**	**Sum of squares**	**F value**	**P value**
Model	13	291.81	26.96	0.0003*	351.84	28.17	0.0003*	312.73	25.33	0.0004*
P	1	47.05	56.51	0.0003*	78.13	81.30	0.0001*	54.29	57.17	0.0003*
S	1	22.18	26.64	0.0021*	41.77	43.47	0.0006*	31.36	33.03	0.0012*
D	1	53.56	64.34	0.0002*	43.34	45.10	0.0005*	55.97	58.93	0.0003*
P S	1	10.37	12.46	0.0124*	1.36	1.42	0.2789	8.36	8.81	0.025*
P D	1	4.37	5.24	0.0619*	3.28	3.41	0.1143	2.16	2.28	0.182
S D	1	5.17	6.21	0.0471	3.54	3.68	0.1034	1.73	1.82	0.2258
P^2	1	17.25	20.72	0.0039*	28.39	29.54	0.0016*	20.36	21.44	0.0036*
S^2	1	0.29	0.35	0.5738	0.03	0.03	0.8751	1.77	1.87	0.221
D^2	1	20.94	25.15	0.0024*	22.00	22.90	0.003*	28.56	30.07	0.0015*
P S D	1	11.21	13.47	0.0105*	12.80	13.32	0.0107*	8.57	9.02	0.0239*
$P^2 S$	1	3.21	3.85	0.0973	2.04	2.13	0.1951	1.73	1.82	0.2256
$P^2 D$	1	37.32	44.83	0.0005*	32.52	33.85	0.0011*	35.99	37.89	0.0008*
PS^2	1	2.55	3.07	0.1305	14.05	14.62	0.0087*	4.58	4.82	0.0705
LoF	1	0.99	1.24	0.3167	3.23	6.37	0.0529	2.08	2.87	0.1508
		Mean		7.00	Mean		6.73	Mean		7.52
		Std. Dev.		0.91	Std. Dev.		0.98	Std. Dev.		0.97

DF: Degrees of freedom; * Significant at 5 percent level; *LoF*: Lack of Fit;Std. Dev.: Standard deviation;

Model equation for SMM model was formulated as equation 4.11.

Miss index (SMM2) = 4.90 – 3.72P + 2.72S – 2.77D – 0.41PS – 0.64PD – 0.67SD + 1.40P^2 + 0.042S^2 + 1.24D^2 + 1.26PSD + 0.79P^2S + 3.13P^2D + 2.06PS^2 … (4.11)

Model equation for SMM1 model was presented as equation 4.12.

Miss index (SMM3) = 5.50 – 3.10P + 2.35S – 3.15D – 1.02PS – 0.52PD – 0.46SD + 1.19P^2 + 0.35S^2 + 1.41D^2 + 1.03PSD – 0.72P^2S + 3.30P^2D + 1.18PS^2 … (4.12)

4.3.2.2 Multiple index for okra seeds

Multiple index of okra seed was varied from 2.11 to 12.68 per cent for the tested seed metering mechanism models. From Table 4.16, minimum multiple index of 2.11 per cent was observed for treatment $P_4S_4D_4$ *i.e.*3 k Pa vacuum pressure, 0.97 m s^{-1} rotor speed and 3 mm cell diameter of SMM2 model whereas, maximum multiple index 12.68 per cent was noticed for run no. 16 of Table 4.16 for SMM1 model.

Statistical attributes of multiple index of okra seeds for all tested models of the study are presented in Table 4.17. Quadratic polynomial model fitted to the experimental results of multiple index shows that model F-value for SMM1, SMM2 and SMM3 were 4.56, 5.17 and 4.41, respectively, implies the model is significant at 5 per cent of level of significance.

The ANOVA for response surface cubic model fitted for SMM1, SMM2 and SMM3 were also expressed by the coefficient of determination (R^2), which was found to be 0.9082, 0.9181 and 0.9052, respectively. It indicates per cent of the variability of the response could be explained by the model

The quadratic polynomial model obtained from regression analysis of multiple index for SMM1, SMM2 and SMM3 in terms of coded factors of the variables is as equations 4.13, 4.14 and 4.15 are depicted below.

For SMM1,

Multiple index (SMM1) = 5.23 + 2.71P – 2.03S + 3.23D + 0.041PS + 0.77PD – 0.29SD + 0.57P^2 – 0.20S^2 – 0.95D^2 + 0.62PSD + 2.37P^2S – 1.72P^2D – 2.48PS^2 … (4.13)

For SMM2,

Multiple index (SMM2) = 4.20 + 2.57P – 2.31S + 4.24D – 0.057PS + 1.47PD – 0.96SD + 0.58P^2 + 0.28S^2 + 1.27D^2 + 0.46PSD + 2.73P^2S – 2.89P^2D – 2.41PS^2 … (4.14)

For SMM3,

Table 4.16 Effect of independent variables (*P*, *S* & *D*) on multiple index of okra seeds

Run	Vacuum Pressure (*P*) k Pa	Forward Speed (*S*) m s^{-1}	Cell Dia. (D) mm	SMM1 model	SMM2 model	SMM3 model
1	2.50	0.83	2.50	5.56	3.89	5.16
2	3.00	0.69	2.00	4.86	4.09	4.47
3	2.50	1.07	2.50	4.89	3.97	4.09
4	2.50	0.83	2.50	4.68	4.52	3.47
5	2.50	0.83	2.50	5.86	4.29	4.79
6	2.50	0.59	2.50	5.12	3.97	3.33
7	3.00	0.69	3.00	3.46	2.86	4.12
8	3.00	0.97	2.00	3.56	2.28	3.78
9	2.50	0.83	2.50	5.89	7.68	4.36
10	1.66	0.83	2.50	3.67	2.98	4.21
11	2.50	0.83	1.66	6.78	5.46	5.97
12	2.50	0.83	2.50	7.46	8.94	8.57
13	2.00	0.69	3.00	5.56	4.59	5.11
14	2.50	0.83	3.34	8.89	7.61	7.19
15	2.00	0.69	2.00	3.56	2.98	2.89
16	2.00	0.97	3.00	12.68	11.61	11.98
17	3.34	0.83	2.50	9.36	10.33	10.06
18	2.50	0.83	2.50	2.53	2.56	2.67
19	3.00	0.97	3.00	3.75	2.11	3.12
20	2.00	0.97	2.00	14.63	16.38	13.16

Table 4.17 Analysis of variance for response of multiple index for okra seeds

Source	DF	SMM1 MODEL			SMM2 MODEL			SMM3 MODEL		
		Sum of squares	F value	P value	Sum of squares	F value	P value	Sum of squares	F value	P value
Model	13	170.25	4.56	0.0363*	240.80	5.17	0.0269*	158.05	4.41	0.0394*
P	1	41.59	14.50	0.0089*	37.24	10.40	0.0180*	41.31	14.97	0.0083*
S	1	23.32	8.13	0.0291*	30.19	8.43	0.0272*	27.31	9.90	0.0199*
D	1	59.19	20.63	0.0039*	101.82	28.43	0.0018*	50.40	18.26	0.0052*
$P\ S$	1	0.01	0.00	0.9473	2.62	0.73	0.4250	0.01	0.004	0.9463
$P\ D$	1	4.70	1.64	0.2480	17.35	4.84	0.0700	3.34	1.21	0.3134
$S\ D$	1	0.68	0.24	0.6440	7.45	2.08	0.1993	1.06	0.38	0.5585
P^2	1	4.70	1.64	0.2478	4.82	1.35	0.2901	7.00	2.54	0.1624
S^2	1	0.56	0.20	0.6730	1.11	0.31	0.5976	1.46	0.53	0.4941
D^2	1	12.99	4.53	0.0774	23.16	6.47	0.0439*	12.90	4.67	0.0739
$P\ S\ D$	1	3.09	1.08	0.3395	1.67	0.47	0.5196	0.06	0.02	0.8848
$P^2\ S$	1	18.68	6.51	0.0434*	24.61	6.87	0.0395*	13.27	4.81	0.0708
$P^2\ D$	1	9.81	3.42	0.1139	27.72	7.74	0.0319*	9.45	3.42	0.1137
PS^2	1	20.30	7.08	0.0375*	19.30	5.39	0.0593	15.73	5.70	0.0542
LoF	1	16.17	77.37	0.0003	21.20	368.45	0.0001*	13.91	26.33	0.0037*
		Mean		6.14	Mean		5.66	Mean		5.63
		Std. Dev.		1.69	Std. Dev.		1.89	Std. Dev.		1.66

DF: Degrees of freedom; * Significant at 5 percent level; *LoF*: Lack of Fit;Std. Dev.: Standard deviation

$$\text{Multiple index (SMM3)} = 4.29 + 2.70P - 2.20S + 2.98D - 0.041PS + 0.65PD - 0.36SD + 0.7P^2 + 0.32S^2 + 0.95D^2 - 0.089PSD + 2P^2S - 1.69P^2D - 2.18PS^2 \quad \ldots (4.15)$$

Where, P is vacuum pressure (k Pa), S is rotor speed (m s^{-1}) and D is cell diameter (mm).

The statistical attributes presented in Table 4.17 revels that, linear terms *P, S* and *D* for all models of study had significant effect on multiple index. P value greater than 0.1 indicates model terms are not significant.

4.3.2.3 Precision index for okra seeds

The experimental results carried out in the laboratory based on CCD of RSM are given in Table 4.18. It is observed that the metering mechanism operated at 0.69 m s^{-1} forward speed, 3 mm cell diameter and 3 k Pa vacuum pressure (run no. 7 in Table 4.18) gives satisfactory results in terms of precision index for all tested models.

ANOVA for response surface cubic model of precision index was presented in Table 4.19. The model F value of 14.04, 9.90 and 15.11 for SMM1, SMM2 and SMM3, respectively implies the model is significant at 5 per cent level of significance. The p values less than 0.05 indicates model terms are significant, hence P, D, P^2S, P^2D and PS^2 variables were found significant model terms of precision index.

The computed R^2 value is 0.9682 for SMM1 model, whereas the predicted R^2 (-5.4673) was found negative, which implies that the overall mean is a better predictor of the response. Adequate precision ratio of model 13.049 which is greater than the desirable (4), hence model can be used to navigate the design space. From coefficient estimate, final model equation 4.16 for SMM1 model in terms of coded factors can be written as follows.

$$\text{Precision index (SMM1)} = 16.40 + 0.71P + 3.26S + 2.37D - 1.48PS + 1.71PD - 1.31SD + 3.75P^2 + 1.03S^2 + 1D^2 + 2.03PSD + 3.99P^2S + 0.60P^2D - 1.36PS^2 \quad \ldots (4.16)$$

The statistical attributes presented in the Table 4.19 of SMM2 model indicates that the model terms S, D, P^2 and P^2S are significant at 5 per cent level. Values greater than 0.1 indicates the model terms are not significant at this level. The coefficient of determination (R^2) was 0.9168, whereas the adjusted R^2 of 0.9555 implies that the overall mean is better predictor of response. Adequate precision ratio is greater than 4 (*i.e.*10.72) which is found desirable to navigate the model design space.

Table 4.18 Effect of independent variables (*P*, *S* & *D*) on precision index of okra seeds

Run	Vacuum Pressure (*P*) k Pa	Forward Speed (*S*) m s^{-1}	Cell Dia. (D) mm	SMM1 model	SMM2 model	SMM3 model
1	2.50	0.83	2.50	15.89	13.46	14.09
2	3.00	0.69	2.00	15.23	14.56	16.98
3	2.50	1.07	2.50	16.86	15.16	16.42
4	2.50	0.83	2.50	16.53	14.56	15.89
5	2.50	0.83	2.50	16.23	15	17.23
6	2.50	0.59	2.50	17.09	15.26	16.42
7	3.00	0.69	3.00	8.33	7.36	9.48
8	3.00	0.97	2.00	10.64	9.46	11.05
9	2.50	0.83	2.50	32.46	31.06	31.89
10	1.66	0.83	2.50	20.75	19.23	21.58
11	2.50	0.83	1.66	17.53	16.23	18.33
12	2.50	0.83	2.50	18.56	17.55	19.37
13	2.00	0.69	3.00	28.33	27.66	29.46
14	2.50	0.83	3.34	31.56	29.46	32.15
15	2.00	0.69	2.00	27.46	28.39	28.46
16	2.00	0.97	3.00	29.86	27.89	30.49
17	3.34	0.83	2.50	15.46	14.88	16.23
18	2.50	0.83	2.50	26.43	25.46	24.81
19	3.00	0.97	3.00	16.88	15.26	17.12
20	2.00	0.97	2.00	24.86	25.46	25.46

Table 4.19 Analysis of variance for response of precision index for okra seeds

Source	DF	SMM1 MODEL			SMM2 MODEL			SMM3 MODEL		
		Sum of squares	F value	P value	Sum of squares	F value	P value	Sum of squares	F value	P value
Model	13	891.50	14.04	0.002*	928.48	9.90	0.0051*	890.71	15.11	0.0016*
P	1	2.88	0.59	0.4717	0.13	0.02	0.8996	2.06	0.45	0.5254
S	1	60.17	12.32	0.0127*	55.97	7.76	0.0318*	36.81	8.12	0.0292*
D	1	31.84	6.52	0.0433*	52.02	7.21	0.0363*	34.78	7.67	0.0325*
$P\ S$	1	17.46	3.58	0.1075	23.98	3.32	0.1181	13.08	2.88	0.1404
$P\ D$	1	23.32	4.77	0.0716	21.95	3.04	0.1318	19.44	4.29	0.0839
$S\ D$	1	13.62	2.79	0.1459	13.86	1.92	0.2151	10.19	2.25	0.1845
P^2	1	203.15	41.59	0.0007	231.33	32.06	0.0013*	249.82	55.08	0.0003*
S^2	1	15.20	3.11	0.1282	20.36	2.82	0.144	14.34	3.16	0.1257
D^2	1	14.42	2.95	0.1365	22.73	3.15	0.1263	23.23	5.12	0.0643
$P\ S\ D$	1	32.89	6.73	0.041*	27.42	3.80	0.0992	22.88	5.05	0.0658
$P^2\ S$	1	52.85	10.82	0.0166*	53.17	7.37	0.0349*	68.77	15.16	0.008*
$P^2\ D$	1	1.20	0.25	0.6374	0.04	0.01	0.9437	1.55	0.34	0.5799
PS^2	1	6.09	1.25	0.3068	1.75	0.24	0.6395	5.01	1.10	0.3337
LoF	1	27.00	58.48	0.006*	41.11	94.05	0.0002*	20.90	16.56	0.0096*
		Mean		20.35	Mean		19.19	Mean		20.65
		Std. Dev.		2.21	Std. Dev.		2.69	Std. Dev.		2.13

DF: Degrees of freedom; * Significant at 5 percent level; *LoF*: Lack of Fit;Std. Dev.: Standard deviation

Final equation 4.17 in terms of coded factors for precision index of SMM2 model was written from coefficient of estimation as follows,

Precision index (SMM2) = $14.78 - 0.15P + 3.15S + 3.03D - 1.73PS + 1.66PD - 1.32SD + 4.01P^2 + 1.19S^2 + 1.26D^2 + 1.85PSD + 4.01P^2S - 0.11P^2D - 0.73PS^2$ … (4.17)

The precision index of SMM3 model for okra seeds was expressed by the coefficient of determination (R^2), which was found to be 0.9704, indicating that 97.04 per cent of the variability of the response could be explained by the model. The adjusteduted R^2 was 0.9061 and adequate precision was 12.723 showed an adequate signal which is greater than desirable, hence model can be used to navigate the design space. The model was formed from the estimated coefficients and presented in the form of final equation of precision index for cotton seeds in terms of coded level as follows.

Precision index (SMM3) = $16.25 + 0.60P + 2.55S + 2.48D - 1.28PS + 1.56PD - 1.13SD + 4.16P^2 + 1S^2 + 1.27D^2 + 1.69PSD + 4.56P^2S + 0.68P^2D - 1.23PS^2$ … (4.18)

The standard deviation for SMM1, SMM2 and SMM3 model were 2.21, 2.69 and 2.13 respectively for precision index. The coefficient of variation was varied 10.32 to 14 per cent (Table 4.19).

4.3.3 Optimization of design and operational parameters for cotton and okra seeds

The designed and operational parameters of pneumatic seed metering mechanism were optimized, based on theoretical seed spacing measure mainly miss index, multiple index and precision index and experimental results were discussed in section 4.2. Numerical optimization technique was used to obtain the optimum treatment combination with best performing seed metering model and multi response optimization constrains of experiments are presented in Table 4.20. The responses predicted by the Design-Expert 7.7.0 software for these optimum process conditions were presented in Table 4.21 and Table 4.22 for cotton and okra seeds respectively.

From Table 4.21 and 4.22, the predicted value of run no.1 of SMM3 model was found satisfactory for the selected seeds with minimum miss, multiple and precision index and maximum combined desirability value. Hence, underlined independent variable values of Table 4.21 and 4.22 were considered as optimum one.

Table 4.20 Multi response numerical optimization constraints

Name	**Goal**	**Limit**	**Limit**	**Importance**
Vacuum Pressure, (k Pa)	is in range	1.65	3.34	3
Rotor speed, (m s^{-1})	is in range	0.59	1.07	3
Cell diameter (mm)	is in range	2.16	3.34	3
Miss Index (per cent)	minimize	2.86	22	5
Multiple Index (per cent)	minimize	2.19	14.46	5
Precision Index (per cent)	minimize	10.88	31.46	5

Table 4.21 Optimum values of independent parameters (*P, S & D*) of cotton seed for tested models

Run No.	**Vacuum pressure (k Pa)**	**Rotor speed** (m s^{-1})	**Cell diameter** (mm)	**Miss index (%)**	**Multiple index (%)**	**Precision index (%)**	**Desirability**	
SMM1 Model								
1	2.91	0.91	2.16	8.987	3.122	8.760	0.872	Selected
2	2.89	0.92	2.16	8.963	3.146	9.610	0.872	
3	2.86	0.95	2.16	8.889	3.223	10.960	0.872	
SMM2 Model								
1	2.13	0.66	2.16	8.908	4.891	11.817	0.790	Selected
2	2.12	0.66	2.16	8.908	4.909	12.179	0.790	
3	2.12	0.66	2.16	8.886	4.927	13.378	0.790	
SMM3 Model								
1	2.72	0.81	2.66	6.764	3.897	10.810	0.880	Selected
2	2.71	0.81	2.37	7.786	4.878	12.810	0.846	
3	2.71	0.81	2.16	7.810	4.859	12.810	0.846	

Table 4.22 Optimum values of independent parameters (*P, S & D*) of okra seed for tested models

Run No.	Vacuum pressure (k Pa)	Rotor speed (m s^{-1})	Cell diameter (mm)	Miss index (%)	Multiple index (%)	Precision index (%)	Desirability	
SMM1 Model								
1	3.27	0.75	1.98	1.606	1.153	8.51	0.889	Selected
2	3.29	0.62	2.36	2.353	3.821	10.20	0.876	
3	3.27	0.61	2.19	2.315	4.623	10.05	0.863	
SMM2 Model								
1	2.65	0.78	2.42	2.835	1.059	9.347	0.893	Selected
2	2.67	0.65	2.36	1.614	1.948	6.636	0.885	
3	2.68	0.63	2.44	1.084	2.041	6.002	0.891	
SMM3 Model								
1	2.34	0.75	2.05	2.604	1.117	7.000	0.907	Selected
2	2.32	0.64	1.88	2.472	1.690	8.662	0.881	
3	2.31	0.66	2.09	2.369	2.267	8.987	0.869	

4.4 Simulation of vacuum pressure using ANSYS FLUENT software

Experimental results showed that, the cell diameter (design parameter) was significantly affected the performance of all the tested pneumatic seed metering mechanism models. Any increase or decrease in cell diameter will directly influences vacuum pressure intensity which results in poor performance of the seed metering mechanism. Considering above discussed facts, vacuum pressure was simulated with respect to selected cell diameters and rotor speeds using theory of computational fluid dynamics (CFD) through fluent solver as explained in section 3.5 of previous chapter. The pressure contours and velocity vectors of vacuum pressure were achieved from the fluid model in Fluent. Due to the compact design of vacuum chamber a SMM3 model was performed satisfactory in terms of all performance indices and got maximum desirability among the designed models. Similarly the air pressure and velocity was also found more in this model which is felt sufficient to carry the selected seeds under different operating conditions. The pressure and velocity contours and vectors were observed through creating iso-surface on x-y plane for SMM3 seed metering model as shown in figures 4.3 to 4.4 and figures 4.5 to 4.6, respectively. The vacuum pressure and velocity of air at inlet point were recorded and variations in vacuum pressure and velocity are presented in Table 4.23. Measuring vacuum pressure at seed pick up and drop point is difficult experimentally, when the airflow passed through them, the variation in the pressure and velocity was observed by simulating in software. Fig. 4.7 and 4.8 shows the simulated air velocity gradients of seed pickup and drop points respectively and velocity contour and the direction of air moment also presented.

The pressure and velocity for the optimized values were also measured for all the selected variables of 2.66 mm cell diameter (Table 4.21), pressure -1980 Pa and velocity of 91 m s^{-1}, which is sufficient to hold the cotton seed against rotor wall during pickup and transport stage. For okra seed (SMM3) model of 2.05 mm cell diameter (Table 4.22), the observed pressure and velocity was -1900 Pa and 95 m s^{-1} which is felt satisfactory to carrying the okra seed.

Due to the compact design of vacuum chamber a SMM3 model was performed satisfactory in terms of all performance indices and got maximum desirability among the designed seed metering mechanism models. Similarly the air pressure and velocity was also found more in this model which is felt sufficient to carry the selected seeds under different operating conditions. Therefore SMM3 model was selected for the final prototype design.

Table 4.23 Pressure and velocity gradient in seed cell at -2500 Pascal vacuum pressure and 0.83 m s^{-1} rotor speed

Cell diameter	Pressure in cell (Pa)			Velocity in cell (m s^{-1})		
(mm)	SMM1	SMM2	SMM3	SMM1	SMM2	SMM3
1.65	-1582	-1561	-1800	46	50	69
2.00	-1600	-1591	-1889	51	59	78
2.14	-1629	-1629	-1960	59	66	88
2.50	-1677	-1672	-2000	66	72	96
3.00	-1732	-1702	-2080	73	79	104
3.34	-1756	-1765	-2160	88	86	113
3.50	-1810	-1800	-2220	93	92	118
3.84	-1906	-1856	-2290	102	98	126

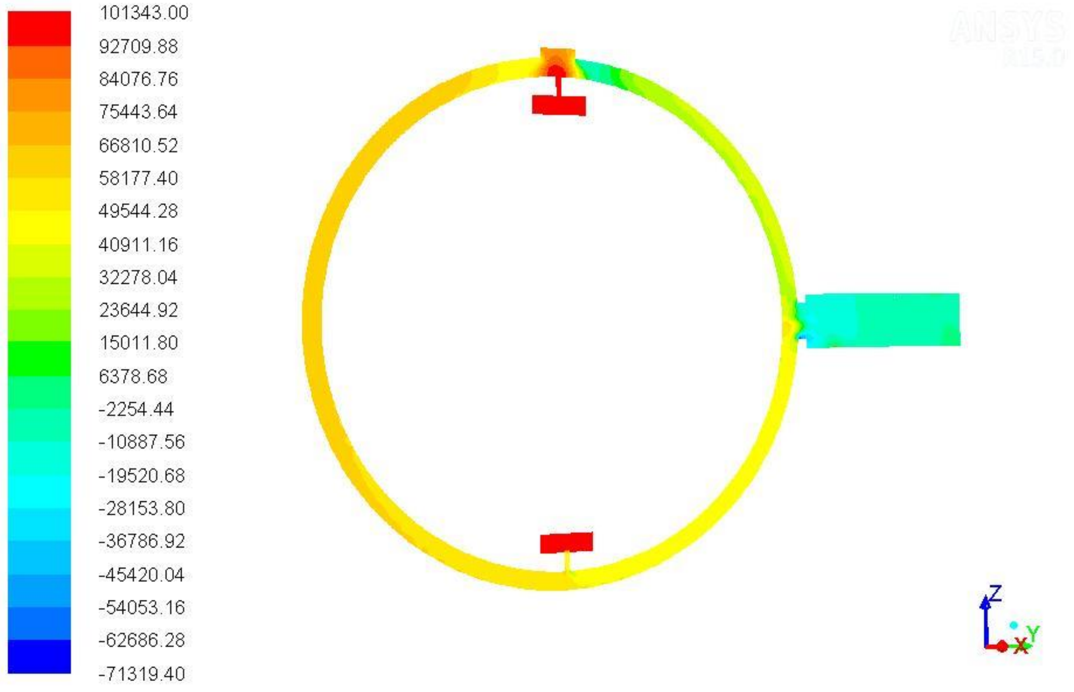


Fig. 4.3 Contours of static pressure for SMM3 model

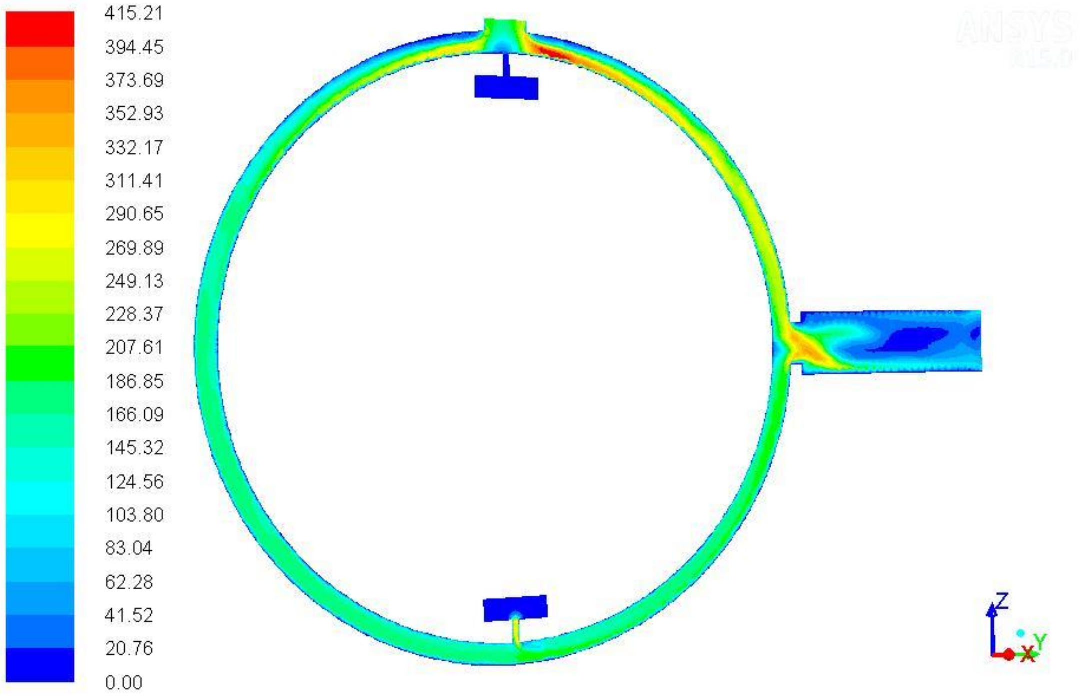


Fig. 4.4 Contours of velocity magnitude for SMM3 model

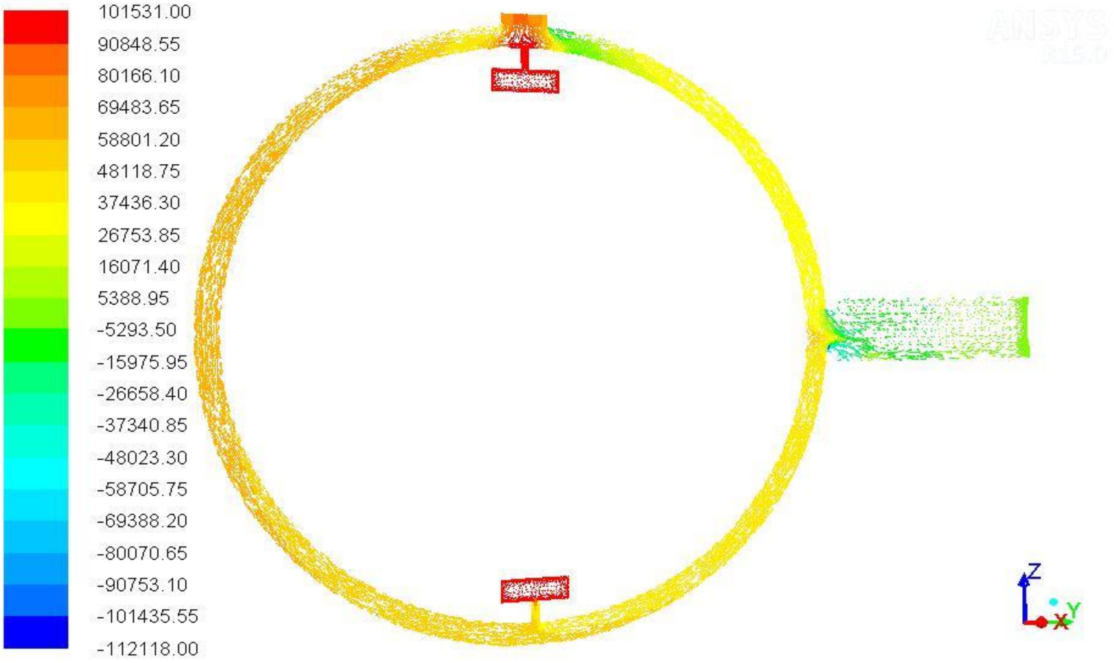


Fig. 4.5 Vectors coloured by static pressure for SMM3 model

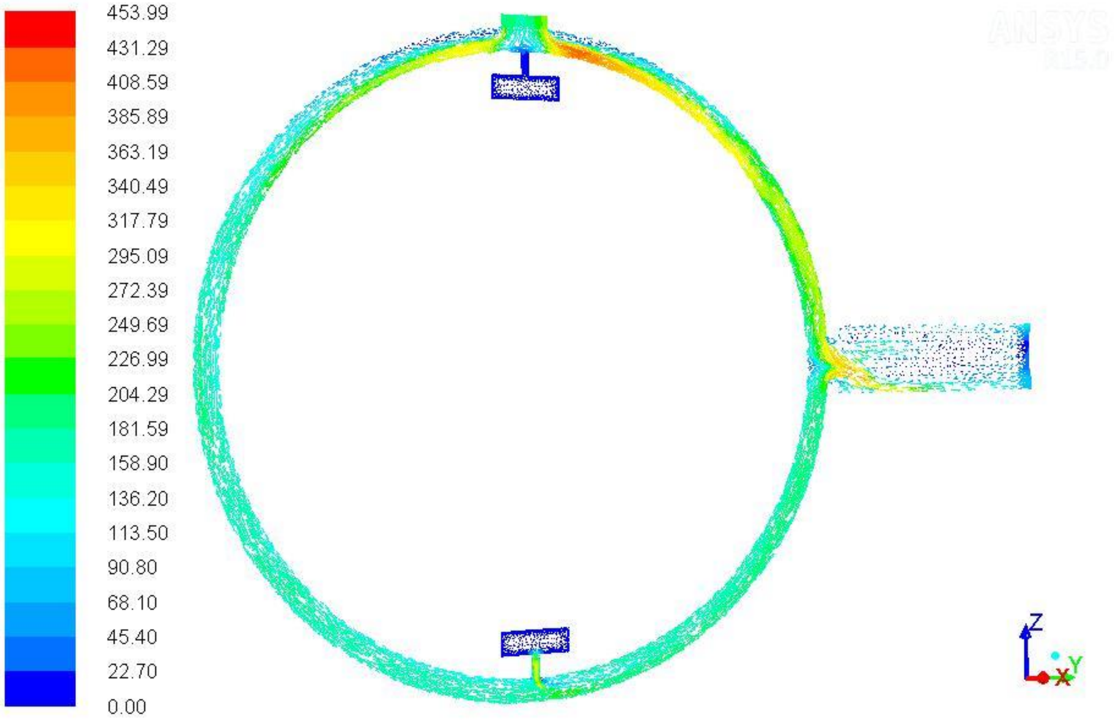


Fig. 4.6 Vectors coloured by velocity magnitude for SMM3 model

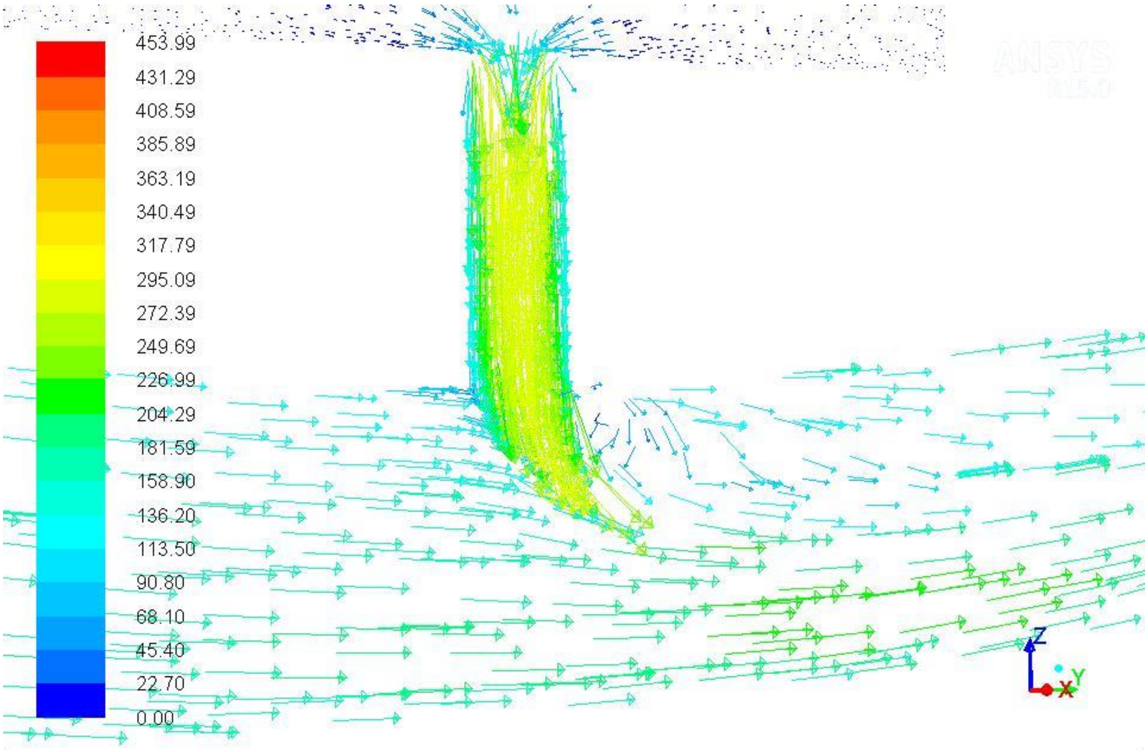


Fig. 4.7 Detailed view of air moment at seed pickup point SMM3 model

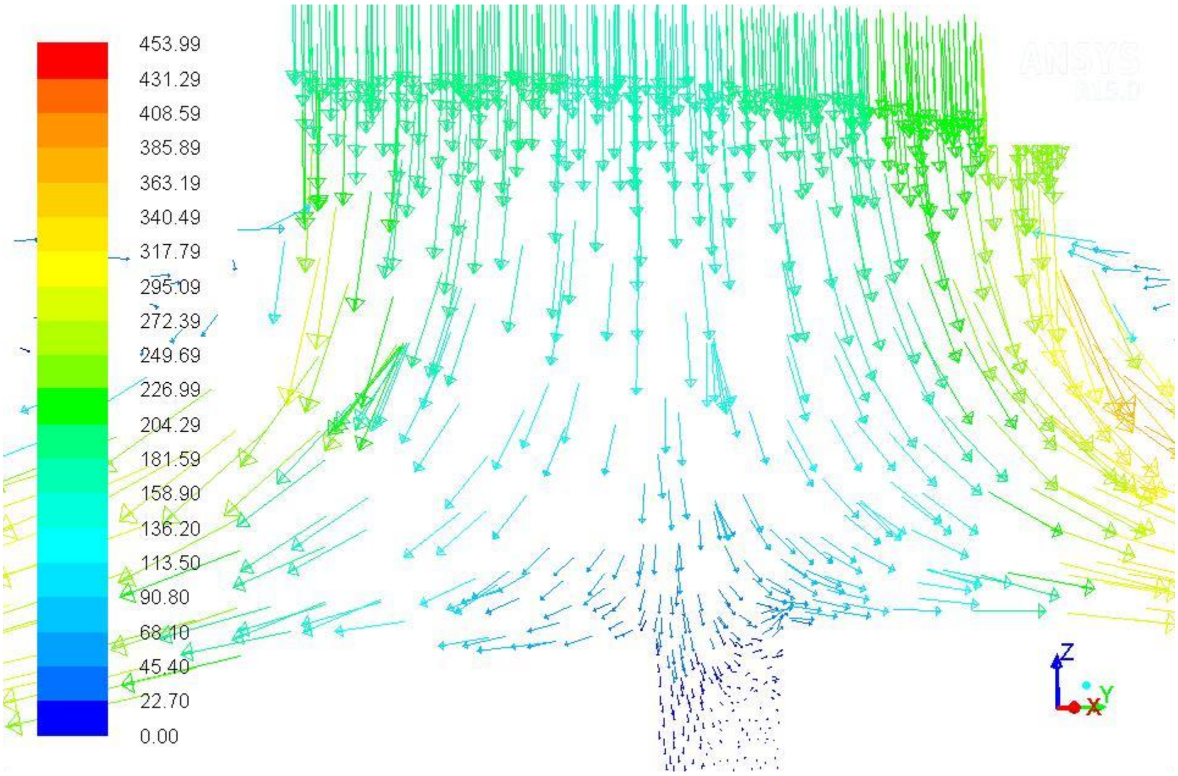


Fig. 4.8 Detailed view of air moment at seed releasing stage SMM3 model

4.5 Computer vision system for measuring seed spacing

Computer vision system is an advance technique used to measure the seed spacing under simulated conditions. The video clips were acquired using procedure justified in the methodology chapter and analysis of video clips was carried out using MATLAB computer vision and image processing tool box as explained in section 3.6. Seed spacing was measured in terms of elapsed time between two successive seeds released from seed metering mechanism and correlated with linear seed spacing on grease belt for the same seed. This method was used to validate the numerically optimized selected and average values of three replications and the results are presented in the Table 4.24.

The data presented in Table 4.24 revels that, the first seed was taken as zero (reference) and successive seed spacing's were measured on grease belt in terms of linear spacing and in terms of elapsed time from video clips analysis. Zero elapsed time of seed number 5 and 14 of okra seeds shows that multiple seed drop and both seed were appeared on the same frame. A strong correlation was observed between both the methods with coefficient of determination (R^2) of 0.91 and 0.99 for cotton and okra seed spacing respectively, hence there is scope for using computer vision system for the seed spacing analysis under the laboratory conditions.

The selected SMM3 seed metering mechanism model was tested with optimum independent variables using same experimental setup and procedure to validate numerically predicted values for both the selected seeds. Experiments were repeated for five times with same set of conditions for both the selected seeds and average was considered as actual value. The validation results of selected model, predicted verses actual under optimum condition were presented in Table 4.25 for all the responses of both selected seeds.

From Table 4.25, it is seen that the optimum cell diameter for cotton seed was found to 2.66 mm and operational parameter *viz*., 2.72 k Pa vacuum pressure and 0.81 m s^{-1} rotor speed. The obtained optimum results of design and operational parameters were used as basic parameters for designing the field prototype of pneumatic planter.

Table 4.24 Measured seed spacing of SMM3 model using computer vision and test rig

Seed No.	Cotton		Okra	
	Spacing (mm)	Time (sec)	Spacing (mm)	Time (sec)
1	0	0	0	0
2	420	0.421	450	0.612
3	450	0.501	490	0.645
4	450	0.492	455	0.614
5	478	0.511	15	0
6	459	0.509	450	0.608
7	490	0.549	460	0.615
8	452	0.497	450	0.601
9	460	0.512	459	0.608
10	20	0	439	0.598
11	455	0.496	455	0.602
12	870	0.982	450	0.606
13	400	0.461	480	0.629
14	458	0.494	30	0
15	470	0.503	460	0.606
16	930	1.09	480	0.621
17	400	0.462	480	0.622
18	460	0.852	880	1.220
19	80	0.106	455	0.602
20	499	0.509	439	0.598

Table 4.25 Predicted and actual values of responses under optimized treatment combination

Sl. No.	Responses	Predicted value	Actual value	Per cent variation
Cotton seeds				
1	Miss index (%)	6.764	8.432	1.668
2	Multiple index (%)	3.897	5.861	1.964
3	Precision index (%)	10.810	14.587	3.777
Okra seeds				
1	Miss index (%)	2.604	4.331	1.727
2	Multiple index (%)	1.117	3.526	1.117
3	Precision index (%)	7.000	10.861	3.861

4.6 Performance evaluation of multi crop pneumatic planter prototype

The prototype of multi crop pneumatic planter was developed with three furrow openers using standard production techniques as per the designed dimensions and the dimensional drawings were presented in section 3.7. The performance of the pneumatic planter was tested and evaluated under laboratory and field conditions respectively and results are discussed in subsections.

4.6.1 Laboratory calibration and testing of multi crop pneumatic planter for selected seeds

Developed multi crop pneumatic planter was calibrated for cotton and okra seeds (Plate 3.4) and tested for seed breakage and uniformity of seed dropping on sand bed as per the BIS (IS: 6316-1971). The viability of seeds collected while calibration of the planter was tested to study internal damages of seeds during metering operation. The calibration of pneumatic planter was carried under laboratory conditions for cotton and okra seeds to determine inter and intra row variations with half, three fourth and full capacity of the hopper for 25 RPM of ground wheel with designed transmission ratio and results were presented in Table 4.26 to 4.28. The difference of seed collected between the means two furrow openers was statistically tested using student's t-test, which is an inferential statistical test for two unrelated group data.

4.6.1.1 Distribution of cotton and okra seeds

The seed distributions in rows with different hopper capacities for cotton are presented in Table 4.26. The average number of seeds discharged was in the range of 76.23 to 77.11, 76.89 to 77.19 and 76.59 to 77.52 numbers for CH1 variety for 1/2, 3/4 and full capacity of the hopper respectively. Also similar trend of seed discharge was observed for CH2 and CH3 varieties. The actual number of seeds discharged from three furrow openers in comparison with the recommended number of seeds to be discharged was statistically analyzed and found to be non-significant for all the three hopper capacities. From the results, it can be inferred the individual seed metering mechanism mounted on three furrow openers worked satisfactorily resulting acceptable variation in the planting rate for all the varieties of cotton.

The data presented in Table 4.27 of okra seed distribution efficiency of multi crop pneumatic planter under laboratory conditions. The number of seeds discharged was found in the range of 79.11 to 81.34 number with irrespective of hopper capacity and furrow opener.

Table 4.26 Cotton seeds collected from each furrow opener at different hopper capacity

Average number of seed collected in 25 RPM of ground wheel CH1						
Furrow openers	**½ Hopper**	**'t' value**	**¾ Hopper**	**'t' value**	**Full Hopper**	**'t' value**
F1	76.23	1.46 (NS)	77.17	0.9 (NS)	76.59	1.12 (NS)
F2	76.99	1.12 (NS)	77.19	0.8 (NS)	77.00	1.56 (NS)
F3	77.11	1.16 (NS)	76.89	1.1 (NS)	77.52	1.88 (NS)
Total seeds	230.33	--	231.25	--	231.11	--
Seeding rate per m^2	2.413	--	2.424	--	2.429	--
Average number of seed collected in 25 RPM of ground wheel CH2						
F1	76.88	1.43 (NS)	77.41	1.26 (NS)	77.59	0.86 (NS)
F2	77.12	0.09 (NS)	76.89	1.47 (NS)	78.02	1.12 (NS)
F3	77.03	1.32 (NS)	77.21	1.11 (NS)	78.21	1.21 (NS)
Total seeds	231.03	--	231.51	--	233.82	--
Seeding rate per m^2	2.423	--	2.427	--	2.450	--
Average number of seed collected in 25 RPM of ground wheel CH3						
F1	77.23	1.11 (NS)	78.06	1.42 (NS)	78.45	1.88 (NS)
F2	76.19	1.24 (NS)	77.81	1.11 (NS)	77.86	1.20 (NS)
F3	78.12	1.86 (NS)	77.77	1.36 (NS)	78.21	1.64 (NS)
Total seeds	231.54	--	233.64	--	234.52	--
Seeding rate per m^2	2.427	--	2.458	--	2.449	--

Table 4.27 Okra seeds collected from each furrow opener at different hopper capacity

Average number of seed collected in 25 RPM of ground wheel OH1						
Furrow openers	**½ Hopper**	**'t' value**	**¾ Hopper**	**'t' value**	**Full Hopper**	**'t' value**
F1	79.26	0.08 (NS)	80.17	0.78 (NS)	80.59	0.65 (NS)
F2	78.99	0.68 (NS)	79.19	0.89 (NS)	81.00	0.96 (NS)
F3	79.11	0.16 (NS)	80.89	0.68 (NS)	79.52	0.80 (NS)
Total seeds	237.36	--	240.25	--	241.11	--
Seeding rate per m^2	3.733	--	3.778	--	3.792	--
Average number of seed collected in 25 RPM of ground wheel OH2						
F1	80.86	0.94 (NS)	81.36	1.11 (NS)	82.02	0.88 (NS)
F2	81.06	1.20 (NS)	80.27	0.95 (NS)	81.23	1.09 (NS)
F3	80.59	1.32 (NS)	80.88	0.89 (NS)	80.56	1.22 (NS)
Total seeds	242.51	--	242.51	--	243.81	--
Seeding rate per m^2	3.814	--	3.814	--	3.835	--
Average number of seed collected in 25 RPM of ground wheel OH3						
F1	79.56	0.99 (NS)	80.56	1.16 (NS)	80.43	0.98 (NS)
F2	80.49	1.22 (NS)	81.26	1.19 (NS)	80.09	1.65 (NS)
F3	80.79	1.24 (NS)	82.10	1.56 (NS)	81.34	1.45 (NS)
Total seeds	240.84	--	243.92	--	241.86	--
Seeding rate per m^2	3.788	--	3.836	--	3.804	--

The t-test shows that, the variation between the means of furrow openers was found to be non-significant for all the hopper capacities. Deviation in seed discharge from recommended was found less as compared to cotton seeds, this may be due to more spherical shape of okra seeds. The variation in seed distribution was within the acceptable level, hence the performance of three row pneumatic planter was found satisfactory for okra seeds also.

4.6.1.2 Seed breakage and germination of cotton and okra seeds

The tested pneumatic seed planter performance was found satisfactory in laboratory conditions for cotton and okra seed spacing. The seed breakage and seed germination per cent of seeds collected while testing multi crop pneumatic planter for cotton and okra seeds are presented in Table 4.28 and Table 4.29. Average seed breakage for cotton (Table 4.28) was varied from 0.517 to 0.743 (CH1), 0.561 to 0.642 (CH2) and 0.577 to 0.673 (CH3) per cent whereas the seed breakage for okra was noticed to vary from 0.21 to 0.41 per cent across the tested varieties and metering devices. The maximum observed seed breakage in case of okra seed was observed to be 0.41 per cent which was less than that of cotton seeds. The variation of seed breakage among three rows was found to be statistically non-significant for the tested seeds across all the furrow openers. The maximum seed breakage for any row was observed to be less than 0.88 per cent. The deviation was found slightly higher than 0.5 per cent for cotton but for okra it was found to be with in the acceptable range.

The variation of seed germination (Table 5.28) among three rows of prototype multi crop pneumatic planter was found to be statistically non-significant. The germination percentage varied from 85.2 to 88.4 across the three selected varieties of cotton whereas, for okra seeds per cent of germination was varied from 89.23 to 93.26 for all tested seed varieties. The maximum deviation of seed germination for any row from the average value was observed to be less than two per cent which is less than the acceptable limit for both cotton and okra seeds. All the deviations were within the range of 5 per cent.

The seed spacing uniformity of pneumatic planter prototype was tested on sand bed and results are presented in Table 4.30. Average seed to seed to distance for cotton and okra was varied between 497.16 to 505.33 mm and 484.40 to 492.05 mm, respectively.

Table 4.28 Observed seed breakage and germination of metered cotton seeds

For CH1 variety								
	Seed breakage (%)						**Germination (%)**	
Furrow openers	**1/2 Hopper**	**‘t’ value**	**3/4 Hopper**	**‘t’ value**	**Full Hopper**	**‘t’ value**	**Average**	**‘t’ test**
F1	0.76	1.25*	0.69	1.12*	0.45	0.99*	85.2	0.4*
F2	0.56	1.33*	0.76	0.85*	0.54	1.10*	87.5	0.6*
F3	0.55	1.12*	0.88	1.06*	0.56	1.53*	86.5	0.3*
Average	0.623		0.743		0.517		86.4	
For CH2 variety								
F1	0.55	1.11*	0.64	1.23*	0.55	1.25*	85.3	0.5*
F2	0.76	1.34*	0.53	1.03*	0.46	1.31*	88.2	0.3*
F3	0.61	0.98*	0.71	0.88*	0.67	1.23*	86.3	0.7*
Average	0.642		0.627		0.561		85.3	
For CH3 variety								
F1	0.65	1.21*	0.61	1.23*	0.56	1.06*	87.3	0.6*
F2	0.62	1.23*	0.56	1.11*	0.59	1.02*	86.2	0.5*
F3	0.69	1.06*	0.60	1.27*	0.56	1.09*	88.4	0.7*
Average	0.673		0.593		0.577		87.3	

* Non significant at 5 per cent level

Table 4.29 Observed seed breakage and germination of metered okra seeds

For OH1 variety								
	Seed breakage (%)						Germination (%)	
Furrow openers	1/2 Hopper	‘t’ value	3/4 Hopper	‘t’ value	Full Hopper	‘t’ value	Average	‘t’ test
F1	0.21	0.23*	0.25	0.33*	0.34	0.26*	92.23	1.11*
F2	0.33	0.45*	0.28	0.42*	0.34	0.24*	91.22	0.93*
F3	0.31	0.34*	0.30	0.26*	0.35	0.46*	90.06	0.89*
Average	0.283		0.277		0.343		91.17	
For OH2 variety								
F1	0.26	0.41*	0.29	0.33*	0.31	0.34*	89.23	1.10*
F2	0.24	0.38*	0.28	0.36*	0.29	0.41*	92.16	0.99*
F3	0.31	0.36*	0.28	0.37*	0.29	0.38*	92.55	0.97*
Average	0.270		0.283		0.297		91.31	
For OH3 variety								
F1	0.39	0.33*	0.38	0.34*	0.37	0.41*	93.26	0.96*
F2	0.38	0.32*	0.41	0.36*	0.41	0.38*	89.41	0.89*
F3	0.36	0.38*	0.37	0.34*	0.41	0.39*	92.31	0.94*
Average	0.377		0.387		0.397		91.66	

* Non significant at 5 per cent level

Table 4.30 Seed planting uniformity of planter on sand bed

Average spacing between two cotton seeds						
Furrow openers	**CH1**		**CH2**		**CH3**	
	Spacing (mm)	**‘t’ test**	**Spacing (mm)**	**‘t' test**	**Spacing (mm)**	**‘t’ test**
F1	498.32	1.91*	496.32	1.33*	500.01	1.23*
F2	493.31	1.67*	510.19	1.49*	499.86	1.41*
F3	499.86	1.86*	498.55	1.41*	516.13	1.35*
Average	497.16		501.69		505.33	
Average spacing between two cotton seeds						
	OH1		**OH2**		**OH3**	
Furrows	**Spacing (mm)**	**t test**	**Spacing (mm)**	**t test**	**Spacing (mm)**	**t test**
F1	479.89	1.92*	488.81	0.90*	490.14	1.21*
F2	482.95	1.30*	486.26	1.33*	497.56	1.10*
F3	490.35	1.51*	490.31	1.12*	488.45	0.99*
Average	484.40		488.46		492.05	

* Non significant at 5 per cent level

The maximum deviation of seed to seed spacing for a given row from the recommended value was 8.97 and 6.79 for cotton and okra, respectively. A null hypothesis of t-test indicates that, the variation of seed dropped from the mean values among the three rows were non-significant.

4.6.2 Field evaluation of multi crop pneumatic planter prototype for cotton

Multi crop pneumatic planter prototype field performance was evaluated by planting of test crops (cotton and okra) as per standard procedure (IS: 6316-1971) and evaluated in terms of seeding rate, plant to plant distance and germination percentage of seeds.

The field experiments were conducted in Brhamanpally village, which is close to Hayatanagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad, for evaluating the performance of the prototype. Prior to the experiments field was prepared for fine tilth which was suitable for seed planting. The soil and machine parameters were studied and recorded as presented in Table 4.31.

A plot size of 50 × 50 m was selected for planting cotton and okra crops separately. The pneumatic planter prototype was mounted over 25.76 kW tractor as a power source and blower was operated from PTO drive. The engine speed was set to get desired PTO speed which rotates the blower fan at an optimum speed and maintains constant air flow. Jaadoo and kaveri-49 hybrids of cotton and okra seeds respectively were used for planting operation with recommended seed spacing of 900 × 450 and 600 × 450 mm, respectively.

The selected research plot has shallow black cotton soil and prior to the planting operation observed moisture content and bulk density was found to be 15.16 per cent and 1.31 mg m^{-3}, respectively.

The necessary settings were made in planter gear ratio to operate planter at 3 km h^{-1} forward speed to the recommended seed rate. Average recorded depth of planting for cotton and okra was 4.8 and 4.6 cm, respectively, with observed average draft of implement was 3869 N. The recorded ground wheel slip during planting operation of cotton and okra was 10.53 and 9.15 per cent, respectively which is close to the accepted value of 10 per cent. The mean fuel consumption was 4.56 liter per hour for operating planter. Hence, the developed pneumatic planter prototype could easily be operated by the medium size tractor of 25.76 kW power.

A field capacity of 0.61 ha h^{-1} was observed at an average speed of 3 km h^{-1} with field efficiency 70.12 per cent during cotton planting and similar field performance results were also observed for okra seed planting.

From Table 4.31 it is observed that the more than 80 per cent of the plants are placed at a plant to plant spacing of 493 to 510 mm spacing, which was found very near to recommended seed spacing of 450 mm for both the planted crops. The deviation in plant spacing from the recommended (450) was found to be 12.06 and 11.59 per cent.

It is noticed that the cotton varieties planted with multi crop pneumatic planter showed more variation as compared to okra, where the per cent of deviation in plant spacing was observed to be less for both the planted crops as compared to recommended plant spacing. The per cent of miss hills observed to be 9.15 and 7.02 per cent for cotton and okra respectively, where the observed single plant population for cotton and okra were 81.23 and 84.38 per cent.

It is evident from the performance tests of pneumatic planter, it discharges 2.05 and 4.10 seeds per square meter for cotton and okra respectively.

The results presented in Table 4.28 to 4.30, in terms of seed germination and plant spacing for cotton and okra crops, indicates that the variations between results of laboratory and field performance were found to be much less, which is acceptable range of any planter. Hence, the results of developed multi crop pneumatic planter prototype performed fairly satisfactory both in laboratory and field conditions for achieving the recommended seed rate with minimum variations in set plant spacing.

4.7 Economics of developed prototype planter

The estimated cost of three row multi crop pneumatic planter was ₹ 54,699 and the cost of operation of the planter with tractor was found to be ₹ 619.47 per hour (Appendix I). The estimated cost of planting operation by newly developed pneumatic planter was found to be ₹ 1009 per ha against ₹ 1900 per ha required for hand dibbling method.

Table 4.31 Field performance of pneumatic planter prototype

Sl. No.	Particulars	Cotton	Okra
1	Size of plot, m	50 × 50	
2	Location of plot	Brahaman Pally Village	
3	Source of power	Tractor (25.76 kW)	
4	Type of soil	Shallow black	
5	Soil moisture, d. b. (%)	15.16	
6	Bulk density, mg m^{-3}	1.31	
7	Seed variety	Jaadoo	Kaveri 49
8	Recommended plant geometry, mm	900 × 450	600 × 450
9	Average depth of sowing, mm	48.23	46.19
10	Speed of operation, km h^{-1}	3	3
11	Average field capacity, ha h^{-1}	0.61	0.47
12	Average field efficiency (%)	70.12	72.23
13	Draft of implement, N	3869 N	3869 N
14	Wheel slip (%)	10.53	9.15
15	Fuel consumption, L h^{-1}	4.56	4.26
16	Seed rate, seeds per m^2	2.34	4.12
17	Germination, (%)	89.23	88.12
18	Plant count per m^2	2.05	4.10
19	Average plant to plant distance, mm	479.46	463.37
20	Deviation from recommended spacing, per cent	12.06	11.59
21	Coefficient of precision (%)	79.15	82.23
22	Missing hills (%)	9.15	7.02
23	Per cent of single plant	81.23	84.38
24	Per cent of double plant	8.16	6.49
25	Per cent of triple or more plant	1.45	2.11

IV. DISCUSSION

In this Chapter, the results of physical, mechanical and aerodynamic properties of cotton and okra seeds are discussed. Design and development of pneumatic seed metering mechanism, its evaluation procedure for test crops using grease belt test rig and computer vision system were also thoroughly discussed in this chapter. Optimization of design and operational parameters of pneumatic planter using response surface methodology was presented and vacuum pressure simulation procedure and its results for all the developed model were also discussed in detail. Development of field prototype from optimized design parameters and its calibration in laboratory for the correct seed rate, seed spacing and its uniformity were discussed. The performance evaluation results of pneumatic planter prototype were presented and discussed the cause and effects. The economics of planter fabrication and planting operation were enlightened.

5.1 Physical, mechanical and aerodynamic properties of cotton and okra seeds

The cotton and okra are major growing commercial crops whose seeds are costly. Due to high yielding hybrid variety of these crops, they were recommended to plant at an exact spacing to get the desired plant density. Hence, majority of Indian farmers are following dibbling method for planting of this crop to avoid excess seed use and thus cost incurred on seed. Therefore, a multi crop pneumatic planter was designed; developed and operational parameters for these crops were optimized based on physical mechanical and aerodynamic properties and from laboratory experimental results.

In order to study the varietal difference of seeds on planter performance, three different varieties of cotton and okra seeds were selected as presented in section 4.1. The major influencing seed parameters like linear dimensions, physical, mechanical and aerodynamic properties were measured and results were presented in section 4.1 of the previous chapter. Results of the seed properties were discussed here under the following sub headings.

5.1.1 Linear dimensions of seeds

The results of linear dimensions of cotton and okra determined by manual and image processing techniques were presented in Table 4.1 and 4.2, respectively. To avoid much variation in linear dimensions of seeds, the seeds picked up from well graded seed lots were used for the study. About 86 per cent of the cotton seeds have length ranging from 8 to 10 mm; about 81 per cent of width of cotton seeds varied between 4.5 to 5.1 mm and thickness of 80 per cent of cotton seeds ranged from 4 to 5 mm across the selected varieties of hybrids and different determination methods. The length and width of same seed in image processing technique was found lower as compared to manual method of determination. Ozarslan (2002) reported that, about 76, 91 and 92 per cent of cotton seeds were in the range of 8.5 to 10.0 mm in length, 4.5 to 5.5 mm in width and 4 to 5 mm thick, respectively.

The differences observed in seed dimensions measured through conventional procedure and image analysis technique may be due to human error while taking measurements of seeds with vernier calipers or may be effect of image quality acquired and analysis process. However, observed highest coefficient of determinants (R^2) were 0.932 and 0.924 for length and width respectively between two methods for cotton seeds (Table 4.2). These values were in close agreement with the findings of Razavi *et al.* (2007) for the basil seeds. Seed analysis by image processing also effected by several factors like quality of image, illumination during image acquisition, technique adopted for processing and setting of scale.

Linear dimensions of okra seeds measured by using both methods were presented in Table 4.3. The 100 seed average length of okra OH1, OH2 and OH3 were observed to be 5.55, 5.19 and 5.59 mm for experimental measurements and 5.39, 5.06 and 5.47 mm in image analysis for respective hybrids. Sedat *et al*. (2005) reported that, the eighty-eight per cent of seeds have a mass ranging from 0.05 to 0.07 g, 76 per cent have a length from 4.5 to 5.5 mm, 86 per cent have a width from 4.2 to 5.5 mm and 90 per cent have a thickness from 3.5 to 4.5 mm at a moisture content range of 6.35 – 15.22 per cent. The regression equation and coefficient of determinant values of both methods for okra seeds were presented in Table 4.4. Similar trend was observed between both methods of determination as that of cotton seeds.

5.1.2 Physical and mechanical properties of cotton and okra seeds

Results of important physical and mechanical properties of cotton and okra seeds were presented in section 4.1.2. Moisture content of CH1, CH2 and CH3 was found to be 9.86, 8.63 and 9.37 per cent dry basis respectively, for cotton seeds from Table 4.5. Among the selected hybrids, the projected area was found higher for CH2 (39.86 mm^2) followed by CH1 (36.173 mm^2) and CH3 (29.73 mm^2). The computed mean values of sphericity for cotton was found to be 0.608, 0.636 and 0.669 for CH1, CH2 and CH3, respectively. The projected area of the seed particle generally indicative of its pattern of behavior in a flowing air of air assisted seeder distribution head (old models of pneumatic seeders) and as well as ease of separating foreign materials from the seed particles during the cleaning by pneumatic means. A considerable variation in sphericity of individual cotton seed will make to behave with greater variation when they move through air stream. Ozarslan (2002) reported that, the projected area and sphericity of cotton seeds was increased with the increasing moisture content. The determined values of projected area and sphericity of selected cotton hybrids in the present study were in close agreement with the values reported by Ozarslan (2002) and Tabak and Wolf (1998) for cotton seeds. The sphericity values of cotton seed (0.61 to 0.67) obtained in this study suggests that, the seeds are of hemispherical shape. Movement of non spherical seed is usually slower under gravity. Since, the metered seeds are to be transferred to the seed placement device quickly, the lower sphericity value of cotton is to be taken into consideration for designing the slope of the seed tubes and seed hopped of pneumatic planter.

The results of Table 4.6 revels that, the moisture content for the selected OH1, OH2 and OH3 okra verities was found to be 9.75, 7.64 and 8.27 per cent on dry basis, respectively. The maximum sphericity was found to be 0.916 for OH3, while the minimum of 0.881 for OH2. The average volume of a single seed for selected okra varieties varied from 49.09 to 54.84 mm^3. The uniform geometry of okra seems to be more spherical in shape, which results in uniform behavior between individual seeds during their moment through air stream. Sedat *et al*. (2005) reported that, the projected area was increased from 0.225 to 0.333 cm^2 as the moisture content increased from 6.35 to 15.22 per cent.

The individual seed weight affects seed flow from seed metering device to the boot and also influences the design of seed hopper. The drag coefficient is linearly related to the weight of individual seed, so weight of seed is expected to influence its behavior in air stream. Hence, one thousand seed mass of cotton and okra seed were determined presented in Table 4.6. The maximum mass of 1000 seeds was found to be 94.68 g for CH1 and 94.37 g for OH3 for cotton and okra, respectively. Higher values of thousand seed weight would imply lesser number of seeds planted for a given seed rate on weight basis and vice versa. The thousand seed weight along with the germination percentage can be used to predict the plant stand for recommended seed rate. The thousand seed mass of delinted cotton seeds increased linearly from 104.06 to 109.64 g as the moisture content increased from 8.33 to 13.78 per cent (d. b.) (Ozarslan, 2002). Similar results were found for the mass of fuzzy cotton seeds varied from 36.5 to 138.3, 41.4 to 127.6 and 38.7 to 127.4 g for MCU 5, LRA 5166 and Rajat 5 varieties, respectively as reported by Manimehalai and Viswanathan (2006).

The average volume of a single seed of cotton for CH1, CH2 and CH3 was found to be 93.917, 89.467 and 86.633 mm^3 from Table 4.5; whereas for okra seeds it was found to be 52.53, 54.84 and 49.09 mm^3 for OH1, OH2 and OH3, respectively (Table 4.6). In a study reported by Ozarslan (2002) stated the average volume for delinted cotton was varied from 95.4 to 109.6 mm^3. Similarly Sedat *et al.* (2005) studied the volume of individual okra seeds at different moisture contents of 6.35, 9.87 and 15.22 per cent on dry basis, reported seed volume were 47.38 ± 0.826, 50.42 ± 0.985 and 54.68 ± 0.898 mm^3, respectively.

Among selected varieties, the bulk density was found higher for CH1 (589.13 kg m^{-3}), followed by CH2 (576.76 kg m^{-3}) and CH3 (480.56 kg m^{-3}) whereas maximum true density of cotton seeds was observed to 1285.43 for CH2 variety in the present study, which is close agreement with the values reported by Ozarslan (2002) for delinted cotton seed. Manimehalai and Viswanathan (2006) also reported that, the bulk density of undivided mass of fuzzy cotton seeds was 226, 203 and 269 kg m^{-3} for the varieties for MCU5, LRA 5166 and Rajat 5, respectively. At higher 1000 seed mass range, the size of the seed is also large resulting in higher mass, rather than increase in volume, which leads to increase in bulk density.

The true density, bulk density and porosity of okra seeds were also presented in the Table 4.6. The maximum value of true density, bulk density and porosity was noticed for the OH3 variety. The bulk density and porosity of okra seed at moisture range of 6.35 to 15.22 per cent was varied from 636.10 to 577.99 kg m^{-3} and 48.92 to 52.08 per cent, respectively, as reported by Sedat *et al.* (2005). The true density effects the drag forces of the seed in an air stream. The force of buoyance experienced by a seed in air is due to difference between the true density and density of air. So, okra seed is expected to have lesser terminal velocity than the cotton seed.

Angle of repose helps to determine the seed flow rate and considered for designing a seed hopper. The maximum angle of repose of cotton and okra seed was found to be 39.19° and 29.16°. Inner surfaces of seed hopper on which the seeds are expected to flow by gravity alone like sides of seed hopper, funnel, seed conveyance tube between feeding and seed spout were designed to be more than 30° to ensure free flow of seed. Manimehalai and Viswanathan (2006) reported, the angle of repose for MCU 5, LRA 5166 and Rajat 5 verities of cotton was 38.5°, 43.3° and 40.3°, respectively.

The static coefficients of friction play an import role in seed holding and transport stages of seed metering devices. The results of coefficient of static friction on three surfaces (Mild Steel, Galvanized iron and Nylon sheet) for cotton and okra are presented in Table 4.5 and Table 4.6, respectively. Among the selected material surfaces, galvanized iron offered the maximum coefficient of static friction followed by mild steel and nylon sheet for both the selected seeds. When the friction angle between seeds and inner surface of seed rotor increased, the seeds will be easily picked by the seed cell (Yasir *et al*., 2013). Ozarslan (2002) reported that, the coefficient of static friction for delinted cotton seed was increased with moisture content on selected structural surfaces *viz*., stainless steel, galvanized iron, plywood and rubber, this may be due to the increased adhesion between seed at higher moisture values.

5.1.3 Aerodynamic properties of selected cotton and okra seeds

The terminal velocity and drag coefficient of cotton and okra seeds are the two important aerodynamic properties used in designing of pneumatic planter. The gravimetric properties of seed mass, bulk density and geometrical properties such as shape, size etc. were some of the parameters which influence the terminal velocity of seed. The maximum measured terminal velocity and drag coefficient of cotton were 8.917 and 0.28 for CH1 and CH2, respectively. Similarly for okra, it was found to be 5.98 and 0.47 for OH1 and OH3, respectively. The higher weight and bulk density of CH1 seed might have contributed to possess higher terminal velocity when compared with other two varieties. Tabak and Wolf (1998) reported that, the terminal velocity increased from 5.8 to 10 m s^{-1} as the mass of seeds increased from 0.08 to 0.15 g with 0 to 4 per cent lint content and reported drag coefficient for the same cotton seeds was in the range of 0.6 to 0.8, while that of the sphere is about 0.4 at the corresponding Reynolds number. Sedat *et al*. (2005) reported a terminal velocity for okra seeds at varied from 5.20 to 5.68 m s^{-1} at moisture range of 6.35 to 15.22 per cent.

5.2 Design and development of pneumatic seed metering mechanism

The process of pneumatic seed metering mechanism design and development was thoroughly explained in the section 3.3.2 and its conceptual 3D model was presented in figure 3.2. The developed seed metering mechanism mainly works on the principle of negative and positive pressure difference. It has seed rotor with vacuum chamber (Fig. 3.3) over which seed cells were drilled with respect to seed spacing. When the seed rotor rotates in its horizontal axis, due to which each seed cell of the vacuum chamber will also subjected to different pressure zones. The continuous suction of air from vacuum chamber while in operation will helps the cell to pick up seed, when it passes under the accumulated seeds. Due to suction pressure of air, the seed would be picked and held tightly against the rotor wall at cell entry point and transported to the top portion of chamber. At exact top center portion of chamber, the atmospheric opening was provided to exposes the seed cell to positive air pressure, due to which the influence of vacuum pressure get reduced on the seed at that particular portion and the seed was released in to seed spout. The detailed operating principles and its diagrammatic representations are presented in section 3.4 of methodology chapter.

The seed rotor was made up of nylon material which was easily machinable to get desired shape of the rotor and vacuum chamber which is also having high strength, durability, heat resistance and free from the rust. Hence this material was chosen for the rotor. In order to provide an additional support the rotor and to make vacuum chamber air tight a 5 mm thick MS was used. Which gives a back support to rotor and provides a path for the rotation of rotor. Hence the structural and functional compatibility of developed seed metering mechanism was studied and discussed in this chapter.

Therefore, three different size models were developed as presented in Table 4.9 with same conceptual design for optimizing vacuum pressure and centrifugal force (rotor speed) acting on seed. As the peripheral speed of rotor increases the influence of centrifugal force also expected to increase. Hence, for the developed model vacuum pressure, rotor speed and cell diameter were optimized by air pressure simulation using theory of CFD and conducting experiments.   .

5.2.1 Dynamic analysis of pickup, transport and seed discharge stages

In this present investigation, the forces acting on seeds at various stages of seed metering through designed seed metering mechanism were analytically studied and presented in the section 3.4.1. In this design, the pick-up process starts at the bottom of the seed rotor (under the seed lot), and the seed which are ready for picking up will be always close to the seed cell influenced by the movement and weight of the other seeds. Therefore, the magnitude of R (distance between seed and cell surface) is very small. When the air flow rate (Q) increased and the distance between seed and cell (R) decreased, the efficiency of sucking will increase. When the friction angle between seeds and seed rotor surface increased, the seeds will be easily picked by seed cell. Enlarging the cell diameter and increasing the negative pressure and friction index should improve the efficiency of picking up seeds, any variation in these factors, however will lead to high values of multiple seed pickups. Keeping acceleration due gravity (g), the radius of the seed plate (Rc) and friction index ($\tan\alpha_g$) are constants, the force of the negative pressure will increase when the rotating speed decreases.

From equation 3.23, it can be deduced that, the force required to pick up the seed was affected by seed parameters, seed density, drag coefficient and seed diameter (ρ_s, C_d, d_s), radius between seed and cell (R), friction angle between seeds and seed rotor surface (α_g) and air characteristics air density and air flow rate (ρ, Q).

The seed sucking force is influenced by both seed density and geometric mean diameter, *i.e.,* the sucking force is directly proportional with seed density and geometric mean diameter. The sucking force is also directly proportional with square of air flow rate (Q^2) and inversely proportional with the distance between seed and cell (R).

Analytically it is proved that, the force of vacuum pressure created in the chamber should be greater than the weight of seed, then only the intended process of pickup and transport of seed will takes place. During the transportation stage, the force of seed weight, gravity, vacuum pressure and centrifugal forces should balance, unless the seed will drop before it reaches to discharge point (Equation 3.33). When seed cell exposes to atmospheric pressure, vacuum pressure will be suppressed at this zone and force of gravity and centrifugal force has more influence, so the seed will drop in to seed delivery spout (Fig 3.8). Hence, cell diameter, negative air pressure and forward speed (in other terms rotational speed of rotator) were considered for the optimization for cotton and okra seeds.

5.3 Testing and optimization of design and operational parameters under simulated conditions

All the developed seed metering mechanisms models are tested under laboratory conditions on grease belt with standard test procedure as explained in section 3.4.2. and its results were presented in section 4.3. Actual level for independent variables used for developing response surface functions are presented in Table 3.1.

5.3.1 Effect of independent variables (*P, S* & *D*) on performance of developed seed metering mechanism model for cotton seeds

The effect of vacuum pressure, rotor speed and cell diameter on the performance of developed seed metering mechanism model for cotton and okra were evaluated in terms of miss index, multiple index and precision index. Experimental results were presented in section 4.3.1 with respect to performance indices and discussed here under.

5.3.1.1 Miss index for cotton seeds

The experimental results for miss index of cotton for all tested model carried out in the laboratory based on CCD are given Table 4.10 and its statistical attributes are presented in Table 4.11. From Table 4.10, it is observed that the seed metering mechanism operated at 2.50 k Pa vacuum pressure with 3.84 mm cell diameter at 0.83 m s^{-1} of rotor speed gave a satisfactory result in terms of miss index for all the tested models. It is observed from the figure 5.1, that the miss index was found to increase by increasing the rotor speed, whereas decreases by increasing the vacuum pressure at 2.26 mm cell diameter for SMM1 model. The response curve plotted between cell diameter and vacuum pressure for SMM1 model at rotor speed of 0.83 m s^{-1} is shown in figure 5.2. The results pointed that, both the parameters are influencing equally. At higher vacuum pressure, all the cell diameters performed satisfactorily whereas at lower pressure range the miss index found to be increased as the cell diameter increases. A miss index 3D surface graph was plotted for SMM1 model between cell diameter and rotor speed at constant pressure in figure 5.3. As the cell diameter increases and rotor speed decreases the miss index was also found to be decreases. This means that, at lower rotor speeds cells getting more opportunity time to pick the seeds even at lower air pressure, hence the miss index was found to be minimum at lower rotor speed and higher cell diameter. The fitted quadratic polynomial model was found significant at five per cent level, which also points out that, the selected all variable had influence on miss index. Arzu and Adnan (2007) was verified the optimum levels of peripheral speed, hole diameter and vacuum pressure for cotton precision seeder and reported similar trends of miss index. Singh *et al*. (2005) also reported similar results for cotton seed for pneumatic planter, miss index values reduces as the pressure is increased, but increases with increased speed with lower vacuum pressure and at higher speeds. The miss index performed similar trends for all the tested models, but the slighter variation was observed in the values of miss index that may be due to varied dimensions of vacuum chamber and atmospheric opening.

5.3.1.2 Multiple index for cotton seeds

The multiple index for all the tested models are greatly influenced by the selected variables as observed from the results presented in Table 4.12. The multiple index for all the tested models was varied from 2.19 to 15.64 per cent. Analysis of variance of response of multiple index for all the tested model was presented in Table 4.13. The multiple index model was found significant at 5 per cent for all the tested models and final equations of model with coded coefficients were depicted in section 4.3.1.2. Response of multiple index plotted in figure 5.4 indicates that, the rotor speed and vacuum pressure were greatly influenced on multiple index. The multiple index of seed metering mechanism was observed to be increased as the vacuum pressure increases, where as it decreases with increasing rotor speed. With larger cell diameter at slower rotor speed, the response of multiple index was observed to be maximum and vice versa (Fig. 5.5) at optimum pressure levels. Figure 5.6 shows the variation in multiple index of SMM1 model as a function of cell diameter and vacuum pressure and indicates a linear relation between the model terms and response. The multiple index was increased by increasing the cell diameter and vacuum pressure which is mainly due to increased cell diameter will increases the vacuum pressure, hence chances of multiple seed picking will also be increases at optimum seed rotor speed. Panning *et al*. (2000) has reported similar trend of variation with respect to multiple index. Singh *et al*. (2005) reported that, the observed multiple index value was found minimum at operating pressure of one k Pa and operating speed was found non-significant although it reduces at higher speeds. Karayel *et al*. (2004) also reported that, the miss index decreased and multiple index increased with increasing vacuum pressure for cotton. The response curves of multiple index for SMM2 and SMM3 model were also showed the similar effects.

5.3.1.3 Precision index for cotton seeds

Precision index is also a measure of the variability in spacing between seeds after accounting for variability due to both multiples and misses. The precision is the coefficient of variation of the spacing that are classified as singles (Katchman and Smith, 1995). The precision index of developed seed metering mechanisms tested for cotton seed were presented in Table 4.14. Precision index across the tested model was varied between 9.76 to 32.54 per cent, which is far lower than the theoretical upper limit (50 per cent). Whereas, a practical upper limit value of precision is 29 per cent (Katchman and Smith, 1995) which would be an indicative of all the spacings being spread uniformly within the target range and values consistently greater than 29 per cent should be viewed with suspicion. Table 4.14 revels that, a 9.76 per cent of precision index value was far less than practical upper limit value, which indicates that all the tested models were performing satisfactorily in terms of precision index.

Analysis of variance of response surface of cubic model for precision index was presented in Table 4.15. The F value of model term implies that, the model was significant at 5 per cent level. It is also observed that, the vacuum pressure (P) and cell diameter were found to be significant at 5 per cent level. Response curve (Fig 5.7) shows that, precision index was found low at lower cell diameter and rotor speed. At lower rotor speed and smaller cell diameter with optimum vacuum pressure miss and multiple index were expected to low, therefore the precision index will be more. Response of precision index was plotted (Fig. 5.8) as a function of cell diameter and vacuum pressure, which indicates that the curve was greatly influenced by both independent variables as said above. It also concludes that, increased vacuum pressure and cell diameter were expected pick up a multiple seed which will reduces the precision index. The response curve was plotted as function of rotor speed and vacuum pressure and is shown as figure 5.9, which indicates that, slower rotor speed and lower vacuum pressure gave satisfactory results of precision index at optimum cell diameter.

Whereas the precision index was found maximum at lower vacuum pressure rate and higher rotor speed at optimum air pressure, this may be due that the miss and multiple index were observed to maximum from figures 5.1 and 5.4. Karayel *et al*. (2009) reported similar results of precision index for maize and soybean sown through precision vacuum seeder at forward speed of 1 and 1.5 m s^{-1} and the precision index obtained varied between 18.9 - 21.8 and 18.1 - 21.9 per cent, respectively and these are in acceptable range as they are below 29 per cent. Singh *et al*. (2005) was reported that, the mean seed spacing and precision of spacing both are affected by the speed and operating pressure of the metering disc. It is also reported that, at pressures lower than 2 k Pa seeds are not able to adhere to the hole and, thus, result in a higher miss index. However, at pressure higher than 2 k Pa, more number of seeds are attached to the disc hole, giving greater number of seeds in a unit length, and thus a higher multiple index.

5.3.1.4 Miss index for okra seeds

As explained in section 5.1.3, all the developed models were also tested for okra seeds in order to optimize the independent variables and results were presented with respect to performance indices as a miss index as explained in section 4.3.2. The results of miss index for okra seeds for all the tested models are presented in Table 4.16 and the generated response curves plotted as figures 5.10 to 5.12. The similar variations as that observed in cotton seed were also observed in case of okra in SMM3 model with respect to rotor speed, cell diameter and vacuum pressure. As compared to cotton seeds, the miss index found of okar seeds was found low (Table 4.16), which might be aroused due to more regular shape of okra seeds. The miss index of okra seeds was increased with respect to cell diameter and rotor speed, whereas it was found decreased with increase in vacuum pressure. A similar variation in miss index was observed for SMM1 and SMM2 models also. Similar results of pneumatic precision device for wheat were presented by Yasir *et al*. (2013). Singh *et al*. (2005); Arzu and Adnan (2007) were also presented similar results of miss index for pneumatic precision planter for cotton seeds. The prediction model of miss index for the tested model was found significant at 5 per cent level and the independent linear variables vacuum pressure (*P*), rotor speed (*S*) and cell diameter and its interaction effects $P \times S$, P × D and $P \times S \times D$ were also found significant (Table 4.17).

5.3.1.6 Multiple index for okra seeds

The variation in multiple index with respect to three tested models namely SMM1, SMM2 and SMM3 were presented in Table 4.18 and the results are statistically analyzed and attributes were presented in Table 4.19. The observed variations of multiple index for okra was found less as compared to cotton seeds for same models, which also may be due the more spherical shape of okra seeds. The statistical attributes presented in Table 4.19 shows that, the model terms for all tested model were found significant at 5 per cent level of significance. Multiple index response curves were plotted as function of rotor speed, vacuum pressure and cell diameter as shown in figures 5.13 to 5.15, which point out the similar kind of variations as that observed in case of cotton seeds. The similar variations in trends was also reported by Singh *et al*. (2005); Arzu and Adnan (2007) and Yasir *et al*. (2013) for pneumatic precision seeders tested for cotton and wheat respectively. There was not much variation was observed in results of other two tested models *i.e.* SMM1 and SMM2 as compared to SMM3 model.

5.3.1.3 Precision index for okra seeds

The results of precision index obtained for all the tested machine models for okra are presented in Table 4.20. It is observed that, the precision index varied from 7.36 to 32.46, which was found closer to the practical upper limit of precision index given by Katchman and Smith (1995). The observations from Table 4.21 revels that, the model terms of all tested metering mechanisms for okra seeds found significant at 5 per cent level of significance. The trend of variation in precision index was found similar for both cotton and okra seeds. It indicates that, lower the precision index values will have minimum variation in seed spacing's. These results are in agreement with the findings reported by Karayel (2009) and Singh *et al.* (2005) for maize and cotton respectively. The pattern of variation in precision index for SMM3 was plotted in figure 5.16 to 5.18 a similar kind of variation patterns were observed across three tested seed metering models.

5.3.2 Optimization of design and operational parameters for cotton and okra seeds

Numerical optimization technique was followed to get optimum levels of independent variables for the designed and tested models using expert 7.7.0 version software. Multi variables response optimization constrains of experiments are presented in Table 4.22 and three best optimal solutions were presented in the Table 4.23 and Table 4.24 for cotton and okra respectively. The best model among the three tested model was found out by considering some other parameters like seed breakage and vacuum pressure analysis using the ANASYS FLUENT solver.

5.4 **Simulation of vacuum pressure using ANSYS FLUENT software**

Vacuum pressure was simulated for all the developed and tested models in order to get optimum dimensions for vacuum chamber. The variations in pressure and velocity of air were determined through fluent solver, Navier-Stokes equations were solved using the standard k-ε turbulence model because, range of the Reynolds number corresponding to suspension of cotton seeds was between 3000 and 4000 (Tabak and Wolf, 1998). The models SMM1 and SMM2 were observed to be recording less vacuum pressure (Table 4.23), which might be due to larger dimensions of the vacuum chambers resulting in reduced in air pressure and velocity. The air moment at seed releasing stage (Fig. 4.8) shows the interaction of positive and negative air pressures and the optimum size of the atmospheric cutoff expected to have direct influence on the miss and precision indexes of seed metering device. Hence, the SMM3 model was chosen as best performing model in terms of higher air pressure and velocity and the metering performance indices namely miss index, multiple index and precision index were found to be minimum as compared to other two models. The experimentally observed variation patterns was found similar with the findings reported by Yu *et al*. (2014) and Xu *et al*. (2012). The vectors vacuum pressure shown in the figure 4.8 shows the importance of atmospheric opening provided over the outer ring which acts as vacuum cut off value. Due to sudden decrease fall of vacuum pressure at cut off point seed was exactly released in the seed delivery spout. The reduced vacuum pressure before seed delivery spout would increases the miss index, which may be due to fall seed before it reach to delivery point.

5.5 Computer vision system for measuring seed spacing

As explained in section 3.6 of methodology chapter an advanced technique called computer vision system was used to test the seed metering mechanism under laboratory conditions. A diagrammatic representation of video acquisition set up was shown in figure 3.12 and the validated results in terms of seed elapsed time, which is an indicator of seed spacing uniformity was presented in Table 4.26. The R^2 value between both the methods had shown a linear correlation between both the methods. The montage of processed binary image samples was presented in Plate 5.1. Two seeds were appeared on ninth frame and observed distance on grease belt for the same frame was found to be 20 mm and elapsed time was zero second. It means that, the two seeds were released by a single cell of the seed metering mechanism. This could be measured as a multiple index. The 12th seed has appeared after 0.982 sec of 11th seed, which is almost twice the average elapsed time and corresponding seed spacing on grease belt was found to be 870 mm, indicating that there is a missing of a seed by cell. Therefore, an interpreted result of image processing technique clearly explains the competency of computer vision technology and also reduces the labour required for laboratory testing and saves time and cost. Hence, computer vision technology may be recommended for laboratory evaluation and calibration of planters. Muller *et al.* (1994) and

Lan *et al*. (1999) used a fully automated opto-electronic measurement system for the evaluation of seed spacing to replace the cost and labour intensive sticky belt method. Opto-electronic measurement systems reduced the labour requirement for seed spacing monitoring considerably, but simultaneously passing seeds at higher frequencies was difficult to detect and reduced the measuring accuracy. Karayel *et al*. (2006) and Okan and Ismet (2009) have been developed computerized measurement system for in row seed spacing accuracy measurement using high speed camera and reported that, the developed system was successfully determined seed spacing distribution.

The predicted optimum values were validated by conducting the experiments and results are presented in Table 4.27 for both cotton and okra seeds. The per cent of variations in the miss, multiple and precision indices were found to be 1.668, 1.964 and 3.777 for cotton and 1.727, 1.117 and 3.861 for okra seeds respectively. Therefore, these optimized variables are considered for designing the field prototype of pneumatic planter for cotton and okra seeds. The measured indices desirability and combined desirability for the optimal solutions are presented in figure 5.19 and 5.20 for cotton and okra respectively for SMM3 model of seed metering mechanism. A desirability and combined desirability value unity will indicates reliable confidence level of predicted values set for design and farther from unity will indicates decrease in confidence level.

5.6 Performance evaluation of multi crop pneumatic planter prototype

The developed planter performance was evaluated under laboratory and field conditions as explained in section 3.8 of methodology chapter and results are presented in section 4.5 of previous chapter.

5.6.1 Laboratory calibration and testing of multi crop pneumatic planter for selected seeds

The fabricated prototype type planter was tested under laboratory conditions in terms of seed distribution at different hopper capacities and its statistical attributes were presented in Table 5.28. There was no significant difference between three furrow openers across different hopper capacities. It indicates that, the individual seed metering devices are properly synchronized in the speed transmission drive and air flow rate. The average seeding rate per m^2 was varied between 2.413 to 2.458 for cotton and 3.733 to 3.836 for okra across the furrow openers and hopper capacity.

Seed breakage and germination of cotton and okra seeds were determined and results are presented in Table 5.30 and Table 5.31 for cotton and okra, respectively. The observed seed breakage was found more in case of cotton compared to okra seed. This may be due to the fact that, cotton seed is oval in shape whose tip was rubbed between the gap of rotor and cover plate. In case of okra this problem was not observed, because okra seeds are regular and more spherical in nature when compared with cotton. In tune with the above observations, the percentage of germination of cotton seed was observed less as compared to okra seeds. However, there was no significant difference was noticed in seed damage and germination percentage across the three furrow openers when a particular seed species considered.

The results of prototype planter planting uniformity for cotton an okra seeds on sand bed was presented in Table 5.32. No significant difference was observed in plating uniformity of cotton and okra between the furrow openers. The maximum observed deviation of seed to seed spacing in given row from the recommended value were 8.97 and 6.79 for cotton and okra respectively, which in the range of precision index.

From the above results, it concludes that the secondary seed accumulator in the rotor was completely suppressed the effect of hopper capacity on seed distribution, hence there was no significant difference was found at various hopper capacities. The deviation in seed spacing uniformity from recommended was found within the range, so variation precision index of prototype planter was expected to be very less.

5.6.2 Field evaluation of multi crop pneumatic planter prototype for cotton

Field evaluation results of multi crop pneumatic planter prototype were presented in Table 5.33. The draft of implement measured was found to be 3869 N. Therefore, the developed planter can be easily operated by a 25.76 kW tractor. The fuel consumption of tractor was found little high, because the engine needs to be operated at full accelerator condition to get desired PTO rpm to operate the aspirator blower of planter.

The planter performance parameters like miss hills and single plant population of 9.15 and 7.02 per cent for cotton and 81.23 and 84.38 per cent for okra respectively, were found to be satisfactory in real field condition. The miss hills were found quite high because, the vibration and uneven drive from the ground wheel was reduces the influence of vacuum over seed which results in dropping the picked seeds in to back to seed chamber, before it reaches to seed discharge point.

5.7 Economics of developed prototype planter

The saving of ₹ 891 per ha in cost of operation was observed by using multi crop pneumatic planter over traditional method and the break-even point of the unit computed as 19 ha per year (Appendix III). The saving in man hour requirement and in terms of cost of planting was quite substantial and hence justified the use of developed planter for high value seeds like cotton and okra.

VI. SUMMARY AND CONCLUSION

The Agricultural machinery and equipments have great potential to aid farmers in timeliness of operation besides reducing energy requirement per operation there by helps in reducing drudgery of human labour and increases the efficiency of utilization of natural resources and farm inputs like seed, fertilizer, pesticide and herbicide in crop production. Application of the new developments in the field of production techniques and electronics technologies in farm machinery research is the need of the hour in our country. This could enhance the quality of the present standard of research work towards innovation of cutting edge technologies for precision and timeliness of agricultural machinery in field operations.

As it is justified in introduction chapter, seed sowing or planting is a crucial operation in crop production. For assured productivity of high yielding variety hybrids like cotton and okra, where single seed germination matters for the farmers hence a quality sowing or planting is must for these commercially growing crops. It would be naive to assume that farmers in the developing countries can meet the food production targets of the coming decade without access to more and better farm power and improved implements and equipment's to utilize that power effectively and efficiently. Agricultural machines play the role of exponents of progress in agricultural pursuits and welfare of farming community.

Therefore, design and operational parameter of multi crop pneumatic planter were optimized based on the optimized results a multi crop pneumatic planter prototype for cotton and okra was designed and developed and also computer vision system was developed to evaluate seed planters' performance under simulated conditions to meet the needs of precision agriculture.

In order to design and develop a multi crop pneumatic planter for cotton and okra seeds, important physical, mechanical and aerodynamic properties were studied and considered for designing the seed metering mechanism.

- Linear dimensions like length, width and thickness were determined by digital Vernier caliper of cotton seeds were varied from 8.263 to 9.197, 4.734 to 5.068 and 4.183 to 4.916 mm, whereas okra seeds dimensions were varied from 5.19 to 5.59, 4.49 to 4.72 and 4.36 to 4.68 mm, respectively across the selected variety seeds.
- Linear dimensions of selected seeds were also determined by using advance image processing technique and results were found to be in close agreement with the values determined by manual measurement. The strong correlation was observed with maximum coefficient of determination of 0.932 (Length) and 0.945 (Width) for cotton seeds and

0.905 (Length) and 0.926 (Width) for okra seeds between both the methods of determination.

- The coefficient of determination value indicates suitability of image processing technique in comparison with manual method of determination, image processing technique has got an advantages of time saving, less human errors and accurate results. Hence, this technique may be recommended to use for determining the seeds linear dimensions.
- Physical and mechanical properties like sphericity, projected area, thousand seed mass, volume, bulk density, true density and coefficient of frictions of cotton and okra seeds were considered in designing various components like seed hopper, seed rotor and angle of seed.
- The maximum terminal velocity and drag coefficient of cotton was found to be 8.917 m s^{-1} and 0.63, respectively. Similarly for okra seeds the maximum observed terminal velocity (5.98 m s^{-1}) and drag coefficient (0.47). Variation in terminal velocity and drag coefficient between the selected cotton and okra varieties was observed to be very less. Hence, the air pressure center value was decided based on the maximum terminal velocity and drag coefficient.
- The developed seed metering mechanism mainly works on the principle of negative and positive air pressure difference. By considering variations in different seeds physical and aerodynamic property and their agronomic requirement seed rotor needs to be changed. Hence, a seed rotor was made as separate component which can be dismantle easily and replaced with other as per the seed requirements.
- Dynamic analysis of pickup, transport and seed discharge stages analytically proved that, the force of vacuum pressure created in the chamber should be greater than the weight of seed, then only the intended process of pickup and transport of seed will takes place.
- The force required to pick up the seed by cell was affected by seed parameters like seed density, drag coefficient and seed diameter (ρ_s, C_d, d_s), radius between seed and cell (R), friction angle between seeds and seed rotor surface (α_g) and air characteristics air density and air flow rate (ρ, Q).
- The seed sucking force is directly proportional with seed density and geometric mean diameter, square of air flow rate (Q^2) and inversely proportional with the distance between seed and cell (R).

- In seed pick up process, it observed in the dynamic force analysis that increasing the air flow rate (*Q*) and by decreasing the distance between seed and cell (*R*), the seed pick up efficiency will increases which reduce the miss index of seed metering device.
- Enlarging the cell diameter and increasing the negative air pressure and friction index will improve the efficiency of picking up of seeds, any variation in these factors, however will lead to high values of multiple seed pickups which results in increased multiple index.
- A structural and functional stability of three designed model were studied by using computational fluid dynamics theory through ANSYS FLUENT software. The fluid models of developed pneumatic precision metering devices were built to obtain the pressure and velocity of seed cell which is directly related to the performance of seed metering devices.
- Due to the compact design of vacuum chamber, the SMM3 model was performed satisfactorily in terms of all performance indices and got maximum desirability among the designed models. Similarly the air pressure and velocity was also found more in this model which is felt sufficient to carry the selected seeds under different operating conditions. Therefore, SMM3 model was selected for the final prototype design.
- Among the designed seed metering mechanism models structural stability and functional optimality was found in SMM3 model with dimensions of 10 × 10 mm vacuum chamber, 50 mm annular space width and 10 × 20 mm atmospheric opening size.
- In order to optimize cell diameter as design parameter and vacuum pressure and rotor speed as an operational parameter, the developed seed metering mechanism were evaluated in terms of miss index, multiple index and quality feed index and experiments were designed as per the central composite design rotatable according to response surface methodology.
- Optimum vacuum pressure, rotor speed and cell diameter for cotton was found to be 2.72 k Pa, 0.81 m s^{-1} and 2.66 mm for the SMM3 model with predicted responses of miss index, multiple index and precision index were observed to be 6.764, 3.897 and 10.810 per cent, respectively with combined desirability of 0.88.
- Similarly the obtained optimum value for the okra seeds was found to be 2.34 k Pa (Vacuum pressure), 0.75 m s^{-1} (Rotor speed) and 2.05 mm (Cell diameter) with the predicted responses of miss index, multiple index and precision index were observed to be 2.604, 1.117 and 7.0 per cent, respectively with combined desirability of 0.907.

- The predicted values were validated through experiments at optimum conditions and noticed per cent variation as compare to actual value was found to be 1.668, 1.964 and 3.777 per cent of miss index, multiple index and precision index respectively for cotton seeds whereas for okra seeds the respective variation was noticed to be 1.727, 1.117 and 3.861 for miss index, multiple index and precision index respectively.
- To adopt easy and fast evaluation of seed metering mechanism an alternative method was developed using advance techniques of computer vision system. The observed linear seed spacing was correlated with elapsed time between the seed (object) frame.
- A strong correlation was observed between sticky belt method and computer vision system with coefficient of determination (R^2) of 0.91 and 0.99 for cotton and okra seed spacing respectively, hence there is scope for using computer vision system for the seed spacing analysis under the laboratory conditions.
- Three row multi crop pneumatic planter was developed based on the optimum design and operational values of SMM3 model and tested and evaluated under laboratory and field conditions for cotton and okra seeds.
- There was no significant difference between three furrow openers across different hopper capacities. The average seeding rate per m^2 was varied between 2.413 to 2.458 for cotton and 3.733 to 3.836 for okra across the furrow openers and hopper capacity.
- The maximum observed deviation of seed to seed spacing in given row from the recommended value were 8.97 and 6.79 for cotton and okra respectively, which is in the range of precision index.
- The test results of multi crop pneumatic planter concludes that, the secondary seed accumulator in the rotor was completely suppressed the effect of hopper capacity on seed distribution, hence there was no significant difference was found at various hopper capacities. The deviation in seed spacing uniformity from recommended was found within the range, so variation in precision index of prototype planter was expected to be very less.
- The planter performance parameters like miss hills and single plant population of 9.15 and 7.02 per cent for cotton and 81.23 and 84.38 per cent for okra respectively, were found to be satisfactory in real field condition.
- The saving of ₹ 891 per ha in cost of operation was observed by using multi crop pneumatic planter over traditional method and the break-even point of the unit computed as 26 ha per year. The saving in man hours requirement and in terms of cost of planting was

quite substantial and hence justified the use of developed planter for high value seeds like cotton and okra.

- The conducted study concludes that, the design and operational parameters of multi crop pneumatic planter parameter mainly vacuum pressure, rotor speed and cell diameter were optimized for cotton was found to be 2.72 k Pa, 0.81 m s^{-1} and 2.66 mm, whereas for okra the optimum value were 2.34 k Pa, 0.75 m s^{-1} and 2.05 mm, respectively for the SMM3 model.
- It is observed from the results of laboratory testing and field evaluation, the developed multi crop pneumatic planter was functioned satisfactory for precision planting of cotton and okra seeds and it was found that the a saving in time and cost by using the developed planter. Hence it is recommended to use the developed multi crop pneumatic planter for planting cotton and okra seeds.

Future scope of study

- Optimization of vacuum pressure, rotor speed and cell diameter for the other crops
- Designing of alternate power source instead of ground wheel
- Preparation of chart variables with respect to crop for easy understanding to the farmers
- Study of theory of simulation and validation using CFD and other methods
- Development of automatic calibration and testing system using computer vision system

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APPENDIX – I

Cost of material for prototype pneumatic planter fabrication

Name of the component	**Material**	**Size**	**Quantity**	**Cost(₹)**
Hitch assembly	St 42-S	45 ×45 ×6 mm	4 m	1200
Main frame	St 42-S	45 × 45× 6 mm	12 m	3600
Furrow opener	C75	430×50×25 mm	1.5 m	1250
Flexible pipe	PVC		1.5 m	50
Seed rotor	Nylon	290 mm ϕ (ID)	3	9000
Seed rotor shaft	45 C 8		3	1200
Seed rotor frame	St 42-S		3	3000
Flange bearing		F204	3	540
Hopper	St 42-S		0.1 m^2	250
Aspirator blower	St 42-S		0.3 m^2	750
PTO pulley shaft	St 42-S		1	1500
Blower shaft	45 C 8		1	150
V grove pulley	Cast iron	450 mm ϕ	1	900
V belt	Type B	No 56		250
Duct pipe	PVC	30 mm ϕ	4 m	2800
Ground wheel	Fe 410	45 ϕ × 6 mm	1	700
Lugs on ground wheel	St 42-S	75 × 50 × 6 mm	12	200
Ground wheel shaft	St 42-S	12 ϕ × 190 mm	1	150
Main shaft	St 42-S	20 ϕ ×1950 mm	1	1200
Sprocket	St 42-S	11, 14, 17 teeth		3300
Roller chain			--	1500
Pedestal bearing	St 60	Bore 20 mm	8	1800
Total cost of material				35,290
Labour charges @ 25 per cent				8822
Production materials cost @ 30 per cent				10,587
			Total	54,699

APPENDIX – II

Estimation of cost of planting operation of tractor drawn multi crop pneumatic planter prototype

i. Cost operation of prime mover (*i.e.* Tractor)

Assumptions

i. Average annual use, h = 100

ii. Life of tractor, Years = 10

iii. Salvage value = 10 per cent of initial cost

iv. Rate of interest = 14 per cent of capital cost

v. Fuel cost, Rs/Liters = 60

vi. Initial investment for 35 hP tractor = Rs.5,50,000/-

A. Fixed cost

$$\text{Depreciation cost per hour} = \frac{\text{C - S}}{\text{L} \times \text{H}}$$

Where,

C = Capital cost

S = Salvage value = C/10

L = Life of tractor in years

H = Working hours per year

$$D/hr = \frac{550000 - 550000 \times 0.1}{10 \times 1000}$$

$$= 49.5 \text{ ₹/h}$$

$$\text{Interest (I)/h} = \frac{\text{C} + \text{S}}{2} \times \frac{i}{H}$$

(i = assumed 14 per cent per year of capital cost)

$$= \frac{550000 + (550000 \times 0.1)}{2} \times \frac{14}{100 \times 1000}$$

$$= \frac{550000 + 55000}{2} \times \frac{14}{100 \times 1000}$$

= 42.35 ₹/h

Housing cost, insurance and taxes (Each @ 1 per cent of the initial cost of tractor)

$$\text{Housing cost per hour} = \frac{550000 \times 1}{1000 \times 100}$$

= 5.5 ₹/h

Housing, taxes and insurance cost @ 3 per cent of the initial investment per year,

Rs = 16.50 ₹/h

Repair and maintenance cost @ 10 per cent of the initial investment per year,

Rs = 55.00 ₹/h

Total fixed cost of tractor per hour = 49.5 + 42.35 + 16.50 + 55.00 = 163.5 ₹/h… (8.1)

B. Variable cost

Fuel cost per hour, Rs = 4.56 × 60 = ₹ 273.60

Lubricants @ 30 per cent of fuel cost = 273.6 × 0.30 = 82.08 ₹/h

Wages of tractor driver @ ₹ 350 per day of 8 hours = 43.75 ₹/h

Variable cost of tractor, Rs = 273.60 + 82.08 + 43.75 = 399.43 … (8.2)

From equation 8.1 and 8.2, Cost of tractor for planting operation was = 163.5 + 399.43

= 562.93 ₹/h … (8.3)

II. For pneumatic planter prototype

Assumption

i. Average annual use, h = 250

ii. Life of pneumatic planter, Years = 10

iii. Salvage value = 10 per cent of initial cost

A. Fixed cost

Initial cost of pneumatic planter equipment (₹) = 54,699 ≈ 55,000

$$\text{Depreciation (₹/h)} = \frac{C - S}{LxH}$$

$$= \frac{55000 - 5500}{10 \text{ x } 250}$$

= 19.8 ₹/h

Interest (Rs/h) $= \frac{C + S}{2} x \frac{I}{H}$

$$= \frac{55000 + 5500}{2} x \frac{14}{100 \times 250}$$

= 16.94 ₹/h

Housing, taxes and insurance cost @ 3 % of the initial investment per year,

Rs = 6.6 ₹/h

Repair and maintenance cost @ 10 per cent of the initial investment per year,

Rs = 2.20 ₹/ h

Fixed cost of pneumatic planter,

Rs = 19.8 +16.94 + 6.6 + 2.2 = 45.54 ₹/h ... (8.4)

B. Variable cost

Repair and maintenance $= \frac{55000}{250} x \frac{5}{100}$

(5 per cent of initial cost)

Total variable cost = 11 ₹/h … (8.5)

Total operating cost of horizontal plate planter with instrument = (8.4) + (8.5)

= 45.54 + 11

= 56.54 ₹/h

… (8.6)

From Eq. 8.3 and 8.6, The total operating cost of tractor with pneumatic planter = total operating cost of tractor + total operating cost pneumatic planter

= 562.93 + 56.54

= 619.47 ₹/h … (8.7)

iii. Cost involved in planting operation using pneumatic planter

Operating cost of planter = 619.47 ₹/h

Field capacity of planter = 0.61 ha/h

The cost of mechanical planting operation ₹/h = 1009 ₹/ha … (8.8)

iv. Cost involved in manual dibbling

The cost of manual planting of cotton 1900 ₹/ha … (8.9)

APPENDIX – III

Calculation of saving cost, breakeven point and payback period

Cost of mechanical planting of cotton, Rs/ha = 1009 Rs/ha

Cost of manual planting of cotton, Rs/ha = 1900 Rs/ha

Saving cost = 53.10 per cent

A. Break Even Point (BEP)

$$BEP\ (\mathrm{hr/annum}) = \frac{\text{Annual fixed cost}}{\text{Custom fee (Rs/h) - operating cost (Rs/h)}}$$

Annual fixed cost, Rs/year = 11250

Custom fee, ₹/h = (Cost of operation per hour + 25 per cent overhead charges) + 25 per cent profit over new cost

= (619.47 + 619.47*0.25)*1.25 = 967.92

Operating cost per hour = 619.47

BEP h/year = 32.28

BEP ha/year = 19.69

Annual utility, ha = 0.61 × 250 = 152.5

Therefore BEP is achieved at about 12.9 ((19.69/152.5) × 100) per cent of the annual utility of 250 hour of use of planter.

B. Payback period

$$\text{Payback period, year} = \frac{\text{Initial cost of machine}}{\text{Avarage net annual profit}}$$

Initial cost of planter, Rs = 55000

Average net annual profit, Rs = (Custom fee, Rs/h-Total operating cost, Rs/h)×Annual utility = (968 – 620) × 250 = 87000

$$\text{Payback period, year} = \frac{55000}{87000} = 0.63$$