DEVELOPMENT AND OPTIMISATION OF AN INTEGRATED SEMI-AUTOMATED GRADING MACHINE FOR COWPEA (*Vigna unguiculata* (L.) WALP) SEEDS

BY

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CERTIFICATION

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DEDICATION

This work is dedicated to God and to my three sons that died during my pursuit of this program. May their gentle and sweet souls rest in peace.

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ABSTRACT

Nigeria is the largest producer of cowpea. Despite this relatively large production, its export has been hindered by poor seed grading and inefficient processing. Existing cowpea grading machines are mostly for unit operations. Integrated grading machine are needed for improved seed grading and efficient processing. Therefore, this study was designed to develop an integrated semi-automated cowpea grading machine.

Standard methods were used to determine the optical and electrical parameters of three indigenous cowpea seed varieties (NG/AD/11/08/0033, NG/OA/11/08/063 and NGB/OG/0055) for the automation unit design considerations. This was carried out at seed moisture levels (8.0, 10.0, 12.0, 14.0 and 16.0%), light wavelength (320, 420, 520, 620 and 720 nm) and current frequency (1, 500, 1000, 1500, 2000 kHz). Thereafter, an integrated semi-automated machine with three separating units was developed and automated using machine vision technology. Operational parameters used for evaluation were speed of drum (40, 60 and 80) rpm, bucket conveyor speed (250, 300 and 350) rpm and metering disc (12, 16 and 20) rpm; seed variety and grade (9.8%, 16.0% and 21.0%) of impurity. The total machine system output was evaluated and optimised in terms of efficiency, throughput, maximum capacity, actual utilisation and backlog, using response surface methodology. Prediction interval and multiple regression analysis were used for validation at α 0.05.

The optical properties ranged from: 0-1.8%, 0-1.0%, 0-12.0%, ([38-92.2%] [0.7-9.0%] [13.6-27.3%]) for absorbance, reflectance, transmittance and colour (L* a* b*), respectively; while electrical properties ranged from 1.926-15.625 Ω, 0.272-2.209 Ωm, 0.064–0.519 S, 0.453–3.671 S/m, 1.800x10-11–1.380x10-7 F, 0.500-4928.570, 6.020 x107-9.040x1021 H) and 1.150x106–1.450x107 Ω, for resistance, resistivity, conductance, conductivity, inductance and impedance, respectively. The two separating units (sieve drums) removed impurities > 12 mm and < 2 mm with efficiency of 76.6±9.343% and 85.3±11.1%; throughput of 0.220±0.139kg/hr and 0.144±0.111kg/hr, respectively. The third digital automated sorting unit separated diseased and insect damaged seeds by colour with efficiency of 82.1±7.2% and throughput of 1.386± 0.758kg/hr. Operational parameters were found to have significant effect on all evaluation terms. The efficiency, throughput, maximum capacity, actual utilisation and backlog of the total system output ranged from 63.5-80.4%, 0.574–3.732 kg/hr, 6.882-44.778 kg/12hr, 0.083-0.083 (8.3%) and 0.03–0.182 kg, respectively. At 80.4% efficiency, the impurity of grade 3 was reduced to grade 2, and 2 to 1 based on the standard export grade range. The integrated machine system optimisation achieved two best solutions. The first and second having maximum total system impurity separating efficiency of 81.3 and 79.9%, maximum total system throughput of 3.470 and 5.077 kg/hr and minimal total system backlog of 0.064 and 0.07 kg, respectively. The validation data were within 95% low and high prediction intervals. The evaluation terms had coefficient of determinations (R2) values > 0.9 showing no significance between predicted and validation data.

The developed integrated semi-automated grading machine for cowpea reduced the impurity in indigenous cowpea varieties to exportable grade.

Keywords: Digital sorting, Machine optimisation, Cowpea grading machine.

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LIST OF SYMBOLS AND ABBREVIATIONS

$	Dollar
%	Percent
ε	dielectric Constant
ρ	Resistivity
σ	Conductivity
Ω	ohms
δ	Angle of friction
σ	Comprehensive Strength
θ	Angle
μ	Coefficient of Friction
γ	Specific Mass
η	Speed of rotation drum
2FI	2 Factor Interaction
2-D	2 Dimensional
3-D	3 Dimensional
4-D	4 Dimensional
kg	Kilogram
Zc	Impedance
Xc	Capacitance Reactance
kHz	Kilo Hertz
nm	Nanometer
m	Meter
mm	millimeter
cm	Centimeter
MHz	Mega Hertz
A	Absorbance
a*	Redness
AC	Alternating Current
ACB	African Center for Biodiversity
AES	Advance Encryption Standard

ANOVA	Analysis of Variance
API	Application Programming Interface
ARM	Advanced RISC Machine.
AOAC	Association of Official Agricultural Chemists
AU	Actual Utilization
B	Backlog
b*	Yellowness
C	Capacitance
CCD	Charged-Coupled Device or Central Composite Design
CDF	Conveyor Diameter Factor
CFH	Capacity in cubic feet per hour
CHF	Conveyor Capacity
COMESA	Common Market for East and South Africa
CPU	Central Processing Unit
CNC	Computer Numerical Control
CS	Conveyor speed
CSI	Camera Serial Interface
DC	Direct Current
DSI	Display Serial Interface
E	Efficiency
EAC	East Africa Community
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture organization Statistic
FHP	Friction Horse Power
FIR	Far-Infrared Spectroscopy
G	Conductance
GND	Ground
GPIO	General-Purpose Input/Output
HBF	Hanger Bearing Factor
HDMI	High-Definition Multimedia Interface
HIS	Hyperspectral Imaging Spectroscopy

HP	Horse Power
IEEE	Institute of Electrical and Electronics Engineers
IITA	International Institute of Tropical Agriculture
IITAR4D	International Institute of Tropical Agriculture Research for Development
IOT	Internet of Things
ISO	International Organization for Standardization
K-NN	Kernel -Nearest Neighbors Algorithm
L	Inductance
L*	Brightness
LAN	Local Area Network
LED	Light Emitting Diode
LCD	Liquid-Crystal Display
MC	Maximum Capacity
MHP	Material Horse Power
MIPI	Mobile Industry Processor Interface
MIR	Mid-infrared Spectroscopy
MMAL	Multi-Media Abstraction Layer
NACGRAB	National Center for Genetic Resources and Biotechnology
NB	Naive Bayes Algorithm
NIR	Near-infrared
NIRS	Near-infrared spectroscopy
NMR	Nuclear Magnetic Resonance Spectroscopy
NTSC	National Television Standards Committee
NoIR	No Infrared Filter
OECD	Organisation for Economic Co-operation and Development
OS	Operating System
PAL	Phase Alternating Line
PAS	Photoacoustic Spectroscopy
PC	Personal Computer
PN	Polyester and Nylon
R	Reflectance or Resistance

RCA	Radio Corporation of America
RSM	Response Surface Methodology
RTI	Radio Tomographic Imaging
SADC	South Africa Development Community
SBCs	Single-board Computers
SD	Secure Digital
SDIO	Secure Digital Input Output
SoC	System-on-a-chip
SVM	Support Vector Machines Algorithm
T	Transmittance or Throughput
TIRS	Transient infrared Spectroscopy
TFT	Thin-Film-Transistor
TSHP	Total Shaft Horse power
UV	Ultraviolet
UK	United Kingdom
US	United States
USB	Universal Serial Bus
VGA	Video Graphics Array
WEP	Wired Equivalent Privacy
Wi-Fi	Wireless Fidelity
WPA	Windows Performance Analyzer

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Production Guideline for cowpea (2011) reported that cowpea (Vigna unguiculata (L.) Walp) as a plant has been around since Neolithic times. Its origin had been a controversial issue; this may be due to lack of archaeological facts. So many literatures have reported its origin to be from Africa, Asia or South America. However, IITA (2015) report shows that Nigeria is the world's largest producer and consumer as at 2014, accounting for 61% of production in Africa and 58% worldwide, but exportation of cowpea was banned from Nigeria. This was due to poor export quality. Other literatures like FAO (2012), ACB (2015) and FAOSTAT (2015) also reported similar trends. In 2020, Nigeria is still the highest producer of cowpea in the world, producing a volume of 3.6 million metric tons. This was followed by Niger and Burkina Faso with a production volume of 2.4 million metric tons and 700 thousand metric tons, respectively (Tridge, 2020). The reasons for lack of exportation are due to: lack of incentive by the government, poor quality of seeds, poor market network structure, lack of handling and processing equipments and technologies among others. These facts mentioned above need to be looked upon from technological point of view to come up with the technology to aid exportation of this commodity, to improve the economy of Nigeria and also other producing countries in Africa.

Keyser (2012) reported that the best way to enhance the trade of agricultural crops is to harmonize quality standard across countries with international ones. He was also of the opinion that various economic analyst had shown that lack of consistency in quality requirements as a non-tariff barrier and called for the harmonization of standards as a prerequisite for improved trade. In Africa, the East African Community (EAC) is seriously pursuing this harmonization of standards to open up global market to EAC exporting countries. COMESA (Common Market for East and South Africa) and SADC (Southern Africa Development Community) are also discussing to follow the same path. The ability for exporting countries to meet product standard is now the determining factor for market accessibility. This in turn will improve the supply chains which are the smallholder farmers for commercial supply. As at 2020 an African country Morocco that do not produce cowpea; was considered the highest cowpea exporter in the world. Morocco has an export value of $220 million with export volume of 118.87 thousand metric tonnes (Tridge, 2020). Therefore, for Nigeria to export and compete in the global cowpea export market; there is need to have an automated industrial cleaning and separating system.

A system is defined as a combination of machines or combination of processes, machine, theory, concept and man operating together to achieve a common goal (Shadbolt *et al.,* 2019). This study will involve the combination of the different machines performing different actions to achieve international grade quality for cowpea export. The actions that will be perform by the develop system in the study are cleaning, conveying (transportation), metering and digital sorting. Analysing a system require either a quantitatively or qualitatively research approach. System modeling is a basic feature in engineering research. Modeling helps Engineers to explain the behavior and changes taking place with components of the system or the entire system. After modeling a system, the developed models are used to optimise the system.

Optimisation is a mathematical method that involve chosen the best condition, considering certain constraints (given situation), from sets of available alternatives. Quantitative researches always produce some kind of optimisation problems (Du *et al.,* 2008). Engineering optimisation problems are often multi-modal (having multiple good solutions). Multi-model optimisation is usually called global optimization. Optimisation can be achieved using different methods. One of the methods mostly used in Engineering is the Response Surface Method.

Response Surface Methodology (RSM) is a statistical analysis introduced by George Box and Wilson in 1951. The main idea of response surface is to use designed experiments to achieve an optimal response; by exploring the relationship between explanatory variables (factors) and response variables (depended variables). Experimental designs that can be used in response surface methodology includes: Box–Behnken design; Central composite design; Optimal designs and Plackett–Burman design (Karmoker *et al.,* 2019).

1.2 Statement of the problem

Nigeria is the highest producer of cowpea in the world, producing about 3.6 million metric tons annually. However, Nigeria was reported from literature to be among the least country in term of exporting this commodity. This is because Nigeria do not meet the quality standard for exporting cowpea (Keyser 2012; FAO 2014; Adebayo and Ibraheem 2015; IITA 2015; Tridge 2020). Although, according to IITA report (2019), about 52% of cowpea seeds produced by the African countries are used for local consumption, 13% for animal feeds, 10% as seeds to be used for planting in the next season, 9% for other uses and 16% is wasted due to poor storage, marketing, handling and processing. A waste of 16% of 7.1million tons produced by African countries amount to 1.136 million tons of cowpea seeds. This is a large amount of waste that should have been used for export, to generate foreign exchange for these African producing countries. This waste also shows that Africa does not have the required developed system to meet export demand. Therefore, the need to develop an integrated system to meet export demand becomes necessary.

Also, all international export transaction documents and trade acceptability are base on quality grade category of the cowpea export seeds. There are different standard document for cowpea export in different regions. America, Europe, Asia and Africa all have their export standard grades. Due to the importance of cowpea seeds grading for export around the world. Therefore, the need to develop an integrated system to meet export demand becomes necessary.

1.3 Objectives of the study

This project seeks to develop a cowpea seeds quality separating system with machine vision incorporated to meet international export grade standard for locally cultivated varieties of cowpea in Nigeria. To achieve the above main objective, the following specific objectives are carried out:

1. Determination, modeling and optimization of some electrical and optical properties of cowpea seeds varieties for automation design consideration.
2. Design and fabrication of the mechanical separating units of the quality separation system.
3. Automation of the separating system with machine vision technology.

4. Evaluation and optimization of the developed system in terms of efficiency, throughput, maximum capacity, actual utilization and backlog.

1.4 Justification

According to Harmond *et al*., (1961) and Harmond *et al*., (1968), impurity separation from seed is as old as crop production. Man starts separating unwanted materials from agricultural product when he starts producing large quantity of food. Seed separation techniques can be grouped into mechanical, aerodynamic, electrical and optical separation. Early seed separation machine developers used mechanical or aerodynamic technique, sometimes a combination of both. The use of electrical and optical separating technique started in the seventeen century (Bee, 2002 and Fowler, 2012). Most optical sorters come with only optical separating technique, sometimes with mechanical or aerodynamic technique. Different grains impurity separation machine had been developed by some researchers using mechanical, aerodynamic, electrical or optical technique. Although, Kawusara (2019) developed a cowpea impurity sorter using a mechanical vibration sieve basin and machine vision technique, none of these researchers had approached their design concept using system thinking approach. They had all considered their design as a unit. This study had departed from such concept and had consider impurity separation as different subsystems coming together to form a super system. This study developed a super system with sub system performing operations such as cleaning (mechanical sorting), conveying (transportation), metering and digital sorting. This concept makes impurity separation an industrial operation than a unit operation. This system thinking approach if applied to other non-export crops can transform poor agrarian communities into crop processing and export industrial hubs.

1.5 Scope

The system was developed solely for cowpea seeds. Although, with some modification the system can also be used for other grains and seeds. Preliminary studies caried out on the cowpea seeds for design consideration were for only optical and electrical properties. Other crop properties need for design were taken from literature.

The mechanical sections of the system were design using physical, frictional and flow properties of cowpea seeds. The automation section of the system was selected base on value ranges obtained from the optical and electrical properties.

Impurities considered for removal by the system were foreign bodies (like, stones, sand and plant parts), broken seeds and diseased seeds (fungal infested). The chemical composition in the seed was not considered because that may require a camera operating outside visible light range, like hyperspectral camera.

Evaluation and optimisation of the developed system was done for only terms like efficiency, throughput, maximum capacity, actual utilization and backlog. These terms are sufficient to determine the acceptability of the separation to international grading system.

CHAPTER TWO
LITERATURE REVIEW

2.1 Cowpea

Cowpea (*Vigna unguiculata* (L.) Walp) is a dicotyledonous herbaceous leguminous plant that is grown annually (Agbogidi and Egho, 2012; OECD, 2016; Spriggs et al., 2018; Michalis *et al*., 2019). According to Sheahan (2012), the plant can grow to a height of 0.6 – 0.9 m. It produces an 8 – 15 cm long pod with about 6 to 13 seeds in it, depending on the variety. Cowpea is of the kingdom –Plantae; of the class – Magnoliopsida; in the order – Fabales; from the family – Fabaceae; of the tribe – Phaseoleae; in the genus – Vigna; within the species – unguiculata (Muhammad, 2014; OECD, 2016). Cowpea seeds are the major source of plant protein for people from developing countries. Clark (2007) reported that it is the most heat adapted productive cover crop used in the United States, to prevent heat loss from the soil. It is grown in nearly every part of the world.

2.1.1 Origin, Importance, Production and Uses

Cowpea is among the oldest crop known to man. According to IITAR4D Fact Sheet (2020), the name 'Cowpea' originated from the United States of America where the crop is used to feed cows. The origin of the crop, cowpea, had been reported by nearly all its researchers to have been domesticated in Africa. The exact location in Africa is in dispute, with some researchers claiming western Africa while others eastern or southern Africa (Ng and Marechaf, 1985; Smartt and Hymowitz, 1985; Gómez, 2004; Mulei et al., 2011; OECD, 2016; Tariku, 2018; Njonjo *et al*., 2019). Production Guideline for cowpea (2011) report argued that, the attribution of the origin to Africa alone was due to no archaeological evidence from other parts of the world. The report is of the view that, its origin could change when archaeological facts begin to pour in from other parts of the world. This is because history has shown that cowpea had been in existence as a crop from Neolithic times. It had been an important source of protein to both man and animal.

Jayathilake *et al.* (2018) reported that a single grain of cowpea contains approximately 23-32% protein, with additional 50-60% carbohydrate and about 1% fat in dry basis. This makes it a very good protein supplement for the food industries. Liyanage et al. (2014) also reported that it contains health benefit substance such as dietary fiber, phenolic compounds, minerals salts compound essential for body development and Vitamin B group's compound. Several authors had reported that epidemiological evidences show that; cowpea seeds consumption protect the body against chronic diseases these include, gastrointestinal disorders, cardiovascular diseases, hypercholesterolemia, obesity, diabetes and many forms of cancer (Khalid and Elharadallou, 2013; Rotimi *et al*., 2013; Chon, 2013; Trehan *et al*., 2015; Barnes *et al*., 2015; Perera *et al*., 2016). Trehan *et al*. (2015) specifically reported that its consumption improve digestion and strengthen blood circulation to vital organs in the body. These immense health benefits of cowpea seeds are evidence to increase cowpea production around the world. This is to improve human life expectancy both in the developed and the developing countries.

According to IITA (2019), the entire world produces more than 7.4 million tons of dried cowpea seeds in 2017, with the entire Africa alone producing up to 7.1 million tons. The largest producer of cowpea in the world is Nigeria, producing about 48% of African total output and about 46% of the total world output. Nigeria is also the world largest consumer (FAOSTAT, 2015). Several researchers had reported that Africa which is the highest producer, do not export cowpea seeds (Gómez, 2004; ACB, 2015; FAOSTAT, 2015; Tariku, 2018; Njonjo *et al*., 2019; IITA report, 2019; FAOSTAT, 2019). The reasons for lack of exportation are due to, lack of incentives by the government, poor quality and standards of seeds, poor market network structure, lack of handling and processing equipments and technologies, among others. Due to cowpea seeds' importance to man, third world producing countries need to be encouraged to export this crop to industrialised and developed countries to further process it into other forms of finished products.

Cowpea seeds are mostly used around the world domestically to prepare many delicacies. These delicacies include: beans porridge, deep fried cake (akara balls), steam cake (moin-moin), buns, fritters, sauces, puddings, soup, stews, purees, casseroles and sauce (Oyeleke *et al*., 1985; National Research Council, 2006; Hamid *et al*., 2016). National Research Council (2006) reported that cowpea seeds are sometimes used for coffee beans substitute. Cowpea seeds have much industrial usage. According to Gómez (2004), it is processed into semolina which is served with soup. Nyankori (2002) reported that cowpea blends can be used for formulation and fortification of baby weaning mixtures in the production of baby food. Maidala and Dass (2017) also reported the use of cowpea seeds to formulate animal feeds. McWatters *et al*. (2003) used composite flour of cowpea seeds to prepare sugar coated cookies and biscuits. Due to the importance of cowpea seeds to both domestic and industrial usage around the world. Therefore, the need to develop an integrated system to meet export demand becomes necessary. Nevertheless, it is also necessary to look at cowpea export and trade around the world.

2.2. Cowpea Seed Export and Trade

Past trade records reported by Tridge (2020) had shown that world cowpea seeds and trades do not depend on the ability to produce the highest quantity of dry cowpea seeds. However, it is important to understand the production of cowpea seeds again, even though it had been mentioned in the previous chapter. This time it is used to understand the reason some high producing countries find it difficult to export cowpea seeds. According to Tridge (2020), it is estimated that about 3.7 million tonnes of cowpea seed was produced worldwide. This estimate was produced on an 8.7 million hectare of land. 87% of this land is in African, 10% in America and 3% in Europe and Asia (IITA, 2015; ACB, 2015; FAOSTAT, 2015; FAOSTAT 2019). According to data collected from 1990 – 1999, Langyintuoa *et al*. (2003) and Gómez (2004) reported that Nigeria is the world highest producer of cowpea accounting to 66%, Brazil 17% and Niger 8%, in descending order of production. In Africa, Nigeria in 2020 according Tridge (2020) was till the highest producer accounting for 45% and Niger 14% while the rest producing African countries account for 41%. Langyintuoa *et al*. (2003) also, reported that Africa is lacking continuous and accurate statistical data for cowpea production and export. This is because in Africa cowpea data sources are mostly from two source; Food and Agriculture Organization (FAO) and socio-economic groups. Langyintuoa *et al*. (2003) concluded that, in Africa cowpea production, Nigeria account for 45%, Niger 14% and the rest is distributed among other African producing countries. Cowpea trade within Africa is also affected by government laws. The Sanitary and phytosanitary (SPS) act No.10 of 1996 plant protection regulatory act is implemented by all ECOWAS and CEMAC member countries. This act state that any grain or seeds known to contain diseased, pest or foreign body should be banned from entering the country. This means that export grains and seeds should be certified by each country before importation. Also, cowpea dominates the grains and seeds market in Africa, accounting for 50% of total grain and seeds handled (Langyintuoa *et al*., 2003; Lowenberg-Deboer, 2003; Imrie, 2000). According to Agfact (2003), cowpea seeds for export are sold by grade. The acceptable grades are about 15 - 20% grade loss. Grade A is the preferred grade for cowpea trade export. Lesser grades are sold very cheap and consider only suitable for livestock consumption. However, recent statistical data on cowpea trades produced by crop trading statistic website had shown African producing countries lagging behind in terms of export.

Tridge (2020) produces a recent statistical report on cowpea export and trade. According to the report, in 2020, Nigeria is the highest producer of cowpea in the world, producing a volume of 3.6 million metric tons. This was followed by Niger and Burkina Faso with a production volume of 2.4 million metric tons and 700 thousand metric tons respectively. In term of export, Morocco was considered the highest cowpea exporter in the world, with and export value of $220 million with export volume of 118.87 thousand metric tons. This was followed by China and Netherlands with and exports value of $117.58 and $100.53 million with export volume of 84.03 and 34.50 thousand metric tons respectively. Table 2.1 shows the statistics of the top 10 cowpea export countries in the world. The trade flow of cowpea seeds in 2020 is also displayed in this table also. The top 10 countries trade flow of cowpea seeds in 2020 are as follows: Morocco exported 144.40 million metric tons to Spain; China exported 116.45 million metric tons to Hong Kong; Guatemala exported 72.79 million metric tons to United States; Mexico exported 66.75 million metric tons to United States; United States exported 58.51 million metric tons to Canada; Kenya exported 48.96 million metric tons to United Kingdom; Morocco exported 42.16 million metric tons to Netherlands; Netherlands exported 37.61 million metric tons to Germany; Netherlands exported 28.31 million metric tons to Belgium; and Senegal exported 23.32 million metric tons to Netherlands (Table 2.1). The highest cowpea seeds importer in 2020 was the United States, with an import value of $ 198 million. This was followed by Spain and UK, with an import value of $162 and $130 million respectively (Tridge, 2020).

Table 2.1: Cowpea Export and Trade flow 2020 (Tridge Report, 2020)

Cowpea Export 2020

S/N	Country	Share in Export Value 2020	Share in Export Value 2020	1-Year Growth in Export Value 2019-2020	3-Year Growth in Export Value 2017-2020	5-Year Growth in Export Value 2015-2020	Export Quantity 2020	1-Year Growth in Quantity 2019-2020	Unit Price of Export 2020	Revealed Comparative Advantage 2020
1	Morocco	21.68%	220.12M	-17.15%	-10.72%	52.05%	118.87K		1.85K	Very Strong
2	China	11.58%	117.58M	2959.58%	2091.81%	5169.53%	84.03K	1666.48%	702.92	Weak
3	Netherlands	9.90%	100.53M	24.91%	38.46%	46.94%	34.50K	23.70%	2.91K	Strong
4	Guatemala	8.61%	87.47M	18.13%	43.22%	81.72%	36.34K	11.45%	2.41K	Very Strong
5	Kenya	8.39%	85.18M	77.62%	114.57%	53.61%	22.70K	18.54%	3.73K	Very Strong
6	United States	7.19%	72.99M	8.66%	22.04%	21.88%	33.53K		2.18K	Medium
7	Mexico	7.06%	71.67M	1.76%	28.86%	40.79%	51.05K	-5.22%	1.48K	Very Strong
8	Spain	5.89%	59.81M	13.42%	46.50%	52.73%	24.38K	12.99%	2.45K	Strong
9	France	5.69%	57.82M	-11.13%	-15.43%	-14.37%	117.77K	9.03%	490.41	Strong
10	Senegal	3.02%	30.67M	55.62%	45.71%	78.07%	19.78K	50.46%	1.55K	Very Strong

Cowpea Trade Flow

S/N	Trade Flow	Share in Export Value 2020	1-Year Growth in Export Value 2019-2020	3-Year Growth in Export Value 2017-2020	5-Year Growth in Export Value 2015-2020
1	Morocco to Spain	144.40M	-13.68%	2.23%	66.14%
2	China to Hong Kong	116.45M	5391.49%	4226.12%	15316.42%
3	Guatemala to United States	72.79M	21.94%	37.04%	66.84%
4	Mexico to United States	66.75M	-1.72%	20.64%	36.70%
5	United States to Canada	58.51M	5.83%	12.53%	10.68%
6	Kenya to United Kingdom	48.96M	181.68%	306.62%	112.52%
7	Morocco to Netherlands	42.16M	3.49%	41.54%	49.76%
8	Netherlands to Germany	37.61M	40.63%	43.94%	77.60%
9	Netherlands to Belgium	28.31M	13.10%	24.20%	19.17%
10	Senegal to Netherlands	23.32M	108.54%	61.82%	164.21%

Source: Tridge Report (2020)

2.2.1 Cowpea Export Standards and Quality

Cowpea export standards for quality of export seeds are defined by region or country. African standard (2012) defined what is termed as quality for cowpea seeds being imported or exported from Africa. Appendix B1 displayed this information. Export grades are divided into three groups. Grade 1 having total defective seeds of 2 % and good seeds of 98%; grade 2 having total defective seeds of 4% and goods seed of 96%; and grade 3 having total defective seeds of 5 % and goods seed of 95%. Anything other than these is considered unfit for export or import from or to African countries. AHCX Commodities Exchange (2014) published a contract document for quality acceptability of cowpea export or import in Malawi. The document defined what is termed as quality for cowpea seeds being imported or exported from Malawi. The contract document was displayed in Appendix B2. The contract document also, divided quality grade of cowpea grains into three grades. Grade 1 having total defective seeds of 6 % and good seeds of 94%; grade 2 having total defective seeds of 7.5% and goods seed of 92.5%; and grade 3 having total defective seeds of 8.5 % and goods seed of 91.5%. Anything other than these was considered unfit for export or import from or to Malawi. United States Standard for beans (2008) published acceptable quality of various types of beans imported or exported to or from USA. The published standard defined what are termed as quality for cowpea seeds being imported or exported from the United States as shown in Appendix B3. In the United States Standard for beans (2008), export grades were divided into three groups. Grade 1 having total defective seeds of 4 % and good seeds of 96%; grade 2 having total defective seeds of 6% and goods seed of 94%; and grade 3 having total defective seeds of 8% and goods seed of 92%. Anything other than these is considered unfit for export or import from or to United States of America.

Due to the importance of cowpea seeds grading for export around the world. Therefore, the need to develop an integrated system to meet export demand becomes necessary. To be able to successfully develop this integrated system, there is need to look at some selected engineering properties of bulk cowpea seeds relevant to design of grading and sorting machines.

2.3 Engineering Properties of Agricultural Products

Barbosa-Cánovas *et al*. (2006), explained that the engineering properties of agricultural products are very important, if not essential, in the process design and manufacture of agricultural machines. These include thermal, optical, electrical, mechanical and physical properties. All these properties are an indication of changes occurring within the agricultural product of interest. Engineering properties are significantly altered by the structural differences between agricultural produce.

Mohsenin (1986) was of the opinion that modern agriculture has brought about the handling and processing of agricultural product using these engineering properties to design handling and processing equipments. For instance, the application of physical properties such as shape which is an important parameter for stress distribution in materials under load is important in developing sizing and grading machines and for analytical prediction of its drying behavior (Esref and Halil, 2007). Therefore, a rational approach to the design of agricultural machinery, equipment and facilities will involve the knowledge of the engineering properties of the products. For this study, only engineering properties relevant for cowpea seeds automation are reviewed. These properties are optical and electrical properties.

2.3.1 Optical Properties of Agricultural Seeds and Grains

Optical properties of agricultural grains and seeds are the behaviors of these grains and seeds, with the interaction of electro-magnetic radiation either within the visible or the non-visible spectrums of light. These optical properties include: colour, refraction, transmittance, reflection, absorbance, gloss, translucency, luminescence, dispersion and diffraction (Gunasekaran *et al*., 1985: Figura and Teixeira, 2007). The study of optical properties of agricultural grains and seeds begins in 1900s. Birth (1960) and Johnson (1960) were the first to report optical properties of grains. Both studied optical properties to determine the presence of smut disease content in bulk wheat grains. It was observed that optical properties like transmittance, absorbance and reflectance can be used to determine the degree of infestation found in bulk wheat grain. Then Johnson (1962) and Stermer et al. (1962) used absorbance properties to determine different stages of yellow maize damage and transmittance properties to determine degree of milling of rice respectively. Kramer *et al*. (1963) reported the use absorbance properties to determine the maturity of peanuts, while

Norris *et al*. (1996) and Massie and Norris (1965) used absorbance, reflectance and transmittance properties of different grains to determine their moisture contents. Paez *et al*. (1968) studied the transmittance of light through a single kernel of corn and found that normal kernel transmits about 0.67% of light through it.

Hawk *et al*. (1969) investigated reflectance properties of twelve different grains (barley, flax, yellow grain sorghum, rye, hard red winter wheat, hard red spring wheat, white wheat, durum wheat, white oats, yellow soybeans and yellow corn). It was concluded that for all the grains investigated, the reflectance properties do not exceed 5% along the spectrum (450 - 700 nm) used. Birth and Johnson (1970) determined the transmittance, reflectance and fluorescence properties of yellow corn. They used these properties to determine mold contamination of yellow corn. Tyson and Clark (1974) and Dickens and Welty (1975) measured the fluorescence properties of pecans and Iranian pistachio nuts respectively at a range of 400 - 900 nm. These properties were used to determine the level of aflatoxin contamination in nuts. Clark and McFarland (1979a) and Clark and McFarland (1979b) investigated the absorbance and transmittance characteristic of cotton seeds at light range of 500 - 900mn. They used the optical densities of the light on these seeds to classify their viability (germinating capacity). All these researchers used Spectrometry or Spectrophotometry methods to determine their optical properties. Modern researchers on optical properties of agricultural grains and seeds are mostly using image sensing methods. These image sensing methods include either machine vision technique through image processing.

The earliest researchers to use machine vision to determine optical properties of agricultural grains and seeds include, Dowell (1992), Casady et al. (1993), Delwiche and Norris (1993), Majumdar *et al*. (1996), Delwiche (2003), Majumdar and Jayas (2000a), (2000b), (2000c), (2000d), Paliwal *et al*. (2001), Delwiche (2003) and Mohan *et al*. (2005). In recent research, Manickavasagan *et al*. (2008) used machine vision to extract optical properties from grey images captured by a monochrome camera at different moisture contents. These extracted features were used to identify and classify eight different classes of wheat. Ravikanth *et al*. (2015) used image processing method to discriminate contaminants from wheat. Near-infrared (NIR) hyper spectral imaging was used to extract optical properties, which was analysed using three statistical classifiers (Support Vector

Machines (SVM), Naïve Bayes (NB), and k-nearest neighbours (k-NN)) for classification. Other researchers that used image processing to extract optical properties include, *Huang et al*. (2016) and Du *et al*. (2016) to classified maize seeds varieties and identified deoxynivalenol content in wheat, respectively using hyper spectral imaging (HSI) technology. Fayyazi *et al*. (2017) processed rice seeds images from CD camera (Sony DSC-H1) to classify rice varieties in bulk mix. Zhang *et al*. (2017) and Senthilkumar *et al*. (2017) used near-infrared hyper spectral imaging to detect and visualize caffeine levels of coffee beans and ochratoxin A contamination levels in bulk wheat grain respectively. Zheng et al. (2018) and Wu *et al*. (2019) identified and classified rice and oats seed varieties respectively using artificial neural network, from images acquired through hyper spectral imaging.

2.3.2 Electrical Properties of Agricultural Seeds and Grains

The electrical properties of agricultural grains and seeds are their behaviors or attributes when exposed to an electric field. This behavior depends on whether the grain or seed conduct, transmit, resist or store electricity. Electrical properties of grains and seeds of interest in agriculture include, resistance, resistivity, capacitance, inductance, conductance, conductivity, impedance of the capacitor or capacitance reactance and dielectric properties (Stroshine,1998; Barbosa-Cánovas *et al.*, 2006; Figura and Teixeira, 2007; Mahesh, 2018). According to Nelson (1973), the behavior exhibited by biological materials within an electrical field is classified as either active or passive. The active behaviors are those that produce some sort of energy (like electromotive force or potential difference) within or between the biological materials. The passive behaviors are those that affect the spreading of electrical current and energy within itself and its surroundings. Also, it was observed that there is no clear-cut difference between electrical and optical properties at high radio and far-infrared frequencies spectrum.

Interest and use of electrical properties of agricultural grains and seeds started in early 1900s. Briggs (1908) was the first to measure and report electrical property of agricultural grain. Using direct current (DC), the electrical resistance of different varieties of wheat grains at different moisture contents and temperature ranges were measured. The measured results were then used to develop a chart to predict the moisture contents of wheat grains. Burton and Pitt (1929) were the first to use alternating current (AC) to measure electric properties of grains. The capacitances of wheat and rye grains were measured using the parallel plate method. The results were used to correlate with the grains moisture contents. This was then used to develop equations to predict moisture contents of wheat and rye. Nelson *et al*. (1953) reported the dielectric properties of barley grains. This was the first reported work on dielectric properties of any grains or seeds. The dielectric property of barley grains at current frequencies of 1 – 50 MHz was measured. It was observed that, the electric permittivity of the grain correlated with the grain's moisture contents. These were the earliest work on the electrical properties of grains and seeds.

Electrical conductivity of various grains and seeds, were measured and determined using different methods by various researchers such as, Tajbakhsh (2000) for wheat grains, Salinas *et al*. (2010) for soy beans, Takos *et al*. (2012) and Santanna-da-Silva *et al*. (2013) for three different varieties of pines seeds and two different varieties of beans seeds, respectively. Sivritepe *et al*. (2015), Shineeanwarialma *et al*. (2019) and Kavan *et al*. (2019) reported for maize, Powell and Mavi (2016) for radish seed (*Raphanus sativus*), Szemruch (2019) for Sunflower seeds. All these researchers concluded that electrical conductivity affects the growth and germinating rate of agricultural grains and seeds. Other very important electrical properties to agricultural grains and seeds are the dielectric properties.

Although dielectric properties of agricultural grains and seeds were first measured and determined as far back as the 1950s. Recent studies reporting the measurement and determination of dielectric properties of agricultural grains and seeds, using different techniques were done by the following researchers: Al-Mahasneh *et al*. (2001) for maize, Govindarajan *et al*. (2005) for bulk wheat grain, Jiao *et al*.(2011), Mahmoud and Reza (2011) for Cowpea, Mung beans, Maize and Lentile seeds, Khan *et al*. (2012) for Argemone seeds, Bhargava *et al*. (2013) for Barley, Pearl Millet and Sorghum, Singh *et al*. (2014), Chandel *et al*. (2014) and Bhargava *et al*. (2014) for neem seeds, Cauliflower seeds and wheat grain respectively, Xie *et al*. (2019) and Jafari *et al*. (2020) for Camellia Oleifera seeds kernel and wheat grains, respectively, Kovalyshyn *et al*. (2020) for winter Rape seeds and its weed (cleaver). The dielectric properties measured and reported by these researchers include dielectric permittivity, dielectric constant, relative permittivity, dielectric loss, loss tangent and depth of penetration. All these researchers contributed to the knowledge in knowing the factors that affect the measurement and accuracy of determining the dielectric properties of agricultural grains and seeds. These factors are: frequency of the current used, required accuracy, temperature of the material or of the environment, nature of material to be measure, sample size/thickness, bulk density of material, contacting/non-contacting of the material, destructive/non-destructive nature of the material and cost of the experiment. However, there are other researchers who measured and determined many electrical properties of agricultural grains and seeds in one study.

Sacilik and Colak (2005), Singh *et al*. (2006), Mane and Puri (2010), Khan and Chandel (2011), Novak (2013) and Muga *et al*. (2018); all measured and determined electrical conductivity and dielectric properties of opium seeds, brassica compestris seeds, sunflower seeds, argemone seeds, maize seeds and maize seeds respectively, using various techniques. All conclusions drawn were those factors such as, frequency of the current used, required accuracy, temperature of the material or of the environment, nature of material to be measure, sample size/thickness, bulk density of material, contacting/ non-contacting of the material, destructive/ non-destructive nature of the material and cost of the experiment affected the measurements. Hlaváčová and Hlaváč (2005) and Hlaváčová *et al*. (2015) measured some electrical properties such as electrical capacity, loss factor, conductivity, resistance, resistivity, capacitance, relative permittivity and impedance using LCR meter, at frequency of 1 - 100 kHz and 30 kHz - 30 MHz respectively. These measurements were done for wheat grain mixture, malting barley, rape oil seeds and sunflower seeds at different storage stages in the silo by Hlaváčová and Hlaváč (2005). Then maize grains hybrids, wheat grains varieties, poppy seeds (mixture), amaranth seeds, sunflower seeds and rape oil seeds varieties at different moisture level by Hlaváčová *et al*. (2015). These studies confirmed that electrical properties of agricultural grains and seeds changes during storage. Also, that drying characteristics affect the measurement of electrical properties. Kardjilova *et al*. (2012) and (2013), measured and reported four electrical properties such as resistance, impedance, capacity, relative permittivity of rapeseed seeds and spelled grains (wheat) with glumes at 3 - 200 kHz for various moisture level, using LCR meter. It was observed that electrical properties values vary as moisture of the seeds and the current frequencies changes. Burubai (2014) measured and also reported some electrical properties such as resistance, conductivity, dielectric constant, loss factor, loss tangent and capacitance of melon seeds at various moisture contents (9 - 32%). Modified Wheatstone bridge circuit connection made up of a function generator, an oscilloscope, multimeters and a sample holder were used. These electrical properties were measured at a current frequency range of 1kHz – 1MHz. It was also observed that like other researchers on the subject, that moisture and frequency played a key role to the determination of values obtained during measurement.

2.3.3 Applications of Optical Properties to Agricultural grains and seeds Processing Operations.

The applications of the knowledge of optical properties of food and agricultural materials, to agricultural operations begin as far back as early twentieth century. This review is only on agricultural grains and seeds processing activities. In agricultural grains and seeds processing operations, knowledge of their optical properties is used, for any of the following processing activities:

i. Determination of grains/seeds moisture content
ii. Identification or classification of varieties, grades or other physical attributes
iii. Detecting the presence of certain nutrients in grains/seeds
iv. Identification of disease-causing organisms and removal of affected grains/seeds
v. Identification of adult, larvae or pupae of insects and removal of damaged grains/seeds
vi. Identification and removal of foreign materials from bulk grain/seeds
vii. Combination of all or some of the activities mention from i – vi as one processing activity

To determine, detect and identify using these seven activities, the following optical technologies are used.

1. X-ray - An invisible light wave with electromagnetic property, with a very short wavelength range of 0.01 - 1 nm. It can penetrate materials opaque to light (see Figure 2.1).
2. Ultraviolet to Visible light spectroscopy – Ultra violet light is radiation with shorter wave length (1 - 380 nm) than visible light. It is also radiations that are beyond or lower than the violet spectrum of visible light. The Visible light is the electromagnetic radiation that the human eyes can see. The visible light range is 380 - 750 nm. So, the range from ultra violet to visible light is 1 - 750 nm.

3. Near, mid and far infrared spectroscopy (NIR, MIR and FIR) - Infrared is an electromagnetic radiation beyond visible light that can not be seen with the naked eye. It has a range of 700nm - 1mm. Near infrared (NIR) ranges from 800 - 2,500 nm. Mid infrared ranges from 2,500 - 25,000 nm and far infrared ranges from 25,000 - 1,000,000 nm (1mm).
4. Nuclear Magnetic Resonance (NMR) Spectroscopy - This is a radio wave frequency radiation spectrum generated by the atomic nucleus of biological material when it is placed in a magnetic medium. The spectrum generated has a wave length ranges from 1 - 5 m.
5. Multispectral imaging - This is a technique that involved capturing images of materials; with instrument that can sense both visible and invisible electromagnetic radiations along the electromagnetic spectrum. Example of multispectral image is an image captures by an instrument operating with a wavelength of different spectral band (e.g. red, green, blue and near-infrared (NIR)). Multispectral imaging ranges from 3 - 15 spectral bands.
6. Hyper spectral imaging - This can also be called imaging spectroscopy. This technique involves acquiring image using continuous spectral band within a pre-defined area on the electromagnetic spectrum. For example, capturing image using ultraviolet (UV) spectrum through visible light spectrum to infrared spectrum. Hyper spectral imaging ranges from 10 – 200 spectral bands. That is spectral band between ultraviolet (UV) to infrared spectrum (UVA, UVB, UVC, red, yellow, blue, brown, orange, green, violet, black, carnation pink, yellow orange, blue green, red violet, red orange, yellow green, blue violet, white, violet red, dandelion, cerulean, apricot, scarlet, green yellow, indigo, gray, near infrared, mid infrared and far infrared).

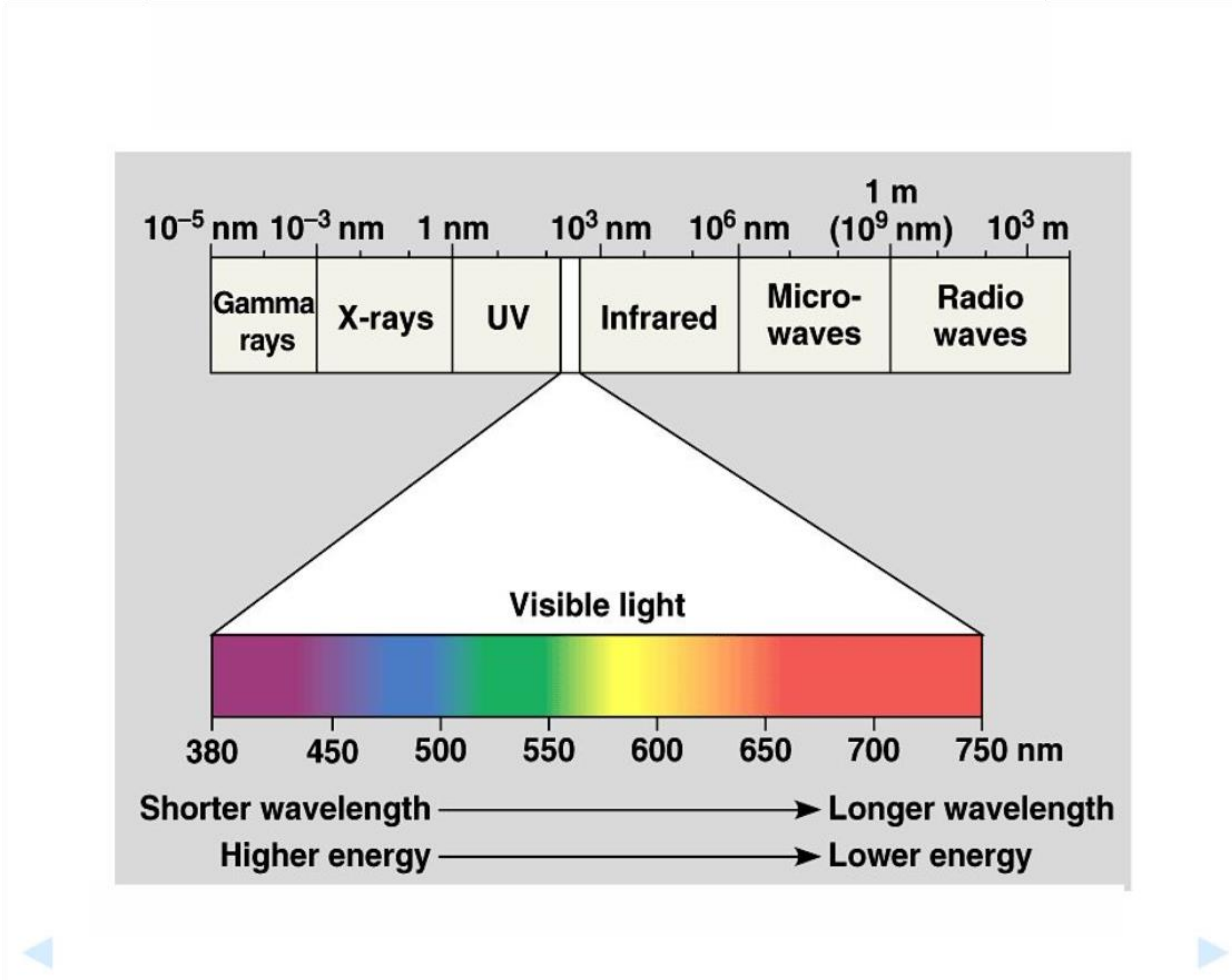


Figure 2.1: Electromagnetic Spectrum

(https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.quia.com. Accessed onJune13 2018)

7. Machine vision – This technology involves the use of camera to capture either still image or moving image, of the material of interest and then process the image. Then program the machine to make decision on actions to be taken. This was the preferred technology used in this research project.

2.3.4 Review of Applications of Optical Properties to Grains and Seeds Processing.

The earliest application of optical proprieties in grains and seeds processing was in detection of micro-organisms and diseases in grains and seeds. Birth (1960), Johnson (1960) and Johnson (1962) used visible to infrared spectroscope to determine fungi contamination in wheat and maize. It was observed that fungi infestation was best detected using visible light transmittance (T) property at spectrum range of 800 to 930 nm, by applying the difference in optical density($\log\frac{1}{T}$). Birth (1960) developed a smut (fungus infestation) meter using this finding. Birth and Johnson (1970) used visible light spectrum to detect mold (fungi disease) in yellow maize seeds; while Tyson and Clark (1974) and Farsaie *et al*. (1978) used ultra-violet (UV) light spectrum to detect aflatoxin infections (fungus infestation) in bulk pecan and pistachio nuts respectively. Both research studies concluded that, the best optical property to use in detecting fungi infestation at ultra-violet and visible light spectrum was its fluorescence (F) property. For yellow maize, molds are detected at visible light fluorescence spectrum range of 442 and 607 nm; while detection of aflatoxin was at ultra-violet fluorescence spectrum of range of 420 to 490 nm.

Also, Shotwell and Hesseltine (1981) used the fluorescence property of ultra-violet ray spectrum to detect aflatoxin contamination in maize seeds. Using findings from the studies of fluorescence properties of ultra-violet ray; Farsaie *et al*. (1981) developed an automated sorting machine for detecting and separation of aflatoxin affected Pistachio nuts from good nuts. The machine has a sorting rate capacity of 18nuts/sec. From this point researchers start going higher or lower in the optical spectral or using entirely different technologies from spectroscopy. Greene *et al*. (1992) used photoacoustic spectroscopy (PAS) and transient infrared spectroscopy (TIRS) techniques to detect mycotoxigenic fungi infection in bulk maize seeds. The research concluded that, both PAS and TIRS techniques can only be used to detect fungi contaminant in bulk seeds or grains. These techniques can not be used to detecting single seed or grain, which is necessary for developing separation machine for seeds and grains. Ruan *et al*. (1998) reported using machine version to identify and estimate fungi infected scab damaged wheat kernels (grain) faster and effectively than human inspection. The study did not report the concentration of the fungi infection on the grains. This is because machine version can not give internal information of seeds and grains. Internal information of agricultural seeds and grain can be gotten by using higher or lower spectrum range than ultraviolet to visible light wave. Hirano *et al*. (1998) used X-ray to detect aflatoxin infected peanut seeds on the surface of bulk peanuts. The study discovers that X-ray was not sufficient to detect seeds inside the seeds lot (bulk seeds). So, nuclear magnetic resonance (NMR) scans were then used to detect affected seed within the bulk seed. The study then concluded that by detecting and removing areas where aflatoxin was higher. The total aflatoxin content concentration of the whole bulk seed can be reduced by half.

Dowel *et al*. (1999) and Gordon *et al*. (1999) used NIR and TIR spectroscopy techniques to detect and estimate concentration of fungi infected wheat grains and maize seeds respectively. Dowel *et al*. (2002a) used reflection and transmission properties of spectrum range of visible light to infrared, to detect fungi infestation on single maize seed. This research concluded that infrared perform better than visible light in detecting infected seed. Dowell *et al.* (2002b) reported the used of high-speed sorter operating with CCD camera and filter using light reflection technology to detect Tilletia indica (fungal infection) on wheat kernels and separate it from good grains. It was concluded that the automated sorter has a capacity of 8,800 kg/h and was able to sort out 100% of infected wheat kernel. Berando *et al*. (2005) and Delwiche (2005) both used near inferred (NIR) to detect fungi infection and concentration in maize seed and wheat kernel respectively. Berando *et al*. (2005) used NIR to detect seeds infestation and concluded that NIR can be used for detection and separation of fugal infestation in maize seeds. Delwiche (2005) on the other hand, actually detected and separated fungal infected in wheat grain and fungal concentration in bulk wheat grains. The study used an automated high-speed optical sorter, with two optical filter for visible light (675nm) and infrared spectrum (1,480 nm). Also, Pearson and Wicklow (2006) reported the use of NIR spectroscopy to detect fungal disease and concluded that NIR (Near infrared) spectroscope can used to detect and separate fungal infected maize seeds from good seeds.

Delwiche (2008) developed a high-speed bi-chromatic device using visible light spectrum reflection. It detects and classifies fungal infected (mold) wheat kernels from good kernels. The study was able to achieve a 95% classification. Williams *et al*. (2012) and Yao *et al*. (2013) investigated the use of hyper spectral imaging to detect fungal infections on single maize seed. Images were acquired within a spectral range of 1000 – 3000 nm. The study concluded that by using hyper spectral imaging maize seed infected by fungi disease can be identify and sorted out. Della Riccia and Del Zotto (2013) and Balut *et al*. (2013) reported the use of near infrared (NIR) spectroscopy to detect fungal infection and concentration in maize seeds and wheat grains respectively. These studies concluded that near inferred spectrum can be used to detect fungal affected seeds and grains from good ones and sorted out. Jin, *et al*. (2014) and De Girolamo *et al*. (2014) applied near infrared spectroscopy to detect fungal infection (deoxynivalenol (DON) levels). It was observed that near infrared should be used to detect fungal infestation in wheat grain when selecting good breed to plant and during quality control.

Fungal disease infestation in maize seeds was also detected with near infrared spectroscopy by Miedaner *et al*. (2015), Levasseur-Garcia and Kleiber (2015) and Levasseur-Garcia *et al*. (2015). These study all recommended that near infrared spectroscopy is very good in detecting diseased affected seeds and grains. Kautzman *et al*. (2015) used near infrared spectroscopy to detect fungal affected and damage wheat kernels and recommend the used of infrared spectroscopy technology for bulk sorting of wheat grains. Mid infrared spectroscopy was used to detect and classified fungal disease affected maize seeds and peanut seeds by Kos *et al*. (2016) and maize seeds, wheat grains and peanut seeds by Sieger et al. (2017). It was observed that mid infrared spectroscopy equally achieved good detecting results as does the near infrared spectroscopy. Stasiewicz *et al*. (2017) used an existing multispectral optical sorter to detect and separate maize seeds infected by fungal disease from good ones. Different electromagnetic spectral (e.g uv-light, visible light and NIR) was used to detect different fungal disease. The study result was used to calibrate the optical sorter. Ropelewska (2019) used scan images of fungal disease infected wheat kernels taking from Epson photo scanner. These images were used to develop a neural network classification model to differentiate diseased kernels from good kernels. The research achieved 99% classification accuracy. Another early use of optical property in

Agricultural grains and seeds processing, is in measurement of moisture content of grains and seeds.

Hoffmann (1963), Norris and Hart (1965) and Ben-Gera *et al*. (1968) were the earliest researchers to apply spectroscopy technology to measure moisture content of grain and seeds. Electromagnetic spectrum used range from visible light to near infrared (NIR). These studies measured the moisture of various grain products, soy beans and wheat. It was observed that the tests were non-destructive, direct, expensive and accurate. Also, near infrared (NIR) spectroscopy technology, was used to determine the moisture contents of wheat, sorghum and maize, sunflower seeds, barley, soy beans, and rice; by Law and Tkachuk (1977), Stermer *et al*. (1977), Robertson and Barton (1984), Downey (1985), Lamb and Hurburgh (1991) and Kawamura *et al*. (1999) respectively. Miralb´es (2003) determined the moisture content of wheat using near infrared (NIR) spectroscopy at a range of 850 - 1048.2 nm. The study also determines wheat protein and gluten content at this spectrum. Apart from moisture determination; insect damage and infestation has also been one the earliest application of optical properties to crop processing and storage technology.

The earliest works on detection of insect infestation or damage of agricultural grains or seeds was carried out by Milner *et al*. (1950) and Hurlock (1963). Milner *et al*. (1950) developed new method for detection of insect and their eggs, larval and pupal in grains. This method was adopted by the US government as standard. The study used X-ray radiation on wheat grains to detect *Sitophilus oryza* L., *Sitophilus granaries* L, granary weevil and rice weevil. Hurlock (1963) on the other hand undertook a comparative analysis between X-ray method, flotation methods, staining technique and carbon dioxide analysis method. It was observed that data collected from X- ray methods was more accurate and precise than the other methods. The study also, experimented on green peas to detect C. *chinensis* (beans weevil) infestation. Street (1971) and Chamber *et al*. (1984) both used nuclear magnetic resonance spectroscopy (NMRS) technology on wheat grains to detect insect infestation. Street (1971) detected internal infestation of adult infestation of *S. oryzae* and *T. castaneum* with their larvae. Chamber *et al*. (1984) reported a comparative study between nuclear magnetic resonance spectroscopy (NMRS), X-ray radiography and weighing. It was observed that both the NMRS and X-ray method did not kill the insects. Also, the study reported that nuclear magnetic resonance spectroscopy (NMRS) method does not detect insect larvae at early stage of development. Schatzki and Fine (1988) and Chamber *et al*. (1992) both studied insect infestation on wheat grains and used X-ray and near infrared (NIR) spectroscopy respectively. These studies were able to detect insect larvae, pupae and adult insects affecting the internal of single wheat grain and bulk stored grain respectively. Again, Keagy and Schataki (1993) and Redgway and Chamber (1996) used X-ray and near infrared (NIR) spectroscopy to detect insect infestation in single wheat grain and bulk wheat grains. Keagy and Schataki (1993) developed an automated machine detector that detects insect's infestation in wheat using x-ray radiation from single and bulk wheat grains. The study was able to detect insect eggs and larvae under different growth conditions, found inside single wheat grain and bulk wheat grains. 50% recognition or detection result was achieved using this developed machine.

Redgway and Chamber (1996) studied possibility of using near infrared (NIR) to detection insect infestation in stored wheat grains. Eggs, larvae pupae and adult of *Oryzaephilussurinamensis* (L) (saw-toothed grain beetle) and *Sitophilus granaries* (L) (grain weevil) insect were investigated, for external and internal infestations of two different wheat varieties. The study concluded that near infrared can be used for rapid detection of insect infestation in stored wheat. Ghaedian and Wehling (1997), Dowell *et al*. (1998) and Zayas and Flinn (1998) detected insects' infestations in wheat grains using X-ray and near infrared spectroscopy (NIR), automated near infrared system and machine version technology respectively. Ghaedian and Wehling (1997) used near infrared spectroscopy (NIR) diffuse reflectance spectra from 1100-2500 nm range, to verify the present of granary weevil larva within a single wheat grain after previously using x-ray radiation to detect them. Detection accuracy obtained by models developed from spectra images of infected wheat grain and good grain range from 80 - 100%. Dowell *et al*. (1998) developed an automated system that is capable of detecting internal infestation rice weevil, lesser grain borer and Angoumois grain moth on single wheat grains. The system is capable to delivering one grain every four seconds. Spectral range used for detections range from 1,000-1,350 and 1,500-1,680 nm. The study concluded that the system can be incorporated into a grain inspection line, to maintain standard and quality. Zayas and Flinn (1998) used machine imaging technology to detect and identify adult and body of lesser grain borer insect in bulk wheat grain. The study recorded a success of 90% identification and recognition. Baker et al. (1999), Dowell *et al*. (1999) and Redgway *et al*. (1999) used near infrared to detect and identified different insect infestation on wheat grains. Identification was done for insect eggs, larvae, pupae an adult insect infestation for both internal and external damage. These studies all concluded that the stage of larvae development affect the spectrum range of identification.

Chamber *et al*. (2001) combined the near infrared and machine vision technology to detect the internal infestation of adult and larvae of insect in wheat grains. Karunakaran (2002) and Brader *et al*. (2002) used X-ray technology to detect and identify insect infestation on wheat grains. Both studies concluded that X-ray technique give a relatively good result and can be used for wheat quality control. Maghirang *et al*. (2003) developed a calibration used to calibrate an automated near infrared (NIR) system, for detection and classification of internal infestation of rice weevil. Detections were done for different stages of the weevil development in stored wheat grains. The study achieved 96% classification of egg, larvae and adult weevil found within the stored wheat grains. Singh et al. (2009) and Singh *et al*. (2010) used near infrared (NIR) hyper spatial spectroscope technology to detect insect infestation and damages on wheat grains. Both studies classification results achieved a range of 95 - 100% detection. These studies concluded that hyper spectral technology gives an excellent result when used to detect insect infestation and damages in grains. Kaliramesh *et al*. (2013) also used near infrared (NIR) hyper spatial spectroscope technology to detect Cowpea weevil insect infestation in Mung bean (*Vigna radiata (L.) R. Wilczek*) during storage. The study produces a classification accuracy range of 82 - 85% accuracy. Huang *et al*. (2013), Ma *et al*. (2014) and Chelladurai *et al*. (2014) all used near infrared (NIR), hyper spatial spectroscope and x-ray technology to detect insect infestation in soy beans. Huang *et al*. (2013) and Ma *et al*. (2014) both developed new techniques for detecting insect infestation using near infrared (NIR) hyper spatial spectroscope technology. Chelladurai *et al*. (2014) on the other hand, did a comparative study between X-ray and near infrared (NIR) hyper spatial spectroscope technology. It was observed that x-ray classify better that near infrared (NIR) hyper spatial spectroscope. The study concluded that combination of X-ray and near infrared (NIR) hyper spatial spectroscope produces a better classification than their individual classifications. Huang *et a*l. (2013), Ma *et al*. (2014) and Chelladurai *et al*. (2014) produce a classification range of 85 – 100% accuracy. Another internal detection of agricultural grains and seeds is the detection of nutritional content of grains and seeds using optical properties.

The earliest research using optical property to detect nutritive properties of grain was carried out by Siska and Hurburgh (1995). The study used the transmittance properties of near infrared spectrum of bulk maize grain, to develop a calibration for maize density measuring instrument (Infratec 1225). The maize optical densities were correlated with their protein and starch content to achieve this. Then, equations were developed to determine maize protein and starch contents. Pazdernik *et al* (1976) and Pazdernik *et al*. (1977) developed equations for determination of protein and fatty acid contents of grounded and whole soy beans seeds. The study used near infrared spectroscopy technology (NIRS) and concluded that this technology gives a better result when used for grounded soy beans than whole soy beans seeds. Kawamura *et al*. (1997) and Kawamura *et al*. (1999) also developed model calibrating equations, using the transmittance property of visible and near infrared spectrum for rice grains. It was observed in these studies that this technology can be used to detect protein and starch content and classify rice into sensory groups like taste and eating conditions. Though, these studies also concluded that this technology is not sufficient to replace the physical sensory test. Sugiyama (1999) developed a colour distribution map of sugar content of melon seed along absorption spectral of near infrared (NIR). This spectral was captured using a CCD camera fitted with near infrared (NIR) filter. It was observed that absorbance wave length of 676nm (near chlorophyll band) show a strong inverse correlation with melon seed Brix (sugar) content. Miralb´es (2003), Bennett *et al*. (2004) and Font *et al*. (2004) used near-infrared (NIR) spectroscopy to determine nutritive contents of wheat, soya beans and mustard seeds respectively. These research studies used modeled transmittance property of near-infrared (NIR) spectroscopy to predict nutritive parameters. These nutritive parameters include, the moisture, protein, wet gluten, dry gluten, and alveograph, sinigrin, gluconapin, 4-hydroxyglucobrassicin, and total glucosinolate contents. Brenna *et al*. (2004) used modeled reflectance property of near-infrared (NIR) spectroscopy to predict carotenoids content in maize. The study concluded that there was a high correction between carotenoids content in maize and the reflectance properties of near-infrared (NIR) spectra. The carbohydrate, inorganic phosphorus and amino acid composition of soya beans were determined using modeled equations developed from near-infrared (NIR) spectra by

Hollung *et al*. (2005), Delwiche *et al*. (2006) and Kovalenko *et al*. (2006) respectively. These researches concluded that nutritive values determined had strong correlation with their near-infrared (NIR) spectral. Kim *et al*. (2006) developed a non-destructive method of determining the Lignans and Lignan Glycosides contents in Sesame Seeds by using near infrared (NIR) reflectance spectroscopy. The study used a reflectance mode of a scanning monochromator scanner to achieve this goal. Other researchers had also used near infrared (NIR) spectroscopy technology to determine nutritive contents of grains and seeds. These researchers include, Kim *et al*. (2007), for oil and fatty acid content of perilla seeds; Zhang *et al*. (2008) for total phenolics, flavonoid contents, and antioxidant capacity of rice grain; Wiley *et al*. (2009) for nitrogen and protein content of barley grains; Hacisalihoglu *et al.* (2010) for protein and starch contents of bean *(Phaseolus vulgaris* L.);Stubbs *et al*. (2010) for neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), carbon (C), sulfur (S), nitrogen (N), and C:N contents of wheat and barley; Wang *et al*. (2013) for protein and amino acid contents of peanuts seeds; Asekova *et al*. (2016) for crude protein (CP), crude fat (CF), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of soya bean seeds. All these researches developed model equations to predict these nutritive contents, using measured near infrared (NIR) spectral optical properties. The developed model equations had a strong correction with their measured near infrared (NIR) spectral optical properties. Another parameter of seeds and grain quality of interest that is determined by optical properties is the foreign body within bulk grains and seeds.

The detection and/or removal of foreign body in bulk agricultural grains and seed using optical properties at different spectrum or spectra had been applied by some researchers. The most common optical technology used for foreign body detection and/or removal was the machine vision technology. Researchers that used machine vision (digital camera) include, Zayas *et al*. (1989) for wheat grain; Elbatawi and Arafa (2008) and Jain *et al*. (2009) for cumin and funnel seeds respectively; Anami and Savakar (2009) for rice, wheat, groundnut gram and jawar seeds; Gujjar and Siddappa (2014) for gram, chennangi and groundnut; and Ghatkamble (2021) for rice. These researchers mentioned only detected, identify and classify the present of foreign body in grains and seeds. These foreign body classifications were done by using different machine learning classification algorithms. Foreign bodies considered by these researchers includes, stones, soil lumps, plant leaves, pieces of stem and weeds. However, none of these studies attempt to remove the foreign bodies. Fernández Pierna *et al*. (2012) used near infrared hyper spectral imaging technology to detect the present of strew, broken grains, grains from other crops, weeds seeds, insect, plastic, stones, piece of wood and animal faces in bulk wheat and barley. This research concluded that near infrared hyper spectral imaging spectroscopy can also be used to detect foreign body in stored grains and seeds. Also, Yuying *et al*. (2019) used hyper spectral imaging technology called terahertz time-domain spectroscopy to detect foreign body in bulk wheat and its flour. Terahertz bans spectrum lies between microwave and infrared region in the electromagnetic spectrum. The study shows that high frequency spectra can achieve good results in detecting foreign body in bulk wheat. Zhu *et al*. (2020) used radio tomography imaging (RTI) technology to detect foreign body in grain granary. This is electromagnetic wave spectrum of radio wave frequency. The detection was based on a technique called received signal strength (RSS). The study was able to prove that radio tomography imaging (RTI) technology can equally detect foreign body in bulk grains and seeds as good as hyper spectral imaging spectroscopy. Another most popular use of optical properties by researchers in crop processing is the classification of variety or physical attributes.

The most used optical technology applied by researchers to classify crop variety is also machine vision. Researchers who used machine vision to classify crop variety include: Zayas et al. (1986) and (1990) for wheat grains; Hehm *et al*. (1991)for canola and mustard seeds respectively; Majumdar *et al*. (1997) for wheat, barley, oats and rye; Shahin and Symons (2001) and Venora *et al*. (2007) for lentil seeds; Kilic *et al*. (2007), Venora *et al*. (2009) and Nasirahmadi and Behroozi-khazae (2013) for beans seeds; Chen *et al*. (2010) for maize grains; Emadzadeh andspeyer (2010) and Cinar and kolar (2019) for rice grains; and Guevara-Hernandez and Gomez-Gil (2011) for wheat and barley grains. These researchers used machine learning algorithms to classify these grains and seeds with accuracies greater than 70%. However, there were other researchers who used machine vision with the aid of machine learning algorithms as well to classify grain/seed physical attributes. These researchers include: Liao *et al*. (1996) for classifying whole and broken maize seeds, Xie and Paulsen (1997) for maize tetrazolium (whiteness) detection, Ni *et al*. (1997) for sorting broken and unbroken maize seeds and Steenhoek and Precetti (2000) for maize seeds size grading, Pearson (1996) for stained and unstained Pistachio nuts, Wan *et al*. (2000) for rice grading, Shahin and Symons (2001) for lentil seed grading, Laurent *et al*. (2010) for hard to cook characteristic of beans and Guevara-Hernandez et al.(2011) for classification of wheat and barley grains using their morphologic, color, and texture features. All these researchers mentioned used machine vision technology with the spectrum range of visible light. There were other researchers who used electromagnetic spectrum higher than the visible light spectrum. The spectrum higher than the visible light spectrum is the infrared spectrum. Researchers who used infrared spectrum to identify and classify grains and seeds variety or other physical attributes include: Downey *et al*. (1997) and Esteban-Die *et al*. (2007) for coffee beans variety; Mahesh *et al*. (2008) for wheat variety; Sirisomboon *et al*. (2009) for soya beans pod defection; Williams *et al*. (2009) and Feng *et al*. (2017) for maize variety; Arngren *et al*. (2011) for barley variety; and Serranti et al. (2013) for oat and groat kernels classification. These researchers used different machine learning algorithms to achieve classifications. There were also, other researches that combine electromagnetic spectrum to detect and classify grains and seeds variety or other physical attributes. Dowel *et al*. (2009) used multi spectral imaging technology to developed an automated sorter for single kernel sorting of quality breeding traits of wheat. Researchers that used hyper spectral image to identify and classify variety or other physical properties include: Zhang *et al*. (2018) for coffee beans variety; Zhao *et al*. (2018) for maizevariety; Zheng *et al*. (2018) for rice variety; Wu *et al*. (2019) for oat seeds variety; Bao *et al*. (2019) for wheat variety. However, there were other researchers who used optical properties to detect, identify, classification or also removal of all or some grains and seeds quality mention so far in a single operation.

Dowell *et al*. (1998), Ridgeway *et al*. (2001) and Pearson *et al*. (2013) all used optical properties to detect different quality parameters of wheat grains in a single operation. Dowell *et al* (1998) used a near-infrared spectrometer to develop a wheat grain separation system. This attached spectrometer scanned and detected single wheat kernel infected and damaged by insects and their larvae. The study then used the kernel moisture and protein content to compare with the detection accuracy of the system. Ridgeway *et al*. (2001) developed a separating system using a monochrome CCD camera and personal computer, to detect and separate damage wheat kernel with insect and larvae from good grains. Pearson *et al*. (2013) developed a multispectral sorting device. The device was used to sort wheat kernel colour and Fusarium head blight (FHB)-damaged kernels from undamaged kernels. These were used to classify wheat kennels into low, medium, and high protein level. Huang *et al*. (2013) used acquired hyper spectral images of normal and insect-damaged soy beans seeds to classify them using machine learning algorithms. Ng *et al*. (1997), Soedibyo *et al*. (2010) and Mesfin *et al*. (2019) used machine vision to identify and classify maize, coffee beans and white pea beans respectively. Ng *et al*. (1997) used machine vision to evaluate classify mechanical damage and mold damage in maize. Soedibyo *et al*. (2010) detected, separated and classified damaged seeds, foreign body, diseased seeds and seed variety of coffee beans. Mesfin *et al*. (2019) developed a grading system for foreign body, rotten and diseased seeds, healthy seeds, broken seeds, discoloured seeds, shriveled seeds and pest destroyed seeds of white pea beans. Grover *et al*. (2021) developed an automated machine vision separating system for coffee bean to separate coffee beans by size and defect.

2.4 Agricultural Seeds and Grains Separation

Acceptability of agricultural seeds and grains for consumption or industrial use can not be achieved without some level of seeds and grains separation. The type or level of separation done to seeds and grains determine its quality. Separation of agricultural seeds and grains is the removal of unwanted materials from the body of grains or seeds. These unwanted materials include: broken seeds/grains, stones, dirt, leaves, stems, animal faces, metal, plastic, diseased infected/damaged seeds/grains, pest infected/damaged, heat damage, other type of seeds/grain and moisture damaged seeds/grains. There are various methods and techniques used for separation of agricultural seeds and grains. The use of these separation techniques depends on availability of tools, technical knowhow and expert personnel (Klein *et al*., 1961; Harmond *et al*., 1968; Seed Certification Manual, 2020)

2.4.1 Agricultural Seeds and Grain Separation Techniques.

There are various seeds and grains separation techniques, these include:

1. Screen/Sieve Separation Technique – This is a separating technique that employ the use of the size differences between the seeds/grains and unwanted materials. Sieves/ Screens are perforated materials that allow smaller size materials to pass through them while

retaining the bigger ones. Sieving/Screening action is achieved by agitation, vibration or rotation (Klein *et al*., 1961; Harmond *et al*., 1968).

2. Specific gravity/ Gravity Separation Technique – A separation technique that use the difference in weight, density, specific gravity/weight or gravity to remove unwanted material from seeds/grains. This technique can also be used when the separating materials are of the same material but having different weight. For example, good seeds and broken seeds or good seeds and damaged seeds. This technique is achieved either by using an inclined surface or by using air (Klein *et al*., 1961; Harmond *et al*., 1968).
3. Air/ Aspiration/Pneumatic Separation Technique – In this separating technique, air is used to remove the unwanted material from the stream of seeds/grains. The air introduced into the chamber of separation, utilizes the aerodynamic properties of these seeds/grains or unwanted materials as means for separation. These aerodynamic properties include terminal velocities, drag coefficient and air flow resistance of the materials to be separated (Klein *et al*., 1961; Harmond *et al*., 1968).
4. Inclined Draper Separation Technique - This separating technique used the differences between the shape or texture of the seeds/grains and the unwanted materials. That is, the ability of either the seeds/grains or the unwanted material to slide or roll down a rolling incline plane (conveyor belt) while the other without the sliding or rolling ability is carried up the rolling plane (conveyor belt) (Klein *et al*., 1961; Harmond *et al*., 1968).
5. Disc Separation Technique - This is a separating technique that employ the use of the size and shape differences between the seeds/grains and unwanted materials. The difference between separating disc and sieve is that holes bored in disc, do not bore through but form collecting pockets for retaining seeds. The holes in sieves bore through it, allowing seeds to pass through it. In disc separation, smaller materials are retained or holdup in the disc hole pocket while larger size materials are rejected. The separating disc is placed inside an enclosed housing (Klein *et al*., 1961; Harmond *et al*., 1968).
6. Velvet Roller Separation Technique – The velvet roller separate is based on difference in shape and surface texture. This separating technique is mostly use as a finishing machine. That is after major or primary separation like thrashing had finished. This technique is very effective in separating seeds/grains with rough seed coat from smooth

seeds. The separating method involves two rolls, rotating in different direction in an enclosed environment (Klein *et al*., 1961; Harmond *et al*., 1968).

7. Buckhorn/ Spiral Separation Technique - This technique uses the roughness of the seeds/grain to separate it alone a spiral path. When seeds/grains are feed into a spiral screw, the round seeds/grains gain speed due to centrifugal force. This increase in speed allows the round seeds to fly out through the opening provided along the screw path. The other materials that are not round just slide along the spiral conveyor (Klein *et al*., 1961; Harmond *et al*., 1968).
8. Magnetic Separation Technique – This technique involves the use of magnet to separate metals found in bulk seeds and grains. The magnetic separators used in this technique come in different sizes and shapes. Although not all metals have magnetic properties. Metal that are not magnetic are separated through other means (Klein *et al*., 1961; Harmond *et al*., 1968).
9. Electrostatic Separation Technique - This technique utilized difference in electrostatic charges among different materials of separations. When an electrostatic field is introduced around separating seeds/grains and unwanted materials. Positively charged materials move away from the negatively charged ones. Electrostatic charge can be introduced on the belt carrying mix material or directly above the conveying mix material to be separated (Klein *et al*., 1961; Harmond *et al*., 1968).
10. Magnetic Resonance Imaging Separation Technique – A separating technique which uses radio wave and a very strong magnet connected to a computer to generate detailed image pictures of seeds/grains and its impurities. These picture images are processed and programmed to identify, detect and separate seeds/grains from its impurities (Stannarius, 2017).
11. X-ray Imaging Separation Technique - This technique used acquired x-ray images of mixed seeds/grains and impurities to separate them. Separation is achieved by imputing the x-ray images on computer. These images are processed and programmed to identify, detect and separate seeds/grains from its impurities (Hirano *et al*., 1998; Karunakaran, 2002; Brader *et al*., 2002; Emadzadeh and Speyer, 2010; Chelladurai *et al*., N. 2014).
12. Machine Vision Separation Technique – A type of computer vision technique, which involves the use of optical camera. This camera has the ability to capture images formed

from different spectrums (spatial), to automatically receive and interpret these images to sort, classify or separate impurity from seeds/grains. Most machine vision images are converted to 2D, before it is used for image processing. Machine vision was the technique used for the automation separation of this study (Liao *et al*., 1994; Majumdar et al., 1997; Majumdar and Jayas, 2000a; 2000b; 2000c; 2000d; Elbatawi and Arafa, 2008; Soedibyo *et al*., 2010; Guevara-Hernández and Gómez-Gil, 2011; Patel *et al*., 2012; Mesfin *et al*., 2019; Grover *et al*., 2021)

13. Stereo Vision Separation Technique – This is a type of computer vision technique, which involves the use of two optical cameras to capture simultaneous images of the same object. Images produced by this technique are mostly 3D. These images are imputed into the computer to interpret for the purpose of sorting, classification and separation of impurity from seeds/grains (Szeliski, 2011).
14. Expert Base System Separation Technique – This technique involves the use of images of seeds/grains and its impurities acquired either by machine or stereo vision. These images are imputed into the computer and programmed to use sets of rules to make decision just like an expert in the field of seeds/grain separation. The decision results in turn separate seeds/grains from its impurities. This is artificial intelligence in seeds/grain separation (Vidas *et al*., 2013).

These are presently the separating techniques used to develop seeds/grain sorting, cleaning, grading or quality separation machine or system. Technique 1 – 7 mentioned can be achieved mechanically, 8 and 9 electrically; 10 achieved using both electrically and optically, while 11 – 12 achieved optically using electromagnetic spectrum (Harmond *et al*., 1961; Harmond *et al*., 1968; Sun *et al*., 2007; Patel *et al*., 2014; Inamdar and Suresh, 2014; Stannarius, 2017).

2.5 Mechanical Separating techniques used in this study

The separating techniques used to develop the system in this study involve both mechanical and optical techniques. The techniques and unit parts involve in this study included:

i. Trommel drum screen/sieve
ii. Screw conveyor

iii. Bucket conveyor
iv. Belt conveyor
v. Seed metering device/mechanism
vi. Automation using machine vision

2.5.1 Trommel Drum Screen/Sieve

Screen or sieve is a separating device or component with holes through them that allow either solid or liquid to pass through them. There are eight different types of screens/sieves separation techniques or devices. These include:

1. Trommel screen/sieve – is a mechanical perforated drum screen/sieve device that separate larger materials from smaller ones with the help of rotational motion. Larger materials are left inside the drum while smaller one falls out through the sieve holes. Single or multiple sizes of holes can be drilled across the drum length; to separate two or more materials (Damgaard and Morton , 2016; Bettina *et al*., 2017).
2. Oscillating screen/sieve – This is a mechanically operated flat perforated screen/sieve device that oscillates (to and fro movement) at 300 to 400 rpm in a plane parallel to the screens/sieves. Single or multiple holes sizes can be drill across screen/sieve length to separate single or multiply materials (Astanakulov, 2020).
3. Gyratory screen/sieve – This is a mechanically operated rotationally perforated screen/sieve device. The screen/sieve does not rotate or revolve around the center of the device (gyration). Also perforated holes on the screen can be uniform or different sizes to separate single or multiple sized materials. This screen/sieve can be used for both dry and wet separation (Orosa *et al*., 2020).
4. Grizzly screen/sieve – This separating screen/sieve device is made up of parallel arranged metal bars on a stationary inclined frame. The metal bars are 3m long having spacing ranges from 50 – 200m. Materials to be separated move downward alone a slope path parallel to the length of the metal bars (Luttrell and Honaker, 2012).
5. Tumbler screen/sieve – A mechanical perforated screen/sieve device that uses three dimensional elliptical movements to separate smaller material from larger ones. This technique can be used for both dry and wet separation. The principle behind this separation is that smaller materials stay on the center of the screen/sieve while larger materials move toward the edges of the screen/sieve (Silin *et al*., 2020).

6. Bucket screen/sieve – This is a bucket-like mechanical perforated screen/sieve device that transport materials as well as screen/sieve them. They come in different shapes. It scoops the materials to be sieved or screened, then sieve or screen then by rotation, oscillation or gyration movement (Pallab and Das 2021).
7. Ballistic screen/sieve – A ballistic sieve/screen separator is a mechanical sorting device with perforated oscillating paddles that runs the length of the sorting perimeter or deck. Agitation of materials on top of the deck or separation region (perimeter) is achieved by setting the paddles to alternate at 60 – 120 degrees out of phase from the adjacent paddle (Möllnitz et al., 2021)
8. Disc screen/sieve - This is a mechanical sieve/screen separating device with horizontal shafts that are mounted with discs at regular intervals. The discs from one shaft interleaf with those on the adjacent shafts, creating open areas between the discs and the shafts. The materials to be separated are agitated when the shaft and the discs are rotated. Therefore, allowing smaller materials to pass through the openings between the shafts and the discs (Muritala *et al* 2020).

Among these screens/sieves mentioned, the one chosen for the construction of the separating system developed in this study was the trommel drum screen/sieve. The perforation shapes of a trommel drum screen/sieve are either round or square. According to Brentwood Recycling Systems (2013), the factors that determine this choice include:

i. The size of the smallest material to be separated
ii. Area of the perforation (aperture). Square shaped contribute to a larger area than round shape
iii. Separating materials magnitude of agitation (speed of the drum)
iv. Drum clean up.

The drum screening/sieving rate formula proposed by Glaub *et al*. (1982) was based on the assumption that particles fall perpendicular to the sieve openings. Therefore, Glaub *et al*. (1982) proposed that the probability of passage, P, is given by Equation 2.1.

$$P = \left(1 - \frac{d}{a}\right)^2 Q \tag{2.1}$$

where d is the particle size, a is the size of aperture (diameter or length) and Q is the ratio of perforated area to the total screen area. Equation (1) holds for both square and circular apertures.

According to Pichtel (2005), trommel drum screens/sieves efficiency of separation is affected by these factors:

i. Trommel drum screen/sieve speed
ii. Separating material feed
iii. Separating material time of residence within drum sieve/screen
iv. Angle of inclination of sieve/screen
v. Apertures size on the sieve/screen
vi. Separating material characteristic

2.5.2 Screw Conveyor

A screw conveyor is a mechanical device used to move loose or granulated material within a close housing unit, with the help of helical screw blade rotating along a shaft center. This helical screw blade is sometimes called flight. Screw conveys can move both liquid and solid materials. Screw conveyors can also be called auger conveyors. This type of conveyor consists of a housing called trough or tube containing a spiral helical blade coiled around a shaft. The shaft is driven at one end and held at the other end. Although there are screw conveyors design these days with a shiftless spiral screw, driven at one end and free at the other end. Screw conveyors are used in many industries to transport bulk granular materials. These industries include: minerals, agriculture (grains), pharmaceuticals, chemicals, pigments, plastics, cement, sand, salt and food processing. There are three types of screw conveyors which are horizontal, vertical and inclined screw conveyors. Although, screw blades (flights) are designed and constructed in various shape. These screw blade (flight) types include: helicoid-flight, sectional-flight, short-pitch, tapering-flight, stepped-diameter, stepped-pitch, long-pitch, double-flight, double-flight, short-pitch, ribbon-flight, abrasion-resistant, corrosion-resistant (Handling Agricultural Materials handbook,1989). The concept of screw conveyor has been with mankind for years.

Alton and Howell (2003) reported that the oldest displacement pump in the world was the water screw pump. This was the first recorded screw water pump; tracing back to ancient Egypt around 3rd century BC. This screw pump was used in ancient times to lift water for irrigation from the Nile River. Some researchers had reported that this was the device used for pumping water to the hanging gardens of Babylon consider to be one of the seven wonders of the seven wonders. Assyrian King Sennacherib inscription dated back to 704–681 BC has been reported by Dalley (2013) to show cast screw water pumps in bronze some 350 years earlier. Archimedes introduces the screw pump from Egypt to Greece. According to Haven (2006) Archimedes mentioned and described the screw pump conveyor when he visited Circa, Egypt in 234 BC. No claim recorded was attributed to Archimedes to have said to invent the screw conveyor. It was Diodorus a Greek historian who attributed the invention of the screw conveyor to Archimedes during his visit to Egypt, 200 years later after Archimedes visit to Egypt. The modern agricultural screw (auger) conveyor used in farming operations today was invented by Peter Pakosh. He was the co-founder of the versatile tractor company. In 1940 Peter Pakosh approached the design department of Massey Harris (now called Massey Ferguson) company with his auger design idea. He was scold by the Massey head designer and told that his idea was unimaginable. However, Pakosh went on to design and build his first prototype in 1945. Eight years later he starts sell tens of thousands under the 'Versatile' name, making it the standard for modern grain augers. The factors that influence the efficiency of a screw conveyor include: the water content of the material, physical property of the material, installation site of the conveyor, blade rotate speed, outer diameter of the screw, pitch of screw, feeding methods (Handling Agricultural Materials handbook, 1989; Pakosh, 2003). In this study a screw conveyor was design and constructed inside the trommel screen/sieve drum. This was to remove large stones that do not passed through screen/sieve holes in the first sieve drum out of the system and grains from the second sieve drum to the bucket conveyor.

2.5.3 Bucket conveyor

A bucket conveyor is a mechanical transporting device used to move bulk material vertically. In agriculture it is also called grain leg. It is usually made up of the buckets that contain the bulk transporting materials; belt or chain that carries the buckets vertically; drivers that power and life the buckets; hopper for loading the materials; discharge chute for receiving the arriving materials and housing for enclosing the transported materials. There are three type of bucket conveyor design: centrifugal discharge elevator, continuous discharge elevator and positive discharge elevator. The factors that influence bucket conveyors are: bucket type, shape and discharge characteristics, optimum speed in relation to pulley size, shape of head and boot, material characteristics such as size, shape and density, angle of repose, coefficient of friction and terminal velocity (Handling Agricultural Materials handbook, 1989; Menegaki *et al*., 2019). Conveyors had been with man since ancient time.

According to Zimmer (1921) ancient Persians used chains of pots to convey water from the well. Also, Needham (1965) reported that the earliest evidence of conveyor device was in Babylon, from a Babylonia text dated back to 700 BC. Donald (1996) in his history of Arabic science reported that in 200 BC, a modified version of the Babylonia chain of pot conveyor was introduced in Egypt. This modified version had mechanical wheel. This modified version was later imported into the Greece and Rome. A Greek engineer Philo of Byzantium who lived most of his life in Alexandra, Egypt wrote about the present of this conveyor device in Greece in 2nd century B.C. Also, Marcus Vitruvius Pollio a roman architect and military engineer wrote about the present of the device in Rome around 30 BC (Donald, 1996). Needham (1965) also reported the use of this conveyor by the Chinese in the 1^{st} century A.D. The earliest Chinese account was a descriptive report given by a Han Dynasty philosopher Wang Chong in 80 A.D. The mining usage of this bucket conveyor in Europe was first reported by Georgius Agricola who was a German Humanist scholar, mineralogist and metallurgist. The conveyor was used in the European Renaissance period ($15^{th}$and 16^{th} centuries). Agricola illustrated and described this conveyor in the book, 'De re metallica' (Agricola 1556).

2.5.4 Belt conveyor

A belt conveyor is a mechanical transporting device consisting of two rotating drums (pulley) with belt rotating about them in a close rotating loop. One pulley is called the drive pulley (the one attached to the power source) and the other called the idler or driven pulley. Belt conveyor is the most versatile and less expensive conveyor system used in industries. It can transport both granular and solid materials. The transporting capacity of the belt can be increased by applying the followings; increasing belt widths, increasing belt speeds, using higher capacity idler geometry, employing low rolling resistance rubber and increasing belt strengths (Boumans, 1985; Fenner Dunlop, 2009). Since the 19th century elementary belt conveyors had been in use.

Rines (1920) reported that Thomas Robins, an American inventor and manufacturer, started a series of inventions which led to the development of a conveyor belt in 1892. This crude belt conveyor then was used to carry mining products like coal and iron ore. After that, a Swedish multinational engineering company called "Sandvik AB" in 1901 invented the steel conveyor belt and produces them for industrial usage. Richard Sutcliffe an Irish mining engineer and inventor in 1905 invented the first real or present belt conveyor belt which revolutionized and changed the mining industry. Henry Ford an American industrialist and business magnate, in 1913 use this conveyor belt to establish an assembly line for his ford automobile manufacturing (Hounshell, 1984). Also, the French society REIin (1972), build the longest belt conveyor in the world at New Caledonia at that period. Although, the Moroccan phosphate mine conveyor belt at BouCraa, has been estimated to be the longest in Africa with a length of 98 km in 1973. The Australian Boddington bauxite mine conveyor belt is estimated as the longest in the world with a span of 31km (Hounshell, 1984). A company called 'Goodrich' patented a conveyor belt called 'Möbius strip'. This is a special half twisted belt, it is no longer in used because the straight belt last longer than it. A Louisiana-based company in the US called "Intralox" was the first to patent all plastic, modular belting in 1970 (Hounshell, 1984).

2.5.5 Seed Metering Device

A seed metering device is a mechanical mechanism that collects seeds/grain and delivers them either one after the other or in a group. It is made up of a hopper, seeds/grain meter and a delivery tube. The seed/grain meters are of different types which are: Fluted feed type, Internal double run type, cup feed mechanism, cell feed mechanism, brush feed mechanism, picker wheel mechanism, star wheel mechanism and auger feed mechanism. The metering mechanism used in this study is the cell feed mechanism. Cowpea seeds are picked and dropped into the delivery tube, by a rotating wooden drum cell with four drilled holes at regular intervals on the drum. Seeds/grains metering devices had been used in seed drills and planters by farmer for planting for many centuries.

Around 1400 BC the Babylonians had started using primitive seed drills for planting, but this Babylonian invention never reaches Europe. In the 2nd century BC the Chinese invented multi-tube iron seed drills. This invention was credited to have contributed for food sustenance of China large population over the centuries. It was this Chinese invention that was imported into Europe. In the 16th century the used of the seed drill becomes popular among peasant farmers in India. The Senate of the Republic of Venice was the first to patent and introduce the first seed drill to Europe in 1556. In England it was introduce by Jethro Tull an English agriculturist in 1701 (Hounshell, 1984; Needham et al., 1987; Irfan, 1987).

2.6 Machine Automation

Automation is a technology that empowers a machine, process, operation or system to operate and accomplish a task with little or no help from humans. Automation involves using control system to accomplish industrial task in various fields. It can be achieved by using various means which includes hydraulic, mechanical, electrical, pneumatic, electronic devices and computers. Also, it can also be achieved by the combinations of these means or all of these means. The advantage of automation includes labor savings, reducing waste, savings in electricity costs, savings in material costs, and improvements to quality, accuracy, and precision. Since 2010 activist, nationalist, protectionist and populist politics in UK, US and other developed nations are of the opinion that loss of Jobs and downward mobility among other factors will be caused by the adoption of automation. The term automation was coined from the word ‘automaton’ which also means automatic. This word was first used 1947 by Henry Ford to describe the action his cars assemble lines. This word was then introduced back in the 1930s when industries were beginning to use feedback controllers. (Rifkin, 1995; Lamb, 2013; Groover, 2014)

2.6.1 Automation in Agricultural Seeds and Grains processing

Automatic separation and sorting of grains began in the 1880s. Crude electrostatic methods were employed to separate light materials from cereal grain. These systems used photodiodes or photo multiplier tubes to discriminate between the overall color of the product and foreign bodies (Bee, 2002). The first-generation color sorters used shades of black and white (monochromatic) to remove the defects and impurities. Today, due to advances in technology, color sorters are using high resolution bichromatic cameras in addition to monochromatic cameras for inspection of grains in wider color spectrum.

Recently, the manufacturers are using infrared and ultraviolet sorting capabilities combined with color detection technology to enable the inspection for foreign material with invisible optical properties (Fowler, 2012). Apart from advancement in cameras, the use of fluorescent or halogen lighting, high speed reliable ejectors, better distribution and uniformity of the feeders have allowed the development of optical sorting machines with much higher operating capacities, more sorting accuracy and yield, consistent sorting performance and high reliability. This has resulted into a much wider application of optical sorting in grains/seeds processing. Optical sorters are taking the place of traditional disc and indented separators in the grains/seeds processing.

2.7 Automation used in this Study

The components of the automated device used in this study are:

i. Raspberry pi board
ii. Raspberry pi camera
iii. TFT screen
iv. Servo motor
v. Python programming language

2.7.1 Raspberry Pi Board

An organization in Britain established a foundation called Raspberry pi foundation. This foundation goal is to establish basic knowledge of computing in emerging nations. It produces small circuit board computers or single-board computers (SBCs) in partnership with Broadcom Incorporated. Broadcom Inc. is an American company that design, develop, manufacture and globally supplies wide range of semiconductor and infrastructure software products. The first raspberry pi board model production sold beyond its targeted market because of its open design, modulation and low. Robotic, computer and electronic industries placed a high demand on raspberry pi boards because of these qualities. The Raspberry foundation sold more than 40 million boards as at, May 2021. This makes the foundation the best-selling British Computer Company. These Raspberry boards are presently manufactured in Sony factories in Wales, China and Japan (Raspberry Pi, 2020).

Many versions of Raspberry pi had been produced over the years. One of them is the Raspberry Pi SBCs. It has an integrated ARM-compatible central processing unit (CPU) within a Broadcom system on a chip (SoC). It also has an on-chip graphics processing unit (GPU). Another model is the Raspberry Pi Pico which has an integrated ARM-compatible central processing unit (CPU) within a RP2040 system on chip. Raspberry Pi Model B developed in 2012 was the first-generation pi board. Raspberry Pi board models and their features are displayed in table 2 (Raspberry Pi, 2020).

2.7.2 Raspberry Pi Camera

Raspberry Pi currently sells two types of camera board: an 8MP device and a 12MP High Quality (HQ) camera. The 8MP device is also available in NoIR form without an IR filter. The original 5MP device is no longer available from Raspberry Pi. All Raspberry Pi cameras are capable of taking high-resolution photographs, along with full HD 1080p video, and can be fully controlled programmatically. Once installed, there are various ways the cameras can be used. The simplest option is to use one of the provided camera applications. There are four Linux command-line applications installed by default. User can also programmatically access the camera using the Python programming language, using the pi camera library. “Libcamera” comand is a new Linux API for interfacing to cameras. Raspberry Pi have been involved with the development of libcamera and are now using this sophisticated system for new camera software. This means Raspberry Pi are moving away from the firmware-based camera image processing pipeline (ISP) to a more open system (Raspberry Pi, 2020). Table 2.2 shows the model families and features.

2.7.3 TFT (Thin-film-transistor) Screen

Screen display technologies are of different forms. One of which is the Thin-film-transistor liquid-crystal display (TFT LCD), this technology was developed to enhance image qualities. The TFT LCD is made up of many segments unlike other types of LCD with few segments. The TFT LCDs technology are used in appliances such as car dashboards, projectors, personal digital assistants, television sets, computer monitors, handheld devices, mobile phones, navigation systems and video game systems. Those who patented various form of display technologies includes: John Wallmark who patented the thin film MOSFET in 1957 and Paul Weimer improved on the thin film MOSFET to develop the thin-film transistor (TFT) and then patent it in 1962. Thin-film transistors (TFT) are consisting of layers of cadmium selenide. Bernard Lechner of RCA Laboratory in the US was the first to conceive the idea of Thin-film transistor (TFT) in liquid crystal display

Table 2.2: Raspberry Pi board design model families and the features.

Family	Model	SoC	Memory	Form Factor	Ethernet	Wireless	GPIO	Released	Discontinued
Raspberry Pi	A	BCM2835	256 MB	Standard[a]	No	No	26-pin	2013	No
Raspberry Pi	A+	BCM2835	512 MB	Compact[b]	No	No	40-pin	2014	Jan-26
Raspberry Pi	B	BCM2835	256 MB	Standard[a]	Yes	No	26-pin	2012	Yes
Raspberry Pi	B+	BCM2835	512 MB	Standard[a]	Yes	No	40-pin	2014	Jan-26
Raspberry Pi 2	B	BCM2836/7	1 GB	Standard[a]	Yes	No	40-pin	2015	Jan-26
Raspberry Pi 3	A+	BCM2837B0	512 MB	Compact[b]	No	Yes	40-pin	2018	Jan-26
Raspberry Pi 3	B	BCM2837A0/B0	1 GB	Standard[a]	Yes	Yes	40-pin	2016	Jan-26
Raspberry Pi 3	B+	BCM2837B0	1 GB	Standard[a]	Yes	Yes	40-pin	2018	Jan-26
Raspberry Pi 4	400 (4 GB)	BCM2711	4 GB	Keyboard	Yes (Gigabit Ethernet)	Yes (dual band)	40-pin	2020	Jan-26
Raspberry Pi 4	B	BCM2711	1 GB	Standard[a]	Yes (Gigabit Ethernet)	Yes (dual band)	40-pin	2019	Mar-20
Raspberry Pi 4	B	BCM2711	2 GB	Standard[a]	Yes (Gigabit Ethernet)	Yes (dual band)	40-pin	2019	Jan-26
Raspberry Pi 4	B	BCM2711	4 GB	Standard[a]	Yes (Gigabit Ethernet)	Yes (dual band)	40-pin	2019	Jan-26
Raspberry Pi 4	B	BCM2711	8 GB	Standard[a]	Yes (Gigabit Ethernet)	Yes (dual band)	40-pin	2020	Jan-26
Raspberry Pi Pico	N/A	RP2040	264 KB	Pico (21 mm × 51 mm)	No	No	26-pin	2021	?
Raspberry Pi Zero	W/WH	BCM2835	512 MB	Zero[c]	No	Yes	40-pin	2017	Jan-26
Raspberry Pi Zero	Zero	BCM2835	512 MB	Zero[c]	No	No	40-pin	2015	Jan-26

1. ^ a b c d e 85.6 mm × 56.5 mm (3.37 in × 2.22 in) 2. ^ a b 65 mm × 56.5 mm (2.56 in × 2.22 in) 3. ^ 65 mm × 30 mm (2.6 in × 1.2 in)

Source: Raspberry Pi, 2020

technology in 1968. Then other researchers such using Bernard Lechner idea in 1971, developed a 2-by-18 matrix display layer LCD driven by a hybrid circuit using the dynamic scattering mode of LCDs. This technology was further improved on by Westinghouse Research Laboratories in 1973. The improvement developed a CdSe (cadmium selenide) TFT which was used to demonstrate the first CdSe thin-film-transistor liquid-crystal display (TFT LCD). Further improvement was done by Brody and Fang-Chen Luo in 1974 to show case the first flat active-matrix liquid-crystal display (AM LCD) using CdSe TFTs. In 1975 the name 'active matrix' was coined by Brody and used to describe TFT. In 2013, almost all modern electric devices with display unit come with TFT-based active matrix displays (Kawamoto, 2012).

2.7.4 Servo Motor

A servomotor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servo motors. Servomotors are not a specific class of motor, although the term servomotor is often used to refer to a motor suitable for use in a closed-loop control system. Servo motors are used in applications such as robotics, CNC machinery or automated manufacturing. A servomotor is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is a signal (either analogue or digital) representing the position commanded for the output shaft. The motor is paired with some type of position encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops. The very simplest servomotors use position-only sensing via a potentiometer and bang-bang control of their motor; the motor always rotates at full speed (or is stopped). This type of servomotor is not widely used in industrial motion control, but it forms the basis of the simple and cheap servos used for radio-controlled models. More sophisticated servomotors use optical rotary encoders to measure the speed of the output shaft and a variable-speed drive to control the motor speed. Both of these enhancements, usually in combination with a PID control algorithm, allow the servomotor to be brought to its commanded position more quickly and more precisely, with less over shooting (Suk-Hwan *et al*., 2008; Sawicz,2012; Ralf and Georg, 2012).

2.7.5 Python Programing language

Python program is an all-purpose programming with high level interpretation. The philosophy behind its design stresses the point of code readability with its notable use of significant indentation. Python language has an object-oriented approach that helps the programmer to understate and write clearly codes for large- and small-scale projects. Python programming language is garbage-collected and dynamically-typed. Python can accommodate multiple programming paradigms such as object-oriented, functional structured (particularly, procedural) programming. Python comes with a comprehensive standard library which makes it robust to use. In the late 1980s, a Dutch programmer name Guido van Rossum created the Python program language. The first version was released in 1991 and called 'Python 0.9.0'. The second version released in 2000 was called 'Python 2.0', this version a contained a more comprehensive library list. In 2008 the third version called 'Python 3.0' was released and this version contains major language modification. This modification makes some language from 'Python 2.0' not to function in 'Python 3.0'. Hence, the release of another version called 'Python 2.7.18' in 2020 to solve this problem. (PEP, 13; Rossum, 2009; Kuhlman, 2013).

The sole responsibility of developing these python programs projects lies sole with Guido van Rossum, as a lead developer. In 2018, Guido van Rossum relinquished his position as the life director of Python. This position was initially bestowed on him by the Python community to reflect his long-term commitment as the project's chief decision-maker in developing all Python program versions. Then, in 2019 a five-member steering council was created by active core Python developers' groups. This council replaced Guido van Rossum and becomes the head of all Python lead project. Although, membership of this council had changed over the years, in 2021 member of the council now includes: Pablo Galindo Salgado, Brett Cannon, Barry Warsaw, Thomas Wouters and Carol Willing. The release of Python 2.0 version saw the inclusion of new features like support for Unicode and cycle-detecting garbage collector. The release of Python 3.0 saw the inclusion language revision that is not compatible to Python 2.0 version. Also, a lot of features in Python 2.0 version that can not be used in Python 3.0 were back ported to Python 2.6.x and 2.7.x version series. Introduction of Python 3.0 comes with some utilities, which help to translate of version 2 code to version 3. Although, not all code uses able to be translated Python 2 to Python 3. Therefore, the need for Python 2.7's which end-of-life date was initially set at 2015 eventually it was postponed to 2020 out of concern that a large natural and manufactured systems or other improvements will be released for it. The release of all Python 2's and their end-of-life, only Python 3.6.x and later versions are supported. Python 3.9.2 and 3.8.8 were expedited as all versions of Python (including 2.7) had security issues, leading to possible remote code execution and web cache poisoning (PEP, 8100; Rossum, 2009).

2.8 System Concept

A system is a collection of related components working together to achieve define goal. A unit part of a system is called a subsystem. A system is characterized by the follow: Orientation towards the objective; Structure of the system; Inputs; Processing of inputs; Outputs; Interdependence. These characters are used to classify or determine a system. There are different types of systems (Lakoff, 1980; Berners-Lee, 2009; Gagniuc, 2017; Shadbolt *et al*., 2019), which include:

1. Conceptual and Empirical Systems – Conceptual system is the use of non-physical things like ideas, theories and concepts to achieve a common goal. These types of systems usually come in form of classification or explanation to form procedures, policies, plans, accounting system, etc. Empirical System is based on observation and experience rather than scientific facts and data of operations. This system is made up of operational activities of materials, people, machines, energy, and other physical things (Lakoff, 1980).
2. Permanent and Temporary systems – Systems that are design to last a long period before stopping are called permanent systems. That which is design to last a short period after performing a specific task is called temporary system (Berners-Lee, 2009).
3. Natural and manufactured systems – Natural systems are interaction of things in the environment that do not require any human effort. Examples of natural systems are solar system, water system etc. Manufacture systems are artificial systems that are produced

by man. Examples of natural systems are transport system, communication system, etc (Berners-Lee, 2009).

4. Deterministic and Probabilistic Systems – Deterministic system is a system where every occurrence of the individual activities and the final outcome are known for certain. A software program carrying out different functions is an example of deterministic system. A probabilistic system on the other hand, is a system where every occurrence of the individual activities and the final outcome is uncertain and there is element of randomness in their operations (Gagniuc, 2017).
5. Subsystems and Super System – Subsystems are the different components (unit) in a system. super system is the sum total of all the individual units that make up the whole system
6. Stationary and Non-Stationary Systems – Stationary systems are systems which operational activities and processes do not vary significantly or do not change with time. Examples are automatic factory and super market operations. Non-Stationary Systems are systems which operational activities and processes vary significantly or change with time. Examples are the human body system, research and development laboratory etc (Gagniuc, 2017).
7. Open and Closed systems – Open systems are systems that have continues interaction with things and object outside (environment) the system. These interactions with the outside causes exchange in information, material and energy. The existence of the system depends on the continuous interactions with the outside (environment). All living things are open system. Closed systems are systems that do not have any interaction with the outside (environment). It does not exchange any information, material or energy with its environment. Chemical reaction in a sealed and insulated container is an example of a closed system (Shadbolt *et al*., 2019).
8. Adaptive and Non-Adaptive Systems – Adaptive systems are systems that change due to the change that took place outside it. That is, it adapts to the changes that around it or in its environment. Most biological systems are adaptive systems. Non-Adaptive Systems are those systems that do not change because of any change that occur outside it or around its environment. These types of system degenerate eventually.

9. Social, People-Machine, and Machine Systems – Social systems are system that are only made of people. Business organizations and social clubs are examples of social systems. People-Machine Systems are systems that involve interaction between people and machines to achieve a particular goal. Information system is an example of people-machine system. Machine systems are systems that involve only machine to machine interaction to achieve a common goal (Shadbolt *et al*., 2019).

The system developed on this study can described as a closed super machine system. This is because the developed quality grading system consists of sub units that can be summed up into a super system. Also, there was no interaction (continuous exchange) between the system and its environment (energy, mass or people).

2.9 Research Gap

Literatures reviewed over the years on impurity removal from grains and seeds of crops in this study had shown some research gaps. Almost all the studies reviewed either used mechanical separation or automation technique but not both. Also, most developed agricultural grains and seed separation machines does not separate foreign bodies, broken seeds (grain) and diseases (damaged) seeds (grain) in one machine. Rather, these are achieved in separate machines or unit operation. Therefore, there is need to introduce a system thinking concept. In order to develop a machine system that will achieve the removal of all impurities in a batch of grain to export standard.

Also, a review on the status of cowpea seed utilization in Africa show a waste amounting to about 7.1 million tons due to poor processing, storage and marketing (IITA, 2019). No research had been tailored toward the utilization of these waste cowpea seeds toward exportation for African countries to earn foreign exchange.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sample

Cowpea (*Vigna unguiculata* (L.) Walp) seeds used for this study were of three varieties namely: NG/AD/11/08/0033 (Oloyin), NG/OA/11/08/063 (Niger white) and NGB/OG/0055 (Efe brown) (Plate 3.1). All the samples' seeds used to purchase bulk quantities were acquired at the National Center for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Nigeria (7°23′47″N 3°55′0″E). These variety were selected because according to NACGRAB report (2019), these were the most cultivated varieties in Nigeria.

3.2 Sample Preparation

Matured cowpea samples collected were divided into their respective varieties and their moisture content conditioned as described according to ASAE standard S352.2 (2017). The samples were conditioned to 8,10,12,14 and 16% db.

3.3 Determination of Optical and Electrical Properties

3.3.1 Optical properties

Colour properties were determined using Konica Minolta hunter Lab Chroma Meter (CR – 410). The L (L = Brightness; ranges from 0 which is black to 100 which is white), a (+ a (100) = red, - a (100) = green) and b (+ b (100) = yellow, - b (100) = blue), readings were read from the instrument. The absorbance and transmittance properties were determined using Unico 1100RS spectrophotometer. The reflectance properties were calculated using Equation 3. 2 derived from Equation 3.1 (Beer-Lambert Law).

$$A = \log(1/R) \tag{3.1}$$

$$R = 10^{-A} \tag{3.2}$$

Where, A is the Absorbance, R is the Reflectance. All optical properties were measured at five visible lights (UV) wavelength range of 320, 420, 520, 620 and 720nm.

(a) NG/OA/11/08/063 (Niger white)

(b) NGB/OG/0055 (Efe brown)

(c) NG/AD/11/08/0033 (Oloyin)

Plate 3.1: Pictures of samples of cowpea varieties

3.3.2 Electrical properties

Electrical properties were determined using the electrical set up arrangements shown in Figure 3.1. Their oscilloscope displays were shown in Appendix A, for Resistance (R), capacitance (C) and inductance (L) measurements. Conductance (G), Resistivity (ρ), Conductivity (σ), Impedance of the capacitor (Zc) or Capacitance Reactance (Xc)relative permissively (dielectric constant) (ε)was calculated using Equation 3.3 – 3.7.

$$G = 1/R \tag{3.3}$$

$$\rho = R\frac{A}{L} \tag{3.4}$$

$$\sigma = \frac{1}{\rho} \tag{3.5}$$

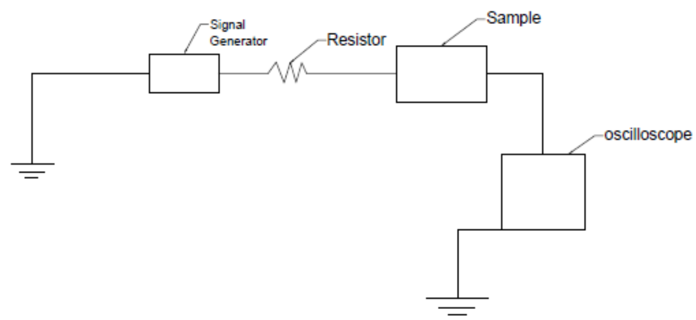
$$X_c = \frac{1}{2\pi fC} \tag{3.6}$$

$$\varepsilon' = \frac{C}{C_o} \tag{3.7}$$

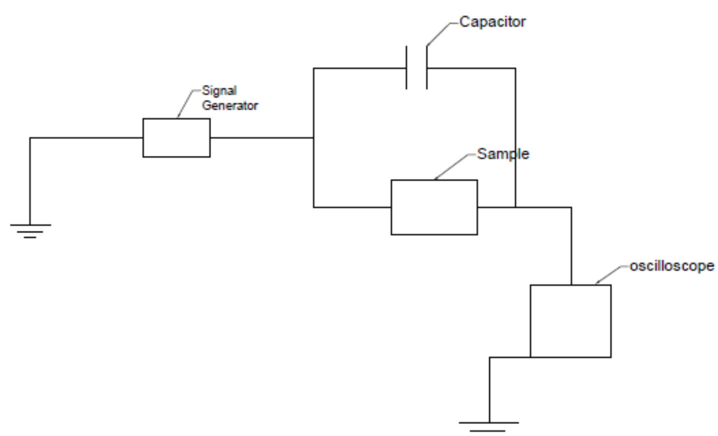
Where:

G = Conductance (S), R = Resistance (Ω), ρ = Resistivity (Ωm), A = Area (m^2), L = Length (m), σ = Conductivity (S/m), Xc = Capacitance reactance (Ω), f = frequency current (Hz), C = capacitance of sample (F), C_o = capacitance of empty capacitor (F). ε^1 = dielectric constant

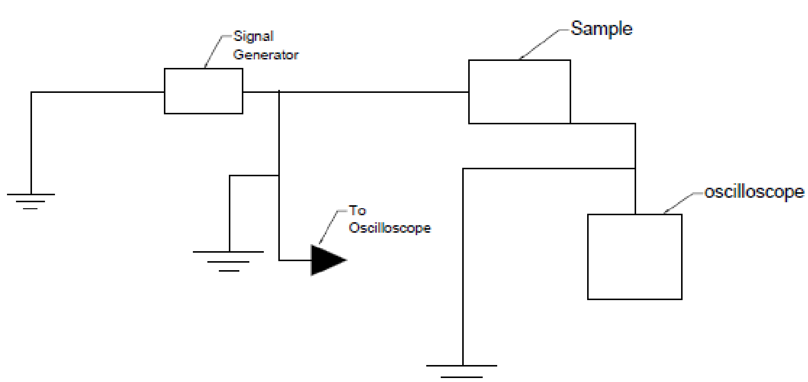
All electrical properties were measured on frequency ranges of 1, 500,1000,1500,2000 kHz.



(a) Set up arrangement for Capacitance determination



(b) Set up arrangement for Inductance determination and a picture of the sample holder



(c) Set up arrangement for Resistance determination

Figure 3.1: Electrical properties experimental set up arrangement

3.4 Modeling and Optimisation of Optical and Electrical properties

Modeling and optimisation of optical and electrical properties were done using Design Expert Software (version 10) produced by Stat Ease company, Minnesota, USA. A single factor response surface design was used to model and optimize the colour properties of cowpea. This experimental design was chosen because only on factor (moisture) inherits to the sample was varied during the colour experiment. Also, a 3-Factors, 5-levels (5^3) Central Composite Design (CCD) was used to optimize and model the absorbance, transmitance and reflectance properties of cowpea. This design was chosen because three factors (variety, sample moisture and light wavelenght) were varied. A 3-Factors, 5-levels (5^3) Central Composite Design (CCD) was used to optimized and model all electrical properties of cowpea.This experimental design was also chosen because three factors (variety, sample moisture and light wavelenght) was varied

3.5 Separating System Flow Design Chart

The operational design flow diagram (chart) of the separating system is illustrated in Figure 3.2. The seeds and its impurities are poured into the system through the hopper. From the hopper, it flows into the first separating unit. This first separating unit is made up of a 12 mm holes rotating drum sieve with a screw conveyor welded inside the drum. Stones and plant stalks (impurities greater than 12 mm) that do not pass through the rotating drum sieve are removed at this point, from the system by the screw conveyor. The screw conveyor carries the stones and stalks to the end of the rotating drum sieve into an exit outlet. The seeds and impurities, less than 12 mm passes through the rotating drum sieve and move into the second separating unit. The second separating unit is made up of a 2 mm holes rotating drum sieve with a screw conveyor welded inside. Sands, dust and smaller particles less than 2mm pass through the drum's sieves into the outlet duct and are removed from the system at this point. The screw conveyor carries the seeds and any other impurities that are of the same sizes with the seeds to the end of the drum, into the bucket conveyor hopper. The bucket conveyor transports seeds and its impurity into the hopper of the seed metering device. The seed metering device is made up of a hopper and a rotating

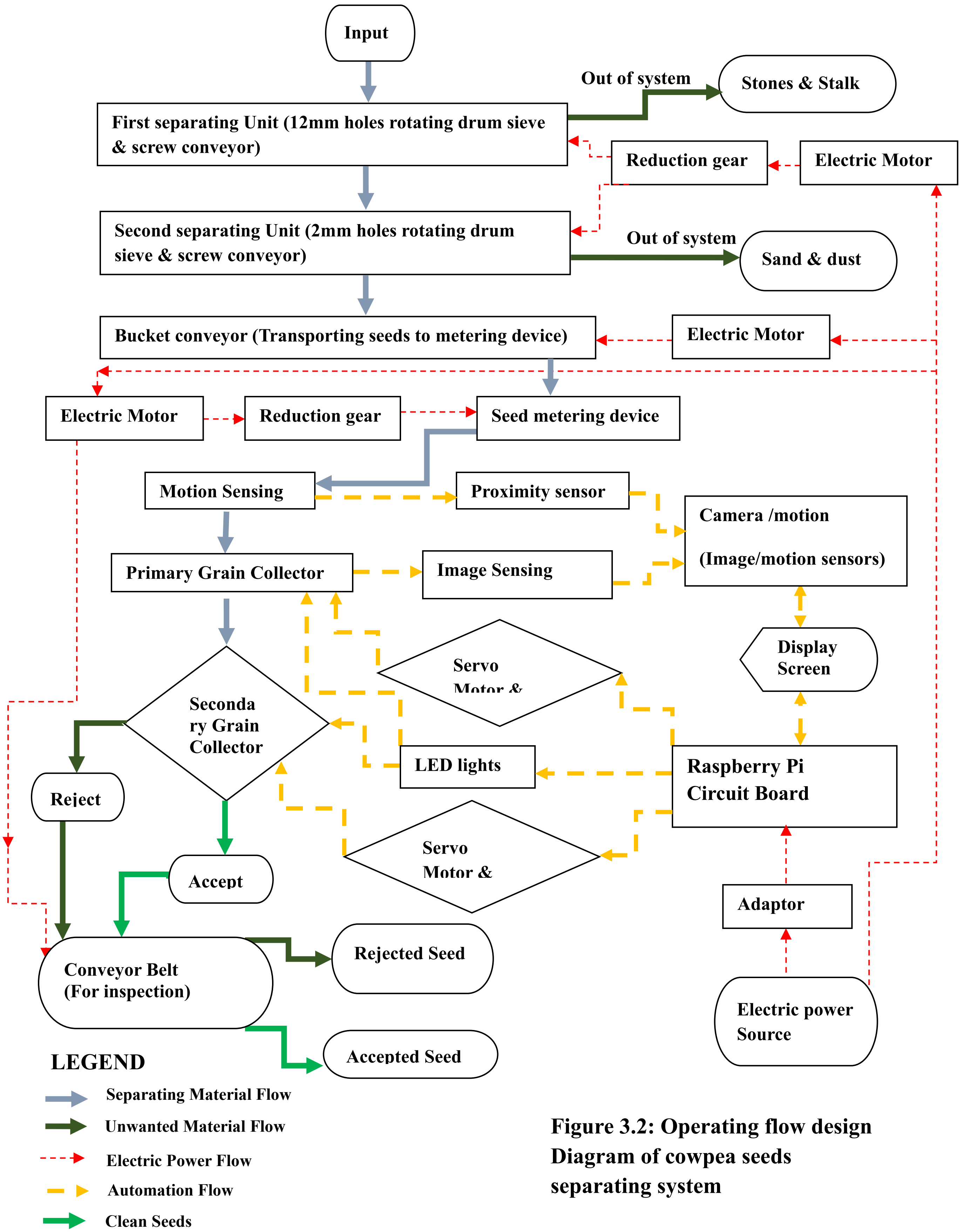


Figure 3.2: Operating flow design Diagram of cowpea seeds separating system

disc. In the seed metering device, a single seed is dropped into the automation unit after every five (5) seconds. In the automation unit, once the seed is dropped into the receiving tube, a motion sensor detects the presence of an incoming object. The sensor then sends the signal to the raspberry pi circuit board, to alert the pi camera to take the image of the approaching seed. When the seed reaches the primary (first) seed collector chamber, image of the seed is taken by the pi camera and sent to the raspberry pi circuit board. The raspberry pi circuit board analyses the image by comparing it with images of seeds stored in its memory. The raspberry pi circuit board now sends signal to the servo motor and flipper (actuator). The motor now controls the flipper to flip open and allow the seed to pass into the secondary seed collector. At the secondary (second) seed collector (chamber), the raspberry pi circuit board sends another signal to the second motor and flipper (actuator) attached to the secondary collector to flip either to the left or the right. This flipping depends on the decision of the raspberry pi circuit board to reject or accept the seed. This automated process takes place in five seconds. The accepted or rejected seed then drop on the conveyor belts for physical inspection before coming out of the collecting units at the end of the conveyor belt (outlets).

3.6 Design of the Separating System

3.6.1 Hopper

All flow properties of cowpea used in the design of system hopper were taken from literature. To design hopper for grain or seed flow, the type of flow within the hopper must first be determined (i.e., between mass flow and funnel flow). The choice of flow for the hopper was mass flow, because according to Schulze (2008), mass flow has the following good characteristics:

i. No seeds flow stagnation
ii. Uses full cross-section of vessel
iii. First-in, first-out flow
iv. Minimizes segregation, agglomeration of materials during discharge

Material selection for the design of the hopper was based on the bulk density of cowpea which ranges from 600 – 1000 kg/m^3 (Yalcin, 2007). Two metal sheets were first selected fit to withstand this weight based on their densities. These metal sheets were aluminum (with its alloy or types) with density range of 2643 – 2803 kg/m^3 and galvanized steel (with its alloy or types) with density range of 7207 – 7870 kg/m^3. Galvanized steel sheets were finally chosen due to its strength properties.

A wedge-shaped Symmetrical slot outlet was chosen as the shape of the hoppers in the system. This was because it is easier and cheaper to construct than conical hoppers. The following design calculations were done for the hopper.

Average angle of wall friction of cowpea on iron metal (δ_w) = 25^0 (Yalcin, 2007)

Average angle of internal friction of cowpea (δ) = 30^0 (Yalcin, 2007)

Semi-included angle (θ) = 27^0 (from chart, see Figure 3.3).

In practical design, the semi-included angle θ is reduced by 3^{0}as a margin of safety.

Therefore, the semi-included angle (θ) is now = 27 - 3 = 24^0.

Flow factor (ff) = 1.86 (taken from hopper design chart, see figure 3.3).

$$\text{minimum outlet diameter}(B) = \frac{(m+1)\sigma_{crit} \sin 2(\delta_w+\theta)}{\rho_{crit} g} \quad \text{(Chase, 2017)} \tag{3.8}$$

Where:

m = shape factor = 0 for wedge hopper, δ_w = wall friction = 25^0, θ = 24^0

σ_{crit} = critical comprehensive strength of the materials (bulk cowpea seeds)

Assuming uniform flow

$$\sigma_{crit} = \frac{\sigma}{\text{ff}} \ \text{kN/m}^2 \tag{3.9}$$

σ = comprehensive strength of the materials (cowpea)

= 7085KN/m^2, average value of cowpea (Faleye *et al.,* 2013).

Then

$\sigma_{crit} = \frac{7085}{1.86}$ = 3809 kN/m^2

ρ= maximum bulk density of cowpea (this was chosen for the hopper to withstand maximum bulk seeds strength). = 1000 kg/m^3

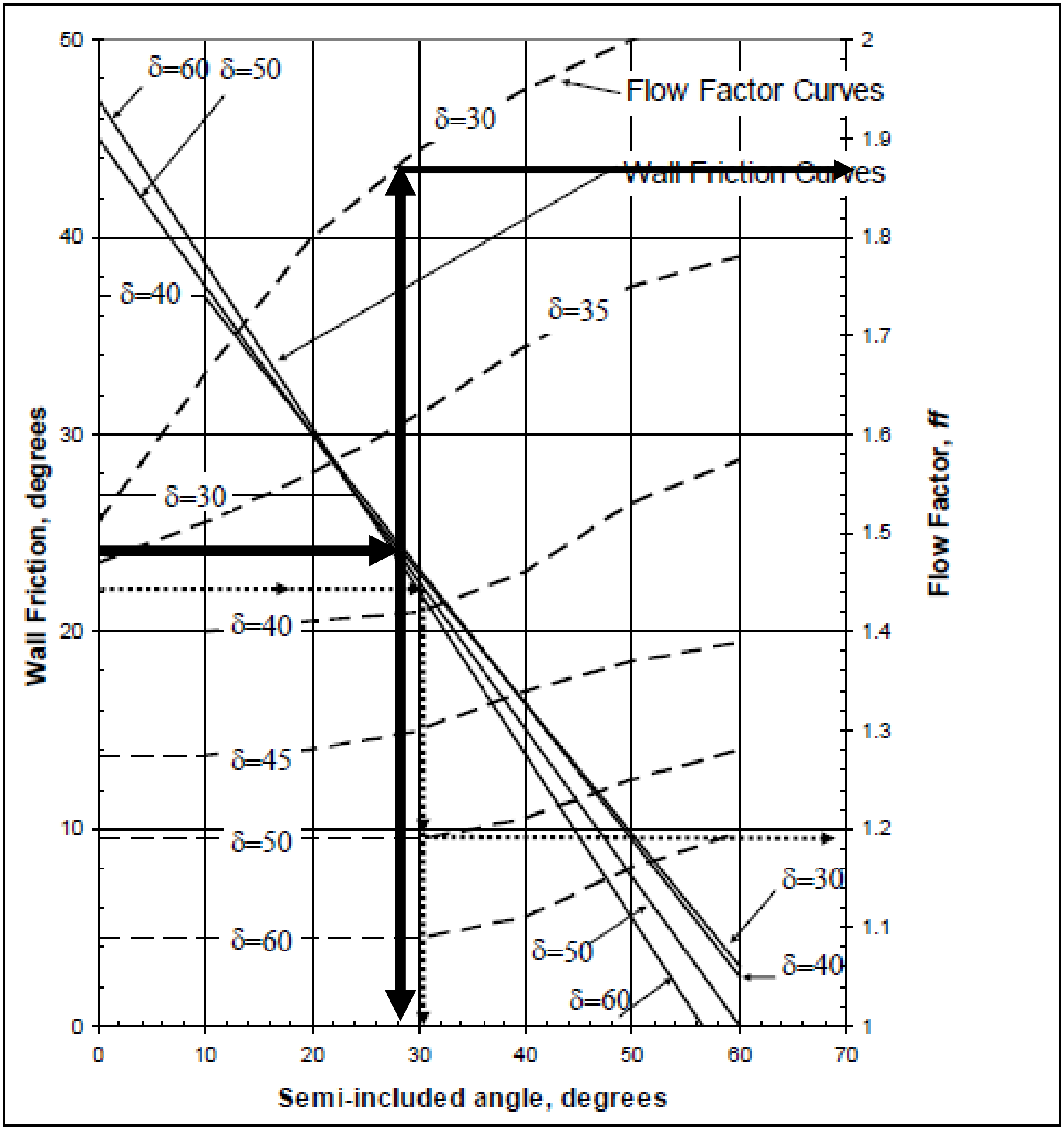


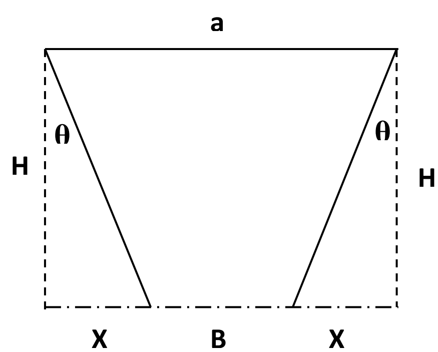
Figure 3.3: Design chart for symmetrical slot outlet hoppers (Chase, 2017)

g = acceleration due to gravity = 9.81m/s^2

$$B = \frac{3809\times2\sin(25+27)}{1000\times9.81} = \frac{3809\times2\sin(52)}{1000\times9.81} = \frac{3809\times2\times0.79}{1000\times9.81} = \frac{6018}{9810} = 0.6 \text{ m}$$

$$\text{Maximum discharge rate (kg/s)} = \sqrt{\frac{Bg}{2(1+m)\tan\theta}} \quad \text{(Mehos and Morgan, 2016)} \tag{3.10}$$

$$= \sqrt{\frac{0.6\times9.81}{2(1+0)\tan 24}} = 2.6 \text{ kg/s}$$



H = height of hopper = 1m (assumed)

θ = 24^0 (Semi-included angle)

x = fraction of the upper side length = 1 x tan24 = 0.45m

B = length of discharge opening = 0.6 m

a = total length of upper side of hopper = x + B + x = 0.45 + 0.6 + 0.45 = 1.5 m

For a square Pyramidal hopper, the volume was calculated using

$$V = \frac{1}{3}(a^2 + aB + B^2)H \quad \text{(Mehos and Morgan, 2016)} \tag{3.11}$$

$$= \frac{1}{3}(1.5^2 + 1.5\times0.6 + 0.6^2)1 = 1.2 \text{ m}^3$$

$$\text{capacity of hopper} = V\times\rho$$

Here assumes average bulk density value of cowpea was used.

Average bulk density (ρ) = 700 kg/m^3

$$\text{capacity of hopper} = 1.2 \times 700 = 840 \text{ kg}$$

Scaling the design down to 1: 4 in dimension

H = height of hopper = 1/4 = 0 .25 m= 250 mm

$\theta = 24^0$ (Semi-included angle)

x = frication of the upper side length = 0.45/4 = 0.1125 = 112.5 mm

B = length of discharge opening = 0.6/4 = 0.15 m =150 mm

a = total length of upper side of hopper = x + b + x = 112.5 + 150 + 112.5 = 375 mm

For a square Pyramidal hopper, the volume was calculated using the formula

$V = \frac{1}{3}(a^2 + ab + b^2)H = \frac{1}{3}(0.375^2 + 0.375x0.15 + 0.15^2)0.25 = 0.3m^3 = 300\ mm^3$

$$\text{capacity of hopper} = \text{volume} \times \text{bulkdensity} \tag{3.12}$$

= 0.3x 700 =210kg

The discharge rate = $\sqrt{\frac{0.3\times 9.81}{2(1+0)\tan 24}}$ = 1.8kg/s (from Equation 3.10)

The feeder head room was 40mm (selected due to the size of the outlet)

The angle of the feeder was 33^0 (maximum angle of wall friction of cowpea)

The length of the feeder was 400mm (this was to for the feeder outlet to move a bit away from the hopper width).

Engineering drawing for the hopper and feeder are shown in Figure 3.4.

3.6.2 Design of Rotating Mesh Drum Sieve

Assuming:

Weight of sieve mesh (G_1) = 5kg

Weight of rotating shaft and drum structure (G_2) = 7kg

Maximum weight of seeds (G_0) = 3kg (from the flow (discharge) rate of the hopper)

Total sieve drum weight (G) = 5+7+3 = 15kg

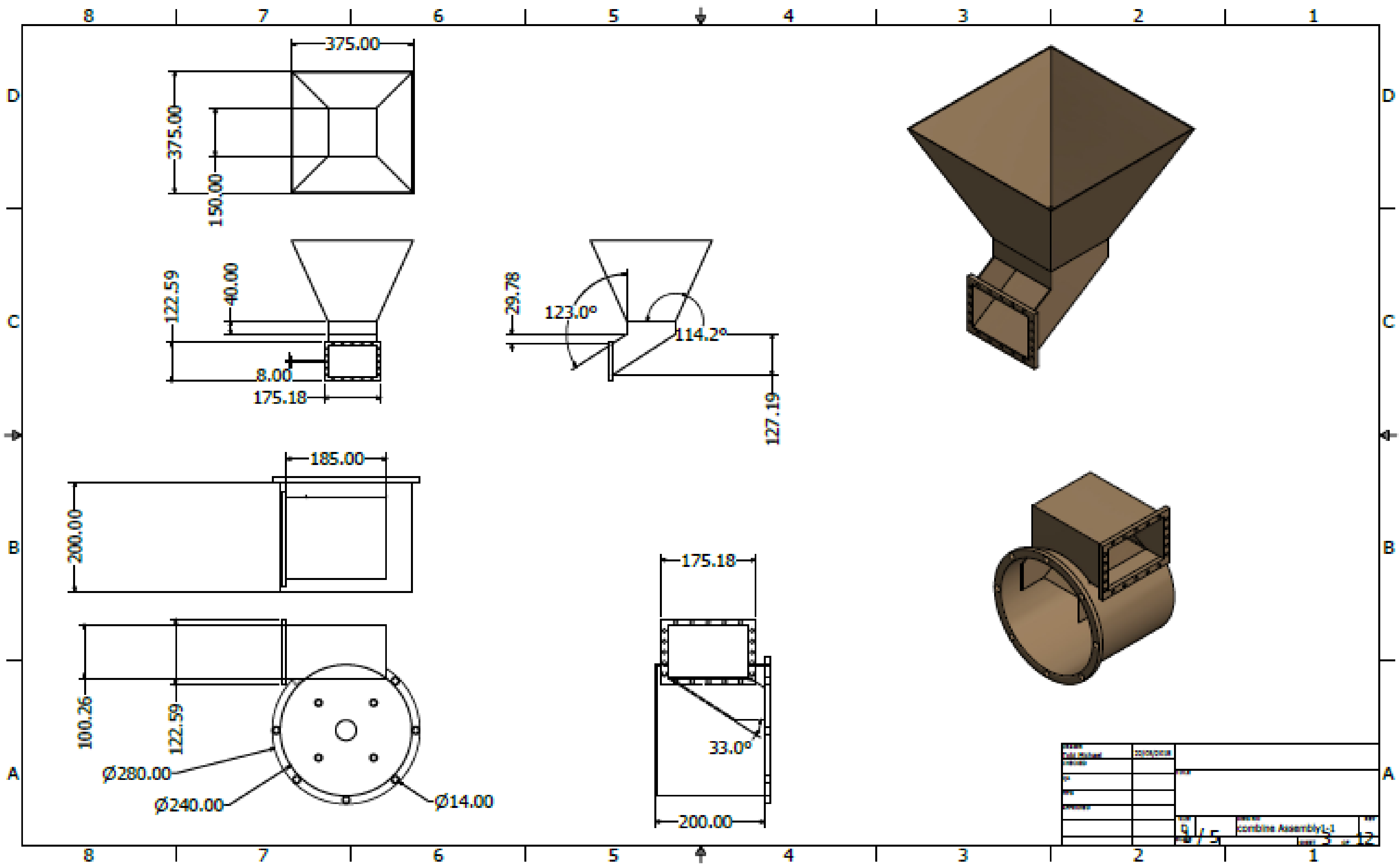


Figure 3.4: Design drawing for hopper and feeder

Given that:

Cowpea seed diameter (Equivalent diameter) range = 3 - 9 mm (Chukwu and Sunmonu, 2010; Boac *et al*., 2010)

Diameter of sieve drum (D) = 200 mm = 0.2 m (to allow the hopper feeder opening)

Radius of drum (R) = 100 mm = 0.1m.

Design calculation:

For rotation of the granular seed bed in the drum, the rotational velocity or critical velocity (η_{kr}) is given as

$$\eta_{kr} = \frac{30}{\pi}\sqrt{\frac{g}{R} - \frac{42.3}{\sqrt{D}}} \text{ rpm (Wodzinski, 2006)} \quad (3.13)$$

g = acceleration due to gravity = 9.81 m/s^2

R = Radius of drum = 0.1m

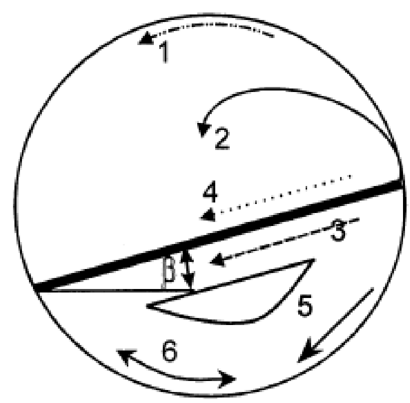
D = Diameter of sieve drum = 0.2 m

$$\eta_{kr} = \frac{30}{3.142}\sqrt{\frac{9.81}{0.1} - \frac{42.3}{\sqrt{0.2}}} = 19 \text{ rpm}$$

The operating speed (η_{rob}) of the sieve drum is

$$\eta_{rob} = \frac{12}{\sqrt{R}} \text{rpm (Wodzinski 2006)} \quad (3.14)$$

$$= 40 \text{ rpm}$$



For a rotary sieve drum, motion of seeds shown above are 1 – rotation, 2 – falling, 3 – sliding, 4 – rolling, 5 – slip and 6 – wavy. For good separation motion 2 is required and to achieve that Wodzinski 2006 recommend a velocity of 0.8 η_{kr} to 0.9 η_{kr}.

The travelling velocity (υ) of the seed bed is

$$\upsilon = 0.105R\eta_{kr}tg(2\alpha) \quad (3.15)$$

$$= 0.105 \times 0.1 \times 19 \times 1 \times 9.81(2 \times 0.47) = 1.8\ \text{m/s}$$

α = wall angle of friction = tan 25= 0.47

Assuming, t = tangential velocity of sieve cylinder = 1m/s

$$\text{Sieve drum screen capacity (Q)} = 0.72\mu\gamma\eta_{kr}tg(2\alpha)\sqrt{R^3xh^3}\ Mg/h \tag{3.16}$$

Loosen coefficient for grains (μ) = 1

Specific mass of grain (γ) =400mg (maximum seed range)

h (seed thickness in the sieve) = 2 x equivalent diameter of seeds = 2 x 9 =18mm = 0.018m

Sieve drum screen capacity (Q)

$$= 0.72 \times 1 \times 400 \times 19 \times 1 \times 9.81(2 \times 0.47)\sqrt{0.1^3 \times 0.018^3}$$

= 1513.8 Mg/h

Power (N) required to put the screen in rotary motion was

$$N = \frac{R\eta_{rob}(G + 13G_0)}{21500}\ \text{kN or HP} \tag{3.17}$$

G = Total drum weight =15 kg

G_0 = weight of seeds in the drum = 3 kg

(η_{rob}) = 40rpm

$N = \frac{0.1(15+13\times3)}{21500}$ = 0.00025 HP

Torque to rotate the drum (T) = 9.81 × G × R = 9.81 × 15 × 0.1 = 14.7 Nm

A square screen mesh was used. This is because the shape of the seeds.

The square screen size for drum 1 is 12 × 12 mm (allowable for seed) and that for drum 2 is 2 × 2 mm (lowest size to restrict the seeds from pass through the screen)

Length of the drum ranges from 2 to 6 times the diameter (www.kscst.iisc.ernet.in/spp/38_series/spp38s/synopsis.../193_38S0965.pd. Accessed on Sept. 1, 2018).

Length of drum (L) chosen was 3 times diameter = 3 × 0.2 = 0.6 m = 600 mm

Residence time (T_R) of seeds in drum is

$$\text{Residence time}(T_R) = \frac{L}{\upsilon} = \frac{0.6}{1.8} = 0.3 \text{ minutes}$$

Effective flow area (A_f),

$$A_f = \frac{\pi D^2}{4} = \frac{3.142 \times 0.2^2}{4} = 0.03142 \text{ m}^2.$$

Design drawings of components of the first and second separating units are shown in Figure 3.5 to 3.9.

3.6.3 Horizontal Screw Conveyor Design

Materials to be conveyed include:

i. Good seeds
ii. Broken seeds
iii. Damaged seeds (Diseased or insect infected)
iv. Plant parts (broken stack, leaves, pods and glumes)
v. Hard solid particles (stones, sands, clay, metal and glass)

Screw type

The standard pitch helicoids flight screw conveyor was chosen which has screw diameter equal to the pitch size. This was because according to Bega Helix (2018) it is recommended for general purpose granular conveying.

Screw shape

All screw conveyors for the separating system are flexible screw conveyors with long pitch. Shape of the first and second conveyor screw were flat wire flexible conveyor screw. The reasons for these selections are based on design requirement in Conveyor Screws-. Syntron Material Handling, 2019.Their screw flights were Helicoids. This was

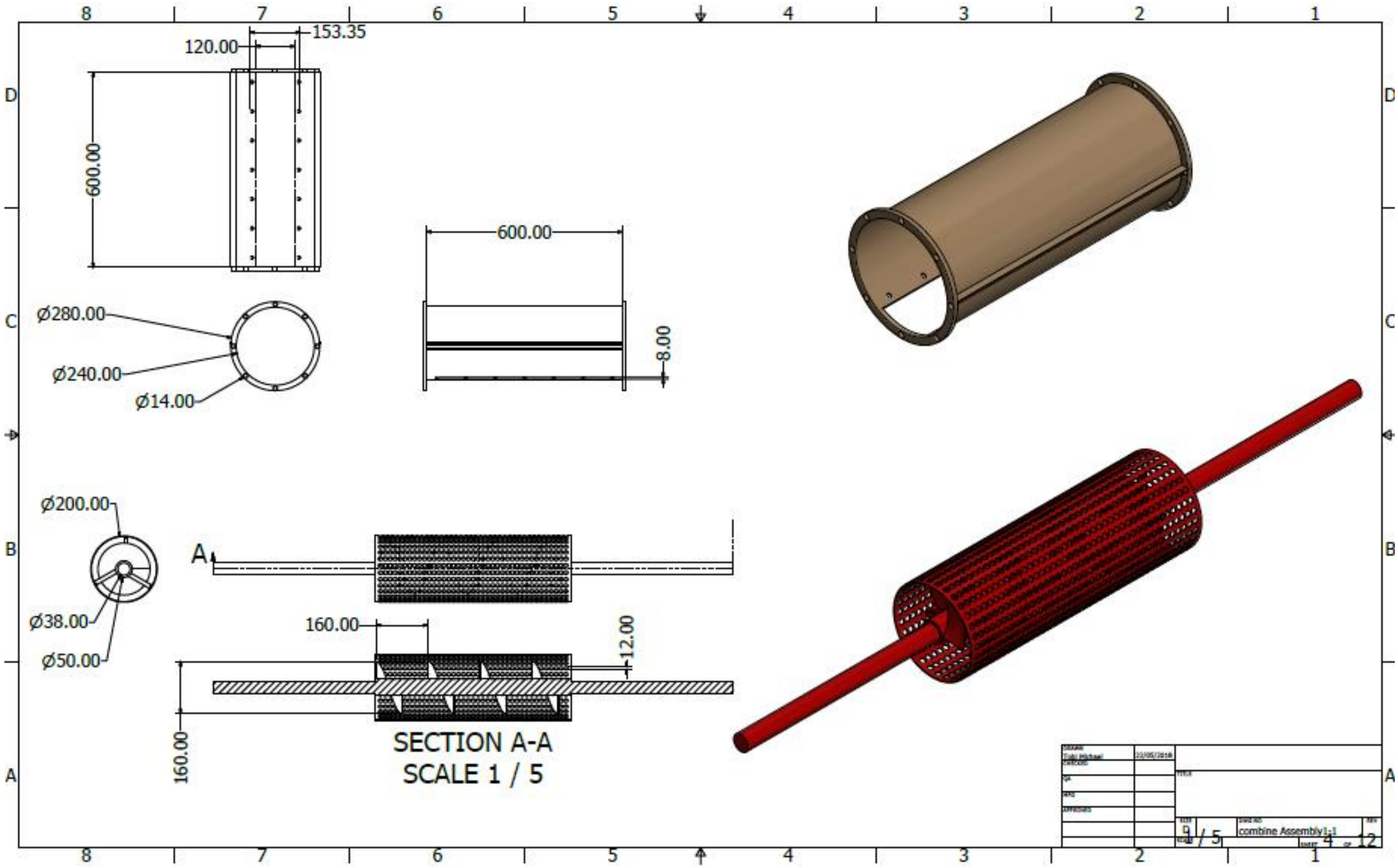


Figure 3.5: Design drawing for the first separating unit sieve drum and screw conveyor

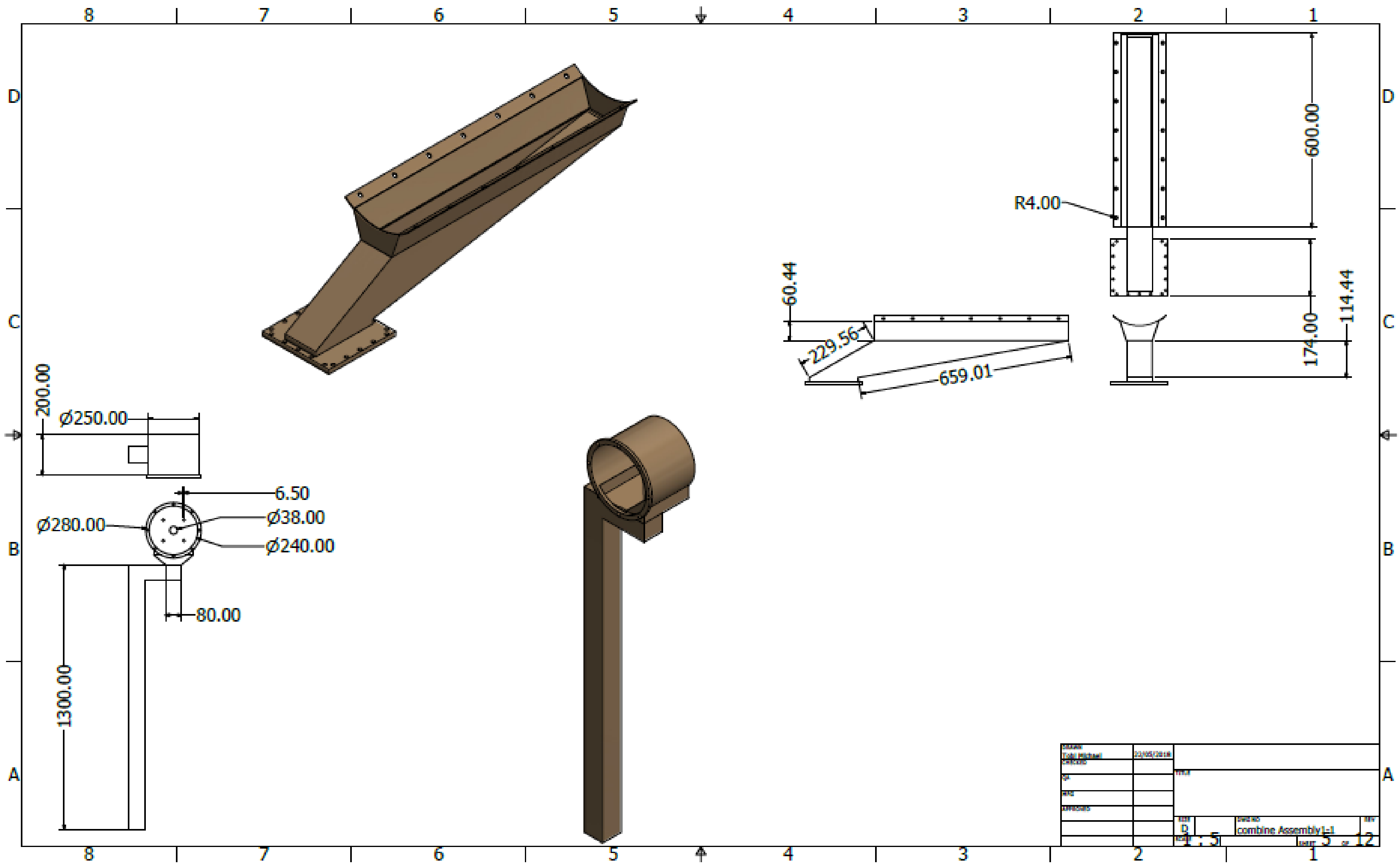


Figure 3.6: design drawing for the first separating unit outlets for seeds and stones

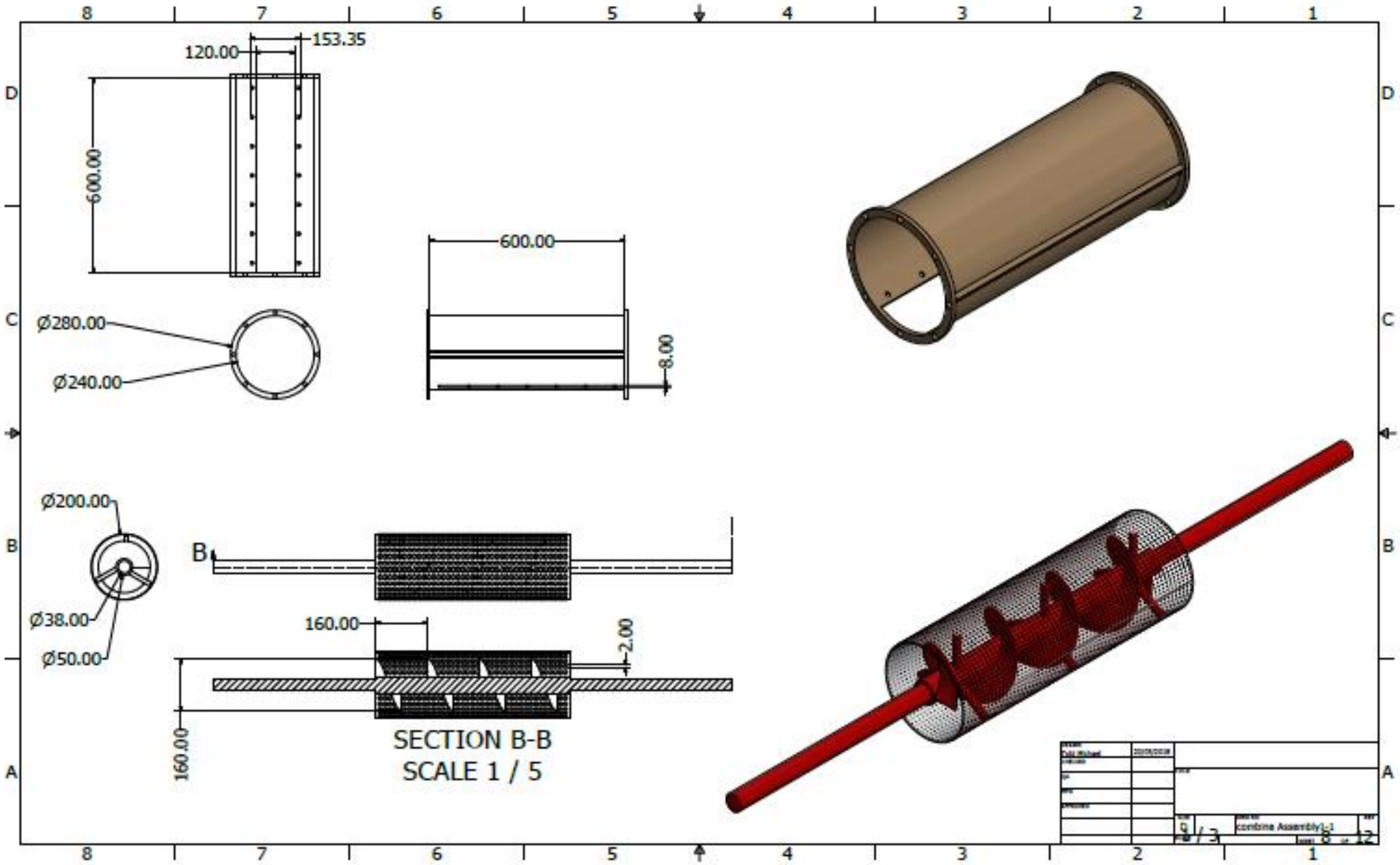


Figure 3.7: Design drawing of the second separating unit sieve drum and screw conveyor.

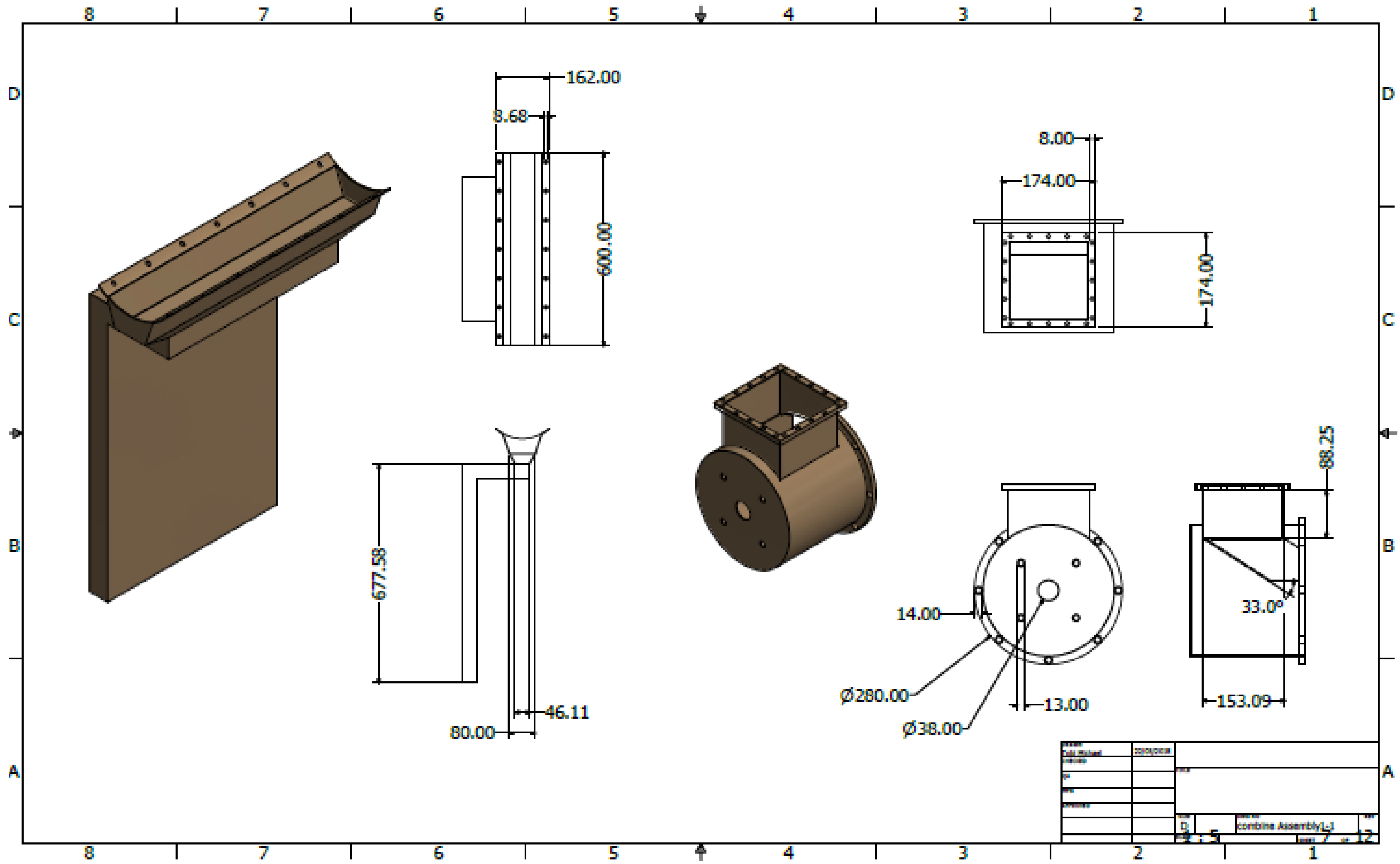


Figure 3.8: design drawing of second separating unit inlet and outlet for sand and dust

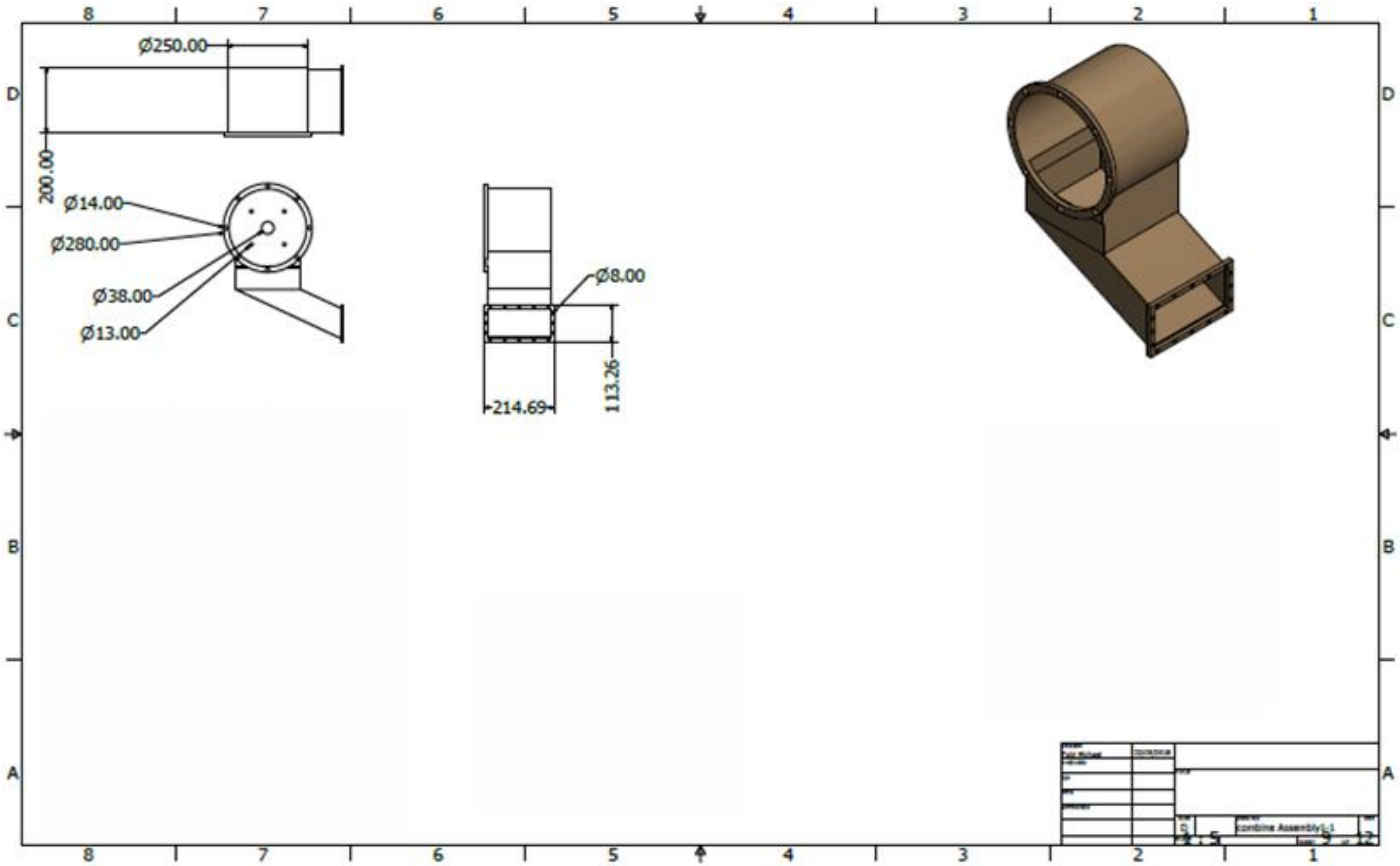


Figure 3.9: Design drawing of second separating unit seeds outlet to bucket conveyor hopper

selected because by virtue of its one-piece construction, it possesses superior strength than sectional flights. The absence of laps, rivets or welds on the carrying face of the Flight promotes and maintains cleanliness and reduces wear (Conveyor Screws-Syntron Material Handling, 2019).

Design calculation of screw conveyor

Using the labeling in Figure 3.10

Let

D = diameter of screw

P = pitch of flight (Screw)

d = diameter of screw shaft

C =radial clearance between screw and sieve drum

R_0 = outside radius of flight

Rc = radius of flight (Screw) shaft

t = Thickness flight (Screw)

Given:

Diameter of sieve drum = 200 mm (see sieve drum design)

Diameter of flight (screw) (D) = 160 mm or 6 inches (chosen to cover the diameter of the sieve)

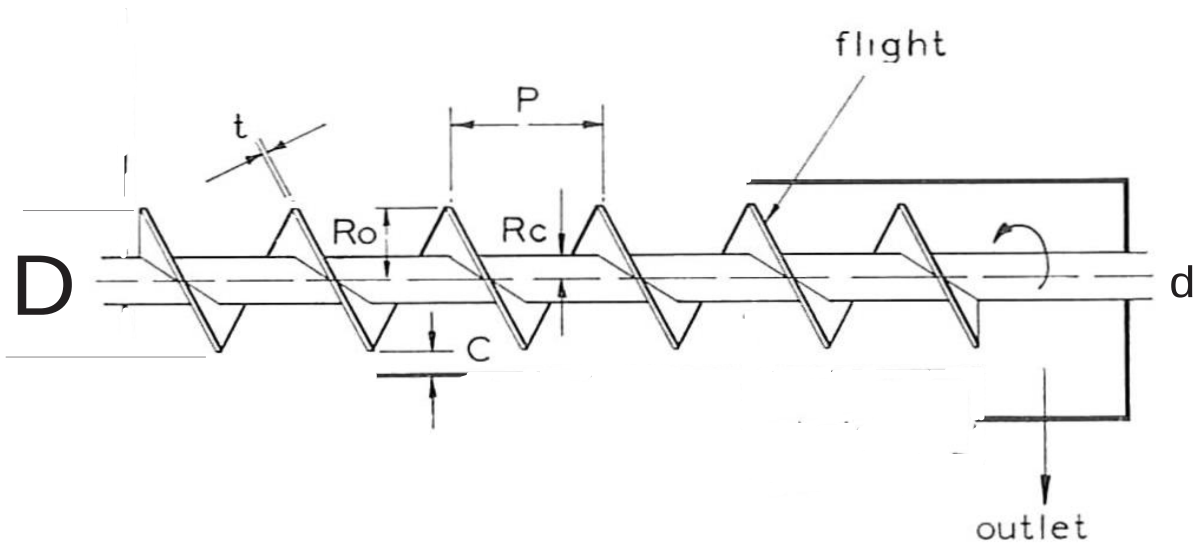
Radial clearance between screw and sieve drum (C) = 20 mm (assumed)

Length of the screw conveyor (L) = 600 mm (chosen to span across the entire sieve drum length)

Calculated or selected:

KWS design engineering manufacturing catalog #sc-1103 classified cowpea to have % loading (or trough loading) of 45%, with a horse power (HP) factor of 0.5.

From the capacities values displayed in table 3.10. For a 160 mm (approximately 6 inches) diameter screw of 45% loading,



LEGEND

D = diameter of screw

P = pitch of flight (Screw)

d = diameter of screw shaft

C =radial clearance between screw and sieve drum

R_0 = outside radius of flight

Rc = radius of flight (Screw) shaft

t = Thickness flight (Screw)

Figure 3.10: Screw conveyor Design Labeling

The maximum revolution is 182 rpm (figure 3.11).

At maximum revolution the capacity of the screw conveyor (CFH) is 413 ft^3 /h (11.69 m^3/h).

At 1rpm the capacity is 2.27 ft^3 /h (0.06 m^3/h).

The maximum lump size that a 160 mm (6 inches) diameter screw can carry is ¾ inches (19.05 mm).

According to KWS design engineering manufacturing catalog #sc-1103

$$\text{Conveyor speed (CS)} = \frac{\text{(CFH) at maximum rpm}}{\text{(CFH) at 1 rpm}} \tag{3.18}$$

Where, CHF is the capacity in cubic feet per hour

$$\text{CS} = \frac{413}{2.27}$$

Conveyor speed = 181.94 rpm

The screw rotation was right hand screw clockwise rotation (A right hand screw push the material away from the point of rotating if the rotation is clockwise). This was chosen because the outlets of the screws are place far from the drive.

Screw conveyor design information for both helicoids and sectional flight (screw) was provided by KWS Design Engineering manufacturing catalog #sc-1103.

For a 6 inches (160 mm) diameter screw conveyor

Nominal pipe size (Outer shaft diameter) (d) = 2 inches (51 mm)

Coupling diameter (Inside shaft diameter) (d_0) =1½ inches (38 mm)

Flight (Screw) root thickness $t_R = \frac{3}{8}$ inches (10 mm)

Flight (Screw) tip thickness $t_T = \frac{3}{16}$ inches (5 mm)

Length of inside shaft diameter = 1600 mm (to accommodate the inlet and outlet chambers)

Total shaft horse power (TSHP) = Friction horse power (FHP) (H.P. required to drive the conveyor empty) + material horse power (MHP) (H.P required to move the material)

$$\text{TSHP} = \text{FHP} + \text{MHP} \tag{3.19}$$

CAPACITY TABLE

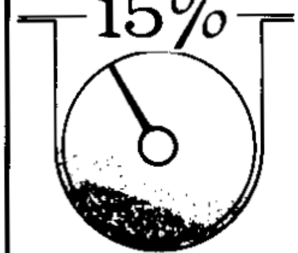
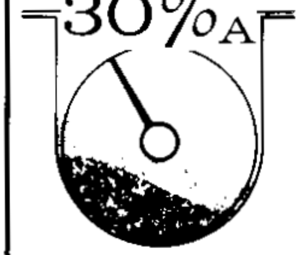
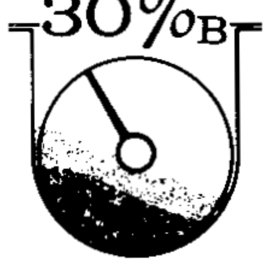
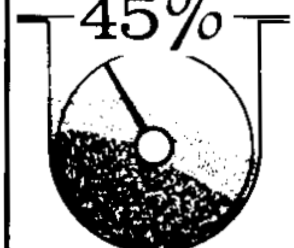
Trough Loading	Screw Dia.	Max. Lump Size (In.)	Max. RPM	Capacity in Cu. Ft. Per Hr. At Max. RPM	Capacity in Cu. Ft. Per Hr. At 1 RPM
15% 	4	1/2	69	14.5	.21
	6	3/4	66	49.5	.75
	9	1-1/2	62	173	2.8
	10	1–3/4	60	222	3.7
	12	2	58	389	6.7
	14	2-1/2	56	588	10.5
	16	3	53	832	15.7
	18	3-1/4	50	1,135	22.7
	20	3-1/2	47	1,462	31.1
	24	4	42	2,293	54.6
30%A 	4	1/2	139	57	.41
	6	3/4	132	198	1.5
	9	1-1/2	122	683	5.6
	10	1-3/4	118	849	7.2
	12	2	111	1,476	13.3
	14	2-1/2	104	2,194	21.1
	16	3	97	3,046	31.4
	18	3-1/4	90	4,086	45.4
	20	3-1/2	82	5,092	62.1
	24	4	68	7,426	109.2
30%B 	4	1/2	69	28	.41
	6	3/4	66	99	1.5
	9	1-1/2	62	347	5.6
	10	1-3/4	60	432	7.2
	12	2	58	771	13.3
	14	2-1/2	56	1,182	21.1
	16	3	53	1,664	31.4
	18	3-1/4	50	2,270	45.4
	20	3-1/2	47	2,919	62.1
	24	4	42	4,586	109.2
45% 	4	1/2	190	116	.61
	6	3/4	182	413	2.27
	9	1-1/2	170	1,360	8.0
	10	1-3/4	165	1,782	10.8
	12	2	157	3,030	19.3
	14	2-1/2	148	4,558	30.8
	16	3	140	6,524	46.6
	18	3-1/4	131	8,659	66.1
	20	3-1/2	122	11,590	95.0
	24	4	105	17,535	167.0

Figure 3.11: Capacity table for designing screw conveyor

Source: KWS Design Engineering manufacturing catalog #sc-1103

Screw conveyor horse power calculation

If the MHP is less than 5 it should be corrected for overload. This correction is done using material overload correction chart provided by KWS Design Engineering manufacturing catalog #sc-1103.

$$FHP = \frac{CDF \times HPF \times L \times S}{1{,}000{,}000} \tag{3.20}$$

CDF = Conveyor diameter factor = 18

HBF = hanger bearing factor = 1

L = Length of conveyor in ft = 600 mm =1.969 ft

S = speed of conveyor in Rpm = 181.94

$$FHP = \frac{18 \text{ x } 1 \times 1.969 \times 181.94}{1000000} = \frac{6448.31748}{1000000} = 0.0064482 \text{ HP}$$

$$MHP = \frac{CHF \times W \times MF \times L}{1{,}000{,}000} \text{ or } \frac{CP \times MF \times L}{1{,}000{,}000} \tag{3.21}$$

CHF = conveyor capacity in ton/hr

W = weight per cu. ft.

MF = Material H.P factor (from material table in KWS design engineering manufacturing catalog #sc-1103for sorghum and beans) = 0.5

L = Conveyor length in ft = 1.969 ft

CP = Capacity in lbs per hr. = 413 cu. ft/h = 25,782.748 m^3/h

$$MHP = \frac{25{,}782.748 \text{ x } 0.5 \text{ x } 1.969}{1{,}000{,}000} = \frac{25{,}383.115}{1{,}000{,}000} = 0.0254 \text{ HP}$$

Now 0.0254HP is less than 5HP, so it needs to be corrected for potential overload. This correction was done by using the material correction chart in KWS Design Engineering manufacturing catalog #sc-1103. Since all values on the upper scale of the chart is greater than 0.0254HP the first corresponding material factor on the lower scale was adopted, which was 0.2 HP

So therefore, corrected material horse power (MHP) = 0.2HP

Total Shaft Horse Power(TSHP) = 0.0064482 + 0.2 = 0.206HP

Design drawings of the screw conveyors for the first and second separating units are shown in Figure 3.5 and 3.7.

3.6.4 Inlet Chambers for first and second separating unit

Material inlet dimension = 150 mm × 150 mm (same as hopper outlet dimension)

Inlet sliding angle = 33^0 (same as hopper)

Length of inlet chamber = 200 mm (assumed)

Diameter of the inlet chamber = 240 mm (same as the drum frame)

Design drawings of outlets are shown in Figure 3.8.

3.6.5 Drum Frames for first and second separating unit

Diameter of drum frame = 240 mm (to allow just enough space between the sieve and the frame)

Length of drum frame = 600 mm = 0.6 m (same as sieve length)

Design drawings of the two drum frames are shown in Figure 3.5 and 3.7

3.6.6 Seeds Discharger for first separating units

Length of seed discharger = 600 mm (to allow all grains from the sieve out of that unit)

Width of seed discharger = 120 mm (assumed)

3.6.7 Impurity Outlet Chambers for First separating unit

Diameter of the outlet chamber = 240 mm (same as the drum frame)

Length of inlet chamber = 200 mm (assumed)

Outlet dimension = 200 × 200 (considering maximum lump size (160mm) allowed by the design)

Outlets design drawings are shown in Figure 3.6.

3.6.8 Bearing

Plate seal bearing was chosen to achieve maximum sealing of both inlet and outlet chambers.

Plate seal was design base on design information provided by KWS design engineering manufacturing catalog #sc-1103

Bearing inlet diameter = 38mm (to fit in the inside shaft diameter)

$$\text{Seal plate thickness} = \frac{5}{8} \text{ inche} = 16 \text{ mm}$$

$$\text{Seal plate dimension} = 5\frac{3}{8} \text{ inches} \times 5\frac{3}{8} \text{ inches} = 136.5 \text{ mm} \times 136 \text{ mm}$$

Distance between bolts on seal plate:

$$\text{Minimum distance} = 4 \text{ inches} = 101.6 \text{ mm}$$

$$\text{Maximum distance} = 4\frac{1}{8} \text{ inches} = 104.8 \text{ mm}$$

$$\text{Bolt size} = \frac{1}{2} \text{ inches} = 12.7 \text{ mm}$$

3.6.9 Smaller Particle collector from the second separating unit

Length of seed discharger = 600mm (to allow all small object and broken seeds from the sieve out of that unit) (see Figure 3.8)

Width of seed discharger = 162mm (assumed)

3.6.10 Bucket Conveyor Design

Convey material design parameters include:

- Service use – To lift cowpea seeds and some impurities into metering hopper
- Material name - Cowpea seeds and some impurities
- Bulk density - 600 – 1000 kg/m^3
- Maximum lump size – 12 mm
- Minimum lump size – 6 mm
- Height product is to be raised (meters) – 1.6m
- Abrasiveness - nil
- Flowability - Cohesive

- Dampness (% moisture) - 8 – 22%
- Friability - Firms and breaks
- Particle shape - Non consistent
- Temperature of product – 30º
- Angle of repose – 20 – 40º
- Corrosiveness – Moist or Dry
- Service required – Intermittent; up to 12 hours per day 6 days a week
- Boot design – Closed boot

Design calculation Parameters:

Height of lift (h) = 1.6 m = 1600 mm

Feeding = Bottom feeding

Bucket volume = 2500 cm^3 = 0.0025 m^3 = 2500000 cm^3 (Assumed)

Distance between bucket (n) = 160 cm = 1.6 m = 1600 mm

Head pulley diameter (d) = 20 cm = 0.2 m = 200 mm

Head pulley radius (r) = 10 cm = 0.1 m

Emptying angle of repose (ϕ) for various grains averages is 28.4° (Handling Agricultural Materials handbook, 1989)

Maximum bulk density for cowpea (ρ) =1000 kg/m^3

Usable bucket capacity (C_v) = The usable bucket capacity is three-quarters of the gross capacity. i.e 75% of the bucket volume = 0.75 × 0.0025 = 0.001875m^3

The loading factor (K_1) = When material is being fed on the up side of the elevator, K_1 = 1.2. When loading on the down side of the elevator, K_1 = 1.5.

Gravitational constant (g) = 9.81 m/s^2

e = Drive efficiency factor, as specified by the manufacturer = 0.75, if manufacturers' specification not available

Design calculations for bucket convey are:

Operational speed is designed as follow

Pulley Head Speed (S_p)

According to the Goodyear theory of centrifugal discharge, the optimum head pulley rotational speed can be calculated using the following formula (Handling Agricultural Materials handbook,1989 and Aoulmi *el al.,* 2019):

$$S_p = \frac{30}{\sqrt{r\tan(60-\phi)}}$$

(3.22)

Handling Agricultural Materials handbook (1989) states that the emptying angle of repose (ϕ) for various grains averages 28.4°. Using this value, the formula becomes:

$$S_p = \frac{38}{\sqrt{r}}$$

(3.23)

$S_p = \frac{38}{\sqrt{0.1}} = \frac{38}{0.3162}$ = 120 rev/min

According to Handling Agricultural Materials handbook (1989), bucket shape affects the optimum head speed, so use the calculated value as a guide only. Actual operating speeds can vary 20% from the calculated optimum. 20% of 120rev/min variation is 144 rev/min.

Belt Velocity (B_v) is design as follow:

$$B_v = \frac{\pi d S_p}{60}$$

(3.24)

$B_v = \frac{3.142 \text{ x } 2 \text{ x } 120}{60} = \frac{754.08}{60}$ =12.6 m/s

Bucket elevator capacity (Cp)

$$C_p = \frac{C_v \rho B_v}{n}$$

(3.25)

$C_p = \frac{0.001875 \text{ x } 1000 \text{ x} 12.6}{2} = \frac{23.625}{2}$ = 11kg/s

Power requirements:

Power requires to drive bucket conveyor (P_b)

$$P_b = \frac{K_1 \text{ x} C_V \text{x} g \text{x } h}{1000}$$

(3.26)

When material is being fed on the up side of the elevator, K_1 = 1.2. When loading on the down side of the elevator, K_1 = 1.5

$$P_b = \frac{1.5 \text{ x } 11 \text{ x } 9.81 \text{ x } 1.6}{1000} = \frac{258.984}{1000} = 0.258984 \text{ Kw}$$

Motor power required (P_m)

$$P_m = \frac{P_b}{e}$$

(3.27)

$P_m = \frac{0.26}{0.75}$ = 0.34Kw = 0.46Hp

e = Drive efficiency factor, as specified by the manufacturer = 0.75, if manufacturers' specification not available.

Figure 3.12 shows the design drawing and picture of the bucket conveyor.

3.6.11 Design of Seed Metering Device

Required design information include following:

Type of seed to be metered = Cowpea

Maximum length of seed (mm) = 10mm (Henshaw, 2008)

Maximum width of seed (mm) = 7mm (Henshaw, 2008)

Maximum thickness of seed (mm) = 6mm (Henshaw, 2008)

Maximum Geometric mean diameter of seed (mm) = 8 mm (Kabas *et al*., 2007)

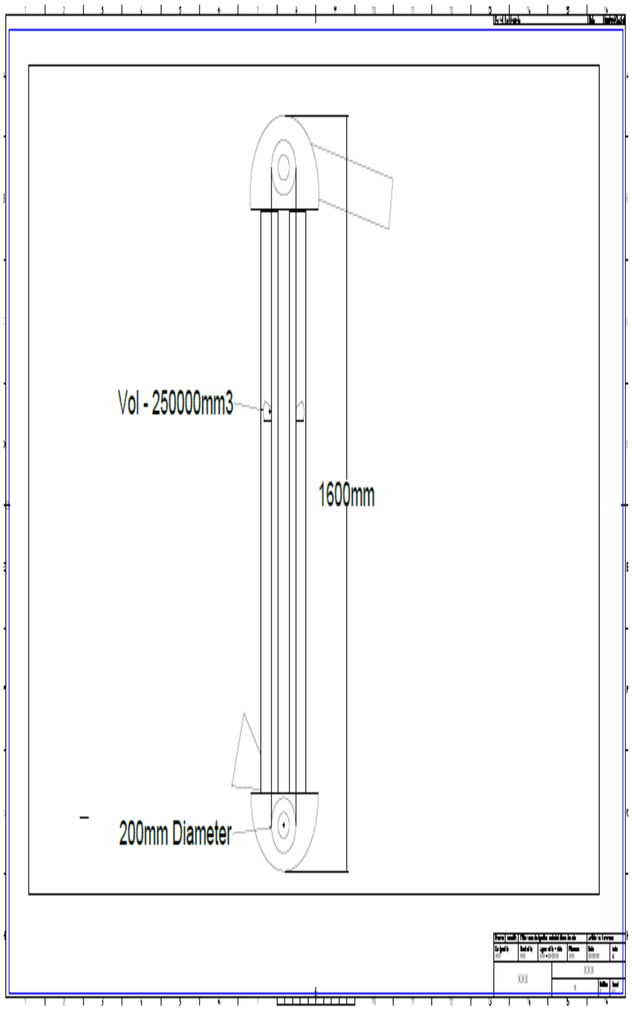


Figure 3.12: Design drawing and Picture of the constructed of Bucket Convey

True density of seed (kg) =1154.8 kg m^{-3} (Yalcin, 2007)

Metering hopper capacity = 11k g/s (same as the bucket conveyor)

Maximum Sphericity = 0.799 or 79.9% (Yalcin, 2007)

Bulk density of seeds (kg) =569.9 kg m^{-3} (Yalcin, 2007)

Minimum outlet diameter (B) = 10 cm

Design calculations for metering device are as follow:

Motor speed = (S_1) = 1450 rev/min (Assumed)

Motor pulley diameter = (d_1) = 80 mm (Assumed)

Reduction gear intake pulley diameter = (d_2) =170mm (Assumed)

From pulley speed ratio speed formula (O'Keefe, 2017)

Speed of reduction gear intake pulley = (S_2) was

$S_2 = \frac{S_1 \times d_1}{d_2} = \frac{1450 \times 80}{170} = 682$ rev/min

Reduction gear speed reduction ratio = 1:80

Speed from reduction gear pulley output pulley = (S_3) = $\frac{682}{80} = 8.5$ rev/min

Diameter of reduction gear output pulley = (d_3) = 250 mm

Metering disc shaft pulley diameter = (d_4) = 50 mm

Again, from pulley speed ratio speed formula (O'Keefe, 2017)

Speed of metering disc shaft pulley = (S_4) = $\frac{S_3 \times d_3}{d_4} = \frac{8.5 \times 250}{50} = 42.5$ rev/min.

Diameter of metering disc (plate) = (d_5) = 140mm (Assumed)

From pulley speed ratio speed formula (O'Keefe, 2017)

Speed transmission ratio between metering disc shaft pulley and metering disc = (i)

$$i = \frac{d_4}{d_5} = \frac{50}{140} = 1:2.8 = 0.36$$

Speed of metering disc (S_5) = $S_4 \times i = 42.5 \times 0.36 = 15.3$ rev/min

Number of holes (cells) on the metering disc (plate) = N

$$N = \frac{\pi d_4}{i \times k} \text{(Sharma and Mukesh, 2010)}$$

$$\mathrm{N} = \frac{3.142 \times 50}{0.36 \times 96} = \frac{157.1}{34.56} = 4.5 \cong 4 \text{ holes (cells)}$$

K = spacing between holes (cells) on the disc (plate) = 96 mm (Assumed)

Metering disc made from wood to avoiding rusting if made from iron plate.

Assuming the metering holes (cells) on the disc (plate) is half ellipsoid in shape.

$$\text{The volume of one hole (cell)} = \mathrm{V_c} = \frac{2}{3}\pi \times \mathrm{L_1} \times \mathrm{L_2} \times \mathrm{L_3}$$

L_1 = radius of major axis of the ellipse = 15 mm (Maximum length of single cowpea seed)

L_2 = radius of minor axis of the ellipse =13 mm (maximum breath of single cowpea seed)

L_3 = width of the ellipse = 10 cm (maximum width of single cowpea seed)

$$\mathrm{V_c} = 0.66 \times 3.142 \times 15 \times 13 \times 10 = 4043.754 \text{ mm}^3 = 4.044^{-6}\text{m}^3$$

According to Srivastava *et al*. (2006), volumetric flow rate of a single seed metering device = Q_R

$$\mathrm{Q_R} = \frac{\mathrm{V_c} \times \mathrm{N} \times \mathrm{S_5}}{60 \times 10^6} = \frac{0.000004044 \times 4 \times 15.3}{60 \times 1000000} = \frac{0.000247492}{60000000} = 4.125^{-12} \text{ L/s}$$

Metering hopper capacity = 11kg/s (same as the bucket conveyor)

Minimum outlet diameter (B) = 10 cm

Selected to cover one seed hole on the metering disc to pick a seed at a time

Upper length of metering hopper = 340 mm

Selected to accommodate the discharged capacity of the bucket conveyor

Upper width of metering hopper = 210 mm

Selected to accommodate the discharged capacity of the bucket conveyor

Lower length of metering hopper = 100 mm

Selected to accommodate the discharged of single seed

Lower width of metering hopper = 60 mm

Selected to accommodate the discharged of single seed

Height of metering hopper = 160 mm

Selected to accommodate the discharged capacity of the bucket conveyor

Height of metering hopper feeder = 40 mm

Diameter of metering disc housing = 150 mm

Selected to discharge a single seed after 5seconds, based on the automation section programming

The metering disc is made of wood, with four holes drilled on the surface.

Diameter for seed metering disc = 120 mm

Width of metering disc = 50 mm

To suit the width of the lower hopper width

Height of metering discharge outlet = 40 mm (assumed)

Metering shaft pulley = 50mm

Selected to reduce the speed coming reduction gear further

Metering shaft diameter = 20 mm

Length of metering shaft = 71 mm

Design selections of metering Stand are:

Metering stand length = 370 mm (to accommodate the metering disc)

Metering stand width = 260 mm (to accommodate the belt convey width)

Metering stand height =920 mm (to accommodate the automation pipe)

3.6.12 Design of Conveyor Belt

A flat belt conveyor type was chosen to enable sorted products to spread across the belt for inspection operation.

Belt carcass and cover

Belt type described by Fenner Dunlop (2009) of carcass type of PN (polyester and Nylon) plain weave (DIN code EP) with strength range of 315 – 2000 kN/m (150 – 400 kN/m/ply) was chosen. It is an excellent general purpose fabric belt, of low elongation with very good impact resistance and good fastener holding. Natural rubber was selected for both top and bottom cover. This is because it has a good weathering, tear and abrasive resistance with and service temperature of 30 – 70^0 (Fenner Dunlop, 2009).

Conveyor Belt design details are:
Assuming:

Bulk density of material to carried by the belt = 1000 kg/m^3 (maximum bulk density for cowpea).

Conveyor Belt width (b_o) = 250 mm (more than the discharge hopper hole length)

Belt thickness (carcass + cover) = 5 mm (Recommended by Dunlop 2016)

Belt length = 1300 mm

Tensile strength = 2000 kN/m (Recommended by Fenner Dunlop 2009 for grains and seeds)

Numbers of piles = 2

Conveyor height = 300 mm (assumed)

According to Fenner Dunlop (2009) recommended belt speed for a 400mm width belt for general purpose belt was 2m/s. It also recommended that for non-abrasive material for belt feeder from hopper, the speed should not exceed 0.5m/s. Therefore,

Assuming that a 250 mm width belt should run at a speed of 1m/s

Belt speed = 1m/s

Capacity (m^3/h) = material cross sectional area (m^2) × speed of belt (m/s) x 3.6. (Boumans, 1985)

Material cross sectional area (m^2) = B × h_g = 147mm × 12mm =0.147m x 0.012m = 0.001764m^2

Cross sectional area of material assumed to be the same, as the cross-sectional area of hopper opening.

Capacity (m^3/h) = 0.001764 × 1 × 3.6 = 0.00635 m^3/h

Capacity (t/h) = material cross-sectional area (m^2) × speed (m/s) × 3.6 × bulk density (Kg/m^3)

Capacity (t/h) = 0.00635 x 1000 = 6.35 t/h

For a feeder belt under a hopper (Fenner Dunlop, 2009)

Mass of material on belt (kg) = M_m

$$M_m = 2 \times (\text{hopper opening width (m)})^2 \times \text{Hopper openig lenght (m)} \times \text{material bulk density (kg/m}^3\text{)} \quad (3.28)$$

$$\text{Mass of material on belt} = 2 \times (B_0)^2 \times B \times \rho = 2(0.012)^2 \times 0.147 \times 1000 = 0.0423\ \text{kg}$$

Effective belt tension (kN) = T_e

$$T_e = \text{overall friction coeficient} \times \text{mass of material on belt} \times 0.00981 \quad (3.29)$$

Overall friction coefficient = 1 (Assuming no roller nor sliding board under the belt)

$$T_e = 1 \text{ x } 0.0423 \text{ x } 0.00981 = 0.000415\ \text{kN}$$

$$\text{Maximun belt tension(kN)}(T_{max}) = (1 + K)T_e$$

K = drive factor =0.97 for 180^0 wrap, screw take up bared pulley (Fenner Dunlop, 2009)

$$T_{max} = (1 + 0.97) \text{ x } 0.000415 = 0.000818\ \text{kN}$$

$$\text{Power requirement for belt (kN)} = T_e \text{ x speed of belt (m/s)} \quad (3.30)$$

$$Power\ requiremwnt\ for\ belt = 0.000415\ x\ 1 = 0.000415\ kw = 0.000556\ Hp$$

Fenner Dunlop (2009) recommended that the height of opening above belt should not be less than three times the maximum size of the conveyed materials.

Height of hopper sliding groove above belt = 3 0mm

$$\text{Required working tension(kN/m)} = \frac{T_{max}\text{(kN)}}{\text{Belt width (m)}} = \frac{0.000818}{0.25} = 0.03272\ \text{kN/m}$$

$$\text{Time cycle of the conveyor belt} = \frac{\text{2 x conveyor center (m)}}{\text{belt speed m/s}} = \frac{2 \times 0.125}{1} = 0.25\ \text{s}$$

Assuming the loading material (cowpea seed) is dropped at the center of the belt.

Pulley drive Type (shape) = cylindrical pulley (Habasit fabric conveyor belts engineering guide)

Pulley Drive diameter (d) = 100 mm (based on SFS, ISO 3684-76 standard.)

Pulley Drive width (b) = (1.08×b_o) + 12 = (1.08×250) +12 = 282mm (recommended by Habasit fabric conveyor belts engineering guide for belt width greater 100mm)

Roughness of pulley surface (R_a) = 1.6 µm (Habasit fabric conveyor belts engineering guide)

Non drive pulley type (Types) = Cylindrical – conical (trapezoidal crowned) (Habasit fabric conveyor belts engineering guide)

Non drive pulley diameter = 100 mm

Non drive pulley width = (1.08×b) + 12 = (1.08×250) +12 = 282 mm (recommended by Habasit fabric conveyor belts engineering guide for belt width greater 100 mm)

Pulley shaft diameter = 40 mm (Thumb rule for pulley shaft is that it should not be less than three times the diameter of the pulley).

Available Take – up length = 1.5% of belt length (Habasit fabric conveyor belts engineering guide). Figure 3.13 shows the design drawing and picture of the constructed metering device and belt conveyor,

3.6.13 Design of the Automated Unit

Automation Information

List of components

1. Raspberry pi 3 board model B
2. Pi Camera board
3. TFT Screen 5″
4. Servo motors – Micro servo SG 90
5. LED lights
6. Plastic flippers
7. Adaptor power cable
8. Automation tube – PVC pipe

Specification of the main components

1. Raspberry pi 3 Board Model B

The Raspberry Pi 3 Model B is the third generation Raspberry Pi. This powerful credit-car d sized single board computer can be used for many applications and supersedes the origin al Raspberry Pi Model B+ and Raspberry Pi 2 Model B. Whilst maintaining the popular bo ard format the Raspberry Pi 3 Model B brings you a more powerful processer, 10x faster t han the first-generation Raspberry Pi. Additionally, it adds wireless LAN & Bluetooth con nectivity making it the ideal solution for powerful connected designs. Figure 3.14 shows th e descriptive and designs drawing while features and installation steps in Appendix C1.

2. Raspberry Pi NoIR Camera Board

The NoIR Camera is the official "night vision" camera board released by the Raspberry Pi Foundation. It attaches to the Pi by way of one of the small sockets on the board's up

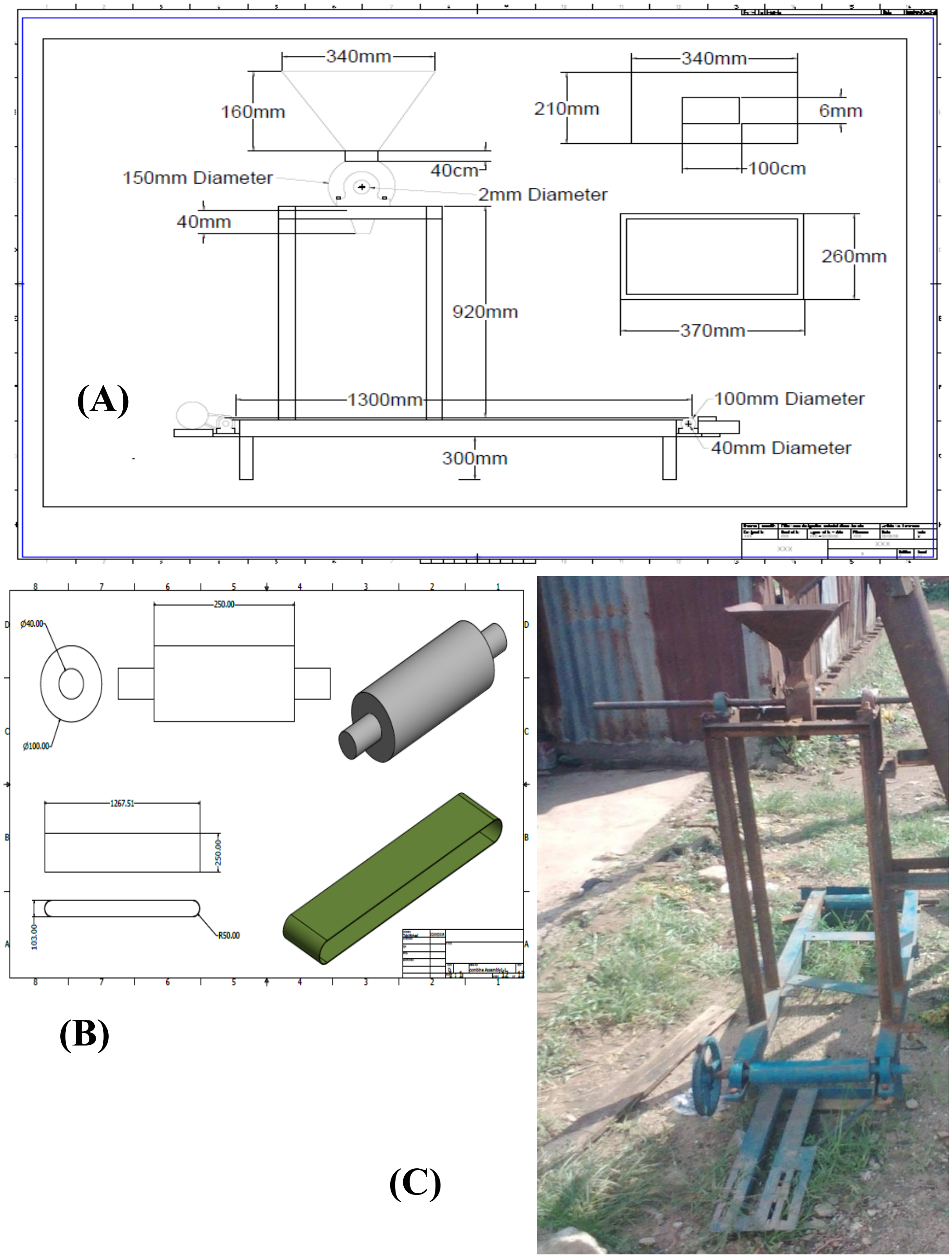


Figure 3.13: (A) Design drawing of metering device and Belt Conveyor (B) Design drawing of Roller and belt (C) Picture of the constructed metering device and belt conveyor

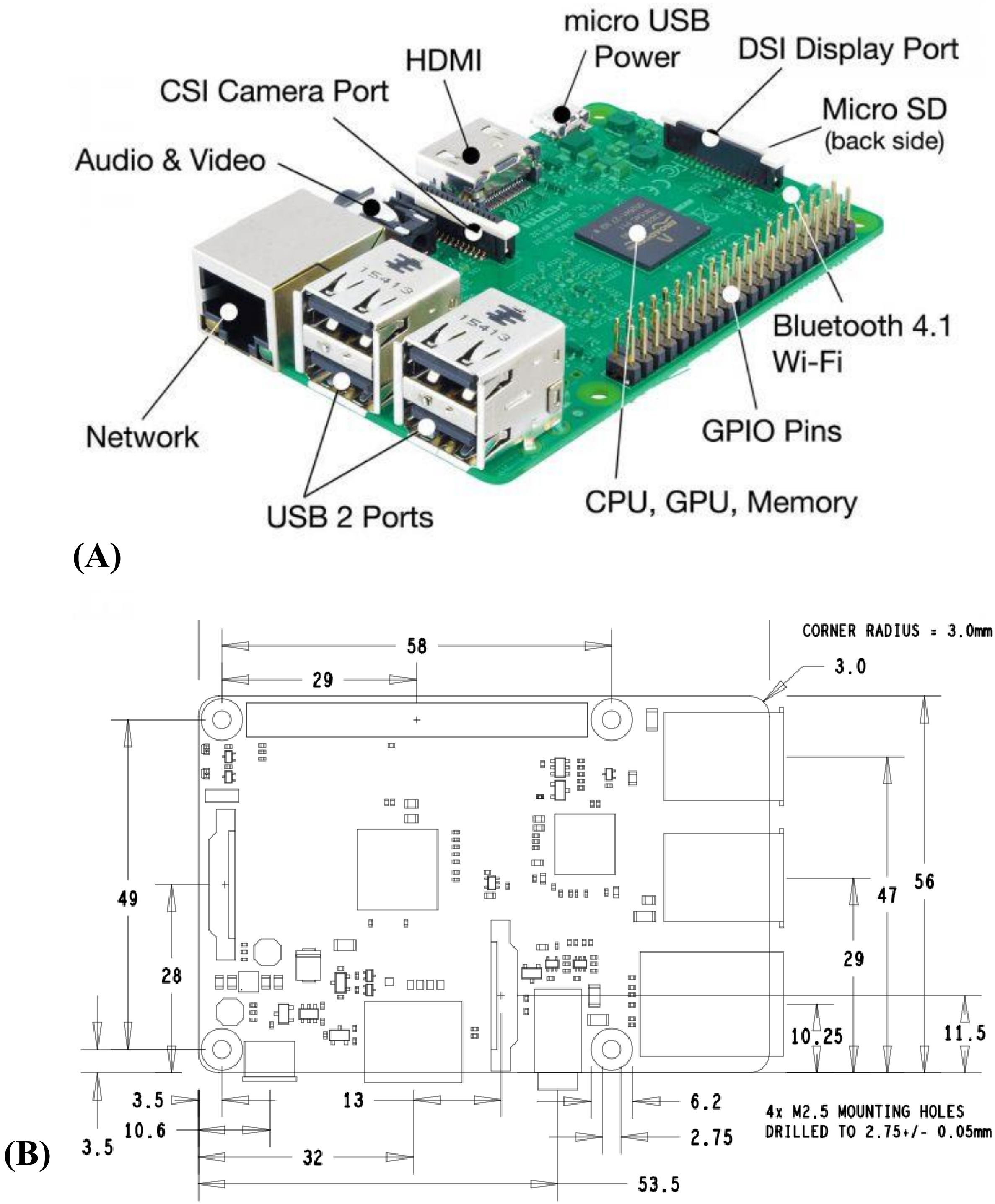


Figure 3.14: (A) Descriptive and (B) Designs drawing of Raspberry pi 3 Board.

per surface and uses the dedicated CSi interface, designed especially for interfacing to cam eras. The CSI bus is capable of extremely high data rates, and it exclusively carries pixel d ata. The NoIR Camera has No InfraRed (NoIR) filter on the lens which makes it perfect fo r doing Infrared photography and taking pictures in low light (twilight) environments. It co nnects to any Raspberry Pi or Compute Module, allowing you to create HD video and still photography. Plate 3.2 shows Raspberry Pi NoIR Camera board and its attachment to Rasp berry pi 3 board. Appendix C2 display features of Pi NoIR Camera used in this study.

3. TFT Screen 5″

HDMI 5 Inch 800×480 TFT Display

This 5inch TFT Display with Touch Screen is a mini panel-mountable HDMI monitor. So small and simple, but you can use this display with any computer that has HDMI output, and the shape makes it easy to attach to an electronic product. Although the 800x480 common HDMI display is made for Raspberry Pi, we can also use it other boards and not only for Raspberry Pi.

Figure 3.15 displays the interface functions of HDMI 5 Inch 800 x 480 TFT Display Installation of HDMI Interface 5 Inch 800×480 TFT Display was done using steps describ ed in Appendix C4

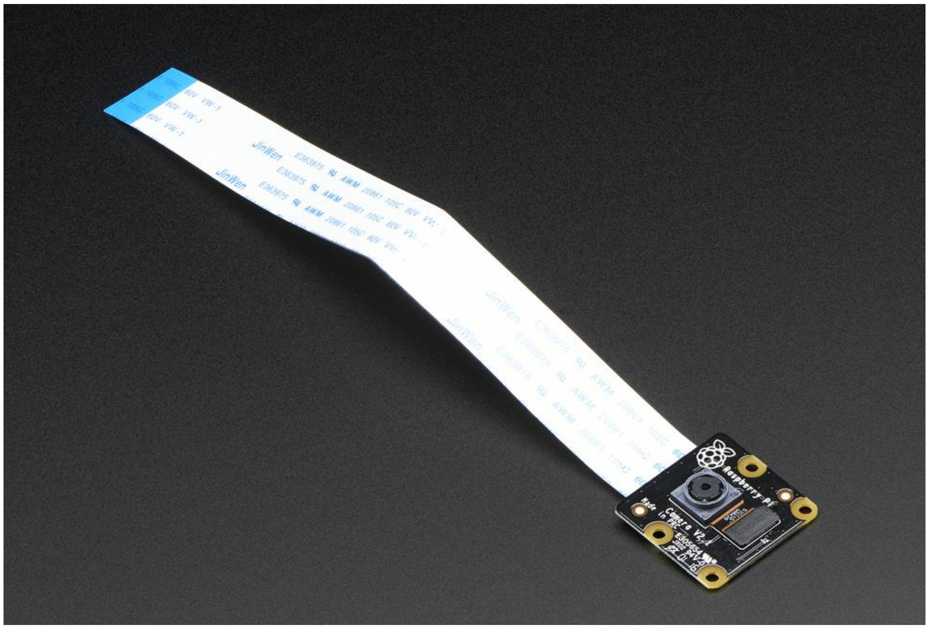
4. Micro Servo motors – Tower Pro SG 90

This motor was tiny and lightweighted with high output power. Servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds but smaller. You can use any servo code, hardware or library to control these servos. Good for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. It comes with 3 horns (arms) and hardware.

Figure 3.16 shows micro servo motors – Tower Pro SG 90 pictures, pin out, position and design drawing

5. LED Lights

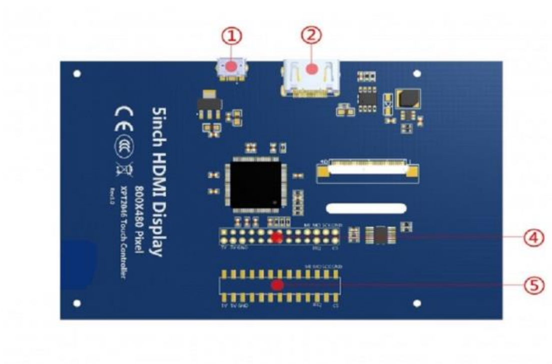
Small LED lights were used to light up the sorting chamber for the camera to take images. The LED lights terminals were connected to the raspberry pi board. Circular plastic



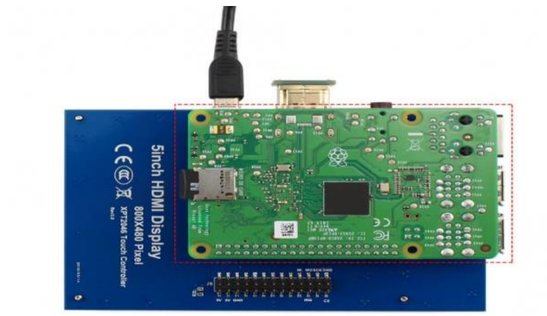
(a) Raspberry Pi NoIR Camera Board

(b) Raspberry Pi NoIR camera board connected to Raspberry pi 3 board

Plate 3.2: Raspberry Pi NoIR camera board and its attachment to Raspberry pi 3 board



(a) Back of TFT screen



(b) TFT screen connected to Raspberry board

PIN NO.	SYMBOL	DESCRIPTION
1, 17	3.3V	Power positive (3.3V power input)
2, 4	5V	Power positive (5V power input)
3, 5, 7, 8, 10, 12, 13, 15, 16, 18, 24	NC	NC
11	Backlight Control	Control the backlight through pin 11
6, 9, 14, 20, 25	GND	Ground
19	TP_SI	SPI data input of Touch Panel
21	TP_SO	SPI data output of Touch Panel
22	TP_IRQ	Touch panel interrupt, low level while the touch panel detects touching
23	TP_SCK	SPI clock of touch panel
26	TP_CS	Touch panel chip selection, low active

(c) Interface function of TFC screen

(d) TFT screen display after complete installation

Figure 3.15: Connection and Interface Functions of HDMI 5 Inch 800×480 TFT Display

flippers were constructed and inserted into the automation tube. The flippers were attached to the servo motors. The servo motor makes it to rotate 0 or 90 when in operation.

6. Plastic flippers

   Circular plastic flippers were constructed and inserted into the automation tube. The fli ppers were attached to the servo motors. The servo motors make it to rotate 0 or 90 deg rees when in operation.

7. Adaptor power cable –

   Hp Laptop AC Adapter - Big Pin + Power Cable - 18.5v/65W

Specifications:

i. Operating Frequency: 60/50Hz
ii. > Output Voltage: 18.5V
iii. > Output current: 3.5A
iv. > Big Pin Connection
v. > Fused Power cable

8. Automation tube – PVC pipe

A 90 mm PVC pipe was used for the automation sorting.

The Assembled components of the automation unit are shown plate 3.3.

3.6.14 Programming of the Automation unit to sort Cowpea Seeds

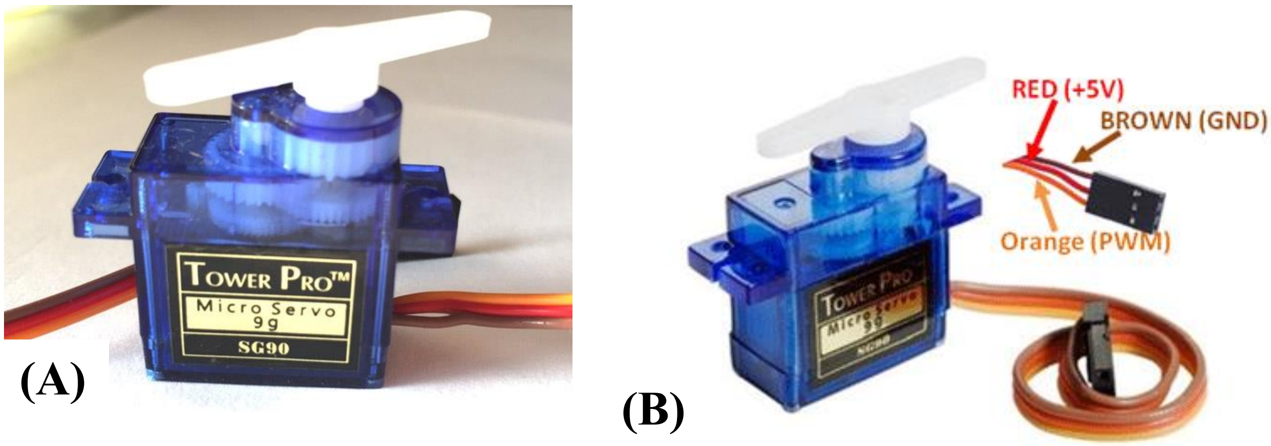
Two programs were developed for the automation unit using Python programming language. The programs are:

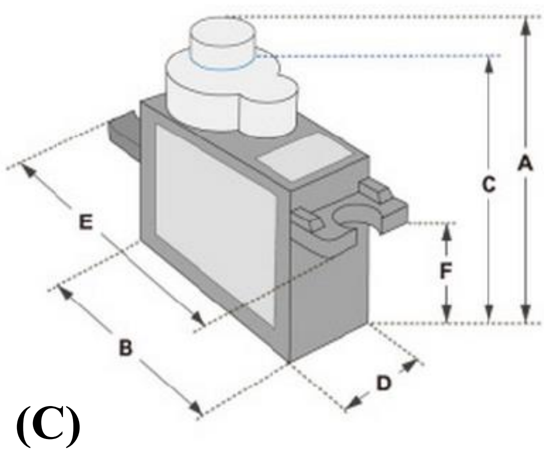
Program 1: For capturing and save images

Program 2: for comparing images

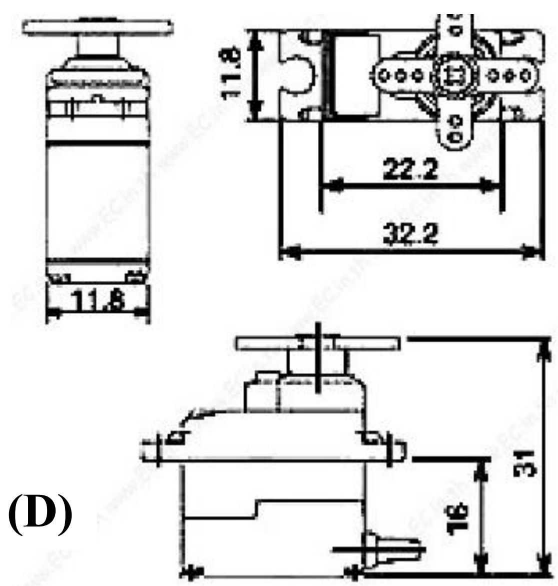
These written programs are shown in Appendix C6 and C7

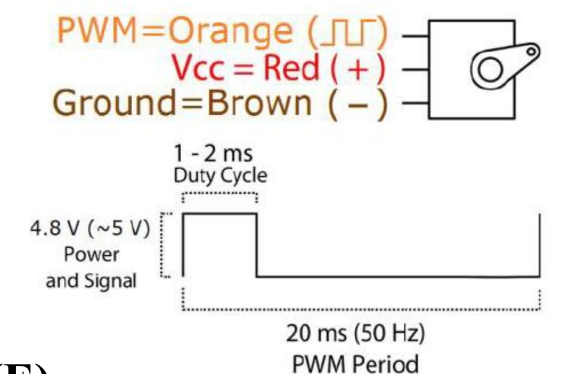
Some captured images of cowpea seeds at different seed orientations within the sorting chamber, taken by the raspberry Pi camera used for developing (writing) the sorting software programs are shown in plate 3.4. Plate 3.5 shows the Automation programming activities.





Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6





(E)

Position "0" (1.5 ms pulse) is middle, "90" (~2 ms pulse) is all the way to the left.

Figure 3.16: Micro Servo motors Tower Pro SG 90. (A) Picture of servo motor (B) Pin out (C) Servo motor dimension (D) Design drawing (E) Servo positioning

Plate 3.3: Assembled components of the automation units

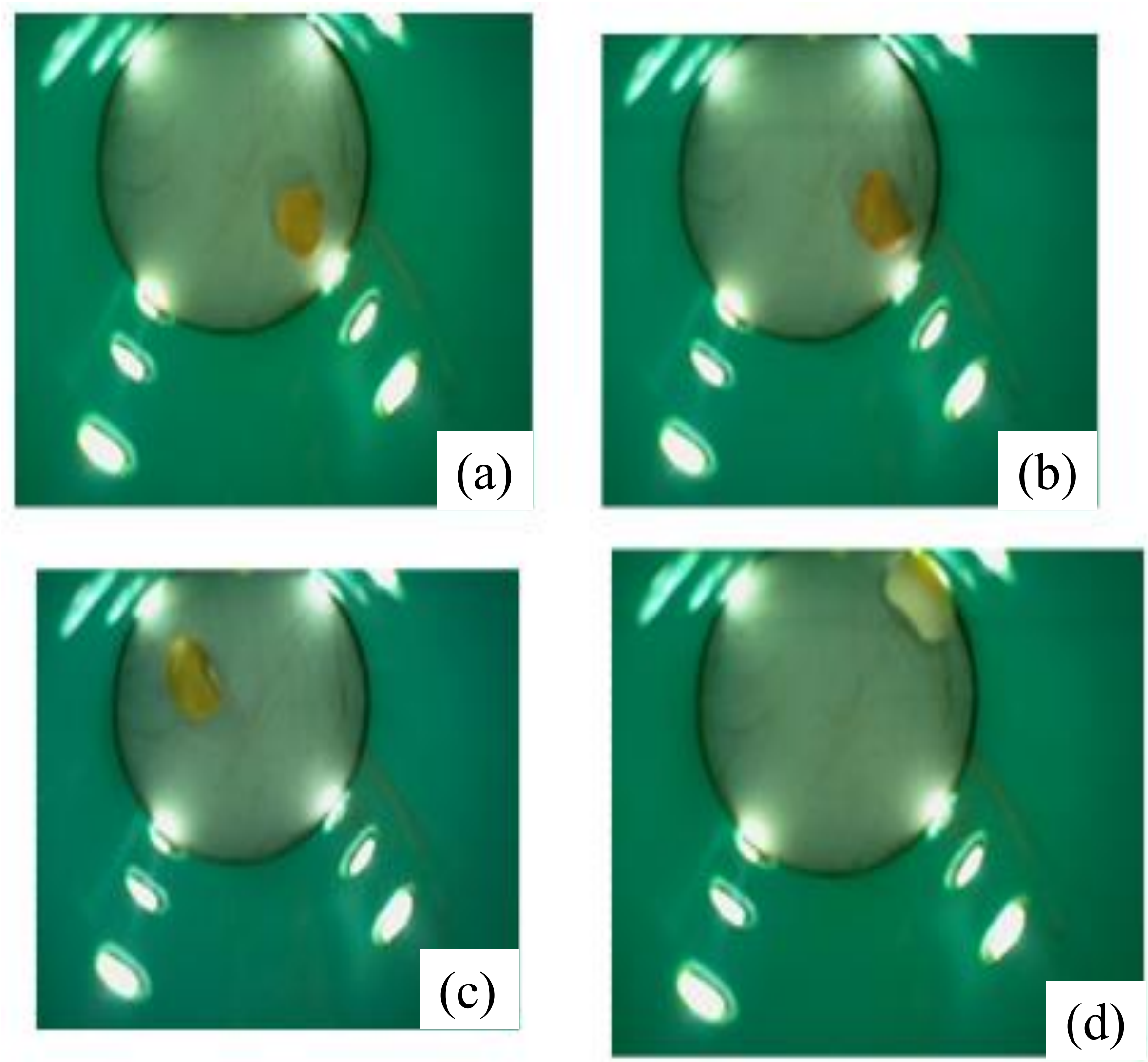


Plate 3.4: Some captured images of cowpea seeds at different seed orientations using different seed variety, captured within the sorting chamber, taken by the raspberry Pi camera that was used for developing the sorting software programs

Plate 3.5: Automation system programming

3.8.15 Operational Principles of the Automation Unit

Figure 3.17 shows the working principle of the automation unit using a flow chart. When an object (whole seeds, broken seeds, damaged seeds or stones) falls into the tube, proximity (motion) sensors on the raspberry pi camera board alert the system. The object enters the primary collection unit where the camera lens captures the image and sends it to the raspberry pi board for analysis and response. The raspberry pi board activates the servo motor and the plastic flipper, which is the bottom of the primary collection unit. This flipper rotates 90 degrees to allow the object fall into the secondary collection unit. While the object remains in the secondary unit, the raspberry pi board analyses the image send to by the camera board. The image sent by the camera board is compared with images already stored in its memory. Then decision is made by the raspberry pi board using the python programmed software weather to reject or accept the object. Whichever decision taken by the raspberry pi board, it causes the servo motor and its flipper which is the bottom of the secondary unit to flip 90 degrees to the left or to the right. This causes the object to come out of the reject or accept pipe hole. The whole sorting process was programmed to last only five second. Figure 3.18 shows the material flow direction inside the system

Test running of the automation units was done using some damaged seeds, broken seeds and stones before carrying out the evaluation test.

3.7 Assembling of the system

The whole system after construction was assembled as shown in Figure 3.18 and Plate 3.6

3.8 Evaluation and optimization of the system

Experimental design for evaluation was I-Optimal Response Surface. This design was chosen because all factors to be used in the evaluation do not have the same level (sub units within a factor)

3.8.1 Evaluation Sample parameters

1. Grain varieties used - NG/AD/11/08/0033, NG/OA/11/08/063, NGB/OG/0055.
2. Percentage of impurity in sample – impurity in the sample was selected according to international standards as shown in Table 3.1. Samples were grouped as grade 1, 2 and 3.

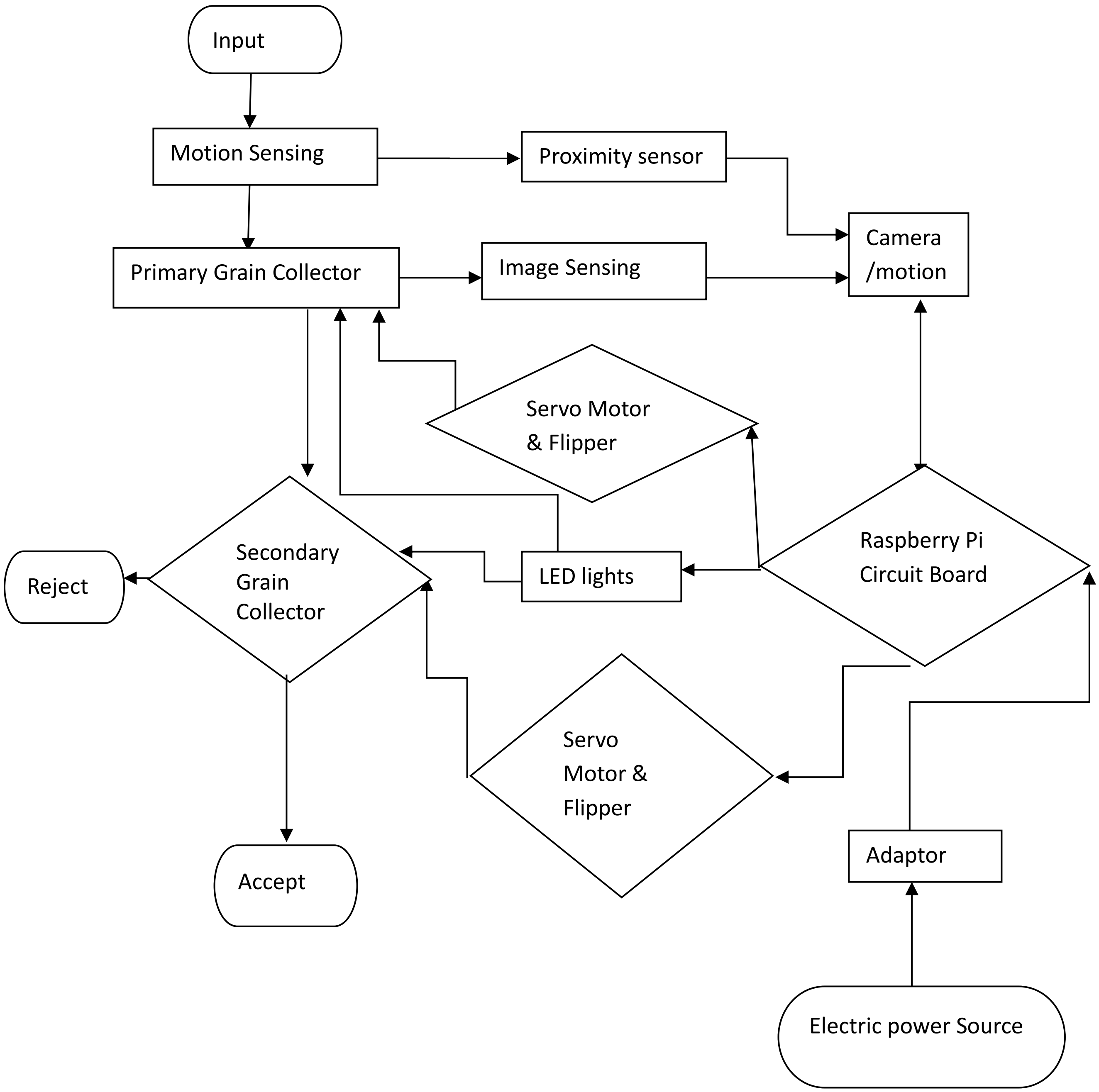


Figure 3.17: Flow chart for automation section of cowpea seed separation system.

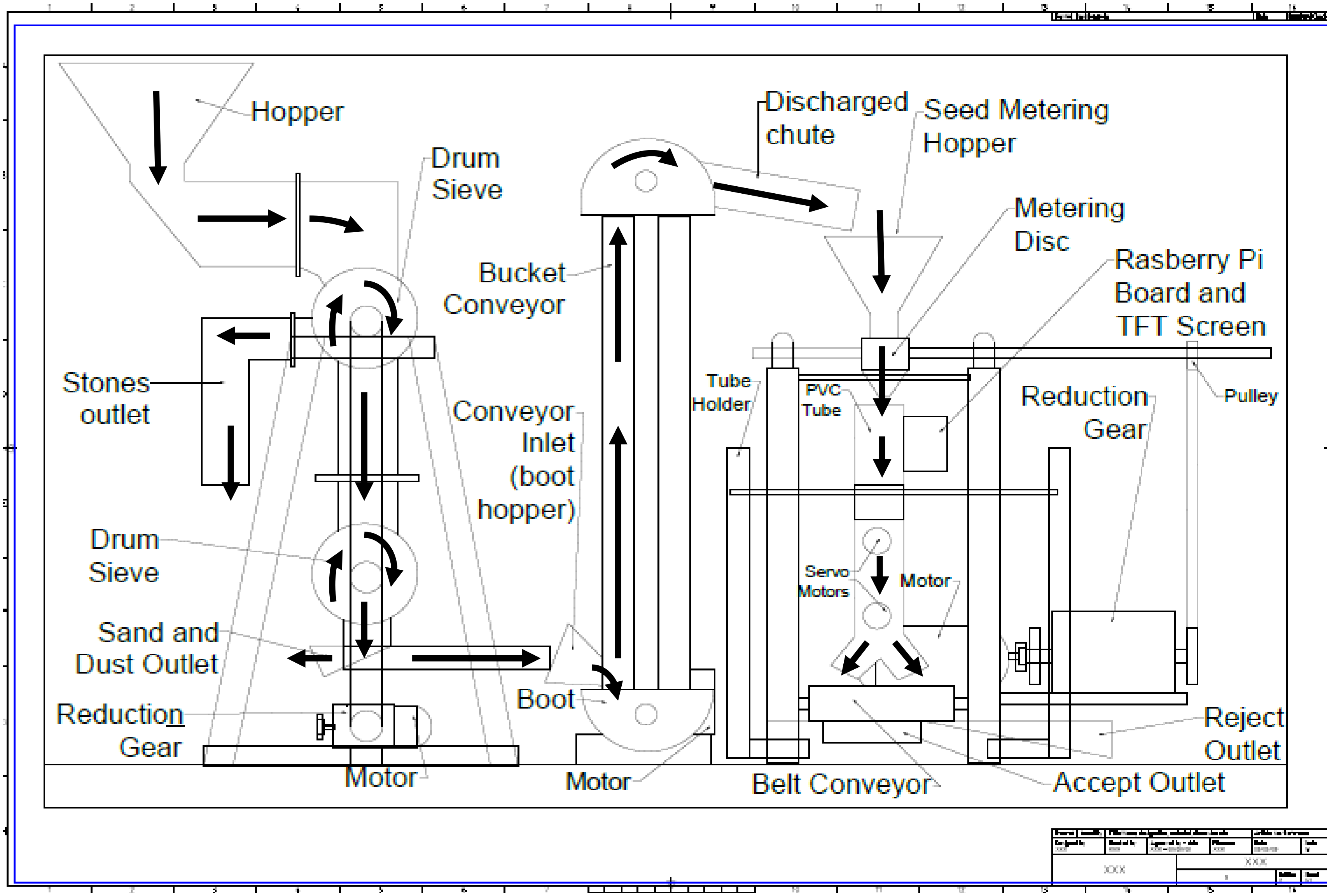


Figure 3.18: Assembled drawing and material flow direction of the entire system

(a) **Assembling of sieve drum units**

(b) **Assembling metering and automation units**

(c) **Assembling of bucket conveyor units**

(d) **Painting of assembled units**

Plate 3.6: Assembling of the cowpea seed grading system

Impurity was called bad portion in the sample as shown in table 3.1. The bad portion was made of:

a) Broken Seeds – Seeds that passes through 4.5mm round holes, 3.75mm slotted screen, 2.38mm round hole.
b) Foreign Body – Stones, Sands and plant parts
c) Damage Seeds - Diseased and insect damaged seeds were allowed at room condition to spoil for 5 months

Plate 3.7 and 3.8 show pictures of impurities used for evaluation.

3.8.2 Evaluation Experimental Procedure.

Samples were prepared according to experimental grades for the three varieties of cowpea. This experimental grade was poured into the system. Collectors were positioned at the four outlets of the system. One at the first separating sieve drum outlet, the second at the second separating sieve drum outlet. The remaining two collectors were placed at the end of the belt conveyor. A stop watch was used to record the time it took to finish processing in, sieve drum one, sieve drum two, bucket conveyor, sensing unit and the whole system. At the end of each experimental runs, collected samples from each outlet were sorted, weighed and recorded.

3.8.3 Evaluation Parameters

1. Efficiency

   Let:

   Efficiency of first separating sieve drum unit be E_1

   $$E_1 = \frac{W_2}{W_1} \times 100 \qquad (3.31)$$

   Where: W_1 is the weight of impurity greater than 12 mm coming out of first drum (kg), W_2 is the weight of impurity greater than 12 mm put into the first drum

   Efficiency of second separating sieve drum unit be E_2

   $$E_2 = \frac{W_4}{W_3} \times 100 \qquad (3.32)$$

Where: W_3 is the weight of impurity greater than 2 mm out of second drum (kg), W_4 is the weight of impurity greater than 2 mm going into the second drum

Table 3.1: Quality parameters assessment and selection

Range of quality parameter limits of cowpea compiled from international standards					
Quality parameters	Below Grade 1	Grade 1	Grade 2	Grade 3	Above Grade 3
Broken Seeds (%)	0	1 –3.6	3 – 5	5.5 – 8.5	9
Foreign Body (%)	0	0.2 – 0.4	0.5 – 1	1.5	2
Damage Seeds (%)	0 - 1	2 - 4	5 – 8	8 – 10	13
Bad portion (%)	0 - 1	3.2 – 8	8.5 – 14	15 - 20	24
Good portion (%)	100 - 99	96.8 – 92	92.5 – 86	87 - 80	76

Sources: African Standard. 2012, Cowpeas: United States Standards for Beans 2008, Draft Malawi Standard 2015. AHCX Commodities Exchange. 2014, Australian Pulse Standards 2014/15. EAC 2010, Codex Standard 171-1989: FDUS EAS 755. 2013

Quality parameters used for preparing cowpea sample for this study in percentage			
Quality parameters	Grade 1	Grade 2	Grade 3
Broken Seeds (%)	3	5	7
Foreign Body (%)	0.8	1	2
Damage Seeds (%)	6	10	15
Bad portion (%)	9.8	16	24
Good portion (%)	89.2	84	76
Total (%)	100	100	100

Quality parameters used for preparing cowpea sample for this study in kg			
Broken Seeds (kg)	0.06	0.1	0.14
Foreign Body (kg)	0.016	0.02	0.04
Damage Seeds (kg)	0.12	0.2	0.3
Bad portion (kg)	0.196	0.32	0.48
Good portion (kg)	0.804	1.68	1.52
Total (kg)	2	2	2

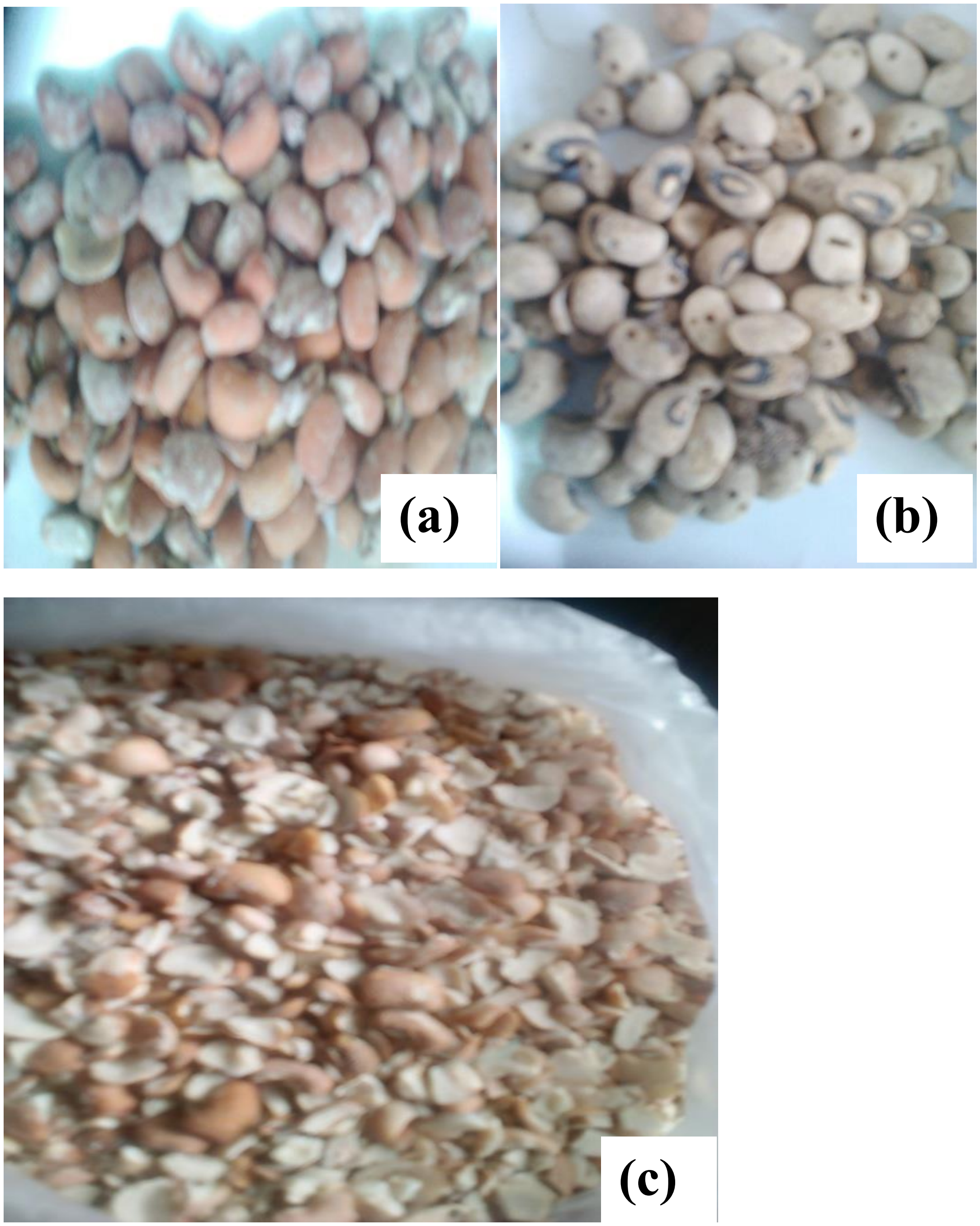


Plate 3.7: Pictures of (a) diseased seeds (b) insect infested seeds (c) broken seeds used for preparing impurity

Plate 3.8: Pictures of (a) Plant parts (b) Stones of size between 4mm to 8mm (c) sand with size less than 2mm (d) stones of sizes greater than 12mm used for preparing foreign body impurity

Efficiency of bucket conveyor be E_3

$$E_3 = \frac{W_5}{W_6} \times 100 \tag{3.33}$$

Where: W_5 is the weight of sample coming out of bucket conveyor (kg), W_6 is the weight of sample going into the bucket conveyor

Weight of sample coming out of the bucket conveyor = Total weight of sample coming out of the system = weight of impurities rejects by the automation unit + weight of good seeds accepted by the automation unit.

Weight of sample going into the bucket conveyor = total weight sample - weight of materials from the two drums.

Efficiency of metering device be E_4

$$E_4 = \frac{F_1}{F_2} \times 100 \tag{3.34}$$

Where: F_1 is the actual flow rate of metering device, F_2 is the design feed rate of the metering device

$$\text{Actual feed rate of metering device} = \frac{4.044 \text{ x } 10^{-6} \times \text{ Speed of metering}}{60 \times 10^6} \tag{3.35}$$

$$\text{Design feed rate of metering device} = \frac{4.044 \text{ x } 10^{-6} \times 4 \times 15.3}{60 \times 10^6} \tag{3.36}$$

(Sharma and Mukesh, 2010)

Efficiency of Automation unit (E_5)

$$E_5 = \frac{W_7}{W_8} \times 100 \tag{3.37}$$

Where: W_7 is weight of impurity rejected by the automation unit, W_8 is the weight of impurity that enter into the metering device

Weight of impurity that enter the metering device = Weight of impurity collected from the rejected outlet of the belt conveyor + weight of impurity collected from the accepted outlet of the belt conveyor.

Efficiency of the system be E_S

Efficiency of the system (E_S) = Efficiency of first separating sieve drum + Efficiency of second separating sieve drum + Efficiency of bucket conveyor + Efficiency of metering device + Efficiency of Automation unit

$$E_S = \frac{E_1 + E_2 + E_3 + E_4 + E_5}{\text{Total } \%} \text{ x } 100 \tag{3.38}$$

2. Throughput

The amount of impurity processed (separated) by the system over the defined period of time (kg/hr)

Unit Throughput: The total amount of impurity separated by each separating unit

Let:

T_1 =First sieve drum separating unit throughput (kg/hr) = weight of impurity greater than 12mm removed at the first separating sieve drum unit in one hour (kg/hr)

T_2 = Second sieve drum separating unit throughput (kg/hr) = weight of impurity less than 2mm removed at the second separating sieve drum unit in one hour (kg/hr)

T_3 = Image sensing and sorting (Automation) unit Throughput (kg/hr) = weight of detected and rejected impurity from the automation unit in one hour (kg/hr)

T_S = System Throughput (kg/hr)

$$T_S = T_1 + T_2 + T_3 \tag{3.39}$$

3. Maximum Capacity (MC_S) in kg/12hrs

Maximum Capacity: The maximum weight of impurity the unit could have processed (separated); assuming the system maximum working capacity is 12hours.

Let:

MC_1 = Unit Maximum Capacity for the first separating sieve drum unit (kg/12hrs)

$$MC_1 = \text{Throughput rate x operation time} = T_1 \text{ x } 12 \text{ hours} \tag{3.40}$$

(Assuming the system safe operation time should not exceed 12 hours)

MC_2 = Unit Maximum Capacity for the second separating sieve drum unit (kg/12hrs)

$$MC_2 = \text{Throughput rate x operation time} = T_2 \text{ x } 12 \text{ hours} \tag{3.41}$$

MC_3 = Unit Maximum Capacity for the colour detecting and sort unit (kg/12hrs)

$$MC_3 = \text{Throughput rate x operation time} = T_3 \text{ x } 12 \text{ hours} \tag{3.42}$$

MCS = System Maximum Capacity (MC_S) in kg/12hrs

$$MC_S = MC_1 + MC_2 + MC_3 \tag{3.43}$$

4. System Actual Utilization (AU_S)

Actual Utilization: The ratio of the component throughput and the component maximum capacity

Machine utilization is a measure of how intensively a machine is being used. Machine utilization compares the actual machine time (setup and run time) to available time.

Let

AU_1 = Actual utilization of first separating units

$$AU_1 = \frac{T_1}{MC_1}$$

(3.44)

AU_2 = Actual utilization of second separating units

$$AU_2 = \frac{T_2}{MC_2}$$

(3.45)

AU_3 = Actual utilization of the colour detecting and sort units

$$AU_3 = \frac{T_3}{MC_3}$$

(3.46)

$$AU_s = \frac{T_s}{MC_s}$$

(3.47)

5. Backlog (B_S)

Materials lost and did not process by the system

Backlog=weight of materials the units can not process at the end of the run

Let:

B_1 = weight of impurity greater than 12mm remaining in the first separating unit at the end of the run (kg)= weight of impurity greater than 12mm (Put into system – out of system)

B_2 = weight of impurity lesser than 2mm remaining in the second separating unit at the end of the run (kg)= weight of impurity less than 2mm (Put into system – out of system)

B_3 = weight of material remaining in the bucket conveyor at the end of the run (kg)

= (Total weight of material – weight of material coming out of the 2 drums) – total weight of material at the end of the conveyor belt.

B_4 = weight of materials other than materials greater than 12mm or lesser than 2mm coming out of both drums

= (weight of materials collected at the outlet of the two drums) – (weight of impurity greater than 12mm + weight of impurity less than 2mm)

B_S = System backlog (kg)

$$B_S = B_1 + B_2 + B_3 + B_4 \tag{3.48}$$

3.8.4. System Optimisation

Optimisation of the system units was done using Design Expert software version 10. These units are: the first sieve drum, Second sieve drum, bucket conveyor, metering device and automation unit. Then the entire system was optimised. Optimisation was done for the evaluating parameter like: efficiency, throughput, maximum capacity, actual utilization and backlog. The optimisation goal was to develop operational settings for the factors to achieve maximum: efficiency, throughput and capacity with minimal backlog.

3.9 Statistical Analysis

Preliminary study of the optical and electrical properties of cowpea was modeled and optimised using response surface methodology. Statistical experimental design employed include: single factor response surface design and central composite design. All modeling analysis employed were polynomials.

Statistical analysis used for evaluating, modeling and optimising the developed grading system was response surface methodology using I-optimal response surface design. Descriptive statistic was also employed to describe results of data from the evaluation experiments. The grading system performance was modeled using polynomial equations. Analysis of variance (ANOVA) was used to determine the significant of the operating factors at $P<0.05$. Regression was also used to determine the strength of the developed modeled equations. Two statistical analyses were used to validated the developed grading system. These are prediction interval analysis and regression analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Modeling and Optimization of Some Electrical and Optical Properties of Cowpea Seeds for Automation Design Consideration.

4.1.1 Modeling of Optical and Electrical Properties of Cowpea Seeds

Tables 4.1 and 4.2 show experimental results for colour, absorbance, reflectance and transmittance properties cowpea seeds. The summary results obtained during modeling of the optical properties considered for this study were displayed in table 4.3. Range of evaluation results obtained for L* a* b*, absorbance, reflectance and transmittance properties were: 38 - 92.2%, 0.7 - 9.7%, 13.6 - 27.3%, 0 - 1.8%, 0 - 1%, and 0 - 12% respectively. Also, with a mean and standard deviation of: 60 and ±17.4%, 3.5 and ±3%, 18.4 and ±3.7%, 1.2 and ±0.46%, 0.13 and ±0.25%, 2.9 and ±2.6%; for L* a* b*, absorbance, reflectance and transmittance properties, respectively. Colour properties (L* a* b*) results values had a wide range (38 – 92%) while the absorbance, reflectance and transmittance properties had a low range (0 – 12%). This colour range (38 – 92%) shows that some varieties were bright in colour while others were dark. The absorbance, reflectance and transmittance properties range (0 – 12%); shows that, 88% of the light directed on the cowpea seeds, were neither absorbed, reflected nor transmitted. This phenomenon is called "scattered reflection" or "diffused reflection". This discovering shows that to harness the full potential of optical properties of cowpea for sensing operation, the light directed on the seeds should be in an enclosed environment. This will reduce the effect of diffused reflection. The standard deviation values of the colour properties are high. This indicates that the experimental values fall within a wide range, rather than concentrating around the mean. The standard deviation values of the absorbance, reflectance and transmittance properties are low. This indicates that the experimental result values concentrated around the means. So far, the optical properties results show that, if light wave

Table 4.1: Experimental Design and Results of Colour Properties used for Modeling and Optimization

Run	moisture % (db)	variety	L %	a %	b %
1	8	55	40.438	6.024	14.928
2	12	33	57.336	1.022	15.752
3	10	63	86.226	3.294	24.096
4	12	55	38.000	6.264	13.648
5	8	55	40.438	6.024	14.928
6	16	33	62.076	1.192	17.744
7	14	33	60.560	1.188	17.094
8	16	55	39.186	8.080	16.078
9	16	63	58.102	1.318	17.518
10	8	33	92.200	3.810	27.308
11	16	63	58.102	1.318	17.518
12	8	33	92.200	3.810	27.308
13	16	33	62.076	1.192	17.744
14	16	55	39.186	8.080	16.078
15	10	55	53.914	9.708	19.282
16	8	63	76.266	0.722	20.746
17	10	33	74.788	1.978	18.282
18	12	63	56.904	1.000	16.234
19	14	55	41.076	7.734	16.472
20	8	63	76.266	0.722	20.746
21	14	63	57.956	0.822	17.530

Table 4.2: Experimental Design and Results of Absorbance, Reflectance and Transmittance Properties used for Modeling and Optimization

Run	Moisture %	Wavelength Nm	Variety	Absorbance %	Reflectance %	Transmittance %
1	16	520	NG/AD/11/08/0033	1.364	0.047	5.820
2	12	520	NG/OA/11/08/063	0.939	0.128	1.820
3	10	420	NG/AD/11/08/0033	0.979	0.109	2.380
4	12	520	NG/OA/11/08/063	0.939	0.128	1.820
5	12	320	NG/AD/11/08/0033	0.000	1.000	0.300
6	10	420	NGB/OG/0055	1.261	0.057	0.000
7	12	520	NGB/OG/0055	1.544	0.032	2.760
8	14	420	NG/AD/11/08/0033	1.113	0.077	10.960
9	12	520	NG/AD/11/08/0033	1.489	0.039	5.180
10	14	420	NGB/OG/0055	1.184	0.066	7.120
11	12	520	NG/OA/11/08/063	0.939	0.128	1.820
12	12	520	NGB/OG/0055	1.544	0.032	2.760
13	10	420	NG/OA/11/08/063	1.170	0.069	0.000
14	14	620	NGB/OG/0055	1.439	0.037	12.040
15	12	520	NG/AD/11/08/0033	1.489	0.039	5.180
16	12	320	NG/OA/11/08/063	0.000	1.000	0.300
17	12	320	NGB/OG/0055	0.000	1.000	0.280
18	12	520	NG/AD/11/08/0033	1.489	0.039	5.180
19	12	520	NG/OA/11/08/063	0.939	0.128	1.820
20	12	520	NGB/OG/0055	1.544	0.032	2.760
21	12	520	NGB/OG/0055	1.544	0.032	2.760
22	8	520	NGB/OG/0055	1.803	0.016	1.600
23	8	520	NG/AD/11/08/0033	1.342	0.045	2.620
24	14	620	NG/AD/11/08/0033	1.008	0.098	0.800
25	12	720	NG/OA/11/08/063	1.293	0.070	0.740
26	12	520	NG/AD/11/08/0033	1.489	0.039	5.180
27	12	720	NGB/OG/0055	1.728	0.019	0.600
28	16	520	NG/OA/11/08/063	1.469	0.040	2.720
29	12	520	NG/AD/11/08/0033	1.489	0.039	5.180
30	10	620	NG/OA/11/08/063	1.633	0.024	2.760
31	12	720	NG/AD/11/08/0033	1.786	0.018	1.880
32	14	620	NG/OA/11/08/063	1.008	0.098	0.800
33	16	520	NGB/OG/0055	1.836	0.015	1.340
34	8	520	NG/OA/11/08/063	1.732	0.019	3.000
35	10	620	NG/AD/11/08/0033	1.807	0.017	2.140
36	12	520	NGB/OG/0055	1.544	0.032	2.760
37	10	620	NGB/OG/0055	1.554	0.029	1.560
38	14	420	NG/OA/11/08/063	1.031	0.093	5.420
39	12	520	NG/OA/11/08/063	0.939	0.128	1.820

Table 4.3: Model Design summary for optical properties of cowpea

Design Summary for colour property										
File Version	Design Expect	10.0.1.0								
Study Type	Response Surface									
Design Type	One Factor									
Subtype	Randomized									
Blocks	No Blocks									
Factor	**Units**	**Type**	**Subtype**	**Min**	**Max**	**Coded**	**Values**	**Mean**	**Std. Dev.**	
Moisture	%	Numeric	Continuous	8.000	16.000	FALSE	1.=16	12	3.286	
Variety		Categorical	Nominal	055	033		Levels: 3			
Response	**Units**	**Obs**	**Analysis**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Ratio**	**Trans**	**Model**
L		21	Polynomial	38.000	92.200	60.157	17.402	2.426	None	Quartic
A		21	Polynomial	0.722	9.708	3.586	3.014	13.450	Square Root	Quartic
B		21	Polynomial	13.650	27.308	18.430	3.746	2.001	None	Quartic
Design Summary for Absorbance, Reflectance and Transmittance property										
Study Type	Response Surface									
Design Type	Central Composite									
Blocks	No Blocks									
Factor	**Units**	**Type**	**Subtype**	**Min**	**Max**	**Coded**	**Values**	**Mean**	**Std. Dev.**	
Moisture	%	Numeric	Continuous	8	16	FALSE	1 = 14	12	1.947	
Wavelength	nm	Numeric	Continuous	320	720	FALSE	1 = 620	520	97.3329	
Variety		Categorical	Nominal	055	033		Levels: 3			
Response	**Units**	**Obs**	**Analysis**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Ratio**	**Trans**	**Model**
Absorbance	%	39	Polynomial	0.000	1.836	1.267	0.465	N/A	None	Quadratic
Reflectance	%	39	Polynomial	0.015	1.000	0.130	0.257	68.590	None	Quadratic
Transmittance	%	39	Polynomial	0.000	12.040	2.974	2.699	N/A	Square Root	Quadratic

Where Min is Minimum, Max is Maximum, Std. Dev. is standard deviation, Obs is Observation, Trans is Transformation is directed on cowpea seed surface, more of the colour properties can be captured (38 – 92%) than the absorbance, reflectance and transmittance properties (0 – 12%). Also, for colour property, the response ratio (ratio of maximum to minimum values) of ‘L’ and ‘b’ is lesser than 10, while that for ‘a’ is more than 10. Response ratio lesser than 10 usually indicate the experimental results are normally distributed. This means the data do not need transformation to create a good predicting model. Response ratio greater than 10 will need data transformation sometimes, before a good predicting model is established. So, ‘a’ experimental results were transformed. Square root transformation was used to bring the ‘a’ data to be normally distributed. For the absorbance, reflectance and transmittance data, only transmittance data was transformed using the square root transformation.

Five polynomial equations (Linear, 2 factor interaction, quadratic, quartic and cubic) were statistically analyzed. This was done to select the appropriate equations to be use for modeling both the optical and electrical properties. Quartic model (Polynomial model rise to the 4^{th} power) was chosen for all colour properties. This is because among all polynomial models tested, quartic model has the highest R-Square value (a measure of the amount of variation around the mean explained by the model). Quadratic model (Polynomial model rise to the 2^{th} power) was chosen for absorbance, reflectance and transmittance properties. This is because the quadratic model equation had the highest R-square value and predicted R-square value (a value that tells how well predicted values are close to the experimental values) among the five polynomial equations tested. All the generated models for all optical properties do not have lack of fit value (the amount the model predictions miss the experimental result obtained). This could be because all equipments use for obtaining the experimental results of the optical properties, were digital electronic devices with high precision and accuracy, having nearly zero variation among readings. The model equations for optical property for various varieties of cowpea seeds are shown in Appendix D1. Optical model equations, R^2 range from 0.5 - 0.9 and predicted R^2 from 0.2 - 0.9. After modeling the optical properties, the electrical properties were modeled.

Electrical properties of cowpea seeds were modeled using response surface central composite design. The results used for modeling the electrical properties of cowpea seeds are displayed in Table 4.4. Summary of the modeling activities done for electrical properties of cowpea seeds are shown in Table 4.5. Experimental results range obtained for the electrical properties are 1 –15Ω, 0 – 0.5S, 0.2 – 2Ω/m, 0.4 – 3.6 S/m, 1.8E-11 - 1.38E-07 F, 0.5 – 4928, 6.02E-07 - 9.04E+21 H and 1.15E+06 - 1.45E+07 Ω for resistance, conductance, resistivity, conductivity, capacitance, dielectric constant, inductance, capacitance reactance (impedance) respectively. The mean and standard deviation values are 4.7 ± 2.9 Ω, 0.2 ± 0.1 S, 0.6 ± 0.4Ω/m, 1.8 ± 0.9 S/m, 1.02E-08 ±3.58E-08 F, 365 ± 1279, 2.32E+20±1.45E+21 H, and 6.54E+06 ±3.16E+06 Ω for resistance, conductance, resistivity, conductivity, capacitance, dielectric constant, inductance, capacitance reactance (impedance) respectively. All electrical properties measured have a high standard deviation. This high standard deviation values means that the experimental values spread away from the means experimental values of the electrical properties. This phenomenon could be because; the experiments were carried out with cowpea seeds of different moisture content with different current frequencies. No data transformation was done on the electrical properties before modeling except for electrical conductance and resistivity property. Inverse square root and natural logarithm transformation was used to transform conductance and resistivity electrical property data respectively, before modeling. These choices of transformation were based on data types. The conductance response data were rate data while resistivity response data were variance (growth) data. Also, their response ratio was less than 10. This is an indication that their data were normally distributed. Nevertheless, a poor R^2 was obtained when modeling the data result. Therefore, it then requires transformation to correct this.

A quadratic model was chosen for resistance, conductance, resistivity, capacitance, dielectric constant, capacitance reactance (impedance) while cubic model (Polynomial model rise to the 3rd power) was chosen for conductivity, and inductance. These model choices were because these model equations had the highest R^2 value among all polynomials tested. All the generated models for all electrical properties do not have lack of fit value. This could be because all equipments used for obtaining the experimental results, were digital electronic devices with high precision and accuracy, having nearly zero variation among readings. Model equations of electrical properties of cowpea seeds are displayed in Appendix D2.

Table 4.4: Experimental Result for Electrical Properties Cowpea Seeds.

Run	M %	F Hz	variety	R ohms	G S	ρ ohms/	σ S/m	C F	ε	L H	X ohms
1	14	1500	NGB/OG/0055	2.50	0.40	0.35	2.83	1.9E-11	0.90	1.05E-06	5,583,659.98
2	14	500	NG/AD/11/08/0033	3.70	0.27	0.52	1.91	2.8E-11	0.97	1.1E-06	11,366,736.38
3	12	1000	NG/OA/11/08/063	4.58	0.22	0.65	1.54	2E-11	0.56	1.07E-06	7,956,715.47
4	12	2000	NG/OA/11/08/063	4.39	0.23	0.62	1.61	2.4E-11	1.60	9.04E+21	3,315,298.11
5	12	1000	NG/AD/11/08/0033	1.95	0.51	0.28	3.63	2.9E-11	0.81	1.25E-06	5,487,389.98
6	12	1000	NGB/OG/0055	3.75	0.27	0.53	1.88	1.8E-11	0.50	1.17E-06	8,840,794.96
7	14	500	NGB/OG/0055	2.86	0.35	0.40	2.47	2.4E-11	0.83	1.17E-06	13,261,192.45
8	8	1000	NGB/OG/0055	14.75	0.07	2.09	0.48	2.8E-11	0.78	1.15E-06	5,683,368.19
9	12	1000	NG/AD/11/08/0033	1.95	0.51	0.28	3.63	2.9E-11	0.81	1.25E-06	5,487,389.98
10	12	1	NG/OA/11/08/063	7.41	0.14	1.05	0.95	1.3E-07	4642.86	1.09E-06	1,224,110.07
11	10	1500	NGB/OG/0055	4.20	0.24	0.59	1.69	2.5E-11	1.19	9.94E-07	4,243,581.58
12	12	2000	NGB/OG/0055	3.32	0.30	0.47	2.13	2.7E-11	1.80	6.02E-07	2,946,931.65
13	12	1000	NGB/OG/0055	3.75	0.27	0.53	1.88	1.8E-11	0.50	1.17E-06	8,840,794.96
14	16	1000	NGB/OG/0055	6.05	0.17	0.86	1.17	2.9E-11	0.81	1.17E-06	5,487,389.98
15	12	1000	NG/OA/11/08/063	4.58	0.22	0.65	1.54	2E-11	0.56	1.07E-06	7,956,715.47
16	12	1000	NG/OA/11/08/063	4.58	0.22	0.65	1.54	2E-11	0.56	1.07E-06	7,956,715.47
17	12	1	NG/AD/11/08/0033	3.63	0.28	0.51	1.95	1.3E-07	4642.86	1.32E-06	1,224,110.07
18	12	1000	NGB/OG/0055	3.75	0.27	0.53	1.88	1.8E-11	0.50	1.17E-06	8,840,794.96
19	12	1000	NG/AD/11/08/0033	1.95	0.51	0.28	3.63	2.9E-11	0.81	1.25E-06	5,487,389.98
20	10	500	NGB/OG/0055	4.20	0.24	0.59	1.69	2.2E-11	0.76	1.15E-06	14,466,755.40
21	8	1000	NG/OA/11/08/063	5.25	0.19	0.74	1.35	2.48E-11	0.69	1.13E-06	6,416,706.02
22	10	500	NG/OA/11/08/063	15.63	0.06	2.21	0.45	2.9E-11	1.00	1.28E-06	10,974,779.96
23	8	1000	NG/AD/11/08/0033	5.32	0.19	0.75	1.33	3.2E-11	0.89	1.15E-06	4,972,947.17
24	12	1000	NGB/OG/0055	3.75	0.27	0.53	1.88	1.8E-11	0.50	1.17E-06	8,840,794.96
25	10	1500	NG/AD/11/08/0033	4.20	0.24	0.59	1.69	3E-11	1.43	1.53E-06	3,536,317.99
26	10	1500	NG/OA/11/08/063	6.05	0.17	0.86	1.17	2.32E-11	1.10	9.94E-07	4,572,824.98
27	12	1000	NG/AD/11/08/0033	1.95	0.51	0.28	3.63	2.9E-11	0.81	1.25E-06	5,487,389.98
28	12	1000	NG/AD/11/08/0033	1.95	0.51	0.28	3.63	2.9E-11	0.81	1.25E-06	5,487,389.98
29	16	1000	NG/AD/11/08/0033	7.41	0.14	1.05	0.95	2.8E-11	0.78	1.12E-06	5,683,368.19
30	14	1500	NG/AD/11/08/0033	2.45	0.41	0.35	2.88	2.8E-11	1.33	1.65E-06	3,788,912.13
31	14	500	NG/OA/11/08/063	6.78	0.15	0.96	1.04	3E-11	1.03	1.13E-06	10,608,953.96
32	14	1500	NG/OA/11/08/063	5.96	0.17	0.84	1.19	2.6E-11	1.24	1.07E-06	4,080,366.91
33	12	1000	NG/OA/11/08/063	4.58	0.22	0.65	1.54	2E-11	0.56	1.07E-06	7,956,715.47
34	10	500	NG/AD/11/08/0033	4.50	0.22	0.64	1.57	3.2E-11	1.10	1.3E-06	9,945,894.33
35	16	1000	NG/OA/11/08/063	5.76	0.17	0.81	1.23	2.7E-11	0.75	1.13E-06	5,893,863.31
36	12	1000	NG/OA/11/08/063	4.58	0.22	0.65	1.54	2E-11	0.56	1.07E-06	7,956,715.47
37	12	1000	NGB/OG/0055	3.75	0.27	0.53	1.88	1.8E-11	0.50	1.17E-06	8,840,794.96
38	12	1	NGB/OG/0055	7.41	0.14	1.05	0.95	1.38E-07	4928.57	1.1E-06	1,153,147.17
39	12	2000	NG/AD/11/08/0033	1.93	0.52	0.27	3.67	2.5E-11	1.67	8.9E-07	3,182,686.19

M=Moisture, F = frequency, R = Resistance, G = Conductance, ρ = Resistivity, σ = Conductivity, C = Capacitance, ε = Dielectric constant, L = Inductance, X = Capacitance reactance (Impedance)

Table 4.5: Modeling Summary for electrical properties of cowpea seeds

Design Summary										
Design Expert	10.0.1.0									
Study Type	Response Surface									
Design Type	Central Composite									
Sub type	Randomized									
Runs	39									
Blocks	No Blocks									
Factor	**Units**	**Type**	**Subtype**	**Min**	**Max**	**Coded**	**Values**	**Mean**	**Std. Dev.**	
M	%	Num	Cont.	8	16	FALSE	1 = 14	12	1.947	
F	Hz	Num	Cont.	1	2000	FALSE	1 = 1500	1000.08	486.502	
V		Cat	Nominal	055	063		Levels:	3		
Response	**Units**	**Obs**	**Analysis**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Ratio**	**Trans**	**Model**
R	ohms	39	Poly	1.926	15.625	4.795	2.910	8.111	None	Quadratic
G	S	39	Poly	0.064	0.519	0.267	0.129	8.111	Inverse Sqrt	Quadratic
ρ	ohms/m	39	Poly	0.272	2.209	0.678	0.411	8.111	Natural Log	Quadratic
σ	S/m	39	Poly	0.453	3.671	1.888	0.910	8.111	None	Cubic
C	F	39	Poly	1.80E-11	1.38E-07	1.02E-08	3.58E-08	7666.670	None	Quadratic
ε		39	Poly	0.500	4928.57	365.288	1279.380	9857.140	None	Quadratic
L	H	39	Poly	6.02E-07	9.04E+21	2.32E+20	1.45E+21	1.50E+28	None	Cubic
X	ohms	39	Poly	1.15E+06	1.45E+07	6.54E+06	3.16E+06	12.5455	None	Quadratic

M=Moisture, F = frequency, R = Resistance, G = Conductance, ρ = Resistivity, σ = Conductivity, C = Capacitance, ε = Dielectric constant, L = Inductance, X = Capacitance reactance, Obs is observation, Min is Minimum, Max is Maximum, Cont is continuous, Num is Numerical, Cat is Category, Std. Dev. is Standard deviation, Trans is Transformation.

4.1.2 Optimization of Optical and Electrical Properties of Cowpea Seeds

Optimization of optical properties was carried out for colour (L* a* b*), absorbance, and reflectance and transmittance properties. The first goal of the optimization was to obtain the optimum colour (L* a* b*) properties, among the range of moisture contents and cowpea varieties used for this study. The second goal was to obtain the optimum absorbance, and reflectance and transmittance properties, among the range of moisture content, wavelength and cowpea varieties used for this study. For both, the first and the second goals, optimal solutions each were obtained with desirability (a mathematical optimum objective function that ranges from zero outside of the limits to one at the goal) of 1 (Appendix D3 & D4). Optimized values obtained for the first goal for colour properties, range from 'L' (38 – 92%), 'a' (0.7 - 7%) and 'b' (14 – 27%) with a desirability of 1. The optimum absorbance, and reflectance and transmittance properties obtained for the second goal; range from absorbance (0.7 – 1.5%), and reflectance (0.01 – 0.3%) and transmittance (0.5 – 7.1%) with a desirability of 1. Among the solutions for the first and second goals; choice for optical sensors selection can be taken. This will depend on the desire and competence of the designer.

Optimization of electrical properties was done for resistance, conductance, resistivity, conductivity, capacitance, dielectric constant, inductance, capacitance reactance (impedance). The goal of this optimization was to achieve optimal range of values for the electrical responds measured; within the moisture and current frequency range used to performed this experiment. Optimal solutions were obtained (Appendix D5). Optimal results obtained ranged from 4 – 6.5Ω, 0.1 – 0.28 S, 0.5 – 0.84 Ω/m, 1.3 – 2 S/m, 1.29E-10 - 3.40E-08F, 4 – 1215, 131072 – 393216 H, 8401708 – 9280112 Ω. These value ranges are for resistance, conductance, resistivity, conductivity, capacitance, dielectric constant, inductance, capacitance reactance (impedance), respectively. Among these optimal solutions, choice can be made base on the electrical property measuring, carrying capacity or sensing range needed.

4.1.3 Automation Design Considerations for the Use of Electrical and Optical Properties for Cowpea Seeds Quality Separation

For automation design purpose, optimal parameters of optical and electrical values were chosen and displayed in Table 4.6, based on optimization of the electrical and optical property. This optimised result shows that, in order to use optical properties to sense and separate cowpea seeds. The moisture of the cowpea seeds should not exceed 16% and should not be below 8% db for optimal performance. Also, when using colour properties for sensing and separating cowpea seeds; the selected sensor should be able to sense colour range of L (40 – 68%) a (1 – 6%) b (14 – 20%). Beyond these value ranges, color sensors performed badly in detecting the colour of cowpea seeds. For the other optical properties, selected sensors should have the ability to sense light absorbance as low as (1 – 1.3%), reflectance (0.02 – 0.3%) and transmittance (2 – 5%). Also, in order to use electrical properties to sense cowpea seeds. Then the seeds moisture should not exceed 13% and should not go below 10% db, for optimum performance. Selection of electrical sensors will depend on the electrical property employed by the sensor for sensing. So, for cowpea seeds sensing using electrical properties, these electrical properties should not exceed values displayed in Table 4.6 for optimal results. These optimum values were Resistance (6.5 Ω), conductance (0.18 S), resistivity (0.84Ω/m), conductivity (1.3 S/m), capacitance (3.4×10^{-8} F), dielectric constant (1,215.62), inductance (393216 H), capacitance reactance (impedance) (8,653,074Ω).

Although, in the design and selection of sensors and other components of the automation unit of the cowpea grading system, only the optimise optical properties were used. Optical experimental results had already shown that colour properties can best be used to detect light better than absorbance, transmittance and reflection properties for cowpea seeds. This information help in the choice of machine vision technology for the automation. The sensor camera range selection was base on the colour properties range obtained from optimisation. These colour range were also used during programing of the raspberry pi board and camera to detect cowpea seeds.

Table 4.6: Optimal ranges of some considered electrical and optical properties of cowpea

Properties	Cowpea Separation Design Consideration	
	Lower Limit	Upper limit
Moisture Content (%) for Optical properties	**8**	**16**
Moisture Content (%) for Electrical properties	**10**	**13**
Wave length (nm)	**420**	**520**
Current Frequency (kHz)	**500**	**500**
L (%)	**40.44**	**68.16**
a (%)	**1.33**	**6.06**
b (%)	**14.99**	**20.19**
Absorbance (%)	**1.06**	**1.29**
Reflectance (%)	**0.024**	**0.31**
Transmittance (%)	**2.52**	**5.21**
Resistance (Ω)	**6.57**	**6.57**
Conductance (S)	**0.18**	**0.18**
Resistivity (Ω/m)	**0.84**	**0.84**
Conductivity (S/m)	**1.34**	**1.34**
Capacitance (F)	**$3.4 x 10^{-8}$**	**$3.4 x 10^{-8}$**
Dielectric Constant	**1,215.62**	**1,215.62**
Inductance (H)	**393216**	**393216**
Capacitance Reactance (Ω)	**8,653,074**	**8,653,074**

4.2 Results Obtained and Steps taken to Correct Some Observations During the Preliminary Developmental Testing Stage of the Grading System

The first (Appendix D6) and the second preliminary designs (Appendix D7) was tested. The following results was obtained and steps were taken to correct the observation:

1. The first design worked on light sensing technology (colour Photo electric sensor) which was found not to be suitable for grains and seeds which have little reflective surface areas. The light sensing technology was replaced with image sensing technology (Pi camera sensor).
2. In the second design, vertical inclined screw conveyor was used to transport cowpea seeds and was found to be breaking the seeds meant for transporting. Also, the speed of the vertical inclined screw conveyor could not be reduced further beyond certain speed limit as the motor was positioned at the top of the conveyor. This seed breaking anomaly was corrected by the introduction of the bucket conveyor to replace the vertical inclined screw conveyor in the third and final design. Also, the motor of the conveyor was placed on the ground to facilitate further reduction of the speed of the conveyor, If the need arises.

4.3 Automation system

4.3.1 Automation System unit test Run

Automated system unit were test run before it was assembled to the system, the result obtained was displayed in Table 4.7. This result only shows the performance of the automation units, on good (healthy) seeds, damaged seeds, stones and broken seeds. This test shows that healthy (good) seeds and damaged (diseased) seeds detection and separation range from 70 – 90% depending on the variety. Broken seed cowpea seed detection and separation ranges from 60 – 80% also depending on the variety. Stones (foreign body) detection and separation was 75%. Delwiche (2008) used high speed biochromatic camera to detect and classify healthy and damage wheat kennels with a detection accuracy of 95%. The reason for the higher detection level maybe due to the speed of the camera used. Although, Dowell *et al.* (2002b) achieved 100% automatic detection and separation of healthy and damage wheat kernels, it was achieved with a combination of high-speed CCD camera and a light reflective filter technology. Also, Sanchez et al. (2019) also used hand

Table 4.7: Test run results of automated Unit before incorporating into the separating system

Cowpea Seed variety / material dropped in	*Percentage Collected at the Accepted outlet*	*Percentage Collected at the rejected out*	*Percentage Total*
Good red seeds (055)	80%	20%	100%
Good white big seeds (033)	90%	10%	100%
Good white small seeds (063)	70%	30%	100%
Damaged red seeds (055)	30%	70%	100%
Damaged white big seeds (033)	10%	90%	100%
Damaged white small seeds (063)	20%	80%	100%
Stones	35%	75%	100%
Broken red seeds (055)	20%	80%	100%
Broken white big seeds (033)	30%	70%	100%
Broken white small seeds (063)	40%	60%	100%

held Raman spectrometer to detect healthy cowpea seeds and insect infected seeds, with an accuracy range of 80 – 100%, depending on the stage of the insect infestation. This result is similar to that obtained in this study for the automation unit testing.

4.4 Evaluation and optimization of the developed system.

The developed system was evaluated by modeling and optimizing the efficiencies, throughputs, maximum capacities, actual utilizations and backlogs of various units and their total in the system. Experimental raw data for calculating these evaluation terms are shown in Appendices D8 – D11.The system was divided into the following units: 1st sieve drum Unit; 2nd sieve drum unit; bucket conveyor unit; metering unit; automation unit. Total system unit depends on the separating parameter being considered.

Table 4.8 displays experimental results obtained for separating efficiencies of the five units of the system, including the total separating efficiency of the system. E1 which is the separating efficiency of the 1st sieve drum, ranged from 58 to 91%. Its lowest value occurred at a drum speed of 80 rpm in grade 2 for cowpea seed variety of 033 (white big seeds). This is because, from design, the best performance of the Trommel drum was at 40 rpm. Also, grade 2 had more impurity to separate. The highest separating efficiency (91%) for E1 occurred at drum speed of 40 rpm for grade 1 using seed variety 033 (white big seeds). This also means the drum worked according to design specification. Also, grade 1 has less impurity to separate. E2 is the separating efficiency of the 2nd sieve drum. The E2 separating efficiency, range from 60 to 97%. Also, its lowest separating efficiency occurs at drum a drum speed of 80 rpm; while the highest separating efficiency occurs at a drum speed of 40 rpm. Similar reasons used to explain the separating efficiency of 1st sieve drum are also applicable for the 2nd sieve drum. These sieve efficiency results obtained in this study were better than that of Adetunji (2012) and Srisang *et al*. (2019) which obtained sieve grading efficiencies range of 63 – 79% and 69 – 79% for cowpea and coffee beans impurity removal. Though, Srisang et al. (2019) employed sieve vibrational method but Adetunji (2012) used sieve drum rotational method as used in this study. E3, which is the efficiency of the bucket conveyor for transporting cowpea seeds into the metering device. These conveyance efficiencies ranged from 94 to 99%. The lowest occurring at bucket speed range of 300 to 350 rpm; while the highest occurring at the bucket speed range from 250 to 300

Table 4.8: Result used for Evaluation, Modeling and Optimization of system Efficiency

Run	Speed of sieve drums	Speeds of bucket conveyor	Speed of seed metering disc	Grade	Variety	E1	E2	E3	E4	E5	Es
	rpm	Rpm	rpm			%	%	%	%	%	%
1	60	300	12	3	055	80.833	80.000	94.872	19.608	77.778	70.618
2	80	250	12	2	055	71.667	71.429	97.674	19.608	68.966	65.869
3	40	250	16	3	063	91.667	97.667	97.300	26.144	82.353	79.026
4	80	350	20	2	055	66.667	78.571	98.029	32.680	76.923	70.574
5	40	350	20	2	033	83.333	97.143	98.226	32.680	89.189	80.114
6	80	350	16	3	033	65.000	73.333	95.436	26.144	90.909	70.164
7	40	300	20	2	063	86.667	94.286	96.349	32.680	81.579	78.312
8	80	350	16	1	063	68.333	60.000	96.184	26.144	82.353	66.603
9	80	250	12	1	033	71.667	64.000	97.497	19.608	94.118	69.378
10	80	250	20	2	063	58.333	80.000	98.548	32.680	80.000	69.912
11	40	250	20	1	033	85.000	94.000	97.810	32.680	90.909	80.080
12	80	350	20	1	033	70.000	62.000	97.603	32.680	92.486	70.954
13	80	350	12	1	055	66.667	63.000	94.927	19.608	73.171	63.474
14	60	350	16	2	063	81.667	85.714	95.263	26.144	83.333	74.424
15	40	300	16	1	033	91.667	95.000	97.293	26.144	91.892	80.399
16	40	350	12	2	055	86.667	96.429	98.726	19.608	68.493	73.985
17	40	250	20	3	055	83.333	97.333	95.848	32.680	76.923	77.224
18	60	300	16	1	063	76.667	84.000	97.164	26.144	79.268	72.648
19	80	250	20	1	055	65.000	64.000	97.760	32.680	77.295	67.347
20	40	250	12	1	055	88.333	96.000	97.293	19.608	77.419	75.731
21	80	300	16	2	033	66.667	81.429	97.938	26.144	89.286	72.293
22	40	350	12	1	063	83.333	92.000	99.336	19.608	80.645	74.985
23	60	250	20	2	055	75.000	87.143	97.017	32.680	71.429	72.654
24	60	250	16	2	063	78.333	88.571	97.991	26.144	80.128	74.234
25	40	250	12	2	033	87.167	94.286	99.543	19.608	90.615	78.244
26	60	300	12	2	063	76.667	90.000	99.898	19.608	82.143	73.663
27	40	300	12	3	033	80.833	96.667	99.642	19.608	90.090	77.368
28	60	350	16	3	055	72.500	86.667	99.538	26.144	72.727	71.515
29	60	350	16	2	063	75.000	88.857	99.491	26.144	79.618	73.822
30	40	350	20	1	055	90.000	91.600	97.549	32.680	74.074	77.181
31	60	250	20	3	033	68.333	82.667	98.201	32.680	90.000	74.376
32	80	250	12	3	055	60.000	80.000	99.897	19.608	76.191	67.139
33	60	300	16	1	063	78.333	86.400	97.060	26.144	82.418	74.071
34	80	250	20	2	033	65.000	80.000	97.212	32.680	90.090	72.996
35	60	250	20	2	055	75.000	90.571	97.483	32.680	71.839	73.515
36	60	350	12	2	033	76.667	91.143	99.229	19.608	90.000	75.329
37	40	300	12	2	063	85.000	97.143	98.121	19.608	80.128	76.000
38	40	300	16	1	033	88.333	95.000	97.395	26.144	91.371	79.649
39	80	350	20	3	063	60.833	82.000	95.386	32.680	81.818	70.544
40	40	250	16	3	063	81.667	97.467	97.350	26.144	82.353	76.996

E1= Efficiency of 1st drum, E2=Efficiency of 2nd drum, E3=Efficiency of bucket conveyor, E4=Efficiency of metering device, E5= efficiency of automation unit, Es = System Efficiency rpm. This occur because high conveyor bucket speed caused the cowpea seeds to break into smaller pieces that the bucket can no longer scoop up. These pieces remain inside the bucket conveyor. E4 are the metering efficiencies of the metering device. These efficiencies range from 19 to 32%. These low efficiencies could be due to design constraints. Design constraints in the sense that these efficiencies were calculated based on the metering device being able to meet certain design value. E5 are the separating efficiencies of the automation unit. Theses efficiencies ranged from 68 to 94%. Observation from the results showed that low automation efficiencies are mostly associated with cowpea variety 055 (Red seeds); while high automation efficiencies were associated with the cowpea variety 063 (white small). These phenomena could be due to pi camera programming, strength or setting. Es are the system efficiencies, which are the total separating efficiencies at different units of the system. System efficiencies ranged from 63 to 80%. Low system efficiencies are mostly associated from high sieve drum and bucket conveyor speed. High system efficiencies are associated with low sieve drum and bucket conveyor speed. Total system efficiency result obtained from this study was close to that obtained by the study of Duan *et al*. (2012) that study the efficiency of the combine processes involve in an automated rice planting machine system. Duan et al. (2012) obtained a total machine system efficiency range of 70 - 95%. Another evaluating parameter to be considered is the system throughput.

Experimental results obtained for throughputs of the system are displayed in Table 4.9. T1 is the impurity separation throughputs of the 1st sieve drum. These separation throughputs ranged from 0.02 to 0.6 kg/hr. Low throughput occurs at high sieve drum speeds while high throughput occurs at low drum speeds. This was caused by the same explanation as that explained for sieve drum separating efficiencies. T2 is the impurity separation throughputs of the 2nd sieve drum. These separation throughputs ranged from 0.03 to 0.4 kg/hr. T2 has the same behaviors and explanations as in T1. Akatuhurira *et al.* (2021) that used similar rotating sieve drum to separate impurity from maize, beans, and groundnuts, had throughputs of 576.5 kg/h, 375.8 kg/h, and 377.4 kg/h, respectively. These high through puts from their study and the low throughputs from this study, were from the methods of calculating the throughputs. This study considered the weight of impurity removed from cleaned seeds per hour, while Akatuhurira et al. (2021) considered the weight of the cleaned seeds/grain removed from the impurity per hour. T3 are the impurity separation throughput

Table 4.9: Result used for Evaluation, Modeling and Optimization of system Throughput

Run	Speed of sieve drums	Speeds of bucket conveyor	Speed of seed metering disc	Grade	variety	T1	T2	T3	Ts
	rpm	rpm	rpm			kg/hr	kg/hr	kg/hr	kg/hr
1	60	300	12	3	055	0.323	0.179	1.129	1.631
2	80	250	12	2	055	0.108	0.057	0.606	0.770
3	40	250	16	3	063	0.647	0.488	2.100	3.235
4	80	350	20	2	055	0.100	0.073	3.000	3.173
5	40	350	20	2	033	0.250	0.166	2.750	3.166
6	80	350	16	3	033	0.195	0.143	1.818	2.156
7	40	300	20	2	063	0.325	0.244	2.583	3.153
8	80	350	16	1	063	0.098	0.038	0.700	0.835
9	80	250	12	1	033	0.096	0.043	0.571	0.710
10	80	250	20	2	063	0.171	0.078	1.967	2.216
11	40	250	20	1	033	0.243	0.124	1.600	1.967
12	80	350	20	1	033	0.102	0.039	1.231	1.372
13	80	350	12	1	055	0.093	0.037	0.500	0.630
14	60	350	16	2	063	0.158	0.086	1.136	1.380
15	40	300	16	1	033	0.275	0.119	0.680	1.074
16	40	350	12	2	055	0.274	0.193	0.690	1.156
17	40	250	20	3	055	0.500	0.374	2.857	3.732
18	60	300	16	1	063	0.124	0.058	0.520	0.702
19	80	250	20	1	055	0.089	0.039	1.231	1.358
20	40	250	12	1	055	0.028	0.117	0.429	0.574
21	80	300	16	2	033	0.098	0.070	1.190	1.358
22	40	350	12	1	063	0.294	0.131	0.577	1.002
23	60	250	20	2	055	0.150	0.094	1.846	2.090
24	60	250	16	2	063	0.152	0.098	1.087	1.337
25	40	250	12	2	033	0.249	0.165	0.875	1.289
26	60	300	12	2	063	0.144	0.086	0.852	1.082
27	40	300	12	3	033	0.462	0.345	1.333	2.140
28	60	350	16	3	055	0.272	0.203	1.333	1.808
29	60	350	16	2	063	0.145	0.091	1.042	1.278
30	40	350	20	1	055	0.300	0.115	1.333	1.748
31	60	250	20	3	033	0.256	0.194	2.647	3.097
32	80	250	12	3	055	0.206	0.150	1.143	1.499
33	60	300	16	1	063	0.127	0.061	0.577	0.765
34	80	250	20	2	033	0.098	0.072	2.308	2.477
35	60	250	20	2	055	0.150	0.101	1.786	2.036
36	60	350	12	2	033	0.144	0.100	0.964	1.208
37	40	300	12	2	063	0.300	0.243	0.962	1.504
38	40	300	16	1	033	0.252	0.113	0.750	1.115
39	80	350	20	3	063	0.209	0.164	2.647	3.020
40	40	250	16	3	063	0.613	0.487	2.100	3.200

T1=Throughput of 1st drum, T2=Throughput of 2nd drum, T3=Throughput of sensing unit, Ts=system Throughput of the automated unit. These separation throughputs ranged from 0.4 to 3 kg/hr. high throughputs is observed to be associated to low metering speed while low throughput is associated with high throughputs. This could be explained from the fact that, the automation units are processing impurity faster that it was fed with sample. Dowell *et al.* (2002b) used combination of high-speed CCD camera and a light reflective filter technology to achieved a separating throughput 8,800 kg/h for impurity in bulk wheat grains. The reason for this high throughput as compares with that obtained in this study is the same as explained for that of the rotating sieve drums. Ts is the system throughput, which is the sum total of throughputs from different units of the system. System impurity separation throughputs ranged from 0.5 to 3.7 kg/hr. After the impurity separation throughput, another evaluation parameter considered was the maximum impurity separation capacity.

Maximum impurity separation capacities of the system at its unit parts are shown in Table 4.10. MC1 are the maximum impurity separation capacities of the 1st sieve drum. These capacities ranged from 0.3 to 7 kg/12 hrs. Low maximum capacities are associated with high sieve drum speed; while high maximum capacities are associated with low sieve drum speeds. The explanation of this behavior is the same as that of separation efficiencies of the sieve drum. MC2 are the maximum impurity separation capacities of the 2nd sieve drum. These capacities (MC2) ranged from 0.4 to 5.8 kg/12 hrs. Also, low maximum capacities of the 2nd sieve drum are associated with high sieve drum speed; while high maximum capacities are associated with low sieve drum speeds. The explanation of this behavior is the same as that of separation efficiencies of the sieve drum. MC3 are the maximum impurity separation capacities for the automation units. They ranged from 5 to 36 kg/12 hrs. MCs are the maximum impurity separating capacities of the whole system. They ranged from 6 to 44 kg/12 hrs. Again, another evaluation parameter is the actual utilization.

Actual utilization which is the usage capacity carried out on the system during the separation. These utilizations are displayed in Table 4.11. The AU1, AU2, AU3, AUs; are actual utilization of 1st sieve drum, 2nd sieve drum, automation unit and the whole system respectively. All actual utilization of for AU1, AU2, AU3, AUs was 0.083 each for all experimental trials. 0.083 is the same as saying 8.3%. This means that only 8.3% of the usable system capacity was used during the experiment. That is, the 2kg of sample used all

Table 4.10: Result used for Evaluation, Modeling and Optimization of Maximum Capacity

Run	Speed of sieve drums	Speeds of bucket conveyor	Speed of seed metering disc	Grade	Variety	MC1	MC2	MC3	MCs
	rpm	rpm	rpm			kg/12hrs	kg/12hrs	kg/12hrs	kg/12hrs
1	60	300	12	3	055	3.880	2.149	13.548	19.578
2	80	250	12	2	055	1.290	0.682	7.273	9.245
3	40	250	16	3	063	7.765	5.860	25.200	38.825
4	80	350	20	2	055	1.200	0.880	36.000	38.080
5	40	350	20	2	033	3.000	1.990	33.000	37.990
6	80	350	16	3	033	2.340	1.714	21.818	25.872
7	40	300	20	2	063	3.900	2.933	31.000	37.833
8	80	350	16	1	063	1.171	0.450	8.400	10.021
9	80	250	12	1	033	1.147	0.519	6.857	8.523
10	80	250	20	2	063	2.049	0.933	23.607	26.589
11	40	250	20	1	033	2.914	1.484	19.200	23.598
12	80	350	20	1	033	1.229	0.471	14.769	16.469
13	80	350	12	1	055	1.116	0.445	6.000	7.561
14	60	350	16	2	063	1.897	1.029	13.636	16.562
15	40	300	16	1	033	3.300	1.425	8.160	12.885
16	40	350	12	2	055	3.284	2.314	8.276	13.874
17	40	250	20	3	055	6.000	4.492	34.286	44.778
18	60	300	16	1	063	1.492	0.690	6.240	8.422
19	80	250	20	1	055	1.064	0.463	14.769	16.296
20	40	250	12	1	055	0.335	1.405	5.143	6.882
21	80	300	16	2	033	1.171	0.844	14.286	16.301
22	40	350	12	1	063	3.529	1.577	6.923	12.030
23	60	250	20	2	055	1.800	1.126	22.154	25.080
24	60	250	16	2	063	1.819	1.181	13.043	16.044
25	40	250	12	2	33	2.989	1.980	10.500	15.469
26	60	300	12	2	063	1.725	1.036	10.222	12.983
27	40	300	12	3	033	5.543	4.143	16.000	25.686
28	60	350	16	3	055	3.263	2.438	16.000	21.700
29	60	350	16	2	063	1.742	1.098	12.500	15.340
30	40	350	20	1	055	3.600	1.374	16.000	20.974
31	60	250	20	3	033	3.075	2.325	31.765	37.165
32	80	250	12	3	055	2.469	1.800	13.714	17.983
33	60	300	16	1	063	1.524	0.730	6.923	9.178
34	80	250	20	2	033	1.170	0.862	27.692	29.724
35	60	250	20	2	055	1.800	1.208	21.429	24.436
36	60	350	12	2	033	1.725	1.196	11.571	14.493
37	40	300	12	2	063	3.600	2.914	11.538	18.053
38	40	300	16	1	033	3.029	1.357	9.000	13.386
39	80	350	20	3	063	2.503	1.968	31.765	36.236
40	40	250	16	3	063	7.350	5.848	25.200	38.398

MC1= Maximum Capacity of 1st drum, MC2= Maximum Capacity of 2nd drum, MC3= Maximum Capacity of sensing unit, MCs=System Maximum Capacity

Table 4.11: Result used for Evaluation, Modeling and Optimization of System Actual Utilization

Run	Speed of sieve drums	Speeds of bucket conveyor	Speed of seed metering disc	Grade	Variety	AU1	AU2	AU3	AUs
	Rpm	rpm	rpm						
1	60	300	12	3	055	0.083	0.083	0.083	0.083
2	80	250	12	2	055	0.083	0.083	0.083	0.083
3	40	250	16	3	063	0.083	0.083	0.083	0.083
4	80	350	20	2	055	0.083	0.083	0.083	0.083
5	40	350	20	2	033	0.083	0.083	0.083	0.083
6	80	350	16	3	033	0.083	0.083	0.083	0.083
7	40	300	20	2	063	0.083	0.083	0.083	0.083
8	80	350	16	1	063	0.083	0.083	0.083	0.083
9	80	250	12	1	033	0.083	0.083	0.083	0.083
10	80	250	20	2	063	0.083	0.083	0.083	0.083
11	40	250	20	1	033	0.083	0.083	0.083	0.083
12	80	350	20	1	033	0.083	0.083	0.083	0.083
13	80	350	12	1	055	0.083	0.083	0.083	0.083
14	60	350	16	2	063	0.083	0.083	0.083	0.083
15	40	300	16	1	033	0.083	0.083	0.083	0.083
16	40	350	12	2	055	0.083	0.083	0.083	0.083
17	40	250	20	3	055	0.083	0.083	0.083	0.083
18	60	300	16	1	063	0.083	0.083	0.083	0.083
19	80	250	20	1	055	0.083	0.083	0.083	0.083
20	40	250	12	1	055	0.083	0.083	0.083	0.083
21	80	300	16	2	033	0.083	0.083	0.083	0.083
22	40	350	12	1	063	0.083	0.083	0.083	0.083
23	60	250	20	2	055	0.083	0.083	0.083	0.083
24	60	250	16	2	063	0.083	0.083	0.083	0.083
25	40	250	12	2	033	0.083	0.083	0.083	0.083
26	60	300	12	2	063	0.083	0.083	0.083	0.083
27	40	300	12	3	033	0.083	0.083	0.083	0.083
28	60	350	16	3	055	0.083	0.083	0.083	0.083
29	60	350	16	2	063	0.083	0.083	0.083	0.083
30	40	350	20	1	055	0.083	0.083	0.083	0.083
31	60	250	20	3	033	0.083	0.083	0.083	0.083
32	80	250	12	3	055	0.083	0.083	0.083	0.083
33	60	300	16	1	063	0.083	0.083	0.083	0.083
34	80	250	20	2	033	0.083	0.083	0.083	0.083
35	60	250	20	2	055	0.083	0.083	0.083	0.083
36	60	350	12	2	033	0.083	0.083	0.083	0.083
37	40	300	12	2	063	0.083	0.083	0.083	0.083
38	40	300	16	1	033	0.083	0.083	0.083	0.083
39	80	350	20	3	063	0.083	0.083	0.083	0.083
40	40	250	16	3	063	0.083	0.083	0.083	0.083

AU1= Actual Utilization of 1st drum, AU2= Actual Utilization of 2nd drum, AU3= Actual Utilization of sensing Unit, AUs= System Actual Utilization through the experiments represent only 8.3% of what the system can handle at a time. This means that if 2 kg represent 8.3%, then 24 kg will represent 100%. Therefore, this means that the system and its unit component can handle 24kg of sample at a time. The last evaluation parameter considered was the backlog.

Backlog which is the amount in weight (kg) of sample which was left behind that the system or units of the system did not process. Backlogs from the system are shown in Table 4.12. B1and B2 was the backlogs from the $1^{st}$and 2^{nd} sieve drums. They ranged from 0.001 to 0.005 kg and 0 to 0.004 kg respectively. High backlogs in the sieve drums are caused by drum from bucket conveyor. Their values ranged from 0.002 to 0.1 kg. B4 are backlogs other than stone and sand coming out of any part of the system. Their values ranged from 0.01 to 0.08kg. Bs was the system backlogs which are the total backlogs in the system at the end of separating process. Their values ranged from 0.03 to 0.18 kg.

4.4.1 System Modeling Evaluation

Evaluation of the system involves modeling the system so the system can be optimized. Summary of the whole system modeling is displayed in Table 4.13. I-optimal response surface design was used in modeling all evaluation parameters for the system. Numerical factors that were considered includes speeds of sieve drums, bucket convey and metering disc. Categorical factors include seeds variety and impurity grade. These factors were used to develop model equations for evaluating parameters like impurity separating efficiencies, throughputs and maximum capacities. Other evaluating parameters include actual utilization and backlog of the system and its units.

4.4.1.1 System Efficiency Modeling and Evaluation

The efficiencies that were modeled were that of the 1^{st} sieve drum (E1), 2^{nd} sieve drum (E2), Bucket conveyor (E3), metering device (E4), Automation unit (E5) and the entire system (Es). Statistical analyses for developing model equations for these efficiencies are shown in Table 4.14. Four polynomial equations (linear, 2FI, quadratic and cubic) were considered. Linear equation was chosen by the software (Design Expert) for all efficiencies considered in this study. Linear equation was chosen because during statistical analysis of the four polynomials equations considered. It has the lowest 'Sequential p-value' (the

Table 4.12: Result used for Evaluation, Modeling and Optimization of System Backlog

Run	Speed of sieve drums	Speeds of bucket conveyor	Speed of seed metering disc	Grade	variety	B1	B2	B3	B4	Bs
	rpm	rpm	rpm			kg	kg	kg	kg	Kg
1	60	300	12	3	055	0.002	0.003	0.100	0.028	0.134
2	80	250	12	2	055	0.002	0.002	0.045	0.056	0.104
3	40	250	16	3	063	0.001	0.000	0.053	0.011	0.066
4	80	350	20	2	055	0.002	0.002	0.038	0.063	0.104
5	40	350	20	2	033	0.001	0.000	0.035	0.015	0.051
6	80	350	16	3	033	0.004	0.004	0.088	0.053	0.149
7	40	300	20	2	063	0.001	0.000	0.072	0.016	0.089
8	80	350	16	1	063	0.002	0.002	0.073	0.080	0.157
9	80	250	12	1	033	0.002	0.002	0.048	0.075	0.126
10	80	250	20	2	063	0.005	0.001	0.028	0.059	0.094
11	40	250	20	1	033	0.001	0.000	0.043	0.027	0.071
12	80	350	20	1	033	0.002	0.002	0.046	0.074	0.123
13	80	350	12	1	055	0.002	0.002	0.097	0.081	0.182
14	60	350	16	2	063	0.001	0.001	0.092	0.047	0.141
15	40	300	16	1	033	0.001	0.000	0.053	0.032	0.086
16	40	350	12	2	055	0.001	0.000	0.025	0.025	0.051
17	40	250	20	3	055	0.002	0.000	0.081	0.024	0.108
18	60	300	16	1	063	0.001	0.001	0.055	0.052	0.109
19	80	250	20	1	055	0.002	0.002	0.043	0.073	0.120
20	40	250	12	1	055	0.001	0.000	0.053	0.032	0.086
21	80	300	16	2	033	0.002	0.001	0.040	0.050	0.094
22	40	350	12	1	063	0.001	0.000	0.013	0.031	0.046
23	60	250	20	2	055	0.002	0.001	0.058	0.045	0.106
24	60	250	16	2	063	0.001	0.001	0.039	0.048	0.089
25	40	250	12	2	033	0.001	0.000	0.009	0.020	0.030
26	60	300	12	2	063	0.001	0.001	0.002	0.027	0.031
27	40	300	12	3	033	0.002	0.000	0.007	0.023	0.033
28	60	350	16	3	055	0.003	0.002	0.009	0.029	0.044
29	60	350	16	2	063	0.002	0.001	0.010	0.025	0.038
30	40	350	20	1	055	0.001	0.000	0.048	0.032	0.081
31	60	250	20	3	033	0.004	0.003	0.035	0.034	0.076
32	80	250	12	3	055	0.005	0.003	0.002	0.049	0.059
33	60	300	16	1	063	0.001	0.001	0.057	0.052	0.111
34	80	250	20	2	033	0.002	0.001	0.054	0.054	0.111
35	60	250	20	2	055	0.002	0.001	0.049	0.042	0.093
36	60	350	12	2	033	0.001	0.001	0.015	0.044	0.061
37	40	300	12	2	063	0.001	0.000	0.037	0.019	0.057
38	40	300	16	1	033	0.001	0.000	0.051	0.032	0.084
39	80	350	20	3	063	0.005	0.003	0.089	0.051	0.148
40	40	250	16	3	063	0.002	0.000	0.052	0.014	0.068

B1= Backlog of 1st drum, B2= Backlog of 2nd drum, B3= Backlog of bucket conveyor, B4= Backlog materials other than stones and sand, Bs= System Backlog

Table 4.13: Summary of Factors and Operational Responses Settings Used for Modeling and Optimization

Experimental Design	
File Version	Design Expert 10.
Study Type	Response Surface
Design Type	I-optimal
Subtype	Randomized
Runs	40
Blocks	No Blocks

Experimental Factors Settings Used for Modeling and Optimization Operating Parameters

Name of Factors	*Units*	*Type*	*Subtype*	*Minimum*	*Maximum*	*Coded*	*Values*	*Mean*	*Std. Dev.*	**Levels:**
speed of sieve drums	rpm	Numeric	Discrete	40	80	FALSE	1=80	59	16.916	3
speeds of bucket conveyor	rpm	Numeric	Discrete	250	350	FALSE	1=350	297.500	43.780	3
speed of seed metering disc	rpm	Numeric	Discrete	12	20	FALSE	1=20	16.1	3.327	3
grade		Categoric	Nominal	1	3					3
variety		Categoric	Nominal	63	55					3

Operational settings Used for Modeling and Optimization

Name of Responses	*Units*	*Runs*	*Analysis*	*Minimum*	*Maximum*	*Mean*	*Std. Dev.*	*Ratio*	*Transformation*	*Model*
Efficiency of 1st drum	%	40	Polynomial	58.333	91.667	76.596	9.343	1.571	None	Linear
Efficiency of 2nd drum	%	40	Polynomial	60.000	97.667	85.338	11.132	1.628	Logit	Linear
Efficiency of bucket conveyor	%	40	Polynomial	94.872	99.898	97.627	1.367	1.053	Logit	Linear
Efficiency of metering device	%	40	Polynomial	19.608	32.680	26.307	5.436	1.667	Square Root	Linear
Efficiency of automation unit	%	40	Polynomial	68.493	94.118	82.058	7.175	1.374	None	Linear
System Efficiency	%	40	Polynomial	63.474	80.399	73.585	4.198	1.267	Logit	Linear
Throughput of 1st drum	kg/hr	40	Polynomial	0.028	0.647	0.220	0.139	23.196	Logit	Quadratic
Throughput of 2nd drum	kg/hr	40	Polynomial	0.037	0.488	0.144	0.111	13.177	Inverse	Quadratic
Throughput of sensing unit	kg/hr	40	Polynomial	0.429	3.000	1.386	0.757	7.000	Inverse Square root	Quadratic
System Throughput	kg/hr	40	Polynomial	0.574	3.732	1.751	0.883	6.506	Inverse Square root	Quadratic
Maximum Capacity of 1st drum	kg/12hrs	40	Polynomial	0.335	7.765	2.645	1.670	23.196	Logit	2 FI
Maximum Capacity of 2nd drum	kg/12hrs	40	Polynomial	0.445	5.860	1.733	1.331	13.177	Inverse	Quadratic
Maximum Capacity of sensing unit	kg/12hrs	40	Polynomial	5.143	36.000	16.635	9.082	7.000	Inverse Square root	Quadratic
System Maximum Capacity	kg/12hrs	40	Polynomial	6.882	44.778	21.014	10.594	6.506	Inverse Square root	Quadratic
Actual Utilization of 1st drum		40	Polynomial	0.083	0.083	0.083	5.62E-17	1.000	None	Linear
Actual Utilization of 2nd drum		40	Polynomial	0.083	0.083	0.083	5.62E-17	1.000	None	Linear
Actual Utilization of sensing Unit		40	Polynomial	0.083	0.083	0.083	0.083	5.62E-17	None	Linear
System Actual Utilization		40	Polynomial	0.083	0.083	0.083	5.56E-17	1.000	None	Linear
Backlog of 1st drum	kg	40	Polynomial	0.001	0.005	0.002	0.001	10.000	Base 10 Log	Linear
Backlog of 2nd drum	kg	40	Polynomial	0.000	0.004	0.001	0.001	20.000	Base 10 Log	Linear
Backlog of bucket conveyor	kg	40	Polynomial	0.002	0.100	0.046	0.026	50.000	Base 10 Log	Linear
Backlog other materials	kg	40	Polynomial	0.011	0.081	0.041	0.019	7.123	None	Linear
System Backlog	kg	40	Polynomial	0.030	0.182	0.090	0.037	5.989	Square Root	Linear

Table 4.14: Statistical Analysis used to Select Model Equation for Efficiency and Throughput

Parameter To be Model	Model Equation to be tested	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	Remark
Efficiency of 1st Sieve Drum	Linear	1.01485E-13	0.7726	0.8686	0.8300	Suggested
	2FI	0.8326	0.578	0.8304	0.1101	
	Quadratic	0.5494	0.5055	0.8198	-2.304	
	Cubic	0.5055		0.8186		Aliased
Efficiency of 2nd Sieve Drum	Linear	3.41429E-15	0.0378	0.8941	0.8631	Suggested
	2FI	0.5511	0.0238	0.8909	-0.2888	
	Quadratic	0.2799	0.0235	0.9017	-1.8788	
	Cubic	0.0235		0.9765		Aliased
Efficiency of Bucket Conveyor	Linear	0.2713	0.3354	0.055	-0.2171	Suggested
	2FI	0.9274	0.1367	-0.3637	-13.9829	
	Quadratic	0.7791	0.0799	-0.5974	-64.9379	
	Cubic	0.0799		0.351		Aliased
Efficiency of Metering Device	Linear	2.84162E-46		0.9988	0.9985	Suggested
	2FI	0.9986		0.9978	0.961	
	Quadratic			1		
	Cubic					Aliased
Efficiency of Automation Unit	Linear	1.92097E-17	0.2806	0.9237	0.9009	Suggested
	2FI	0.0882	0.5363	0.9537	0.6567	
	Quadratic	0.7723	0.3892	0.946	0.1082	
	Cubic	0.3892		0.9531		Aliased
System Efficiency	Linear	6.37395E-18	0.2684	0.9288	0.9074	Suggested
	2FI	0.0501	0.6158	0.962	0.5504	Suggested
	Quadratic	0.2529	0.7235	0.9665	0.5042	
	Cubic	0.7235		0.9574		Aliased
Throughput of 1st Sieve Drum	Linear	6.09581E-08	0.0059	0.6903	0.5806	Suggested
	2FI	0.0082	0.0387	0.8851	-1.0144	
	Quadratic	0.0326	0.1128	0.9355	-0.8769	Suggested
	Cubic	0.1128		0.9694		Aliased
Throughput of 2nd Sieve Drum	Linear	3.9525E-13	0.0003	0.8567	0.8039	
	2FI	1.52605E-06	0.0732	0.9877	0.8739	
	Quadratic	0.0341	0.2039	0.993	0.9062	Suggested
	Cubic	0.2039		0.9956		Aliased
Throughput of sensing Unit	Linear	3.52992E-15	0.0129	0.8939	0.8642	
	2FI	0.4739	0.0089	0.897	-1.0183	
	Quadratic	0.0006	0.1738	0.9748	0.4696	Suggested
	Cubic	0.1738		0.9854		Aliased
System Throughput	Linear	1.0068E-13	0.0023	0.8687	0.8316	
	2FI	0.3872	0.0018	0.8814	-1.3491	
	Quadratic	0.0002	0.0676	0.977	0.3467	Suggested
	Cubic	0.0676		0.9913		Aliased

*Aliased (This means that there are not enough unique design points to independently estimate all the coefficients for this model)*2FI is 2 Factor Interaction Equation probability that the order terms are modeling noise rather than helping explain the trend in the response) and the highest 'Lack of Fit p-value' (the amount the model predictions miss the experimental value). Also, it has the highest 'Adjusted R-Squared' value (measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model); and the highest 'Predicted R-Squared' value (measure of the amount of variation in new data explained by the model). Although, linear equation was chosen for modeling all efficiencies in the system; experimental data generated were not normally distributed, except for that for the 1st sieve drum and the automated unit.

So, data used for generating the final model equations were transformed (process of changing data structure from on form to another, so the data will be normally distributed for statistical analysis) except for data of 1st sieve drum and automated unit. Data transformation choices used were, logit transformation (log of odd ratio) for data of 2nd sieve drum, bucket conveyor and the total system; and Square Root transformation for data of metering device. After transforming these data, the final equations generated are displayed in Appendix D12. Analysis of variance (ANOVA) for the developed efficiencies equations are displayed in Table 4.15. The analysis show that the factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) used to developed the equations of efficiencies for the unit parts of the system were all significant at $p<0.05$; except for the automation unit where metering device speed was not significant at $p<0.05$ to its separating efficiency. This could be because the automation time of processing a single seed had already been fixed to 5 seconds by Raspberry Pi board processor by the manufacturer's design. So, increasing or reducing the seed metering speed will not increase the automation processing time which in turn will not increase its automation efficiency. All equation model developed for the unit's parts of the systems efficiencies were all significant at $p<0.05$. Lack of fit values for all developed equation of unit's parts of the system were all not significant at $p<0.05$, except for 2nd sieve drum which was significant at $p<0.05$ and metering device which do not have any lack of fit value. It is desirable for model's lack of fit not to be significant at $p<0.05$. This is because, lack of fit not being significant at $p<0.05$ means that, the probability that the equation chosen to represent the data behavior was the correct one was greater than 5%.

Table 4.15: Analysis of Variance (ANOVA) of Operational Efficiencies models for the System Optimization

Operational Parameter	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob > F	
Efficiency of 1st Sieve Drum	Model	3002.9	3	1000.97	89.73	9.00616E-17	significant
	Speed of drums	2897.84	1	2897.84	259.77	4.82734E-18	significant
	Grade	112.51	2	56.25	5.04	0.0117	significant
	Residual	401.6	36	11.16			
	Lack of Fit	322.43	31	10.4	0.66	0.7884	not significant
	Pure Error	79.17	5	15.83			
	Cor Total	3404.49	39				
Efficiency of 2nd Sieve Drum	Model	44.87	3	14.96	118.88	9.79037E-19	significant
	Speed of drums	41.57	1	41.57	330.38	1.0107E-19	significant
	Grade	3.75	2	1.87	14.89	1.94162E-05	significant
	Residual	4.53	36	0.13			
	Lack of Fit	4.38	31	0.14	4.75	0.0446	significant
	Pure Error	0.15	5	0.03			
	Cor Total	49.4	39				
Efficiency of Bucket Conveyor	Model	6.91	1	6.91	6.36	0.016	significant
	Speed of metering disc	6.91	1	6.91	6.36	0.016	significant
	Residual	41.25	38	1.09			
	Lack of Fit	37.25	33	1.13	1.41	0.3799	not significant
	Pure Error	4.01	5	0.8			
	Cor Total	48.16	39				
Efficiency of Metering Device	Model	11.18	3	3.73	11352.43	1.30065E-53	significant
	Speed of metering disc	11.16	1	11.16	33986.07	3.65379E-55	significant
	Variety	2.75E-03	2	1.37E-03	4.18	0.0233	significant
	Residual	0.012	36	3.28E-04			
	Lack of Fit	0.012	31	3.81E-04			
	Pure Error	0	5	0			
	Cor Total	11.19	39				
Efficiency of Automation Unit	Model	1878.24	5	375.65	98.57	3.1148E-19	significant
	Speed of metering disc	1.02	1	1.02	0.27	0.6086	not significant
	Grade	41.87	2	20.94	5.49	0.0086	significant
	Variety	1811.6	2	905.8	237.69	1.03624E-20	significant
	Residual	129.57	34	3.81			
	Lack of Fit	117.49	29	4.05	1.68	0.2971	not significant
	Pure Error	12.08	5	2.42			
	Cor Total	2007.81	39				
System Efficiency	***Model***	***4.42***	***7***	***0.63***	***73.68***	***6.374E-18***	***significant***
	Speed of drums	***3.43***	***1***	***3.43***	***400.78***	***1.158E-19***	***significant***
	Bucket conveyor speed	***3.91E-03***	***1***	***3.91E-03***	***0.46***	***0.5045***	***not significant***
	Speed of metering disc	***0.25***	***1***	***0.25***	***29.41***	***5.804E-06***	***significant***
	Grade	***0.056***	***2***	***0.028***	***3.27***	***0.051***	***significant***
	Variety	***0.54***	***2***	***0.27***	***31.4***	***2.842E-08***	***significant***
	Residual	***0.27***	***32***	***8.57E-03***			
	Lack of Fit	***0.25***	***27***	***9.21E-03***	***1.79***	***0.2684***	***not significant***
	Pure Error	***0.026***	***5***	***5.13E-03***			
	Cor Total	***4.69***	***39***				

So, for the 2nd sieve drum efficiency equation to be significant at $p<0.05$ and still be chosen; was from the fact that after data transformation, the 'R-square' value (A measure of the amount of variation around the mean explained by the model) and the 'Predicted R-square' value of this equation became very high. This means that, even though the model equation was not a true representation of the data behavior. It has the power to predict correctly the data within the experimental range (R-square) and outside the experimental range (Predicted R-square). Also, the model equation for the efficiency of metering device has no lack of fit value; but was still chosen because, after data transformation, the equation R-square value and prediction R-square value became very high. This also means that, this equation can still perform better with a lack of fit value. Analysis of variance (ANOVA) carried out for the developed model equation for the entire system shows that, the model equation was significant at $p<0.05$. This means that the error that the chosen model was the wrong model was less than 5%. All factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) used in developing the equation were all significant at $p<0.05$; except for speed of bucket conveyor which was not significant at $p<0.05$. This could be that no impurity separation took place at the bucket conveyor. So, the system does not consider it as being part of the efficiency of separation of the system. The lack of fit for the system separating efficiency was not significant at $p<0.5$. This means that the probability that the equation we chose for modeling the behavior of the separating efficiency of the entire system is the correct one was greater than 5%. Now let evaluate the effects of the operating factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) to the efficiencies of the system.

The effect of the evaluating numerical factors (speeds of sieve drums, bucket conveyor and metering device speeds of sieve drums, bucket conveyor and metering device) on the unit components separating efficiencies of the system are graphically displayed in Figure 4.1. The figure shows that the efficiency of the 1st sieve drum (E1) decreases linearly with increase in drum speed. This is because from the design calculation, the effective sieve drum speed was calculated to be 40 rpm. The drum speed was increase to deviate from the design speed. Evaluation result shows that moving away from the design speed reduces the efficiency of the 1st sieve drum separating efficiency. In the case of the separating efficiency of the 2nd sieve drum (E2), increase in the drum speed reduces the separating efficiency

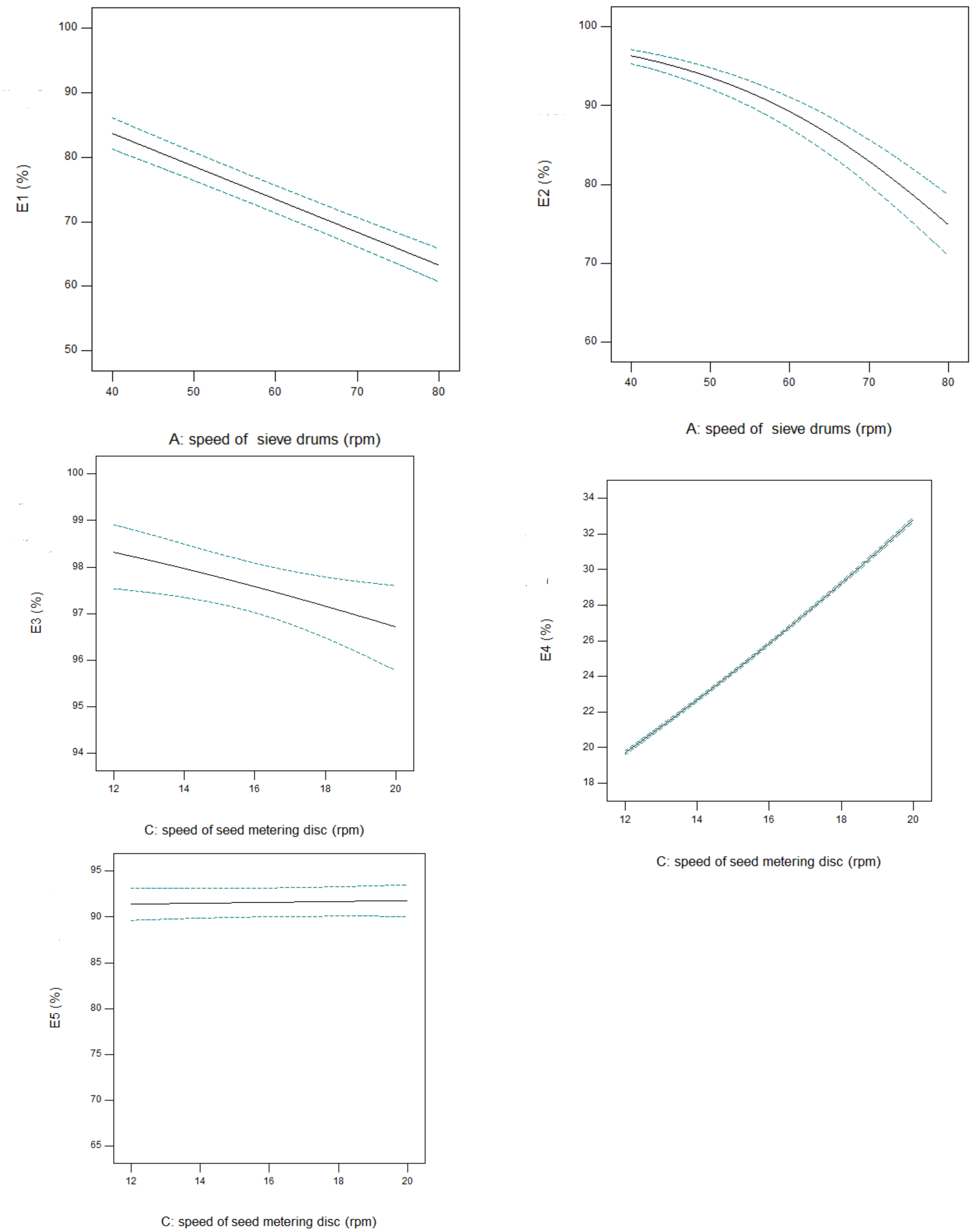


Figure 4.1: Typical Graphs of effect of numerical factors that affect the efficiencies of first (E1) and second (E2) sieve drums, bucket conveyor (E3), metering device (E4) and automation unit (E5) of the system

quadratically. The same explanation used for the 1st sieve drum speed can also be used to explain the 2nd sieve drum speed. Except for the quadratic reduction behavior, this was caused by the increase in sieve holes size of the 2nd sieve. The bucket conveyor efficiency (E3) was compared with the metering device speed. This shows a linear decrease the bucket conveying efficiency (E3) as the metering device speed increases. This could be because; these increments are so small comparing to the speed of the bucket conveyor speed that it negatively affects the performance of the bucket conveyor. The efficiency of the metering device (E4) shows linear increment with increase of the metering disc speed. This phenomenon could be caused by the metering disc, rotating fast enough to avoid seeds in the disc hole been crushed and broken in between the disc drum housing before the seeds are dropped out. Graph of the separating efficiency of the automated unit (E5) against the metering device speed; shows that metering speed of the seeds had no effect on the efficiency of the automation device. This is because the time a seed speed in the automated unit during processing was determined by the processing programming and the speed of the raspberry pi board processor. So, no matter how fast you metered the seeds. Each seed would have to spend 5 second within the automated unit before it is processed. Figure 4.2 display the effects of categorical factors (seed variety and grade) on the efficiencies of the unit components of the system. Seed variety had no effect on the efficiency of the 1st sieve drum separating efficiency (E1); while (E1) reduces slightly as the grade of the sample is increased (that is increase in impurity in the sample). This slightly reduction in separating efficiency was due to increment in stones in the sample. This caused the sieve holes to be blocked for a short period of time, until it was cleared during the separating process. Both seed variety and grade do not have any effects on the separating efficiency of 2nd sieve drum (E2). This is because cowpea seeds do not pass through the 2nd sieve drum but was rather convey out of the drum by an internal screw conveyor in the drum. This conveyor all sizes of seeds. Also, the only impurity removed here are sand and dust. These can easily pass through the 2nd sieve drum. The efficiency of the bucket conveyor (E3) and the metering device (E4) was affected by neither the seed variety nor the grade. This is because no seed separation occurs here only transportation and metering of seeds occur respectively.

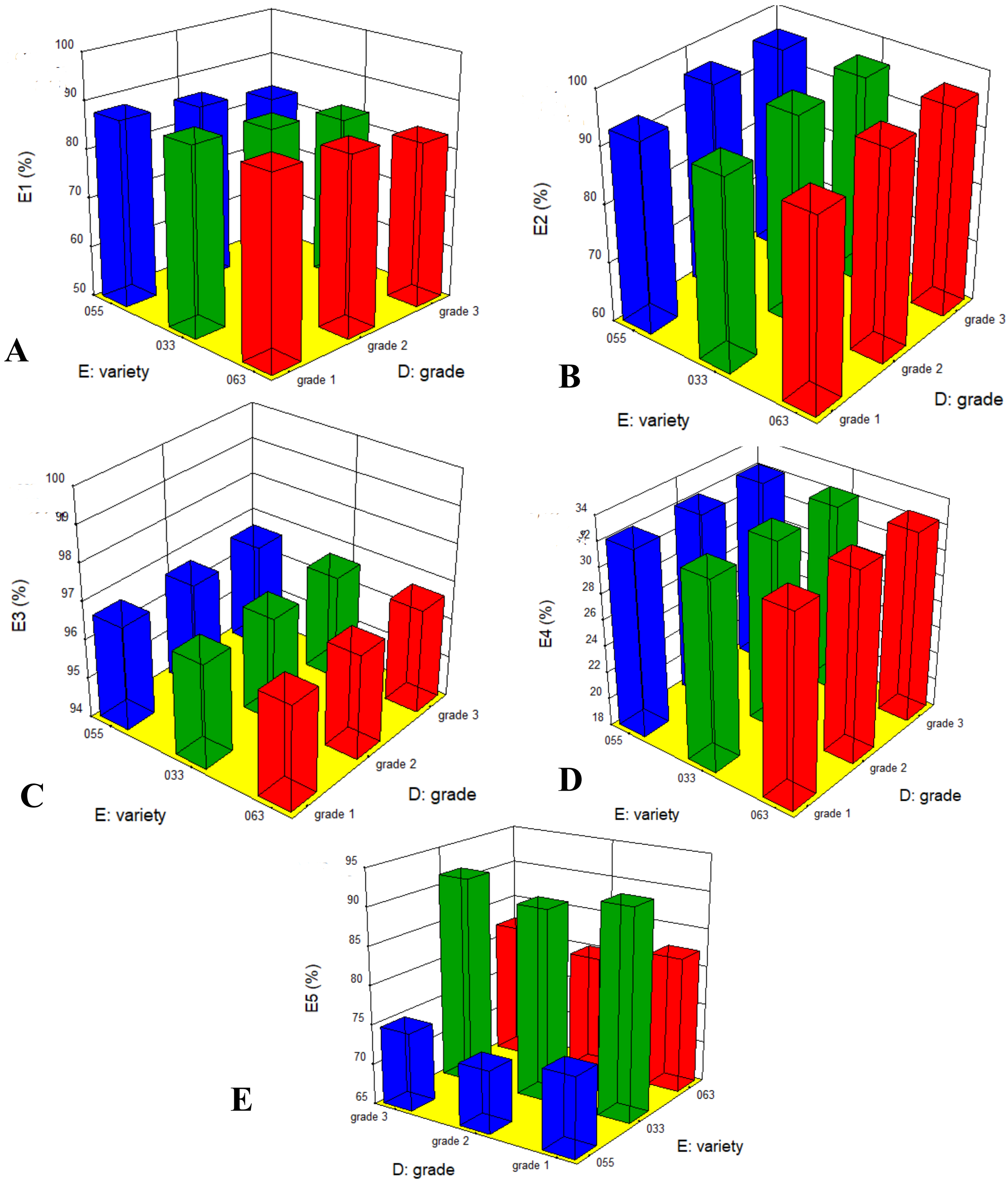


Figure: 4.2 Typical Graphs of effect of categorical factors that affect the efficiencies of the E1 (A), E2 (B), E3 (C), E4 (D) and E5 (E) of the system

Separating efficiency of the automated unit (E5) was affected by both the seed variety and grade. The variety 033 (white big seeds) had the highest separating efficiency followed by 063 (white small seeds) then 055 (red seeds). This is because the bright colour and the size of variety 033 were easier for the raspberry pi camera to detect; than the variety 055 that have a red colour that was not uniformly distributed across the seed batch (that is some are light res while others are dark red). Also, as the grade is increased E5 decreased and then increase again. This could be because of certain impurity in the mix at grade 2, which is causing this reduction in the separating efficiency. After looking at unit components of the system, then the effect of these evaluating factors on the entire system is now considered.

The effect of the evaluating factors on the separating efficiency of whole system was displayed in Figure 4.3. A 3-D graph of speed of bucket conveyor and drum against system separating efficiency (Es) shows that speed of bucket conveyor had no effect on the separation system, just as the ANOVA suggested (Table 4.15). It also shows that Es decreases as the drums speeds increases. These phenomena have already been explained using the table ANOVA. Again a 3-D graph of speed of metering device and drum against the separating efficiency of the system (Es); show that metering device speed has no effect on Es, while Es decrease as drums speed increase. These phenomena have already been explained using the ANOVA table. A plotted 3-D categorical graph of seeds variety and grade against system separating efficiency; show a small increment in Es as the grade of the sample increase. Also, it shows that Es in highest at variety 033 and lowest that variety 055.These phenomena occur as a result of the effect of the separating efficiency of the automation unit, which has already been explained. A cube graph plotted for speed of bucket conveyor, drums and metering device against separating efficiency of the system (Es) also show the effect on these factors on Es.

4.4.1.2 System Throughput Modeling and Evaluation

The impurity separating throughputs that were modeled were that of the 1st sieve drum (T1), 2nd sieve drum (T2), Automation unit (T3) and the entire system (Ts). Statistical analyses for choosing model equations for these throughputs are shown in table 4.13.

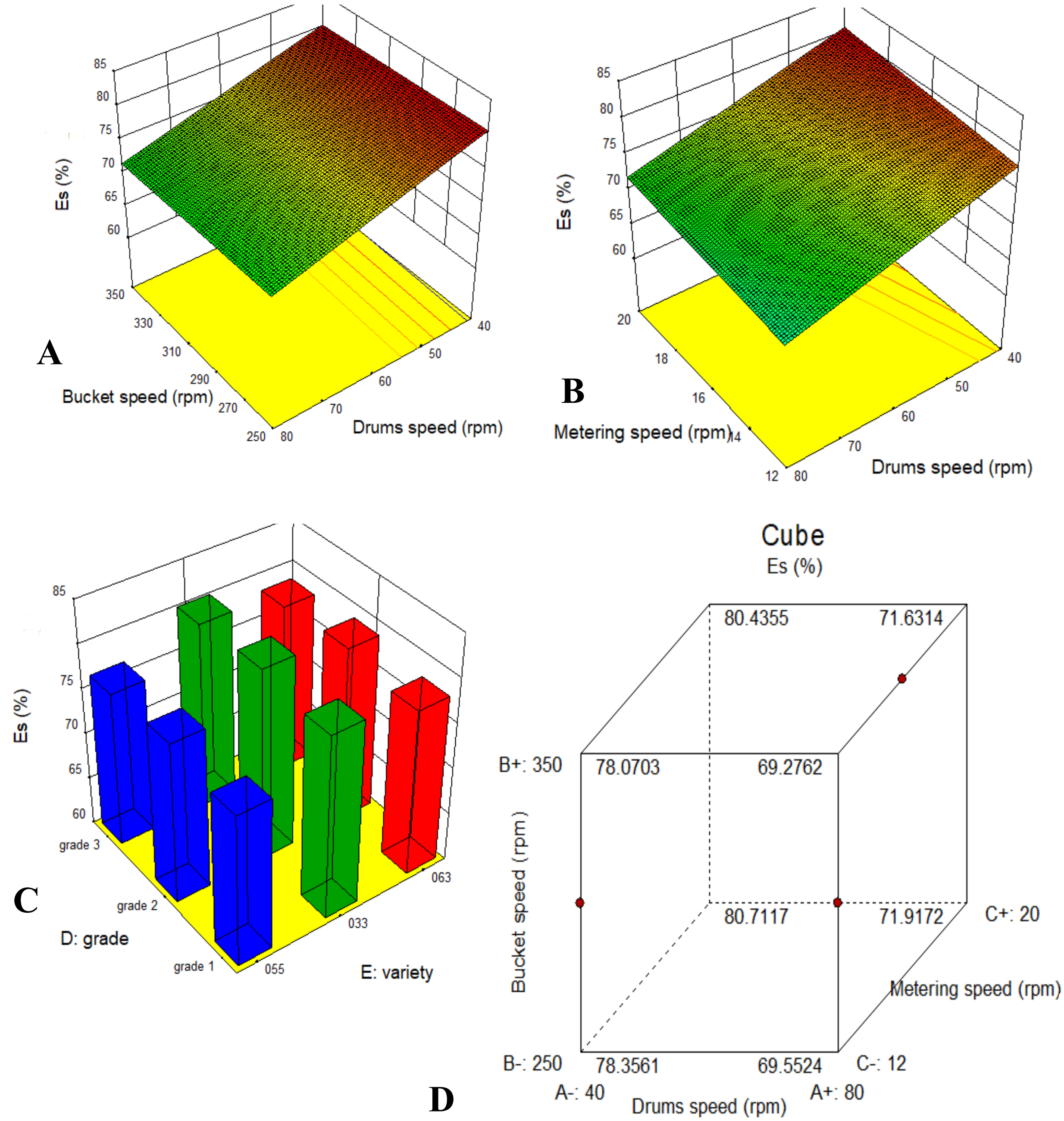


Figure 4.3: Typical Graphs of effect of numerical factors (A and B), categorical factors (C) and of all factors (D) that affect the total efficiency of the system (Es)

Four polynomial equations (linear, 2FI, quadratic and cubic) were considered. Quadratic equation (Polynomial equation rise to the second power) was chosen by the software (Design Expert) for all throughputs considered in this study. Quadratic equation was chosen because during statistical analysis of the four polynomials equations considered. It has the lowest 'Sequential p-value', the highest 'Lack of Fit p-value', the highest 'Adjusted R-Squared' value and the highest 'Predicted R-Squared' value. Although, quadratic equation was chosen for modeling all throughputs in the system; experimental data generated were not normally distributed for all throughput data. So, data used for generating the throughput model equations were transformed. Data transformation choices used were, logit transformation for data of 1st sieve drum, inverse transformation (random generation of sample numbers from distribution probabilities given its distribution cumulative function) for 2nd sieve drum, and inverse Square Root transformation for data of automated units and the entire system throughput. After transforming these data, the throughput equations generated are displayed in Appendix D13. Analysis of variance (ANOVA) for the developed throughputs equations are displayed in Table 4.16. The analysis show that all equation models developed for the units' parts of the systems throughputs were all significant at $p<0.05$. This means that the chance that the developed model equations are predicting errors is less than 5%. Also, lack of fit values for all developed equations of units' parts of the system were all not significant at $p<0.05$. It is desirable for model's lack of fit not to be significant at $p<0.05$. This is because, lack of fit not being significant at $p<0.05$ means that, the probability that the equation chosen to represent the data behavior was the correct one, was greater than 5%. The throughputs ANOVA table shows that, for the 1st sieve drum throughput equation model, and metering device; seed variety and grade) and their interactions used; were significant at $p<0.05$ except for bucket conveyor speed, metering device speed and the interaction of the speed of drum x bucket conveyor speed. This could because the sieve drums, bucket conveyor and the metering device are all driven by separate electrical motor. This makes them to have some level of independency in operation, which in turn affect so level of their interactions. The ANOVA of the 2nd sieve drum separating throughput models' equation shows that, all evaluating factors and its interactions were

Table 4.16: Analysis of Variance (ANOVA) of Operational Throughput models for the System optimization

Operational Parameter	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob > F	
Throughput of 1st Sieve Drum	Model	42.35	23	1.84	23.71	1.9252E-08	significant
	Speed of drums	7.55	1	7.55	97.16	3.3557E-08	significant
	Bucket conveyor speed	6.397E-03	1	0.006397	0.082	0.7778	not significant
	Speed of metering disc	0.19	1	0.19	2.39	0.1413	not significant
	Grade	15.55	2	7.78	100.12	8.9809E-10	significant
	Variety	2.35	2	1.18	15.15	0.0002	significant
	Speed (drum X bucket)	0.3	1	0.3	3.8	0.069	not significant
	Speed (drum X metering)	0.64	1	0.64	8.28	0.0109	significant
	Speed (bucket X metering)	1.06	1	1.06	13.61	0.002	significant
	Bucket speed X Grade	0.97	2	0.49	6.25	0.0099	significant
	Bucket speed X Variety	0.7	2	0.35	4.48	0.0284	significant
	Metering speed X Grade	0.8	2	0.4	5.12	0.0191	significant
	Metering speed X Variety	1.2	2	0.6	7.71	0.0045	significant
	Grade X Variety	2.2	4	0.55	7.09	0.0018	significant
	Speed of drums ^{2}	1.15	1	1.15	14.8	0.0014	significant
	Residual	1.24	16	0.078			
	Lack of Fit	1.07	11	0.097	2.85	0.1289	not significant
	Pure Error	0.17	5	0.034			
	Cor Total	43.59	39				
Throughput of 2nd Sieve Drum	Model	1896.22	26	72.93	245.48	9.6314E-14	significant
	Speed of drums	795.43	1	795.43	2677.31	1.9251E-16	significant
	Bucket conveyor speed	0.38	1	0.38	1.28	0.2778	not significant
	Speed of metering disc	1.99	1	1.99	6.71	0.0224	significant
	Grade	680.45	2	340.23	1145.15	2.4286E-15	significant
	Variety	3.15	2	1.58	5.3	0.0207	significant
	Speed (drum X metering)	1.66	1	1.66	5.58	0.0344	significant
	Drum speed X Grade	166.89	2	83.44	280.86	2.0146E-11	significant
	Drum speed X Variety	4.55	2	2.27	7.65	0.0064	significant
	Bucket speed X Grade	2.81	2	1.41	4.73	0.0286	significant
	Bucket speed X Variety	5.54	2	2.77	9.33	0.0031	significant
	Metering speed X Grade	2.58	2	1.29	4.34	0.0361	significant
	Metering speed X Variety	4.44	2	2.22	7.48	0.0069	significant
	Grade X Variety	3.99	4	1	3.36	0.0427	significant
	Speed of drums ^{2}	1.46	1	1.46	4.93	0.0448	significant
	Speed of metering disc ^{2}	1.98	1	1.98	6.66	0.0228	significant
	Residual	3.86	13	0.3			
	Lack of Fit	2.8	8	0.35	1.64	0.3028	not significant
	Pure Error	1.06	5	0.21			
	Cor Total	1900.08	39				

Operational Parameter	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob > F	
Throughput of automation sensing Unit	Model	2.67	18	0.15	63.57	2.4559E-14	significant
	Speed of drums	1.782E-03	1	1.78E-03	0.76	0.3919	not significant
	Bucket conveyor speed	0.011	1	0.011	4.55	0.0449	significant
	Speed of metering disc	1.17	1	1.17	502.76	3.7687E-16	significant
	Grade	1.12	2	0.56	240.11	3.412E-15	significant
	Variety	0.046	2	0.023	9.96	0.0009	significant
	Metering speed X Grade	0.059	2	0.029	12.58	0.0003	significant
	Metering speed X Variety	0.053	2	0.026	11.33	0.0005	significant
	Grade X Variety	0.024	4	6.08E-03	2.61	0.0649	not significant
	Speed of drums ^{2}	0.015	1	0.015	6.33	0.0201	significant
	Bucket conveyor speed ^{2}	4.556E-03	1	4.56E-03	1.95	0.1768	not significant
	Speed of metering disc ^{2}	0.033	1	0.033	14.11	0.0012	significant
	Residual	0.049	21	2.33E-03			
	Lack of Fit	0.044	16	2.74E-03	2.69	0.1391	not significant
	Pure Error	5.090E-03	5	1.02E-03			
	Cor Total	2.72	39				
System Throughput	***Model***	***1.81***	***26***	***0.069***	***72.12***	***2.5451E-10***	***significant***
	Speed of drums	***0.034***	***1***	***0.034***	***35.8***	***4.5679E-05***	***significant***
	Bucket conveyor speed	***0.015***	***1***	***0.015***	***15.1***	***0.0019***	***significant***
	Speed of metering disc	***0.68***	***1***	***0.68***	***701.53***	***1.0704E-12***	***significant***
	Grade	***0.79***	***2***	***0.4***	***412.08***	***1.7474E-12***	***significant***
	Variety	***0.029***	***2***	***0.014***	***14.85***	***0.0004***	***significant***
	Drum speed X Grade	***6.593E-03***	***2***	***3.30E-03***	***3.42***	***0.0639***	***not significant***
	Drum speed X Variety	***3.359E-03***	***2***	***1.68E-03***	***1.74***	***0.2133***	***not significant***
	Speed (bucket X metering)	***0.012***	***1***	***0.012***	***12.21***	***0.004***	***significant***
	Bucket speed X Grade	***3.064E-03***	***2***	***1.53E-03***	***1.59***	***0.2409***	***not significant***
	Bucket speed X Variety	***0.011***	***2***	***5.26E-03***	***5.47***	***0.0189***	***significant***
	Metering speed X Grade	***0.031***	***2***	***0.016***	***16.3***	***0.0003***	***significant***
	Metering speed X Variety	***0.036***	***2***	***0.018***	***18.78***	***0.0001***	***significant***
	Grade X Variety	***0.013***	***4***	***3.27E-03***	***3.4***	***0.0413***	***significant***
	Speed of drums ^{2}	***0.028***	***1***	***0.028***	***29.27***	***0.0001***	***significant***
	Speed of metering disc ^{2}	***0.021***	***1***	***0.021***	***22.07***	***0.0004***	***significant***
	Residual	***0.013***	***13***	***9.63E-04***			
	Lack of Fit	***0.01***	***8***	***1.31E-03***	***3.24***	***0.1055***	***not significant***
	Pure Error	***2.023E-03***	***5***	***4.05E-04***			
	Cor Total	***1.82***	***39***				

significant at $p<0.05$ except for the speed of bucket conveyor. The same explanation used for the 1st sieve drum can also be used for the 2nd sieve drum. Again, the ANOVA of the automation sensing separating unit throughput models' equation shows that, all evaluating factors and its interactions were significant at $p<0.05$ except for the speed of drums, interaction of seed variety x grade and the square of bucket conveyor speed. These phenomena are caused by the fact that the sieve drum and the automated units are separating different type of impurities in the sample. The drums separate foreign bodies and some broken, while the automated unit separates damaged seeds and some broken seeds. The interaction of the variety x grade not being significant was because independently both variety and grade are already significant to the throughput of the automated unit, and since they are categorical factors interaction in real life is not possible. The non-significant of the square of the speed of the bucket conveyor is because, even if you double the speed of the bucket conveyor. It will not change the metering device speed which operates using a different motor from that of the bucket conveyor. This in turn, can not affect the automation separating process. Analysis of variance (ANOVA) carried out for the developed model equation for throughput of the entire system shows that, the model equation was significant at $p<0.05$. This means that the error that the chosen model was the wrong model was less than 5%. All factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) and their interaction used in developing the entire system throughput equation were all significant at $p<0.05$; except for Drum speed x Grade, Drum speed x Variety and Bucket speed x Grade which was not significant at $p<0.05$. This could be because the grade and the seed variety as categorical factors could not actually interact with drum speed in real life. This makes it impossible for their interaction to have a significant effect on the entire system throughput. Also, the bucket conveyor speed does not depend on seed grade to conveyer seeds to the metering device. This is because no separating operation takes place at the bucket conveyor. This is why the interaction of the bucket conveyor speed and the grade cannot affect the entire system throughput. The lack of fit for the entire system separating throughput was not significant at $p<0.5$. This means that the probability that the equation we chose for modeling the behavior of the separating throughput of the entire system is the correct one was greater than 5%. Now let evaluate the effects of the operating factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) to the throughputs of the system.

The effect of the evaluating factors on the unit components throughput and the entire system throughput are graphically displayed in Figures 4.4 and 4.5. 3-D graphs in the figure shows that the throughput of the 1st sieve drum (T1) decrease quadratically with increase in drum speed. This is because from the design calculation, the effective sieve drum speed was calculated to be 40 rpm. The drum speed was increase to deviate from the design speed. Evaluation result shows that moving away from the design speed reduces the throughput of the 1st sieve drum separating throughput. Also, 1st sieve drum throughput (T1) decreases slightly with increase in the speed of bucket conveyor and metering device; although ANOVA had already shown that this decrease had no significant effect on the throughput of the 1st sieve drum (T1). Throughput of the 1st sieve drum (T1) also shown that it increases as the grade (impurity) increases and have different values for different seed variety. This occur because as impurity (grade) is increase in a sample the processed volume (throughput) will also increase while variety 063(white small seeds) has the highest T1. Variety 063 having the highest throughput could be because of the small size of the seeds makes it possible to have more cowpea seeds in the 2kg sample than other variety. In the case of the separating throughput of the 2nd sieve drum (T2), increase in the drum speed also reduces the separating throughput quadratically. The same explanation used for the 1st sieve drum speed can also be used to explain the 2nd sieve drum speed. The 2nd sieve throughput output was examined as the bucket conveyor speed was compare with the metering device speed. This shows no increase or decrease in of T2. This confirms the ANOVA which states that neither the speed of the bucket conveyor nor that the metering device had any effect on the throughput of the 2nd sieve drum. 3-D graph of seed variety and grade plotted against the throughput of the 2nd sieve drum; shows that throughput increases as the seeds grade increase while variety 055 (red seeds) had the highest throughputs. This same behavior was observed in the 1st sieve drum throughput and the same explanation given for the 1st sieve drum throughput can also be used here. Graph of the separating throughput of the automated unit (T3) plotted against the metering device speed; shows that as the metering speed

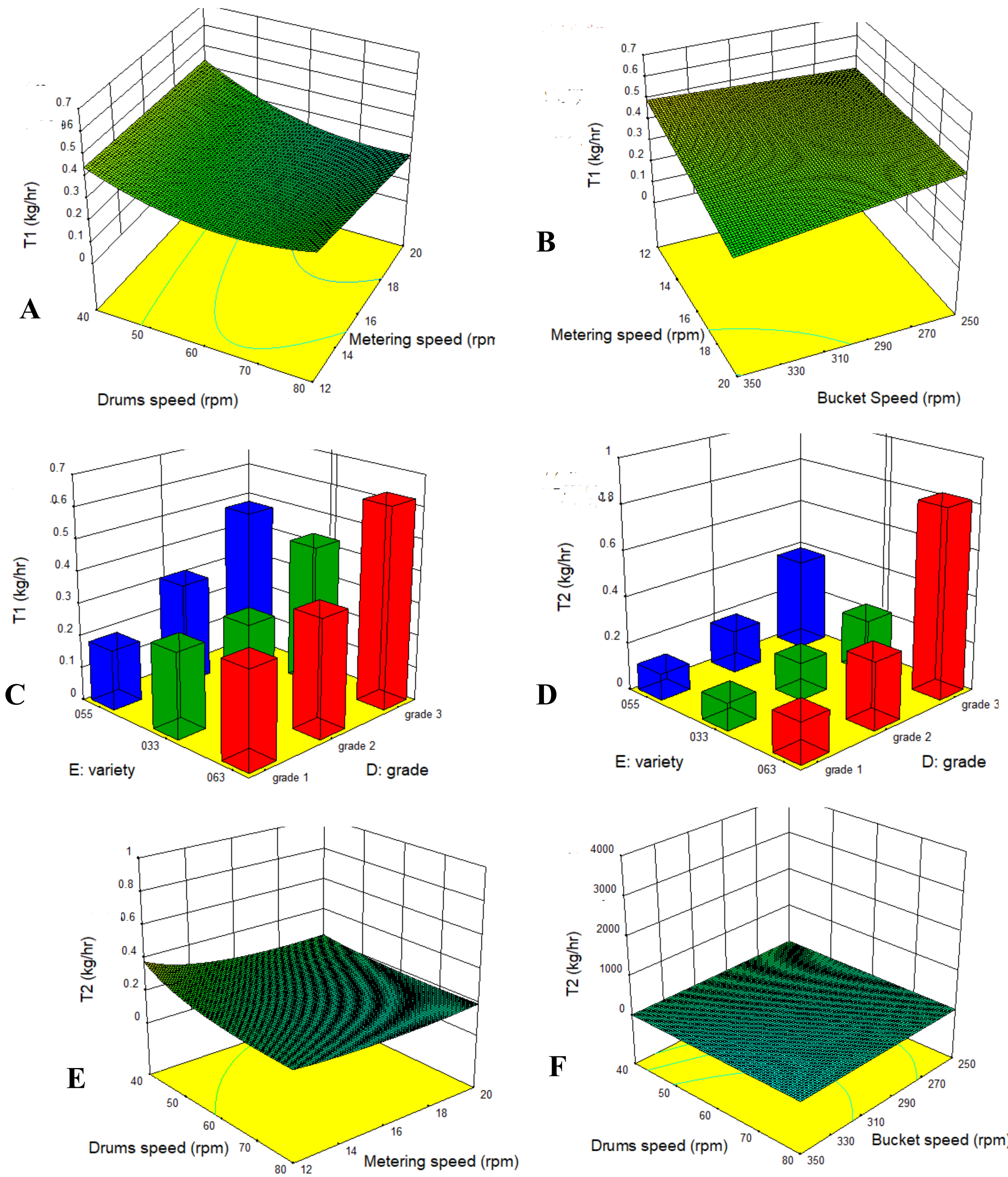


Figure 4.4: Typical Graphs of effect of numerical and categorical factors that affect the throughput T1 (A, B abd C) and T2 (D, E and F) of sieve drums of the system

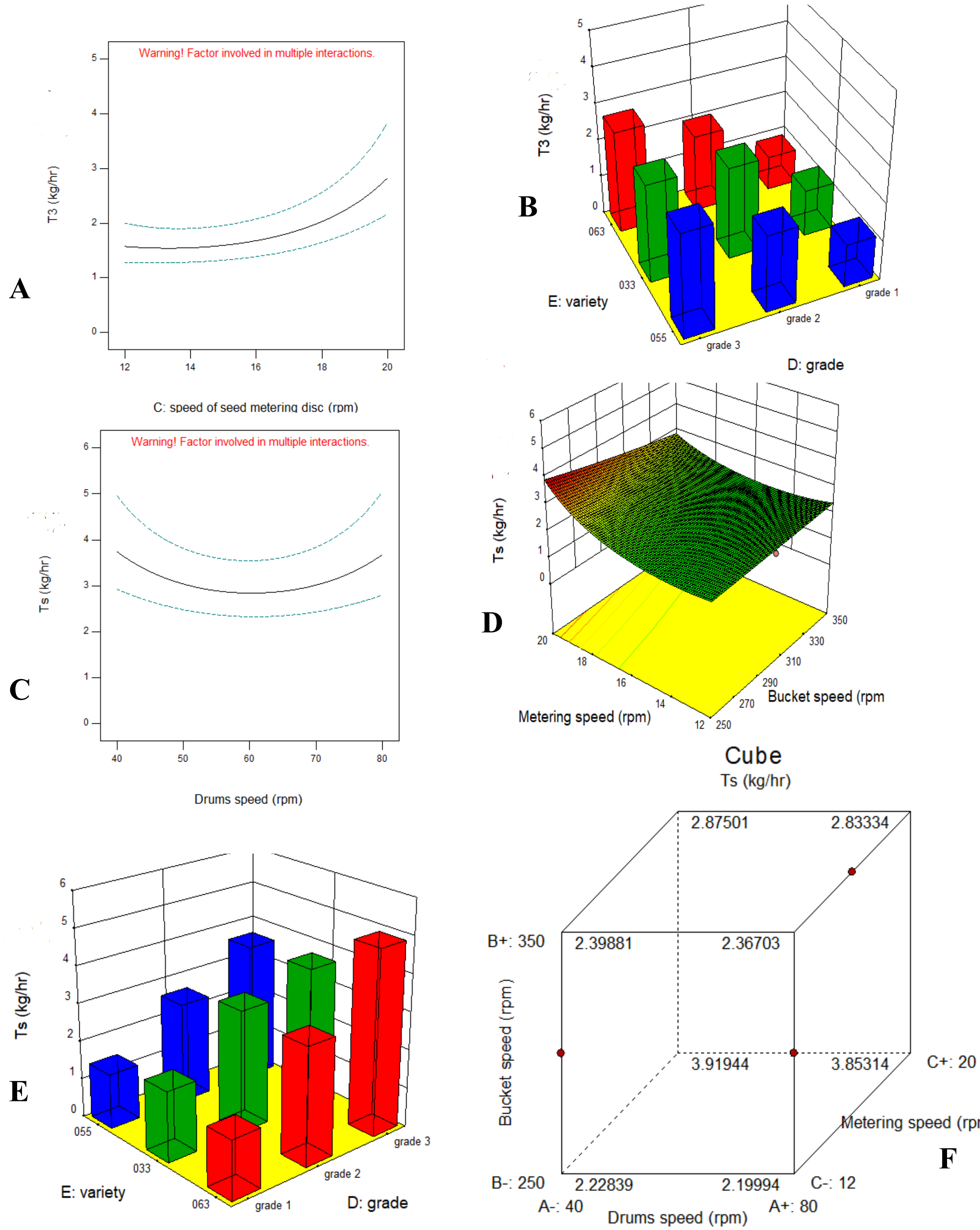


Figure 4.5: Typical Graphs of the effect of numerical and categorical factors that affect throughput T3 (A and B) and the total throughput of the system Ts (C, D, E and F)

increases the throughput of the automation device (T3) decreases quadratically (i.e., it decreases to a point and then start increasing). This phenomenon can be because increase in the metering speed can cause the breakage of seeds being metered reducing the automation throughput. At certain metering speed this breakage will stop and the throughput will increase slightly. Also, the effects of categorical factors (seed variety and grade) on the throughput of the automation unit (T3); shows that seed variety 033 (white big seeds) had the highest separating throughput while the automated throughput (T3) values reduce as seed grade (impurity) increases. These phenomena occur because the large sizes and bright colour of the seed variety (033) make it easy for the pi camera to easily identify them. Also, to many impurities (grade) in the sample slow down the volume (throughput) of processed seeds achieved by the automation unit. A graph of the entire system throughput plotted against sieve drum speed; shows that entire system throughput decreases quadratically as the drum speed is increased. The explanation used for throughput of 1st and 2nd sieve drum can also be used to explain this behavior of the entire separating system throughput. 3-D graph of the entire system separating throughput plotted against speed of bucket conveyor and metering device: shows that separating throughput of the entire system decreases as both the speed of bucket conveyor and metering device increases. These phenomena occur because increase in speed of both the speed of bucket conveyor and metering device cause seeds breakage which in turn reduces the volume (throughput) of seed being processed. Also, 3-D graph of the entire system separating throughput (Ts) plotted against seed variety and grade; shows that seed variety 063 (white small seeds) has the highest entire system separating throughput (Ts) while as the seed grade (impurity) increases the entire system throughput increases. These phenomena occur because due to the small seed sizes of variety 063; there will be more cowpea seeds in the sample than any other variety. This makes the volume (throughput) of processed seeds of variety 063 more than any other variety. Also, if there is more impurity (grade) in a sample, more separation will take place; thereby increasing the volume (throughput) of separated impurity in the entire system (Ts). Figure 5(f) is a cube graph (4-D graph) of the entire system throughput (Ts) plotted against speed of drum, bucket conveyor and metering device. This 4-D graph displayed various values of the entire system separating throughput (Ts) using the combinations of these three speeds in the system.

4.4.1.3 System Maximum Capacity Modeling and Evaluation

The impurity separating maximum capacity in kg/12hrs that were modeled for that of the 1st sieve drum (MC1), 2nd sieve drum (MC2), Automation unit (MC3) and the entire system (MCs). Statistical analyses for choosing model equations for these maximum separating capacities are shown in Table 4.17. Four polynomial equations (linear, 2FI, quadratic and cubic) were considered. Quadratic equation (polynomial equation rise to the second power) was chosen by the software (Design Expert) for predicting maximum separating capacity considered in this study. Quadratic was used for all equations of maximum capacity of various units, except for the 1st sieve drum which was a2-factor interaction (2FI) equation. Quadratic and 2 factor interaction (2FI) equations were chosen because during statistical analysis of the four polynomials equations considered. These two equations have the lowest 'Sequential p-value', the highest 'Lack of Fit p-value', the highest 'Adjusted R-Squared' value and the highest 'Predicted R-Squared' value. Although, quadratic and 2 factor interaction (2FI) equations were chosen for modeling all maximum separating capacity in the system; experimental data generated were not normally distributed for all data. So, data used for generating the maximum separating capacity model equations were transformed. Data transformation choices used were, logit transformation for data of 1st sieve drum, inverse transformation for 2nd sieve drum, and inverse Square Root transformation for data of automated units and the entire system maximum separating capacity. After transforming these data, the maximum separating capacity equations generated are displayed in Appendix D14. Analysis of variance (ANOVA) for the developed maximum separating capacity equations are displayed in Table 4.18. The analysis show that all equation models developed for the unit's parts of the systems maximum separating capacities were all significant at $p<0.05$. This means that the chance that the developed model equations are predicting errors is less than 5%. Also, lack of fit values for all developed equations of units' parts of the system were all not significant at $p<0.05$. It is desirable for model's lack of fit not to be significant at $p<0.05$. This is because, lack of fit not being significant at $p<0.05$ means that, the probability that the equation chosen to represent the data behavior was the correct one, was greater than 5%. The maximum separating capacity ANOVA table shows that, for the 1stsievedrum maximum separation

Table 4.17: Statistical Analysis used to Select Model Equation for Maximum Capacity, Actual Utilization and Backlog.

Parameter To be Model	Model Equation to be tested	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	Remark
Maximum Capacity of 1st Sieve Drum	Linear	1.92451E-07	0.0505	0.6659	0.5509	Suggested
	2FI	0.0107	0.2528	0.8696	-0.8606	Suggested
	Quadratic	0.0862	0.4476	0.9097	-0.7569	
	Cubic	0.4476		0.9153		Aliased
Maximum Capacity of 2nd Sieve Drum	Linear	3.9525E-13	0.0003	0.8567	0.8039	
	2FI	1.52605E-06	0.0732	0.9877	0.8739	
	Quadratic	0.0341	0.2039	0.993	0.9062	Suggested
	Cubic	0.2039		0.9956		Aliased
Maximum Capacity of sensing Unit	Linear	3.52992E-15	0.0129	0.8939	0.8642	
	2FI	0.4739	0.0089	0.897	-1.0183	
	Quadratic	0.0006	0.1738	0.9748	0.4696	Suggested
	Cubic	0.1738		0.9854		Aliased
System Maximum Capacity	***Linear***	***1.0068E-13***	***0.0023***	***0.8687***	***0.8316***	
	2FI	***0.3872***	***0.0018***	***0.8814***	***-1.3491***	
	Quadratic	***0.0002***	***0.0676***	***0.977***	***0.3467***	***Suggested***
	Cubic	***0.0676***		***0.9913***		***Aliased***
Actual Utilization of 1st Sieve Drum	Linear	1				Suggested
	2FI	1				
	Quadratic	1				
	Cubic	1				Aliased
Actual Utilization of 2nd Sieve Drum	Linear	1				Suggested
	2FI	1				
	Quadratic	1				
	Cubic	1				Aliased
Actual Utilization of sensing Unit	Linear	1				Suggested
	2FI	1				
	Quadratic	1				
	Cubic	1				Aliased
System Actual Utilization	***Linear***	***1***				***Suggested***
	2FI	***1***				
	Quadratic	***1***				
	Cubic	***1***				***Aliased***
Backlog of 1st Sieve Drum	Linear	1.70213E-12	0.8369	0.8427	0.7973	Suggested
	2FI	0.8714	0.6386	0.7887	-0.5694	
	Quadratic	0.3946	0.6494	0.7934	-1.3136	
	Cubic	0.6494		0.7565		Aliased
Backlog of 2nd Sieve Drum	Linear	2.21331E-14	0.0322	0.8807	0.8458	Suggested
	2FI	0.6464	0.017	0.868	-0.1996	
	Quadratic	0.067	0.0354	0.9135	-1.2664	
	Cubic	0.0354		0.9754		Aliased
Backlog of bucket conveyor	Linear	0.2293	0.2662	0.071	-0.1957	Suggested
	2FI	0.9213	0.1035	-0.3285	-13.9534	
	Quadratic	0.7922	0.0584	-0.5643	-66.6247	
	Cubic	0.0584		0.4466		Aliased
Backlog materials other than stones and sand	Linear	7.28316E-16	0.7779	0.904	0.8819	Suggested
	2FI	0.5922	0.7431	0.898	0.6825	
	Quadratic	0.7845	0.5989	0.8803	0.2085	
	Cubic	0.5989		0.8662		Aliased
System Backlog	***Linear***	***0.0005***	***0.7908***	***0.4269***	***0.2783***	***Suggested***
	2FI	***0.9632***	***0.465***	***0.1158***	***-6.286***	
	Quadratic	***0.7909***	***0.3211***	***-0.0406***	***-27.3592***	
	Cubic	***0.3211***		***0.1839***		***Aliased***

Table 4.18: Analysis of Variance (ANOVA) for Operational Maximum Capacity Models for the System Optimization

Operational Parameter	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob > F	
Maximum Capacity of 1st Sieve Drum	Model	48.63	14	3.47	15.2	7.199E-09	significant
	Speed of drums	11.52	1	11.52	50.4	1.929E-07	significant
	Grade	19.13	2	9.57	41.87	1.047E-08	significant
	Variety	1.81	2	0.91	3.97	0.0319	significant
	Speed (drum X bucket)	0.98	1	0.98	4.28	0.0491	significant
	Drum speed X Grade	1.72	2	0.86	3.77	0.0371	significant
	Bucket speed X Grade	1.85	2	0.93	4.06	0.0298	significant
	Grade X Variety	4.29	4	1.07	4.69	0.0058	significant
	Residual	5.71	25	0.23			
	Lack of Fit	5.12	20	0.26	2.17	0.1994	not significant
	Pure Error	0.59	5	0.12			
	Cor Total	54.34	39				
Maximum Capacity of 2nd Sieve Drum	Model	13.17	26	0.51	245.48	9.631E-14	significant
	Speed of drums	5.52	1	5.52	2677.31	1.925E-16	significant
	Bucket conveyor speed	2.647E-03	1	2.647E-03	1.28	0.2778	not significant
	Speed of metering disc	0.014	1	0.014	6.71	0.0224	significant
	Grade	4.73	2	2.36	1145.15	2.015E-11	significant
	Variety	0.022	2	0.011	5.3	0.0207	significant
	Speed (drum X metering)	0.012	1	0.012	5.58	0.0344	significant
	Drum speed X Grade	1.16	2	0.58	280.86	2.015E-11	significant
	Drum speed X Variety	0.032	2	0.016	7.65	0.0064	significant
	Bucket speed X Grade	0.02	2	9.764E-03	4.73	0.0286	significant
	Bucket speed X Variety	0.038	2	0.019	9.33	0.0031	significant
	Metering speed X Grade	0.018	2	8.95E-03	4.34	0.0361	significant
	Metering speed X Variety	0.031	2	0.015	7.48	0.0069	significant
	Grade X Variety	0.028	4	6.929E-03	3.36	0.0427	significant
	Speed of drums ^{2}	0.01	1	0.01	4.93	0.0448	significant
	Speed of metering disc ^{2}	0.014	1	0.014	6.66	0.0228	significant
	Residual	0.027	13	2.063E-03			
	Lack of Fit	0.019	8	2.429E-03	1.64	0.3028	not significant
	Pure Error	7.39E-03	5	1.477E-03			
	Cor Total	13.2	39				
Maximum Capacity of automation sensing Unit	Model	0.22	16	0.014	70.99	9.373E-16	significant
	Speed of drums	8.658E-04	1	8.658E-04	4.43	0.0464	significant
	Bucket conveyor speed	0.1	1	0.1	522.91	2.558E-17	significant
	Speed of metering disc	0.095	2	0.048	244.22	3.226E-16	significant
	Grade	3.655E-03	2	1.828E-03	9.35	0.0011	significant

Operational Parameter	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob > F	
	Variety	4.507E-03	2	2.253E-03	11.53	0.0003	significant
	Metering speed X Variety	4.943E-03	2	2.472E-03	12.65	0.0002	significant
	Grade X Variety	2.364E-03	4	5.909E-04	3.02	0.0385	significant
	Speed of drums ^{2}	1.319E-03	1	1.319E-03	6.75	0.0161	significant
	Speed of metering disc ^{2}	2.931E-03	1	2.931E-03	15	0.0008	significant
	Residual	4.494E-03	23	1.954E-04			
	Lack of Fit	4.069E-03	18	2.261E-04	2.66	0.141	not significant
	Pure Error	4.242E-04	5	8.484E-05			
	Cor Total	0.23	39				
System Maximum Capacity	***Model***	***0.15***	***25***	***6.014E-03***	***74.73***	***4.698E-11***	***significant***
	Speed of drums	***3.565E-03***	***1***	***3.565E-03***	***44.3***	***1.086E-05***	***significant***
	Bucket conveyor speed	***1.212E-03***	***1***	***1.212E-03***	***15.06***	***0.0017***	***significant***
	Speed of metering disc	***0.055***	***1***	***0.055***	***679.62***	***2.884E-13***	***significant***
	Grade	***0.065***	***2***	***0.032***	***402.92***	***4.234E-13***	***significant***
	Variety	***2.541E-03***	***2***	***1.271E-03***	***15.79***	***0.0003***	***significant***
	Drum speed X Grade	***3.559E-04***	***2***	***1.780E-04***	***2.21***	***0.1464***	***not significant***
	Drum speed X Variety	***4.813E-04***	***2***	***2.406E-04***	***2.99***	***0.0829***	***not significant***
	Speed (bucket X metering)	***8.847E-04***	***1***	***8.847E-04***	***10.99***	***0.0051***	***significant***
	Bucket speed X Variety	***8.054E-04***	***2***	***4.027E-04***	***5***	***0.0229***	***significant***
	Metering speed X Grade	***2.660E-03***	***2***	***1.330E-03***	***16.53***	***0.0002***	***significant***
	Metering speed X Variety	***2.764E-03***	***2***	***1.382E-03***	***17.17***	***0.0002***	***significant***
	Grade X Variety	***1.068E-03***	***4***	***2.670E-04***	***3.32***	***0.0414***	***significant***
	Speed of drums ^{2}	***2.301E-03***	***1***	***2.301E-03***	***28.58***	***0.0001***	***significant***
	Bucket conveyor speed ^{2}	***1.716E-04***	***1***	***1.716E-04***	***2.13***	***0.1664***	***not significant***
	Speed of metering disc ^{2}	***1.867E-03***	***1***	***1.867E-03***	***23.19***	***0.0003***	***significant***
	Residual	***1.127E-03***	***14***	***8.048E-05***			
	Lack of Fit	***9.582E-04***	***9***	***1.065E-04***	***3.16***	***0.1092***	***not significant***
	Pure Error	***1.686E-04***	***5***	***3.372E-05***			
	Cor Total	***0.15***	***39***				

capacity (MC1) equation model, all evaluation factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) and their interactions used; were significant at $p<0.05$. The ANOVA of the 2nd sieve drum separating maximum separating capacity (MC2) models' equation shows that; all evaluating factors and its interactions were significant at $p<0.05$ except for the speed of bucket conveyor. This could be because the action of the 2nd sieve drum comes before the action of the bucket conveyor. Also, the ANOVA of the automation sensing unit separating maximum capacity (MC3) models' equation shows that; all evaluating factors and its interactions were significant at $p<0.05$. Analysis of variance (ANOVA) carried out for the developed model equation maximum separating capacity (MCs) of the entire system shows that, the model equation was significant at $p<0.05$. This means that the error that the chosen model was the wrong model was less than 5%. All factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) and their interaction used in developing the entire system maximum separating capacity (MCs) equation were all significant at $p<0.05$; except for Drum speed x Grade, Drum speed x Variety and Bucket speed^2 which was not significant at $p<0.05$. This could be because since the drum design was done with the highest seed size consideration; then it does not matter the variety of the seed, the drum would continue to separate impurity. Also, since the grades (impurity) are the same across variety, then it will not have much effect on the capacity the drum can separate in 12hours. Doubling the bucket conveyor speed will not affect the capacity of the entire system separation capacity. This is because no separating operation takes place at the bucket conveyor. The lack of fit for the entire system separating throughput was not significant at $p<0.5$. This means that the probability that the equation we chose for modeling the behavior of the separating maximum capacity of the entire system is the correct one was greater than 5%. Now let evaluate the effects of the operating factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) to the maximum separating capacities of the system.

The effect of the evaluating factors on the unit components maximum separating capacities and the entire system components maximum separating capacity are graphically displayed in Figures 4.6 and 4.7. 3-D graphs in the Figure 4.6 shows that the maximum separating capacity of the 1st sieve drum (MC1) decrease with increase in drum speed. Same explanation for the throughput of 1st drum can also be used here. Also, 1st sieve drum

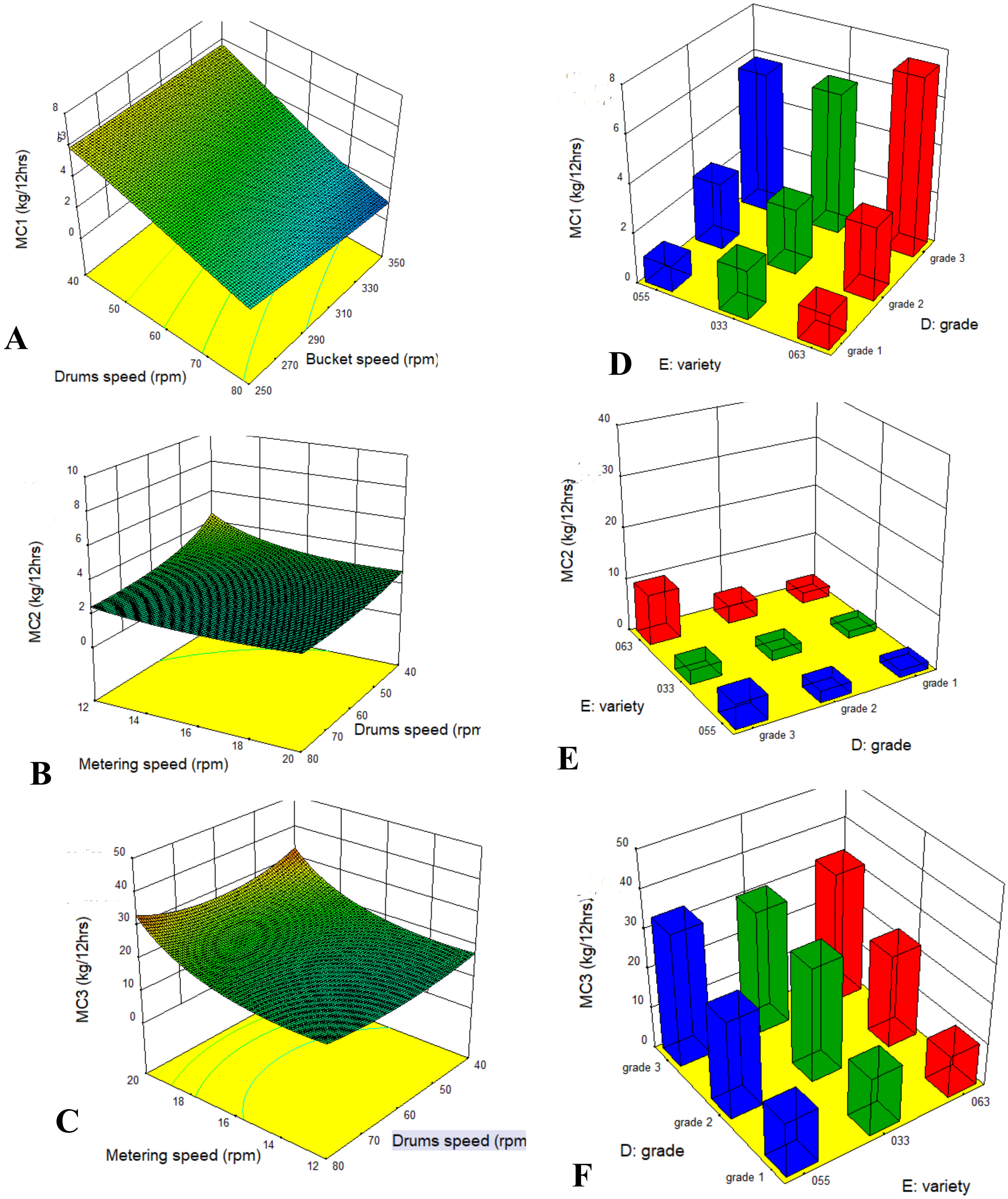


Figure 4.6: Graphs of effect of numerical factors (A, B and C) and categorical factors (D, E and F) that affect the MC1, MC2 and MC3 of the system

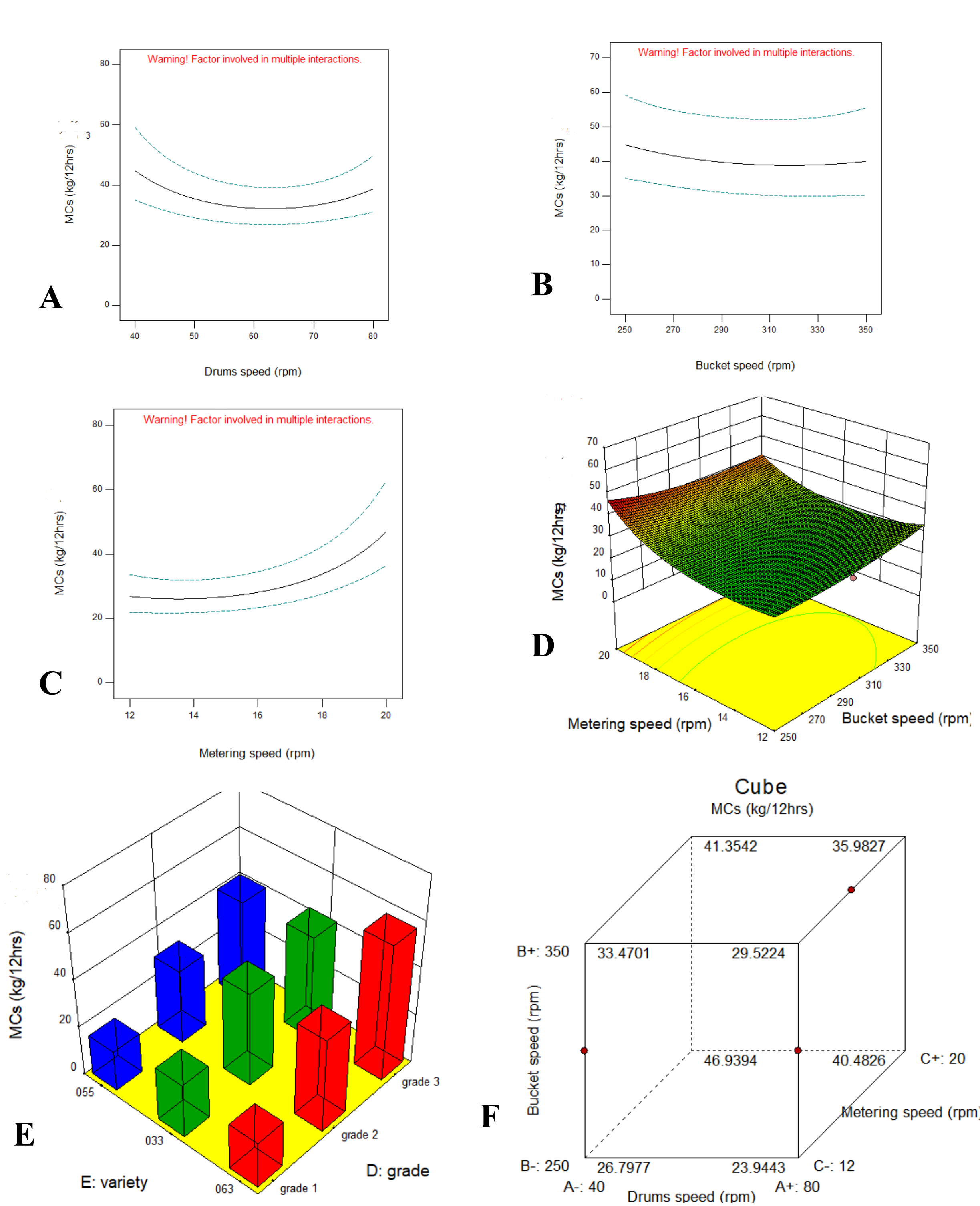


Figure 4.7: Graphs of effect of numerical factors (A, B, C and D), categorical factors (E) and combination of all factors that affect the total system capacity (MCs)

maximum separating capacity (MC1) increases slightly with increase in the speed of bucket conveyor and metering device; This could be because as the bucket conveyor conveys the cowpea seeds faster, it leaves more room for the sieve drum o empty it content. Maximum separating capacity of the 1st sieve drum (MC1) also shown that it increases as the grade (impurity) increases and have different values for different seed variety. This occur because as impurity (grade) is increase in a sample the processed total volume in 12 hours (maximum separating capacity) will also increase while variety 063(white small seeds) has the highest MC1(maximum separating capacity). Variety 063 having the highest maximum separating capacity could be because of the small size of the seeds makes it possible to have more cowpea seeds in the 2kg sample than other variety. In the case of the maximum separating capacity of the 2nd sieve drum (MC2), increase in the drum speed also reduces the maximum separating capacity quadratically. Same explanation for the throughput of 2nd sieve drum can also be used here. Also, increase in metering speed increases maximum separating capacity of the 2nd sieve drum (MC2). This could be that as the metering device speed was increased, it created room for the bucket conveyor to convey more seeds; which in turn create room for the 2nd sieve drum to empty more content into the bucket conveyor. 3-D graph of seed variety and grade plotted against the maximum separating capacity of the 2nd sieve drum (MC2); shows that maximum separating capacity increases as the seeds grade increase while variety 063(white small seeds) had the highest maximum separating capacity. This same behavior was observed in the 1st sieve drum maximum separating capacity (MC1) and the same explanation given for the 1st sieve drum maximum separating capacity can also be used here. 3-D graph of the maximum separating capacity of the automated unit (MC3) plotted against the metering device and drum speed; shows that as both the metering and sieve drum speed increases the maximum separating capacity of the automated unit (MC3) decreases quadratically (i.e., it decreases to a point and then start increasing). This phenomenon can be because increase in the metering speed can cause the breakage of seeds being metered, thus reducing the automation maximum separating capacity. At certain metering speed this breakage will stop and the maximum separating capacity will increase slightly. Also, increase sieve drum speed will reduce the seeds being send to the metering device; this in turn will reduce the automation maximum capacity. The effects of categorical factors (seed variety and grade) on the maximum separating capacity of the automation unit

(MC3); shows that seed variety 055 (red seeds) had the highest maximum separating capacity while the automated maximum separating capacity (MC3) values increase as seed grade (impurity) increases. These phenomena occur because the sizes and colour of the seed variety (055) make it easy for the pi camera to easily identify them and their impurity. Figure 4.17 displayed the effect of factors used for evaluation on the total system capacity. A graph of the entire system maximum separating capacity (MCs) plotted against sieve drum speed; shows that entire system maximum separating capacity (MCs) decreases quadratically as the drum speed is increased. The explanation used for throughput of 1st and 2nd sieve drum can also be used to explain this behavior of the entire system maximum separating capacity. Two more graphs for the entire system maximum separating capacity (MCs) against bucket conveyor speed and metering speed; show that as the bucket conveyor speed and the metering device speed increase the entire system maximum separating capacity (MCs) reduce quadratically. The decrease of MCs from increase in bucket conveyor speed and the metering device speed was because the increase in speed causes breakage of cowpea seeds. This in turn reduces the entire system maximum separating capacity (MCs). 3-D graph of the entire system maximum separating capacity (MCs) plotted against speed of bucket conveyor and metering device: shows that the entire system maximum separating capacity (MCs) decreases as both the speed of bucket conveyor and metering device increases. These phenomena occur because increase in speed of both the speed of bucket conveyor and metering device cause seeds breakage which in turn reduces the volume of seed being processed in 12 hours (maximum separating capacity). Also, 3-D graph of the entire system maximum separating capacity (MCs) plotted against seed variety and grade; shows that seed variety 063 (white small seeds) has the highest entire system maximum separating capacity (MCs) while as the seed grade (impurity) increases the entire system maximum separating capacity (MCs) increases. These phenomena occur because due to the small seed sizes of variety 063; there will be more cowpea seeds in the sample than any other variety. This makes the volume of processed seeds in 12 hours (maximum separating capacity) of variety 063 more than any other variety. Also, if there is more impurity (grade) in a sample, more separation will take place; thereby increasing the volume of separated impurity in 12 hours (maximum separating capacity) in the entire system. Figure 4.7 (F) is a cube graph (4-D graph) of the entire system maximum separating capacity (MCs) plotted against speed of drum, bucket conveyor and metering device. This 4-D graph displayed various values of the entire system maximum separating capacity (MCs) using the combinations of these three speeds in the system.

4.4.1.4 System Actual Utilization Modeling and Evaluation

The actual utilizations that were modeled were that of the 1st sieve drum (AU1), 2nd sieve drum (AU2), Automation unit (AU3) and the entire system (AUs). Statistical analyses for choosing model equations for these actual utilizations are also shown in Table 4.17. Four polynomial equations (linear, 2FI, quadratic and cubic) were considered. Linear equation was chosen by the software (Design Expert) for all actual utilizations considered in this study. Linear equations were chosen because during statistical analysis of the four polynomials equations considered. Linear equation had the lowest 'Sequential p-value', the highest 'Lack of Fit p-value', the highest 'Adjusted R-Squared' value and the highest 'Predicted R-Squared' value. Although, linear equations were chosen for modeling all actual utilizations in the system; experimental data generated were all normally distributed for all data. So, data used for generating the actual utilizations model equations were not transformed. Equations generated actual utilizations are displayed in Appendix D15. Analysis of variance (ANOVA) for the developed actual utilizations equations are displayed in Table 4.19. The analysis show that all equation models developed for the unit's parts of the systems actual utilizations were all significant at $p<0.05$. This means that the chance that the developed model equations are predicting errors is less than 5%. Also, lack of fit values for all developed equations of units' parts of the system were either not significant at $p<0.05$ or do not a value. It is desirable for model's lack of fit not to be significant at $p<0.05$. This is because, lack of fit not being significant at $p<0.05$ means that, the probability that the equation chosen to represent the data behavior was the correct one, was greater than 5%. The absence of lack of fit value shows that data may have been gotten from a digital device with less variation between result readings. The actual utilizations ANOVA table shows that, for the 1st sieve drum actual utilizations (AU1) equation model, all evaluation factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) used; were not significant at $p<0.05$. This could be because the same quality of sample passes through the 1st sieve drum during the experiments. The ANOVA of the 2nd sieve drum actual

Table 4.19: Analysis of Variance (ANOVA) of Operational Actual Utilization Models for the System Optimization

Operational Parameter	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob > F	
Actual Utilization of 1st Sieve Drum	Model	9.632E-32	3	3.211E-32	42.9	5.6358E-12	Significant
	Speed of drums	9.182E-34	1	9.182E-34	1.23	0.2753	not significant
	Bucket conveyor speed	1.126E-33	1	1.126E-33	1.51	0.2278	not significant
	Speed of metering disc	8.216E-34	1	8.216E-34	1.1	0.3017	not significant
	Residual	2.694E-32	36	7.483E-34			
	Lack of Fit	2.694E-32	31	8.69E-34			
	Pure Error	0	5	0			
	Cor Total	1.233E-31	39				
Actual Utilization of 2nd Sieve Drum	Model	9.632E-32	3	3.211E-32	42.9	5.6358E-12	significant
	Speed of drums	9.182E-34	1	9.182E-34	1.23	0.2753	not significant
	Bucket conveyor speed	1.126E-33	1	1.126E-33	1.51	0.2278	not significant
	Speed of metering disc	8.216E-34	1	8.216E-34	1.1	0.3017	not significant
	Residual	2.694E-32	36	7.483E-34			
	Lack of Fit	2.694E-32	31	8.69E-34			
	Pure Error	0	5	0			
	Cor Total	1.233E-31	39				
Actual Utilization of sensing Unit	Model	9.632E-32	3	3.211E-32	42.9	5.6358E-12	significant
	Speed of drums	9.182E-34	1	9.182E-34	1.23	0.2753	not significant
	Bucket conveyor speed	1.126E-33	1	1.126E-33	1.51	0.2278	not significant
	Speed of metering disc	8.216E-34	1	8.216E-34	1.1	0.3017	not significant
	Residual	2.694E-32	36	7.483E-34			
	Lack of Fit	2.694E-32	31	8.69E-34			
	Pure Error	0	5	0			
	Cor Total	1.233E-31	39				
System Actual Utilization	***Model***	***6.225E-32***	***3***	***2.0749E-32***	***12.809***	***7.553E-06***	***significant***
	Speed of drums	***1.59E-35***	***1***	***1.5898E-35***	***0.0098***	***0.9216339***	***not significant***
	Bucket conveyor speed	***1.384E-33***	***1***	***1.3839E-33***	***0.8543***	***0.3614903***	***not significant***
	Speed of metering disc	***2.149E-36***	***1***	***2.1494E-36***	***0.0013***	***0.9711436***	***not significant***
	Residual	***5.832E-32***	***36***	***1.6199E-33***			
	Lack of Fit	***5.832E-32***	***31***	***1.8812E-33***			
	Pure Error	***0***	***5***	***0***			
	Cor Total	***1.206E-31***	***39***				

utilizations (AU2) models' equation shows that; all evaluating factors were not significant at $p<0.05$. The same explanation used for the 1st sieve drum can be used for the 2nd sieve drum. Also, the ANOVA of the automation sensing unit actual utilizations (AU3) models' equation shows that; all evaluating factors were not significant at $p<0.05$. This could be because the same quality of sample passes through the automation unit during the experiments. Analysis of variance (ANOVA) carried out for the developed model equation for actual utilizations (AUs) of the entire system shows that, the model equation was significant at $p<0.05$. This means that the error that the chosen model was the wrong model was less than 5%. All factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) used in developing the entire system actual utilizations (AUs) equation were all not significant at $p<0.05$; This could be because the same quality of sample passes through the entire system during the experiments. The lack of fit for the entire system actual utilizations had no value. This means that there were no variations in the sample quantity use for the experiments. The lack of sample variation causes lack of result value variation. This makes it difficult to plot graphs for actual utilizations.

4.4.1.5 System Backlog Modeling and Evaluation

The backlogs that were modeled were that of the 1st sieve drum (B1), 2nd sieve drum (B2), bucket conveyor (B3), materials other than Stone (B4) and the entire system (Bs). Statistical analyses for choosing model equations for these backlogs are also shown in Table 4.17. Four polynomial equations (linear, 2FI, quadratic and cubic) were considered. Linear equation was chosen by the software (Design Expert) for all backlogs considered in this study. Linear equations were chosen because during statistical analysis of the four polynomials equations considered. This is because linear equations have the lowest 'Sequential p-value', the highest 'Lack of Fit p-value', the highest 'Adjusted R-Squared' value and the highest 'Predicted R-Squared' value. Although, linear equations were chosen for modeling all backlogs in the system; experimental data generated were not normally distributed for all data, except for data of backlog of materials other than stone (B4). So, data used for generating the backlogs model equations were transformed except for B4. Data transformation choices used were, Base 10 Log (transformation that make positively skewed data more normal, to account for curvature in a linear model) for data of 1st sieve drum backlog (B1), 2nd sieve drum backlog (B2) and bucket conveyor backlog (B3); no data transformation for backlog of materials other than stone and sand (B4) while the entire system backlog (Bs) data was transformed with square root transformation. After transforming these data, the backlog equations generated are displayed in Appendix D16. Analysis of variance (ANOVA) for the developed backlog equations are displayed in Table 4.20. The analysis show that all equation models developed for the units' parts of the systems backlogs were all significant at $p<0.05$. This means that the chance that the developed model equations are predicting errors is less than 5%. Also, lack of fit values for all developed equations of units' parts of the system were all not significant at $p<0.05$ except backlog for 2^{nd} sieve drum. It is desirable for model's lack of fit not to be significant at $p<0.05$. This is because, lack of fit not being significant at $p<0.05$ means that, the probability that the equation chosen to represent the data behavior was the correct one, was greater than 5%. The lack of fit of the 2^{nd} sieve drum being not significant could be from the choice of number of factors (only two) used in forming the model equation. The backlog ANOVA table shows that, for the 1^{st} sieve drum backlog (B1) equation model, all evaluation factors used; were significant at $p<0.05$. The ANOVA of the 2^{nd} sieve drum backlog (B2) models' equation shows that; all evaluating factors were significant at $p<0.05$ as well. The ANOVA of the bucket conveyor backlog (B3) models' equation shows that; all evaluating factors were significant at $p<0.05$ except for seed grade. This is because all grades have some level of backlog at the bucket conveyor. This occurs because all grades during the separation will contain small debris that the buckets of the conveyor cannot convey at the bottom of the bucket conveyor. Also, the ANOVA of the backlog of materials other than stones and sand (B2) models' equation shows that; all evaluating factors were significant at $p<0.05$. Analysis of variance (ANOVA) carried out for the developed model equation backlog (Bs) of the entire system shows that, the model equation was significant at $p<0.05$. This means that the error that the chosen model was the wrong model was less than 5%. All factors used in developing the entire system backlog (Bs) equation were all significant at $p<0.05$. The lack of fit for the entire system backlog was not significant at $p<0.5$. This means that the probability that the equation we chose for modeling the behavior of the backlog of the entire system is the correct one was greater than 5%. Now let evaluate the effects of the operating factors (speeds of sieve drums, bucket conveyor and metering device; seed variety and grade) to the backlog of the system.

Table 4.20: Analysis of Variance (ANOVA) of Operational Backlog Models for the System Optimization

Operational Parameter	Source	Sum of Squares	df	Mean Square	F Value	P-value Prob > F	
Backlog of 1st Sieve Drum (B1)	Model	2.17	3	0.72	73.73	1.938E-15	significant
	Speed of drums	1.27	1	1.27	129.4	1.781E-13	significant
	Grade	0.96	2	0.48	48.62	5.886E-11	significant
	Residual	0.35	36	9.826E-03			
	Lack of Fit	0.27	31	8.866E-03	0.56	0.8538	not significant
	Pure Error	0.079	5	0.016			
	Cor Total	2.53	39				
Backlog of 2nd Sieve Drum (B2)	Model	5.13	3	1.71	105.5	6.784E-18	significant
	Speed of drums	4.57	1	4.57	281.92	1.31E-18	significant
	Grade	0.68	2	0.34	21.02	8.93E-07	significant
	Residual	0.58	36	0.016			
	Lack of Fit	0.57	31	0.018	5.06	0.039	significant
	Pure Error	0.018	5	3.604E-03			
	Cor Total	5.71	39				
Backlog of bucket conveyor (B3)	Model	1.52	3	0.51	3.59	0.0228	significant
	Speed of metering disc	1.11	1	1.11	7.87	0.0081	significant
	Grade	0.44	2	0.22	1.57	0.2215	not significant
	Residual	5.07	36	0.14			
	Lack of Fit	4.6	31	0.15	1.59	0.3215	not significant
	Pure Error	0.47	5	0.093			
	Cor Total	6.59	39				
Backlog materials other than stones and sand (B4)	Model	0.013	3	4.387E-03	134.67	1.266E-19	significant
	Speed of drums	0.011	1	0.011	329	1.082E-19	significant
	Grade	2.518E-03	2	1.259E-03	38.66	1.088E-09	significant
	Residual	1.173E-03	36	3.257E-05			
	Lack of Fit	9.268E-04	31	2.990E-05	0.61	0.8224	not significant
	Pure Error	2.458E-04	5	4.917E-05			
	Cor Total	0.014	39				
System Backlog (Bs)	***Model***	***0.082***	***4***	***0.02***	***9.07***	***3.882E-05***	***significant***
	Speed of drums	***0.051***	***1***	***0.051***	***22.84***	***3.126E-05***	***significant***
	Speed of metering disc	***8.748E-03***	***1***	***8.748E-03***	***3.89***	***0.0565***	***significant***
	Grade	***0.019***	***2***	***9.463E-03***	***4.21***	***0.023***	***significant***
	Residual	***0.079***	***35***	***2.248E-03***			
	Lack of Fit	***0.062***	***30***	***2.064E-03***	***0.62***	***0.8163***	***not significant***
	Pure Error	***0.017***	***5***	***3.354E-03***			
	Cor Total	***0.16***	***39***				

The effect of the evaluating factors on the unit components backlogs and the entire system backlog are graphically displayed in Figures 4.8 and 4.9. Graphs in the Figure 4.8 shows that the backlogs of the 1st sieve drum (B1) increase with increase in drum speed. This occurs because increase in the drum speed reduces the separating ability of the sieve. This in turn causes samples to remain in the drum long enough to be considered as backlog. Also, 1st sieve drum backlog (B1) increases with increase in the increase in sample grade (impurity); this could be because the present of more impurity in the drum is likely to leave behind more backlogs. In the case of the backlog of the 2nd sieve drum (B2), increase in the drum speed also increases it backlog. Same explanation for the backlog of 1st sieve drum can also be used here. Also, increase in sample grade (impurity) increases backlog of the 2nd sieve drum (B2). Same explanation used for 1st sieve drum can also be used here as well. Graph of bucket conveyor backlog (B3) plotted against metering device speed shows that; increase in metering speed increases the bucket conveyor backlog (B3). This increase in speed can cause seed breakage which will result in more backlog. Increasing the grade (impurity) of the sample reduces the bucket conveyor backlog. Analysis of variance (ANOVA) tells us that this reduction was not significant. In Figure 4.9, a plot of backlog of other materials other than stone and sand (B4) shows that, increase in drum speed increases backlog of other materials other than stone and sand (B4). The same explanation used for B1 can also be used here. Another graph of B4 plotted against the sample grade (impurity) shows that; backlog other than stone and sand (B4) reduces as the grade of the sample increases. This occurs because as the impurity of the sample increases, the likelihood that more backlogs other than sand and stone present in the sample will be left behind in the drum unprocessed. A graph of the entire system backlog (Bs) plotted against sieve drum speed, shows that the entire system backlog (Bs) increases as the drum speed is increased. The explanation used for backlog of 1st and 2nd sieve drum can also be used to explain this behavior of the entire system backlog capacity. Two more graphs for the entire system backlog (Bs) against metering device speed and seed grade; show that as the metering speed increases there was a slight increase in the entire system backlog (Bs) while increase in grade (impurity) decreases the entire system backlog (Bs). This slight increase caused by metering speed as displayed in the ANOVA (Table 20) was significant. On the other hand,

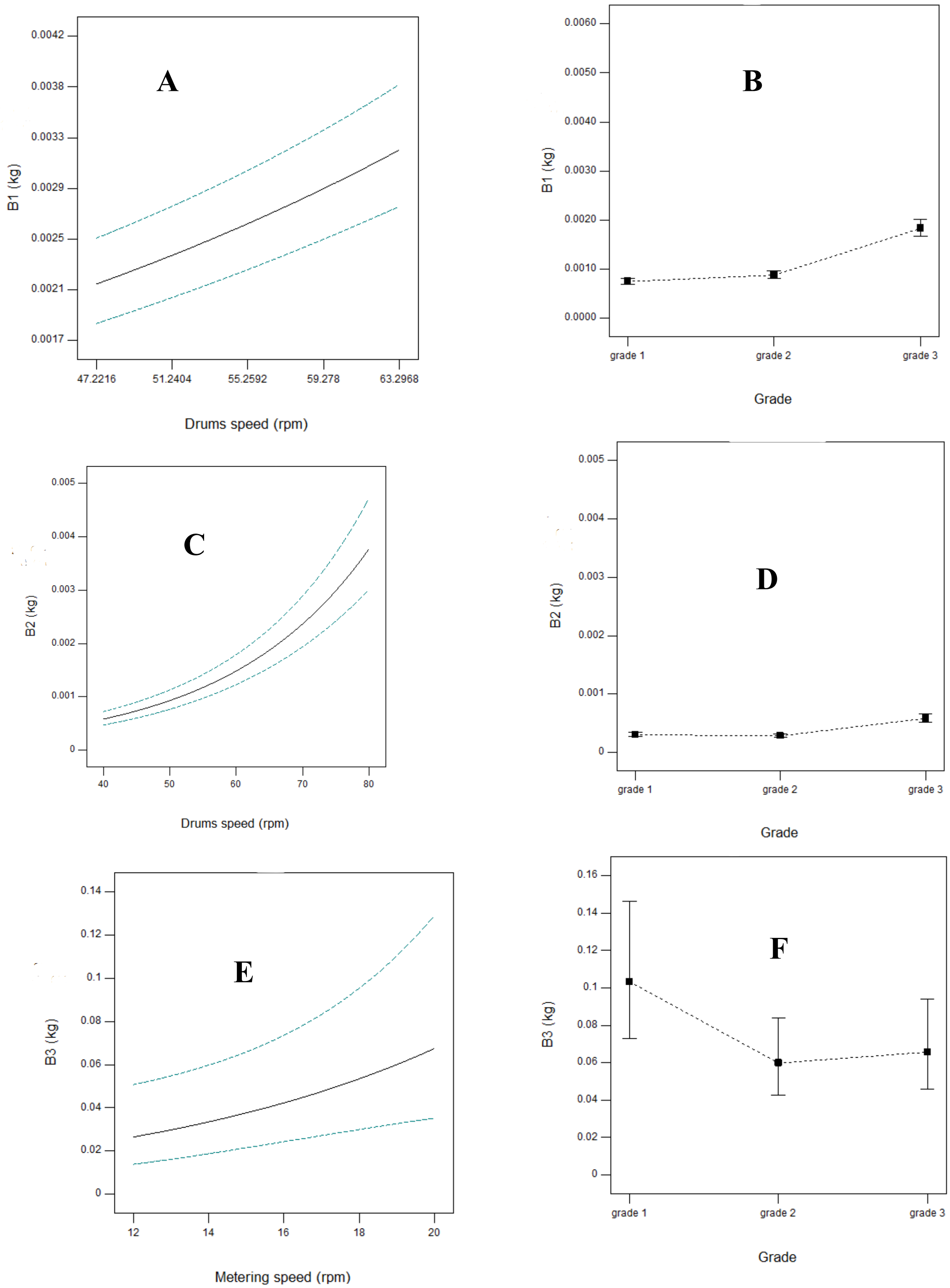


Figure 4.8: Effect of numerical and categorical factors that affect the backlogs of the B1 (A and B), B2 (C and D) and B3 (E and F) of the system

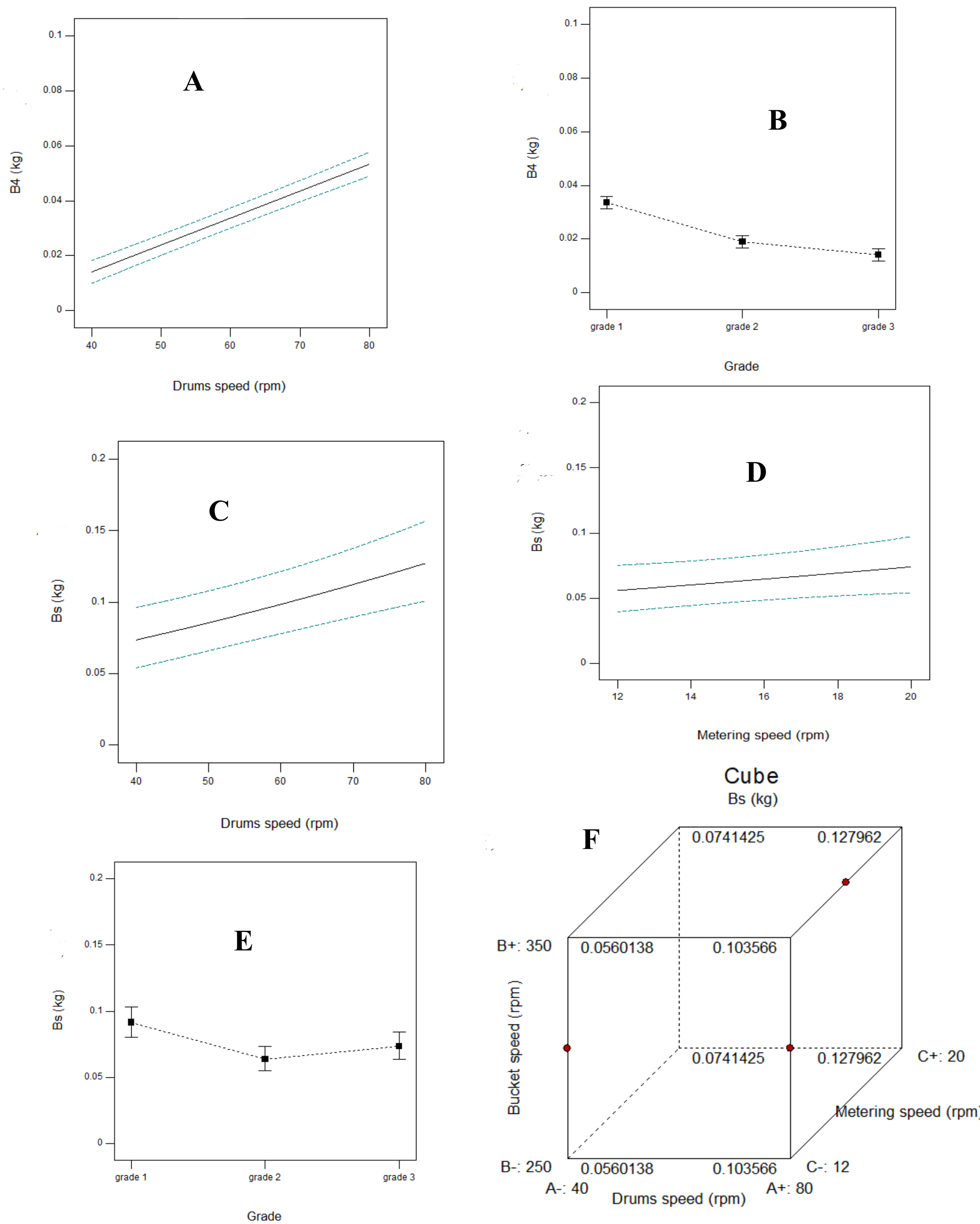


Figure 4.9: Effect of numerical and categorical factors that affect the backlogs of material other than stone and sand B4 (A and B) and the total system Bs (C, D and F)

the decrease in the entire system backlog cause by increase in grade (impurity) occurs; because more impurity means more separation. This in turn reduces the backlog. Figure 4.9 (f) is a cube graph (4-D graph) of the entire system backlog (Bs) plotted against speed of drum, bucket conveyor and metering device. This 4-D graph displayed various values of the entire system backlog (Bs) using the combinations of these three speeds in the system.

4.5 System Optimization

The optimization of the system was done only for the separating efficiency of the entire system (Es), separating throughput of the entire system (Ts), maximum separating capacity of the entire system (MCs), actual utilization of the entire system (AUs) and backlog of the entire system (Bs). To achieve this optimization, optimization goals are set. The optimization goals are displayed in Table 4.21. The set optimization goals are:

1. To obtain the maximum separation efficiency of the entire system (Es) using different combinations of system unit (component) efficiencies (E1, E2, E3, E4 and E5) within the experimental range of seed grade, seed variety, speed of sieve drum, speed of bucket conveyor and speed of metering device used in this study.
2. To obtain the maximum separation throughput of the entire system (Ts) using different combinations of system unit (component) throughputs (T1, T2 and T3) within the experimental range of seed grade, seed variety, speed of sieve drum, speed of bucket conveyor and speed of metering device used in this study.
3. To obtain the highest maximum separation capacity of the entire system (MCs) using different combinations of system unit (component) maximum separating capacities (MC1, MC2 and MC3) within the experimental range of seed grade, seed variety, speed of sieve drum, speed of bucket conveyor and speed of metering device used in this study.
4. To obtain the maximum actual utilization of the entire system (AUs) using different combinations of system unit (component) actual utilizations (E1, E2, E3, E4, E5) within the experimental range of seed grade, seed variety, speed of sieve drum, speed of bucket conveyor and speed of metering device used in this study.
5. To obtain the minimum (lowest) backlog of the entire system (Es) using different combinations of system unit (component) backlogs (B1, B2, B3 and B4) within the experimental range of seed grade, seed variety, speed of sieve drum, speed of bucket conveyor and speed of metering device used in this study.

Table 4.21: Constrains placed on Factors and Responds of System Parameters to carryout Optimization

Constraints						
Name	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**	**Importance**
Speed of sieve drums	in range	40	80	1	1	3
Speeds of bucket conveyor	in range	250	350	1	1	3
Speed of seed metering disc	in range	12	20	1	1	3
Grade	in range	1	grade 3	1	1	3
Variety	in range	63	55	1	1	3
E1	none	90	95	1	1	3
E2	none	60	97.6667	1	1	3
E3	none	94.8718	99.8981	1	1	3
E4	none	19.6078	32.6797	1	1	3
E5	none	90	100	1	1	3
Es	maximize	63.4744	80.3991	1	1	3
T1	none	0.027895	0.64706	1	1	3
T2	none	0.037059	0.48833	1	1	3
T3	none	0.428571	3	1	1	3
Ts	maximize	0.573539	3.7315	1	1	3
MC1	none	0.334737	7.76471	1	1	3
MC2	none	0.444706	5.86	1	1	3
MC3	none	5.14286	36	1	1	3
MCs	maximize	6.88247	44.778	1	1	3
AU1	none	0.083333	0.08333	1	1	3
AU2	none	0.083333	0.08333	1	1	3
AU3	none	0.083333	0.08333	1	1	3
AUs	maximize	0.083333	0.08333	1	1	3
B1	none	0.0005	0.005	1	1	3
B2	none	0.0002	0.004	1	1	3
B3	none	0.002	0.1	1	1	3
B4	none	0.01135	0.08085	1	1	3
Bs	minimize	0.03034	0.1817	1	1	3

E1= Efficiency of 1st drum, E2 = Efficiency of 2nd drum, E3 = Efficiency of bucket conveyor, E4 = Efficiency of metering device, E5 = efficiency of automation unit, Es = System Efficiency, T1 = Throughput of 1st drum, T2 = Throughput of 2nd drum, T3 = Throughput of sensing unit, Ts = system Throughput, MC1 = Maximum Capacity of 1st drum, MC2 = Maximum Capacity of 2nd drum, MC3 = Maximum Capacity of sensing unit, MCs = System Maximum Capacity, AU1= Actual Utilization of 1st drum, AU2= Actual Utilization of 2nd drum, AU3 = Actual Utilization of sensing Unit, AUs = System Actual Utilization, B1= Backlog of 1st drum, B2 = Backlog of 2nd drum, B3 = Backlog of bucket conveyor, B4 = Backlog materials other than stones and sand, Bs = System Backlog

The software (Design Expert) was used to set and combine these goals. 100 (one hundred) optimized solutions was achieved after optimization analysis. These solutions are displayed in Appendix D17 – D21. Among the 100 optimized solution generated by the software. Two solutions are of interest to this study. These solutions were solution number 23 and 55 as displayed in Table 4.22. The first choice, which was solution number 23 was chosen and recommended for the operation of the system. This choice was recommended when the operator desire was to achieve high system separating efficiency with low system backlog. The second choice is solution number 55, was chosen and recommended for the operation of the system. This choice was recommended when the operator desire was to achieve high system separating throughput with maximum system separating capacity. Therefore, the follow recommendation was developed for system operators:

i. To achieve the maximum separating efficiency of 81% with minimal backlog 0.064kg. The system must operate under the following conditions: drum speed should be 40rpm, bucket conveyor speed at 350 rpm and metering device speed at 20rpm. Preferably separating only grade 2 sample of variety 033.

ii. To achieve the maximum separating throughput of 5kg/hr with maximum separating capacity 60kg/12hrs. The system must operate under the following conditions: drum speed should be 40 rpm, bucket conveyor speed at 350 rpm and metering device speed at 20 rpm. Preferably separating only grade 3 sample of variety 063.

In conclusion which ever choice you pick the drum speed should be 40rpm, bucket conveyor speed at 350rpm and metering device speed run at 20rpm

4.5.1.1 Entire System Efficiency Optimization Evaluation

The system efficiency (Es) was optimized and the optimized values used to plot a 4-D cube graph, of the entire system separating efficiency against the speed of: drum, bucket conveyor and metering device. This cube graph is displayed in Figure 4.10. Evaluation of this optimized values graph shows that, as drum speed was increased from 40 to 80 rpm. There was and a decrease in the entire system separating efficiency from 78.9 to 70%. This occurs because from the design calculation, the effective sieve drum speed was calculated to be 40 rpm. The drum speed was increase to deviate from the design speed. Optimization

Table 4.22: Selected Optimized Choices for Optimal Operation of the Separation System

Parameters Optimized	Optimize Choice	
	1	2
Solution No.	23	55
Speed of sieve drums	40.009	40
Speeds of bucket conveyor	250.027	250.019
Speed of metering disc	20	19.919
Grade	grade 2	grade 3
Variety	033	063
E1 (Efficiency of 1st sieve drum in %)	86.407	83.685
E2 (Efficiency of 2nd sieve drum in %)	96.325	96.326
E3 (Efficiency of bucket conveyor in %)	96.715	96.734
E4 (Efficiency of metering disc in %)	32.819	32.792
E5 (Efficiency of automation unit in %)	89.738	82.494
Es (Efficiency of the whole system in %)	***81.29***	78.885
T1 (Throughput of 1st sieve drum in kg/ hr)	0.271	0.628
T2 (Throughput of 2nd sieve drum in kg/ hr)	0.165	0.862
T3 (Throughput of automation unit in kg/ hr)	2.711	2.87
Ts (Throughput of whole system in kg/ hr)	3.47	***5.077***
MC1(Maximum capacity of 1st sieve drum in kg/ 12hr)	2.745	7.442
MC2 (Maximum capacity of 2nd sieve drum in kg/ 12hr)	1.981	10.35
MC3 (Maximum capacity of automation unit in kg/ 12hr)	31.466	34.406
MCs (Maximum capacity of whole system in kg/ 12hr)	43.519	***60.57***
AU1 (Actual Utilization of 1st sieve drum)	0.083	0.083
AU2 (Actual Utilization of 2nd sieve drum)	0.083	0.083
AU3 (Actual Utilization of automation unit sieve drum)	0.083	0.083
Aus (Actual Utilization of whole system sieve drum)	0.083	0.083
B1 (Backlog of material greater than 12mm in kg)	0.001	0.002
B2 (Backlog of material less than 2mm in kg)	0	0.001
B3 (Backlog of bucket conveyor in kg)	0.061	0.067
B4 (Backlog of materials other than stones and sand in kg)	0.019	0.014
Bs (Backlog of whole system in kg)	**0.064**	0.074
Desirability	0.911	0.897

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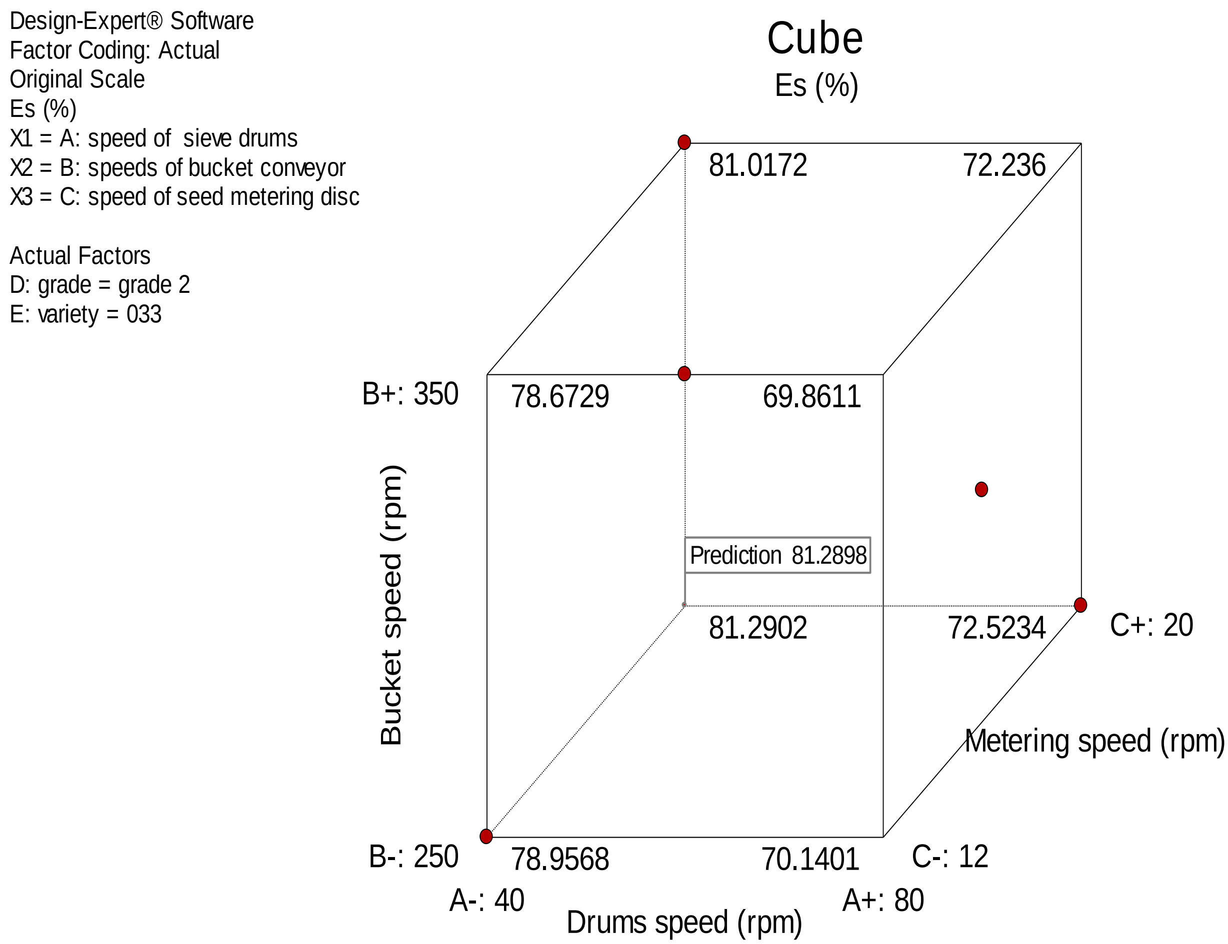

Figure 4.10: Typical Cube plot of optimized valves of the entire system separating efficiency

evaluation result shows that moving away from the design speed reduces the separating efficiency of the entire system. Increasing the bucket conveyor speed from 250 to 350 rpm reduces the separating efficiency slightly from 78.9 to78.6%. Although ANOVA of the system efficiency had initial stated that this decrease is not significant at $p<0.05$ to the entire system separating efficiency. Also, increase in metering device speed from 12 to 20 rpm increases the separating efficiency from 70 to 72.5%. According to ANOVA of system efficiency, this increase was significant at $p<0.05$. This increase was as a result of reduction of seed breakage caused by the metering disc. That is, as the speed of the metering disc was increase the cowpea seeds brush less on the metering disc housing casing, therefore causing less breakage. This in turn increases the separating efficiency of the automation unit, which changes the entire system separating efficiency. The cube graph also indicates that the highest separating efficiency of 81.2% was achieved at drum speed of 40rpm, bucket conveyor speed of 250rpm and metering device speed of 20 rpm.

4.5.1.2 Entire System Throughput Optimization Evaluation

The entire system throughput (Ts) was optimized and the optimized values used to plot a 4-D cube graph, of the entire system separating throughput against the speed of: drum, bucket conveyor and metering device. This cube graph is displayed in Figure 4.11. Evaluation of this optimized values graph shows that, as drum speed was increased from 40 to 80 rpm. There was and a decrease in the entire system separating throughput from 3.3 to 2.8 kg/hr. According to ANOVA of the system throughput the decrease was significant at $p<0.05$. The same explanation given for the entire system efficiency with drum speed can also be used to explain this decrease in the entire system throughput. Increasing the bucket conveyor speed from 250 to 350rpm increases the separating throughput slightly from 3.3 to 3.6 kg/hr. Also, the ANOVA of the system throughput had initial stated that this increase was significant at $p<0.05$ to the entire system separating throughput. An increase in metering device speed from 12 to 20 rpm increases the system separating throughput from 2.8 to 4.3 kg/hr. According to ANOVA of the system throughput this increase was significant at $p<0.05$. This increase was as a result of reduction of seed breakage caused by the metering disc. That is, as the speed of the metering disc was increase the cowpea seeds brush less on the metering disc housing casing, therefore causing less breakage. This in turn increases the

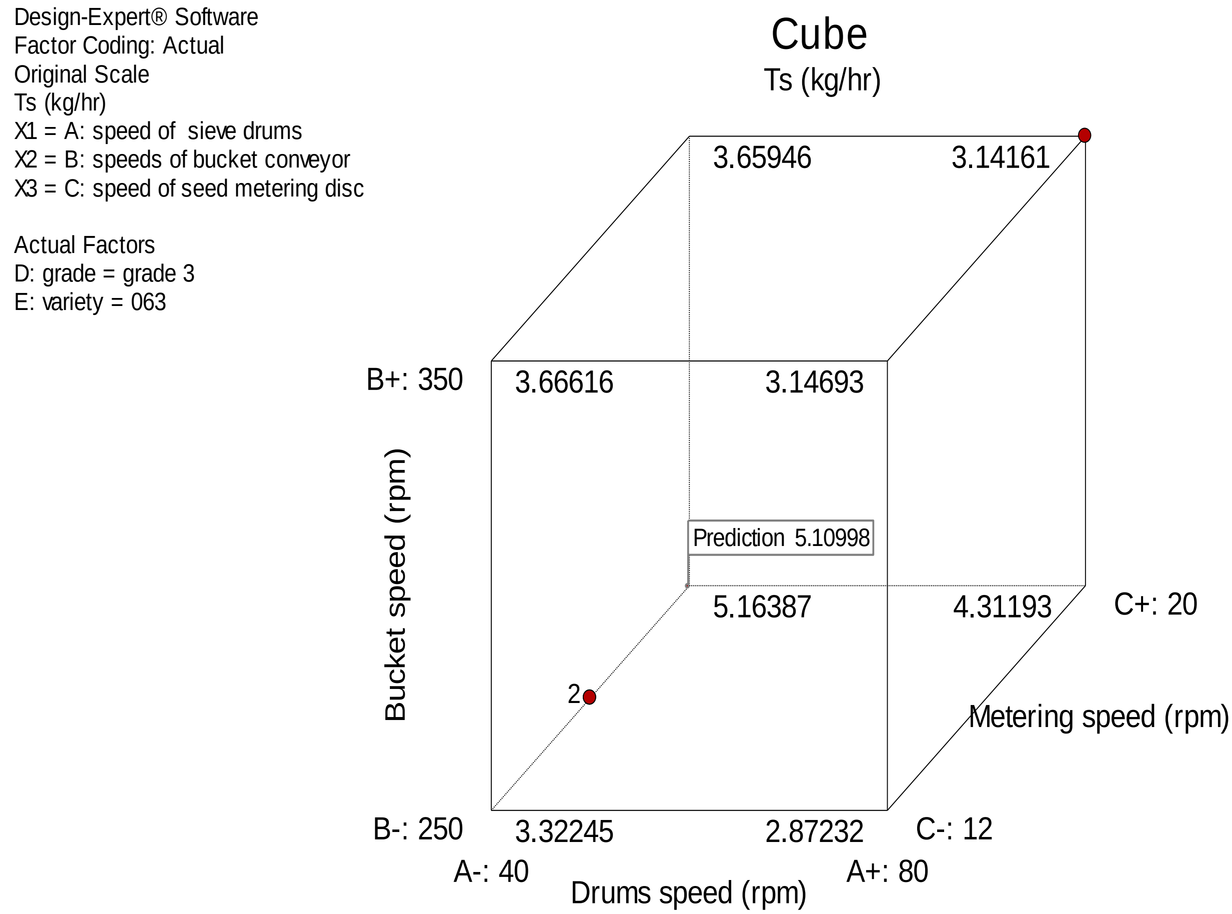

Figure 4.11: Typical Cube plot of optimized valves of the entire system separating throughput

separating throughput of the automation unit, which changes the entire system separating throughput. The cube graph also indicates that the highest entire system separating throughput of 5.1kg/hr was achieved at drum speed of 40rpm, bucket conveyor speed of 250rpm and metering device speed of 20rpm.

4.5.1.3 Entire System maximum Capacity Optimization Evaluation

The whole system maximum separating capacity (MCs) was optimized and the optimized values used to plot a 4-D cube graph, of the whole system maximum separating capacity against the speed of: drum, bucket conveyor and metering device. This cube graph is displayed in Figure 4.12. Evaluation of this optimized values graph shows that, as drum speed was increased from 40 to 80 rpm. There was and a decrease in the entire system maximum separating capacity from 40 to 29.8kg/12hr. According to ANOVA of the system maximum capacity the decrease was significant at $p<0.05$. The same explanation given for the entire system efficiency with drum speed can also be used to explain this decrease in the entire system maximum separating capacity. Increasing the bucket conveyor speed from 250 to 350rpm increases the whole system maximum separating capacity from 40 to 53kg/12hr. Also, ANOVA the system maximum capacity had initial stated that this increase was significant at $p<0.05$ to the entire system maximum separating capacity. An increase in metering device speed from 12 to 20 rpm increases the system maximum separating capacity from 29 to 42 kg/12hr. According to ANOVA of the system maximum capacity this increase was significant at $p<0.05$. This increase was as a result of reduction of seed breakage caused by the metering disc. That is, as the speed of the metering disc was increase the cowpea seeds brush less on the metering disc housing casing, therefore causing less breakage. This in turn increases the separating maximum separating capacity of the automation unit, which changes the entire system maximum separating capacity. The cube graph also indicates that the highest entire system maximum separating capacity of 60.9 kg/12hr was achieved at drum speed of 40 rpm, bucket conveyor speed of 250 rpm and metering device speed of 20rpm.

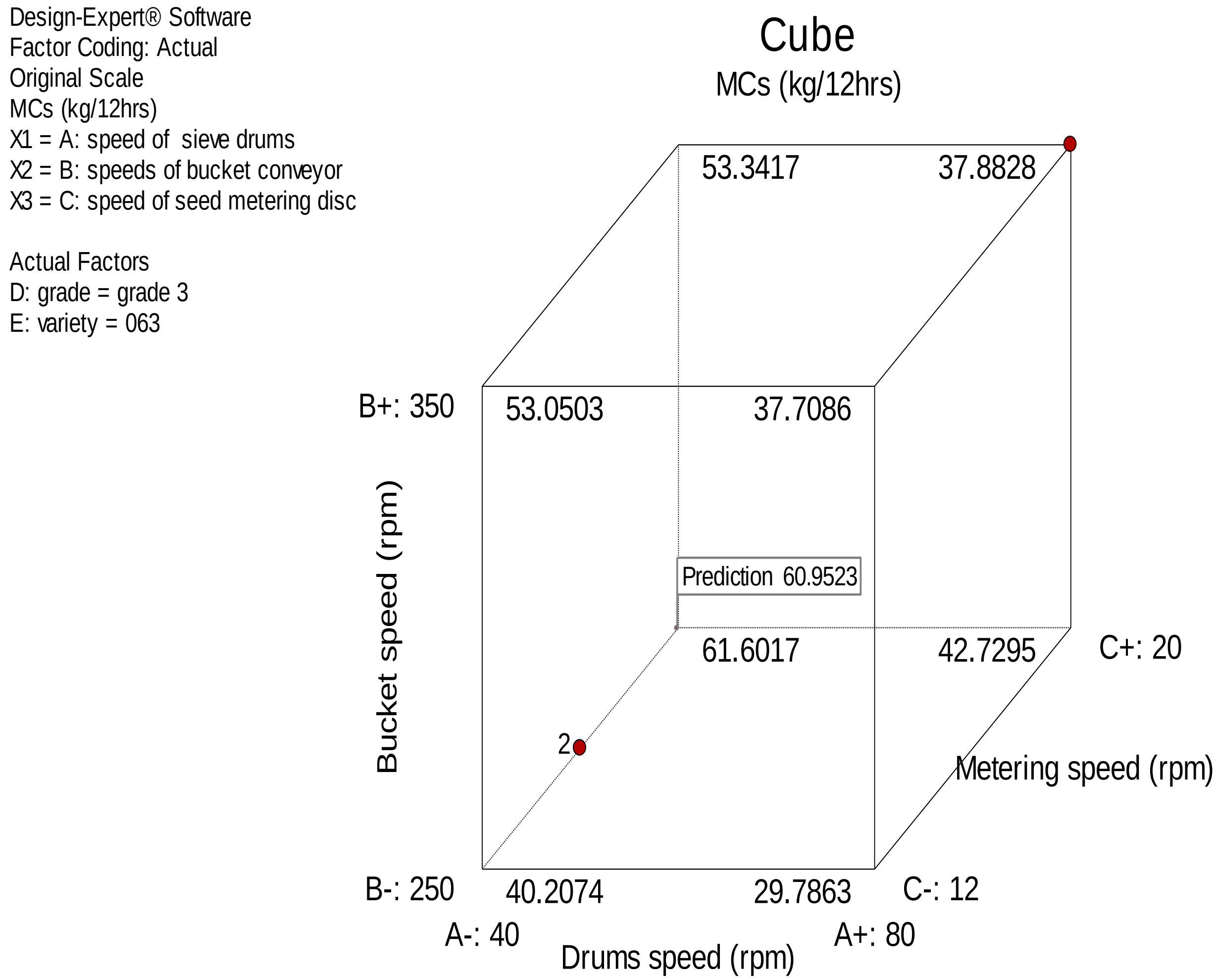

Figure 4.12: Typical Cube plot of optimized valves of the entire system separating maximum capacity

4.5.1.4 Entire System Actual Utilization Optimization Evaluation

The entire system actual utilization (AUs) was optimized. The value of the optimized actual utilization was not used to plot a 4-D cube graph. This was because there was no variation in the sample weight (2 kg) that was use in all experiment done. Values of actual utilization achieved in all system components and the entire system remain 0.083(8.3%). Since the actual utilization values remain the same (0.083) in all components of the system. Plotting any graph with the same numbers will not show any effect.

4.5.1.5 Entire System backlog Optimization

The whole system backlog (Bs) was optimized and the optimized values used to plot a 4-D cube graph, of the whole system backlog (Bs) against the speed of: drum, bucket conveyor and metering device. This cube graph is displayed in Figure 4.13. Evaluation of this optimized values graph shows that, as drum speed was increased from 40 to 80 rpm. There was and a increase in the entire system backlog (Bs) from 0.04 to 0.09kg. According to ANOVA of the system backlog, the increase was significant at $p<0.05$. This increment occurs because high drum speed (greater than it designed speed of 40rpm) reduce the sieving power. This allow backlog of sample to remain in the drum, which will later be removed as waste by the screw conveyor inside the sieve drum. Increasing the bucket conveyor speed from 250 to 350rpm neither increases nor decreases the whole system backlog (Bs); the backlog value the same (from 0.04 to 0.04kg). This occurs because separation does not really take place at the bucket conveyor. An increase in metering device speed from 12 to 20rpm increases the system backlog (Bs) from 0.09 to 0.11 kg. According to ANOVA of the system backlog, this increase was significant at $p<0.05$. This increment occurs because at a certain speed of the metering disc. The cowpea seeds are broken either because the holes in the metering disc could not properly hold this seed at this speed or the seeds are been broken by it rubbing on the disc housing casing. The cube graph also indicates that the highest entire system backlog (Bs) of 0.06 kg was achieved at drum speed of 40 rpm, bucket conveyor speed of 250 rpm and metering device speed of 20 rpm.

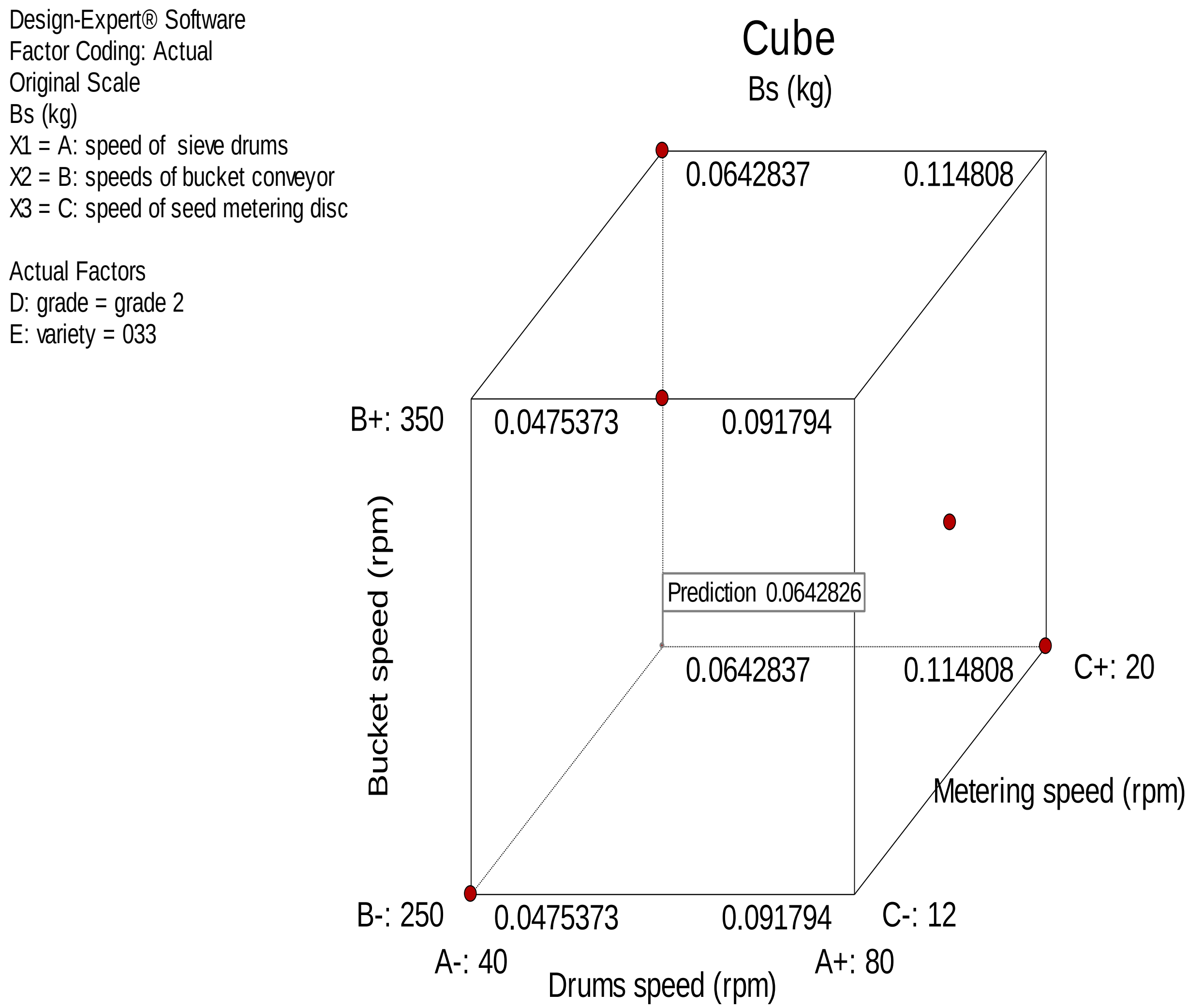

Figure 4.13: Typical Cube plot of optimized valves of the entire system backlog

4.6 System Validation

The entire system was confirmed or validated using prediction interval statistical analysis and regression analysis. The prediction interval statistical experimental table was created by the software (Design Expert). The validation experimental information created from the optimized values was displayed in Table 4.23. According to this table validation experiment on the system was carried out using the optimum operating values obtained by the optimization. So, the optimum operating values were drum speed at 40 rpm, bucket conveyor speed at 250 rpm, metering device speed of 20 rpm, using sample with grade 2 impurity of seed variety of 033 (white big seeds). These five validation factors were used to perform 3 validation tests and their mean value recorded. Validation parameters of the system determined were: separating efficiency of sieve drum 1(E1) which was 90%, separating efficiency of sieve drum 2 (E2) which was 96%, separating efficiency of bucket conveyor (E3) which was 96%, separating efficiency of metering device (E4) which was 32%, separating efficiency of automation unit (E5) which was 91%, separating efficiency of entire system (Es) which was 81%, separating throughput of sieve drum 1(T1) which was 0.36 kg/hr, separating throughput of sieve drum 2 (T2) which was 0.19 kg/hr, separating throughput of automation unit (T3) which was 2.9 kg/hr, separating throughput of the entire system (Ts) which was 3.5 kg/hr, maximum separating capacity of sieve drum 1 (MC1) which was 3.2 kg/12 hrs, maximum separating capacity of sieve drum 2 (MC2) which was 1.9 kg/12 hrs, maximum separating capacity of automation unit (MC3) which was 40 kg/12 hrs, maximum separating capacity of the entire system (MCs) which was 46 kg/12 hrs actual utilization of sieve drum 1 (AU1) which was 0.083, actual utilization of sieve drum 2 (AU2) which was 0.083, actual utilization of automation unit (AU3) which was 0.083, actual utilization of the entire system (AUs) which was 0.083, backlog of sieve drum1(B1) which was 0.0008 kg, backlog of sieve drum 2 (B2) which was0.00018 kg, backlog of bucket conveyor (B3) which was 0.059kg, backlog of materials other than stones and sand (B4) which was 0.0084 kg, backlog of the entire system (Bs) which was 0.068kg. These mean values of the system validation parameters were used to compare with their statistically calculated prediction interval 95% low (95% PI low) and prediction interval 95% high (95% PI high). The mean values of all validation parameters all fall within the range of the

Table 4.23: Confirmation (Validation) of the entire separating system using the Optimized information

Confirmation Report setting used for Experiment

Two-sided Confidence = 95% n = 1

Factor	Name	Level used for confirmation test
A	Drums Speed (rpm)	40
B	Bucket speed (rpm)	250
C	Metering speed	20
D	Grade	grade 2
E	Variety	033

Confirmation Report Experimental Result

Response	Predicted Mean	Original Experimental Data Mean	Predicted Median	Standard Deviation	Trial	Standard Error of prediction	95% PI (prediction interval) low	Confirmation Experimental mean	95% PI (prediction interval) high
E1 (%)	86.411	76.596	86.411	3.340	3	3.495	79.324	90.562	93.499
E2 (%)	96.327	85.338	96.510	1.194	3	N/A	93.045	96.437	98.303
E3 (%)	96.715	97.627	97.197	2.209	3	N/A	92.263	96.722	99.575
E4 (%)	32.818	26.307	32.817	0.208	3	N/A	32.376	32.048	33.262
E5 (%)	89.738	82.058	89.738	1.952	3	2.089	85.492	91.236	93.984
Es (%)	81.290	73.585	81.302	1.084	3	N/A	78.821	81.401	83.658
T1 (kg/hr)	0.271	0.220	0.270	0.046	3	N/A	0.151	0.360	0.411
T2 (kg/hr)	0.165	0.144	0.164	0.015	3	N/A	0.129	0.198	0.225
T3 (kg/hr)	2.711	1.386	2.661	0.425	3	N/A	1.856	2.993	4.131
Ts (kg/hr)	3.471	1.751	3.437	0.398	3	N/A	2.502	3.551	5.012
MC1 (kg/12hrs)	2.746	2.645	2.679	0.857	3	N/A	1.058	3.267	4.996
MC2 (kg/12hrs)	1.981	1.733	1.966	0.177	3	N/A	1.546	1.952	2.699
MC3 (kg/12hrs)	31.471	16.635	30.911	4.869	3	N/A	21.828	40.851	47.112
MCs (kg/12hrs)	43.510	21.013	43.063	5.110	3	N/A	31.379	46.07	62.731
AU1	0.083	0.083	0.083	0.000	3	0.000	0.083	0.083	0.083

AU2	0.083	0.083	0.083	0.000	3	0.000	0.083	0.083	0.083
AU3	0.083	0.083	0.083	0.000	3	0.000	0.083	0.083	0.083
AUs	0.083	0.083	0.083	0.000	3	0.000	0.083	0.083	0.083
B1 (kg)	0.001	0.002	0.001	0.000	3	N/A	0.00053	0.000805	0.00139
B2 (kg)	0.000	0.001	0.000	0.000	3	N/A	0.00015	0.000174	0.00051
B3 (kg)	0.061	0.046	0.045	0.045	3	N/A	0.00717	0.059232	0.27941
B4 (kg)	0.019	0.041	0.019	0.006	3	0.006	0.00687	0.008437	0.03109
Bs (kg)	0.064	0.090	0.062	0.024	3	N/A	0.021	0.068648	0.124

E1= Efficiency of 1st drum, E2 = Efficiency of 2nd drum, E3 = Efficiency of bucket conveyor, E4 = Efficiency of metering device, E5 = efficiency of automation unit, Es = System Efficiency, T1 = Throughput of 1st drum, T2 = Throughput of 2nd drum, T3 = Throughput of sensing unit, Ts = system Throughput, MC1 = Maximum Capacity of 1st drum, MC2 = Maximum Capacity of 2nd drum, MC3 = Maximum Capacity of sensing unit, MCs = System Maximum Capacity, AU1= Actual Utilization of 1st drum, AU2= Actual Utilization of 2nd drum, AU3 = Actual Utilization of sensing Unit, AUs = System Actual Utilization, B1= Backlog of 1st drum, B2 = Backlog of 2nd drum, B3 = Backlog of bucket conveyor, B4 = Backlog materials other than stones and sand, Bs = System Backlog, N/A = Not available due to transformation of the original data.

statistically calculated 95% PI low and 95% PI high. This indicates that all validation parameters are confirmed to be valid. The validation experimental readings are displayed in Appendix D22. Another validation was done using regression analysis.

A regression analysis was also done to validate the system parameters like: separating efficiencies of the system (E1, E2, E3, E4, E5 and Es), separating throughputs of the system (T1, T2, T3 and Ts), maximum separating capacities of the system (MC1, MC2, MC3 and MCs) and backlogs of the system (B1, B2, B3, B4 and Bs). The system actual utilizations were exempted from the validation because there was no change in their values. A graph of the validation experiment values was plotted against predicted mean values and displayed Figure 4.14. The R-square (a statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable or variables in a regression model) of the graph was used to validate the system parameters. That is, if the confirmation (validation) experimental results where the same as the ones predicted by the developed model equations. R-square (R^2) is also the square of the correlation relationship between the independent variable (X-axis) and the dependent variable (Y-axis). The separating efficiencies of the system regression graph shows an R-square (R^2) value of 0.995 (99.5%). This means that the validation (Confirmation) experimental results for the separating efficiencies of the system were explaining 99.5% of the same things that the predicted results obtained from the developed models' equations were explaining. The R-square (R^2) value of the system separating throughputs regression graph was 0.996 (99.6%). This means that the validation (confirmation) experimental results for the separating throughputs of the system were explaining 99.6 % of the same things that the predicted results obtained from the developed models' equations were explaining. The maximum separating capacities of the system regression graph shows an R-square (R^2) value of 0.978 (97.8%). This means that the validation (confirmation) experimental results for the maximum separating capacities of the system were explaining 97.8% of the same things that the predicted results obtained from the developed models' equations were explaining. The R-square (R^2) value of the system backlogs regression graph was 0.975 (97.5%). This means that the validation (confirmation) experimental results for the backlogs of the system were explaining 97.5 % of the same things that the predicted results obtained from the developed models' equations were explaining. So therefore, we can now say that

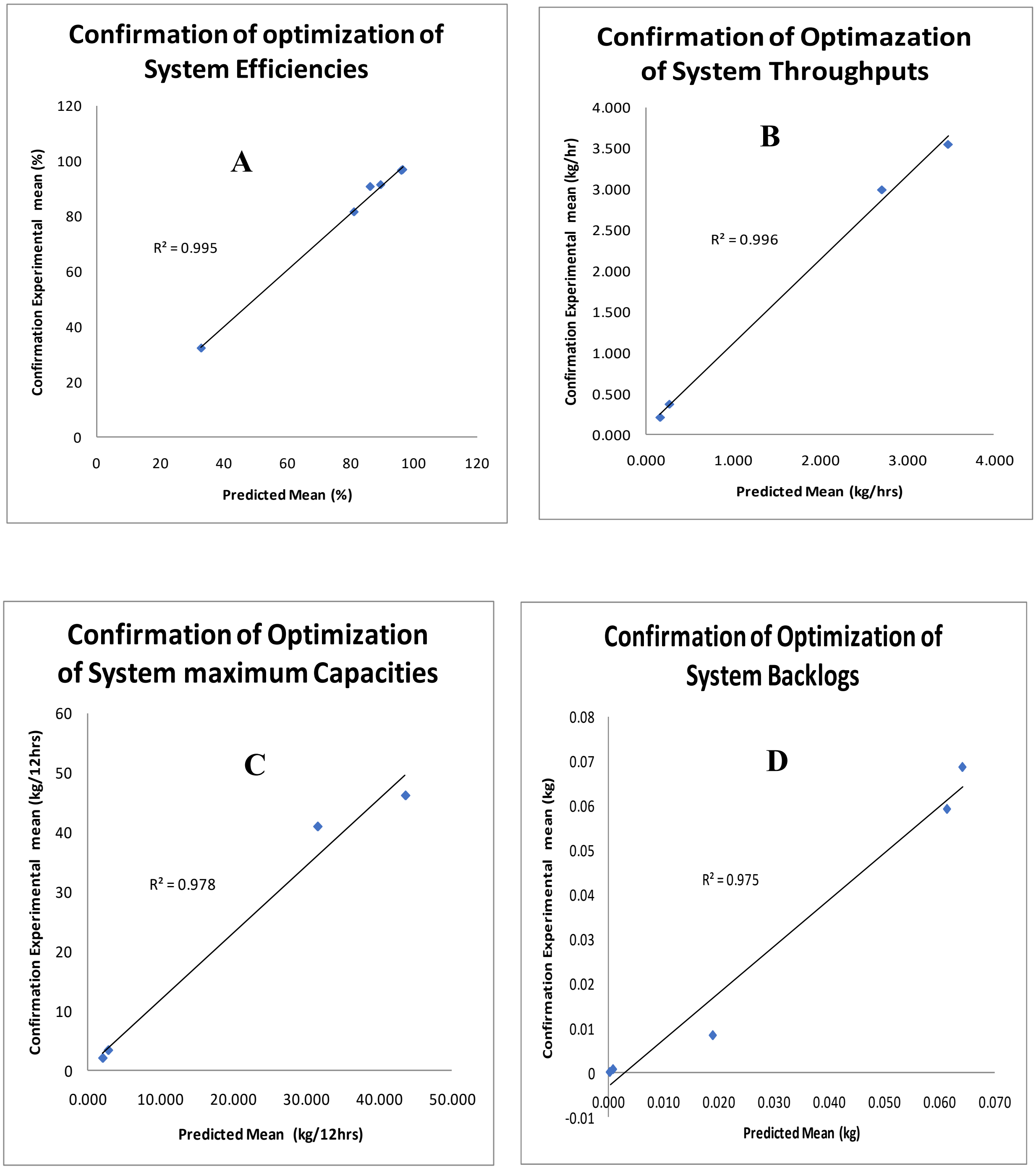

Figure 4.14: Graph of Experimental confirmation data and model predicted data used as test for confirmation

CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

An integrated semi-automated cowpea seeds grading machine was developed. The machine was design using optimised values of cowpea seeds physical, optical and electrical properties. Standard methods were used to construct each unit of the machine. The machine was divided into six operational units. These units are: the first separating unit (with a sieve rotating drum, where unwanted materials > 12mm leave the system); the second separating unit (with a sieve rotating drum where unwanted materials < 2mm leave the system); the conveying unit (materials are transported by a bucket conveyor); the metering unit (materials are metered one after the other, by a rotating disc); Automation unit (Raspberry pi camera and board with a 5″ TFT screen attached for sensing while separation was achieved with servo motors actuators having plastic flippers) using Python program; the belt conveyor unit (for transporting and inspection of final product). Evaluation of the system was done by modeling and optimizing impurity separating parameters. The evaluation result ranges show that the total impurity separating: efficiency, throughput, maximum capacity, actual utilisation and backlog of the system were from 63 - 80%, 0.5 – 3.7 kg/hr, 6 - 45 kg/12hr, 0.083 - 0.083 (8.3%) and 0.03 –0.182 kg respectively. The validation experiments carried on the machine show that correlation between physical experimental results and predicted model values were above 90% at P value <0.05.

5.2 Conclusions

The conclusions of this study are as follows:

i. Optical and electrical properties of cowpea seeds were determined and its values were modeled and optimized. The optimized values were used to select optimum values limit for selecting optical and electrical properties for automation consideration. Also, during evaluation of these properties, it was discovered that for optical properties, the colour properties (L* a* b*) were a better property for cowpea seed recognition for automation process than the absorbance, transmittance and reflectance properties. This is because mean experimental values of L* a* b* are 60%, 3% and 18% respectively; while that of absorbance, reflectance and transmittance were 1.2%, 0.1% and 2.9%. Therefore, about 95% of light that hit the surface of cowpea seeds, were neither absorbed, transmitted nor directly reflected. These rays are assumed to scatter in different directions upon hitting the surface of the cowpea seed. This means that in other to use the absorbance, transmittance and reflectance properties, the seed will have to be placed in an enclosed environment with sensors place all around the enclosed environment to capture the scatted light. Electrical properties were found to be useful only in bulk cowpea seeds detection and not in single seed sorting.

ii. A cowpea seed separating system was physically designed and constructed for separating quality parameters for different cowpea variety. This quality parameters were seed grades which were made up of foreign body (sand, stone and cowpea dry pods and stalk), broken seeds and damaged (diseased and insect infected) seeds.

iii. The system was automated using Python programming language to detect image and compare captured images with stored images in system memory and make decisions on the detected seed.

iv. The developed system operational parameters were modeled and optimized for both its unit components and the entire system. Operational parameters considered were separating efficiency, separating throughput, maximum separating capacity, actual utilization and backlog. Optimization analysis done for the system show that, optimum separation efficiency that can be achieved by the entire system was 81.29%. Optimum separating throughput that can be achieved by the entire system was 5.07kg/hr. Optimum maximum separating capacity that can be achieved by the entire system was 60.57kg/12hr. Maximum actual utilization that can be achieved by the physical size of the constructed entire system was 24kg. Optimum backlog that can be achieved by the entire system was 0.064kg. Also, the optimum operational speed to operate the entire system were 40rpm for the two sieve drums, 250rpm for bucket conveyor and 20rpm for metering device speed. Evaluation of the entire system and its components parts show that; factors like speed of drum, speed of bucket conveyor, speed of metering disc, seed grade and variety; affect the system performance parameters like separating efficiency, separating throughput, maximum separating capacity, actual utilization and backlog. These effects according to ANOVA were found to be significant at $p<0.05$. Two separate validation (confirmation) analyses which were prediction interval (PI) and regression analysis done on the system show similar conclusion. The prediction interval analysis concludes that since all validation experimental results values lies within the statistically calculated 95% high and 95% low prediction interval (PI) range. Then the system is working within the same limit that the developed models can predict. The regression analysis concludes that, all performance parameter values gotten in the validation experiment has above 95% correlation to the predicted values of the same performance parameter values predicted by the developed system model equations. These validation (confirmation) analyses have proven that the developed model equations can be used as a representation of the real operational activities of the system.

5.3 Recommendations

This study deduces the following recommendations:

i. The operating speed of sieve drum, bucket conveyor and seed metering should not exceed or go below 40, 250 and 20 rpm; for optimum system efficiency, throughput, and backlog.
ii. The efficiency of the metering device could further be improved by carrying out more investigated on it.
iii. To prevent some seeds from coming out with the stones outlet the first sieve drum should be tilted a little at an angle.

5.4 Contribution to Knowledge

The new aspect this study term to contribute to the body of knowledge is on the application of system thinking approach to cowpea seed impurity separation. Existing cowpea grading machines are mostly for unit operations. Integrated grading machine are needed for improved seed grading and efficient processing. Also, the study had shown that cowpea waste of about 1.136 million tons in Africa can be converted to exportable grade. Hence increase the foreign exchange of producing African countries.

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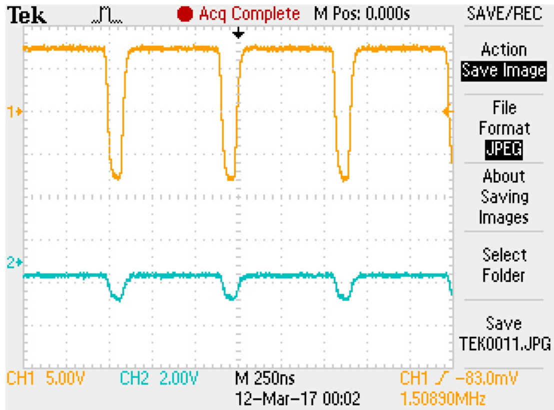
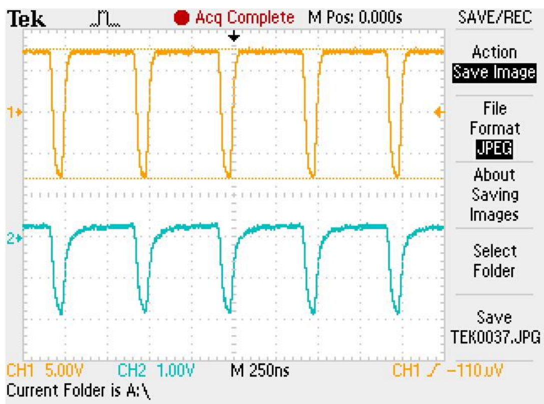
APPENDICES

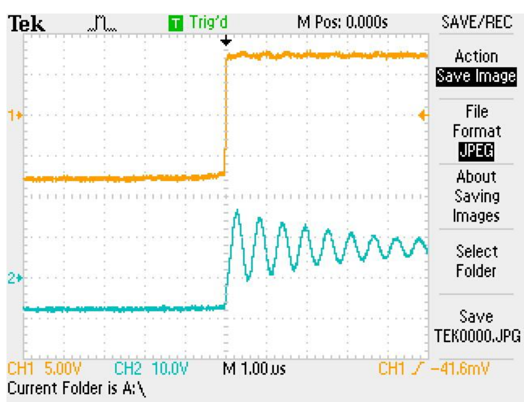
Appendix A: A typical Oscilloscope Measurement Display for electrical properties



(a) Resistance Measurement Display



(b) Capacitance Measurement Display



(c) Inductance Measurement Display

Appendix B1: African Standard for Cowpea Quality

Definitions

For the purpose of this standard the following definitions apply.

cowpeas

dry mature seeds of Vigna unguiculata L.

broken cowpeas

pieces of cowpeas that are less than three-quarters the size of a whole seed

damaged

whole or broken cowpeas that are sprouted, frost damaged, heated, damaged by insects, distinctly deteriorated or discoloured by weather or by disease, or that are otherwise

shrivelled cowpeas

cowpeas which are under-developed and wrinkled over their entire surface excluding wrinkled chickpeas

split

broken pieces of cowpeas that are less than three-quarters of the whole seed, and cotyledons that are loosely held together by the seed coat

foreign matter

any extraneous matter than cowpeas or other food grains comprising of

(a) "inorganic matter" includes metallic pieces, shale, glass, dust, sand, gravel, stones, dirt, pebbles, lumps or earth, clay, mud and animal filth etc;

(b) "organic matter" consisting of detached seed coats, straws, weeds and other inedible grains etc.

poisonous, toxic and/or harmful seeds

any seed which if present in quantities above permissible limit may have damaging or dangerous effect on health, organoleptic properties or technological performance such as Jimson weed — datura (D. fastuosa Linn and D. stramonium Linn.) corn cokle (Agrostemma githago L., MachaiLalliumremulenum Linn.) Akra (Vicia species), Argemone mexicana, Khesari and other seeds that are commonly recognized as harmful to health

Characteristics	Maximum limits			Method of test
	1	Grade 2	Grade 3	
Foreign matter, % m/m	0.2	0.6	1.0	ISO 605
Inorganic matter, % m/m	0.1	0.5	0.75	
Broken/split grains, % m/m	1	2	3	
Pest damaged grains, % m/m	2	3	6	
Rotten and diseased grains, % m/m	0.5	0.5	1	
Discoloured grains, % m/m	1	1	3	
Immature/shrivelled grains, % m/m	1	2	3	
Filth, % m/m	0.1	0.1	0.1	
Total defective grains, % m/m	2	4	5	
Moisture, % m/m	14.0	14.0	14.0	ISO 24557
Total aflatoxin (AFB_1+AFB_2+AFG_1 +AFG_2)), ppb, max	10			ISO 16050
Aflatoxin B_1 only, ppb, max	5			
Fumonisin, ppm, max	2			AOAC 2001.04

Source: African Standard. 2012

ISO 605, Pulses — Determination of impurities, size, foreign odours, insects, and species and variety — Test methods.

ISO 24557, Pulses — Determination of moisture content — Air-oven method

ISO 16050, Foodstuffs — Determination of aflatoxin B1, and the total content of aflatoxin B1, B2, G1 and G2 in cereals, nuts and derived products — High performance liquid chromatographic method

AOAC Official Method 2001.04, Determination of Fumonisins B1 and B2 in corn and corn flakes — Liquid chromatography with immunoaffinity column cleanup

Appendix B2: AHCX Cowpea quality Contract

General Definitions

- Moisture content: expressed on a wet weight bases, shall be determined using an approved moisture meter.
- Impurities: The sum of the damaged Cowpeas, broken kernels, foreign matter and other grains.
- Under developed & broken Kernels: Cowpeas and pieces of Cowpeas that pass through 4.5mm round hole sieve and remains on top of a 2.38mmsieve
- Foreign Matter: All matter except other grains that pass through a 2.38mm round hole sieve and all matter other than Cowpeas remaining on top of the 4.5mm and 2.38mm sieve after sieving.
- Damage: A piece of Cowpeas that are; Germ damage, Heat damaged, Mold damaged, Stained grains, Discolored grains, Diseased grains, Sprouted grains, Immature grains, Insect damaged, Otherwise damaged
- Good Natural Colour: The natural appearance of the grain, which is pure and has not been affected by natural or man-made factors.
- Objectionable smell: Unpleasant smell that is caused by weathering, chemical contamination, mould infection, disease or damage caused by insect.
- Other Grains: Grains, whole or broken, other than grain under consideration.
- Test Mass: A measure of grain density determined by weighing a known volume of grain and expressed as *Kilogram per Hectoliter.*
- Mixed Cowpeas: Mixture of different natural colors of Cowpeas grain.
- Immature grains: Grains or pieces of grains that are not fully developed.
- Heat Damaged: Grains or pieces of grains of Cowpeas which have been materially damaged by spontaneous heat or as a result of heat caused by fermentation.
- Contrasting Color: Cowpeas kernels that have a seed coat color that is different from the predominant kernel color.

Parameter	1	Grade 2	Grade 3
Test Mass kg/hl. % min.	75.0	72.0	69.0
Moisture content	Less than 12%	12.01 to 13.00%	13.01 to 14%
Total Impurities, max % by weight	6	7.5	8.5
Of Which:			
Under developed & broken kernels, max % by weight	2.0	2.0	2.0
Foreign matter, max % by weight	0.5	1.0	1.0
Damage, max % by Weight	2.0	2.0	2.0
Other grains, max % by weight	0.5	0.5	0.5
Contrasting Color, max % by weight	1.0	2.0	3.0

Source: AHCX Cowpea Contract 2014

Appendix B3: US Standard for Beans

Grades.
Grades shall be the numerical grades, substandard grades, sample grades, and special grades provided for in 125 through 135. *[47 FR 19310, May 5, 1982][62 FR 52967, Oct. 10, 1997]*

Soundbeans.
Sound beans shall be beans that are free from defects.

Defects.
Defects for the classes Baby Lima and Miscellaneous Lima beans shall be damaged beans, contrasting classes, and foreign material. Defects for all other classes of beans shall be splits, damaged beans, contrasting classes, and foreign material.

Splits.
Splits shall be pieces of beans that are not damaged, each of which consists of three-fourths or less of the whole bean, and shall include any sound bean the halves of which are held together loosely.

Damagedbeans.
Damaged beans shall be beans and pieces of beans that are damaged by frost, weather, disease, weevils or other insects, or other causes.

Badly damaged beans.
Badly damaged beans shall be beans and pieces of beans that are materially damaged or discolored by frost, weather, disease, weevils or other insects, or other causes so as to materially affect the appearance and quality of the beans.

Foreign material.
Foreign material shall be stones, dirt, weed seeds, cereal grains, lentils, peas, and all matter other than beans.
[44 FR 73007, Dec. 17, 1979]

Stones.
Stones shall be concreted earthy or mineral matter, and other substances of similar hardness that do not disintegrate readily in water.

Contrasting classes.
Contrasting classes shall be beans of other classes that are of a different color, size, or shape from the beans of the class designated.

Classes thatblend.
Classes that blend shall be sound beans of other classes that are similar in

color, size, and shape to the beans of the class designated, and shall include white beans in the class Yelloweye which are similar in size and shape to the Yelloweye beans.

Brokenbeans.
Broken beans shall be sound beans with some but less than one-fourth of each bean broken off or with one-fourth or more of the seedcoat removed.

Blisteredbeans.
Blistered beans shall be sound beans with badly blistered or burst seedcoats.

Wrinkledbeans.
Wrinkled beans shall be sound beans that have deeply wrinkled seedcoats and/or are badly warped or misshapen.

Weevily beans.
Weevily beans shall be beans that are infested with live weevils or other insects injurious to stored beans or that contain weevil-bored beans.

Clean-cut weevil-boredbeans.
Clean-cut weevil-bored beans shall be beans from which weevils have emerged, leaving a clean-cut open cavity free from larvae, webbing, refuse, mold, or stain.

Well screened.
Well screened, as applied to the general appearance of beans, shall mean that the beans are uniform in size and are practically free from such small, shriveled, underdeveloped beans, splits, broken beans, large beans, and foreign material that can be removed readily by the ordinary process of milling or screening through the proper use of sieves.

119 30/64 sieve.
A 30/64 sieve shall be a metal sieve 0.0319-inch thick perforated with round holes 0.4687 (30/64) inch in diameter which are 11/16 inch from center to center. The perforations of each row shall be staggered in relation to the adjacent rows.

120 28/64 sieve.
A 28/64 sieve shall be a metal sieve 0.0319-inch thick perforated with round holes 0.4375 (28/64) inch in diameter which are 19/32 inch from center to center. The perforations of each row shall be staggered in relation to the adjacent rows.
[34 FR 7863, May 17, 1969, as amended at 54 FR 51344, Dec. 14, 1989]

121 24/64 sieve.

A 24/64 sieve shall be a metal sieve 0.0319-inch thick perforated with round holes 0.3750 (24/64) inch in diameter which are 17/32 inch from center to center. The perforations of each row shall be staggered in relation to the adjacent rows.

Grades and grade requirements for the class Black eye Beans.

Grade	Percent Maximum Limits of ---						
	Moisture[1]	TotalDefects (Total damaged, Total foreign material, Contrastingclasses, & Splits)	Total Damaged	Foreign Material		Contrasting Classes[2]	Classes that Blend[3]
				Total (including stones)	Stones		
U.S. No. 1	18.0	4.0	2.0	0.5	0.2	0.5	5.0
U.S. No.2	18.0	6.0	4.0	1.0	0.4	1.0	10.0
U.S. No. 3	18.0	8.0	6.0	1.5	0.6	2.0	15.0

U.S. Substandard shall be beans which do not meet the requirements for the grades U.S. No. 1 through U.S. Sample grade. Beans which are not well screened shall also be U.S. Substandard, except for beans which meet the requirements for U.S. Sample grade.

U.S. Sample grade shall be beans which are musty, sour, heating, materially weathered, or weevily; which have any commercially objectionable odor; which contain insect webbing or filth, animal filth, any unknown foreign substance, broken glass, or metal fragments; or which are otherwise of distinctly low quality.

[1]Beans with more than 18.0 percent moisture are graded High moisture.
[2]Beans with more than 2.0 percent contrasting classes are graded Mixed beans.
[3]Beans with more than 15.0 percent classes that blend are graded Mixed beans.
[47 FR 19311, May 5, 1982] [47 FR 20547, May 13, 1982] [60 FR 36030, July 13, 1995] [62 FR 52967, Oct. 10, 1997] [69 FR 75504, Dec. 17, 2004]

Source: US Standard for beans (2008)

Appendix C1: Technical Specification and installation for Raspberry Pi 3 Board

Technical Specification:

(a) Processor

- Broadcom BCM2387 chipset.
- 1.2GHz Quad-Core ARM Cortex-A53 (64Bit) 802.11 b/g/n Wireless LAN and Blu etooth 4.1 (Bluetooth Classic and LE)
- IEEE 802.11 b / g / n Wi-Fi. Protocol: WEP, WPA WPA2, algorithms AES-CCMP (maximum key length of 256 bits), the maximum range of 100 meters.
- IEEE 802.15 Bluetooth, symmetric encryption algorithm Advanced Encryption Sta ndard (AES)with 128-bit key, the maximum range of 50 meters.

(b) GPU

- Dual Core Video Core IV® Multimedia Co-Processor. Provides Open GL ES 2.0, ha rdware-acceleratedOpen VG, and 1080p30 H.264 high-profile decode.
- Capable of 1Gpixel/s, 1.5Gtexel/s or 24GFLOPs with texture filtering and DMA infr astructure

(c) Memory

- 1GB LPDDR2

(d) Operating System

- Boots from Micro SD card, running a version of the Linux operating system or Wind ows 10 IOT

(e) Dimensions

- 85 x 56 x 17mm

(f) Power

- Micro USB socket 5V1, 2.5A

(g) Connectors:

i. Ethernet
   - 10/100 Base T Ethernet socket

ii. Video Output
   - HDMI (rev 1.3 & 1.4)
   - Composite RCA (PAL and NTSC)

iii. Audio Output

- Audio Output 3.5mm jack
- HDMI
- USB 4 x USB 2.0 Connector

iv. GPIO (general-purpose input-output) Connector

- 40-pin 2.54 mm (100 mil) expansion header: 2x20 strip
- Providing 27 GPIO pins as well as +3.3 V, +5 V and GND supply lines

v. Camera Connector

- 15-pin MIPI Camera Serial Interface (CSI-2)

vi. Display Connector

- Display Serial Interface (DSI) 15 ways flat flex cable connector with two da ta lanes and a clock lane

(h) Memory Card Slot

- Push/pull Micro SDIO

Installation of Operating System (OS) to the Raspberry pi Board was done as follow:

- The 16GB micro-SD card was taken out from the Raspberry pi board for installation of OS.
- The OS software was downloaded from this website [https://www.raspberrypi.org/downloads/] ('NOOBS' recommended for beginners)
- The SD card was formatted, and then the OS was installed on the SD memory card using a desktop computer.
- After installation of the OS card was inserted into the Raspberry pi board.
- Monitor, keyboard and mouse was connected to the Raspberry pi board through its 2 USB ports.
- Raspberry pi board was then powered by using a micro-USB connector.
- Once the power was tuned ON the Raspberry pi board automatically start running the OS installed in the SD memory card and then start booting itself.
- After booting and checking all drivers the Raspberry pi board asked for authorization, this was set by default and can be changed.

Authorization was given which then allow the Raspberry pi board to have access to the desktop, where all application programs development starts.

Appendix C2: Features/Specification and Benefit of the Pi NoIR Camera

Features and benefits of the Pi NoIR

- High quality imagery
- High data capability
- 5 mega-pixel fixed focus
- Supports 1080p, 720p60 & VGA90
- Omni vision 5647 sensor
- Reduces image contamination such as fixed pattern noise & smearing
- Automatic control functions such as exposure control, white balance & luminance detection
- Perfect for botanical, wildlife & night-time security applications

Connecting the Pi NoIR camera board to the Raspberry Pi 3 Board was done as follow:

- The 15 cm ribbon cable attached to the Pi NoIR was slotted into your Pi Camera Serial Interface port (CSI).
- Once connected, the camera board was accessed via the Multi-Media Abstraction Layer (MMAL) by Pi camera Python.
- Via Raspbian there are 3 applications that you can use to take your photos or videos – Raspistill orRaspistillyuv for photography and Raspivid for videos.

Pi NoIR camera Specifications used in this study were:

Dimensions: 8.5 x 8.5 x 5mm

Height: 5mm

Length: 8.5mm

Maximum Frame Rate Capture: 30fps

Maximum Operating Temperature: 70°C

Maximum Supported Resolution: 2592 x 1944

Minimum Operating Temperature: -30°C

Number of Channels: 1

Supported Bus Interfaces: I2C

Supported Hardware Compression: H.264

Supported Video Ports: DVI

Type: Camera Module

Appendix C3: Features and Specifications of TFT Display

Features:

- A good solution for those seeking for a bigger resolution display
- Good touch response
- Large viewing angle
- Fast response time
- Support backlight control alone
- Not only for Raspberry Pi
- Not only for mini-PCs, it can work as a computer monitor
- With detail user guide and image

Specifications:

- 5inch TFT Resistive touch screen display, 800x480 Resolution
- HDMI input
- Usb touch and power, 5V@1A
- Touch: 4-wire resistive touch
- Lcd driver IC: ILI9486L
- Refresh rate：60HZ
- Lcd Size ：121.11mm x 77.93mm
- Weight:175g

Appendix C4: Installation Steps for TFT Display

Installation of HDMI Interface 5 Inch 800×480 TFT Display was done using these steps:

The installation steps were as follows:

Step1: Install the 5inch LCD

Installation of the 5inch LCD to Raspberry-Pi B board was placed as shown in figure 3.15 (b)

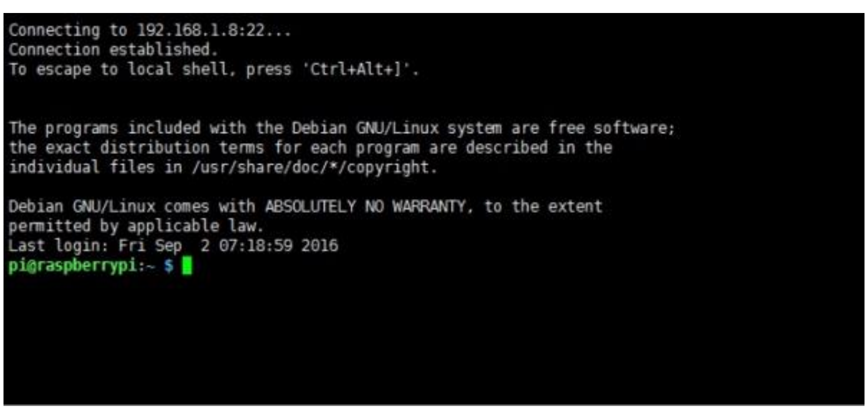
Step 2: Modification of config.txt file

The SD card was removed from the Raspberry pi 3 board and insect into a window laptop. The config.txt in the SD's root directorate was located and opened. Then the following cod e was added to the end:

```
# --- added by elecrow-pitft-setup  ---
hdmi_force_hotplug=1
max_usb_current=1
hdmi_drive=1
hdmi_group=2
hdmi_mode=1
hdmi_mode=87
hdmi_cvt 800 480 60 6 0 0 0
dtoverlay=ads7846,cs=1,penirq=25,penirq_pull=2,speed=50000,keep_vref_on=0,swapxy=0,pmax=255
,xohms=150,xmin=200,xmax=3900,ymin=200,ymax=3900
display_rotate=0
# --- end elecrow-pitft-setup  ---
```

Step3: Power ON and open terminal

The Raspberry startup then display the next step needed to install the driver



Step4: the driver was down loaded by running the gist clone address.

Run:

```
git clone: https://github.com/goodtft/LCD-show.git
```

Step5: Install driver was done by running these addresses

Run: *mount /dev/mmcblk0p1 /boot/*

next

Run:

```
chmod -R 755 LCD-show
cd LCD-show/
sudo ./LCD5-show
```

Then the screen then starts working as shown in figure 3.15 (d)

The touch screen was calibrated as follows:

To install the xinput-calibrator this address was first run

Run:*sudo apt-get install -y xinput-calibrator*

then the flowing steps were followed:

- Click the **Men** button on the task bar; choose **Preference** -> **Calibrate Touchscreen**.
- Calibration was completed following the prompts.Rebooting was done to make calibration active.
- You can create a 99-calibration.conf file to save the touch parameters (not necessary if file exists).

```
/ect/X11/xorg.conf.d/99-calibration.conf
```

- The touch parameter was saved as follows:

```
Section "InputClass"
        Identifier      "calibration"
        MatchProduct    "ADS7846 Touchscreen"
        Option  "Calibration"   "208 3905 288 3910"
        Option  "SwapAxes"      "0"
EndSection
```

Appendix C5: Specifications of Servo Motor

Specifications of servo motor were as follows:

- Weight: 9 g
- Dimension: 22.2 x 11.8 x 31 mm approx.
- Stall torque: 1.8 kgf·cm
- Operating speed: 0.1 s/60 degree
- Operating voltage: 4.8 V (~5V)
- Dead band width: 10 µs
- Temperature range: 0 ºC – 55 ºC
- Operating Voltage is +5V typically
- Torque: 2.5kg/cm
- Gear Type: Plastic
- Rotation: 0°-180°
- Package includes gear horns and screws

Appendix C6: Program 1: For capturing and save images

```
import picamera
import cv2

val = 150000
sensor = 13
servoPIN = 5
servoPIN2 = 6
PIN3 = 16
PIN4 = 20
GPIO.setmode(GPIO.BCM)
GPIO.setup(sensor,GPIO.IN)
GPIO.setup(servoPIN,GPIO.OUT)
GPIO.setup(servoPIN2,GPIO.OUT)
GPIO.setup(PIN3,GPIO.OUT)
GPIO.setup(PIN4,GPIO.OUT)

p = GPIO.PWM(servoPIN,50)
p.start(2.5)
q = GPIO.PWM(servoPIN2,50)
q.start(9)

try:
 while True:
  res = 0
  if GPIO.input(sensor):
   with picamera.PiCamera( ) as camera:
camera.resolution = (640, 480)
camera.start_preview()
time.sleep(2)
camera.capture_sequence( [ '/home/pi/images/p.bmp', ])
camera.stop_preview( )

p.ChangeDutyCycle(6)
time.sleep(1)
   if res <> 0:
q.ChangeDutyCycle(4.5)
GPIO.output(PIN3, 1)
GPIO.output(PIN4, 0)
   if res == 0:
q.ChangeDutyCycle(13.5)
GPIO.output(PIN4, 1)
GPIO.output(PIN3, 0)
time.sleep(0.5)

p.ChangeDutyCycle(2.5)
q.ChangeDutyCycle(9)
time.sleep(0.5)

except KeyboardInterrupt:
q.stop( )
p.stop( )
GPIO.cleanup( )
  cv2.waitKey(0)
  cv2.destroyAllWindows()
```

Appendix C7: Program 2: for comparing images

```
import time
import picamera
import cv2

val = 150000
sensor = 13
servoPIN = 5
servoPIN2 = 6
PIN3 = 16
PIN4 = 20
GPIO.setmode(GPIO.BCM)
GPIO.setup(sensor,GPIO.IN)
GPIO.setup(servoPIN,GPIO.OUT)
GPIO.setup(servoPIN2,GPIO.OUT)
GPIO.setup(PIN3,GPIO.OUT)
GPIO.setup(PIN4,GPIO.OUT)

p = GPIO.PWM(servoPIN,50)
p.start(2.5)
q = GPIO.PWM(servoPIN2,50)
q.start(9)

img1 = cv2.imread('/home/pi/images/p1.bmp')
img2 = cv2.imread('/home/pi/images/p2.bmp')
img3 = cv2.imread('/home/pi/images/p3.bmp')
img4 = cv2.imread('/home/pi/images/p4.bmp')
img5 = cv2.imread('/home/pi/images/p5.bmp')
img6 = cv2.imread('/home/pi/images/p6.bmp')
img7 = cv2.imread('/home/pi/images/p7.bmp')
img8 = cv2.imread('/home/pi/images/p8.bmp')
img9 = cv2.imread('/home/pi/images/p9.bmp')
img10 = cv2.imread('/home/pi/images/p10.bmp')

img11 = cv2.imread('/home/pi/images/p11.bmp')
img12 = cv2.imread('/home/pi/images/p12.bmp')
img13 = cv2.imread('/home/pi/images/p13.bmp')
img14 = cv2.imread('/home/pi/images/p14.bmp')
img15 = cv2.imread('/home/pi/images/p15.bmp')
img16 = cv2.imread('/home/pi/images/p16.bmp')
img17 = cv2.imread('/home/pi/images/p17.bmp')
img18 = cv2.imread('/home/pi/images/p18.bmp')
img19 = cv2.imread('/home/pi/images/p19.bmp')
img20 = cv2.imread('/home/pi/images/p20.bmp')

img21 = cv2.imread('/home/pi/images/p21.bmp')
img22 = cv2.imread('/home/pi/images/p22.bmp')
img23 = cv2.imread('/home/pi/images/p23.bmp')
img24 = cv2.imread('/home/pi/images/p24.bmp')
img25 = cv2.imread('/home/pi/images/p25.bmp')
img26 = cv2.imread('/home/pi/images/p26.bmp')
img27 = cv2.imread('/home/pi/images/p27.bmp')
img28 = cv2.imread('/home/pi/images/p28.bmp')
img29 = cv2.imread('/home/pi/images/p29.bmp')
```

```
img30 = cv2.imread('/home/pi/images/p30.bmp')

img31 = cv2.imread('/home/pi/images/p31.bmp')
img32 = cv2.imread('/home/pi/images/p32.bmp')
img33 = cv2.imread('/home/pi/images/p33.bmp')
img34 = cv2.imread('/home/pi/images/p34.bmp')
img35 = cv2.imread('/home/pi/images/p35.bmp')
img36 = cv2.imread('/home/pi/images/p36.bmp')
img37 = cv2.imread('/home/pi/images/p37.bmp')
img38 = cv2.imread('/home/pi/images/p38.bmp')
img39 = cv2.imread('/home/pi/images/p39.bmp')
img40 = cv2.imread('/home/pi/images/p40.bmp')

img41 = cv2.imread('/home/pi/images/p41.bmp')
img42 = cv2.imread('/home/pi/images/p42.bmp')
img43 = cv2.imread('/home/pi/images/p43.bmp')
img44 = cv2.imread('/home/pi/images/p44.bmp')
img45 = cv2.imread('/home/pi/images/p45.bmp')
img46 = cv2.imread('/home/pi/images/p46.bmp')
img47 = cv2.imread('/home/pi/images/p47.bmp')
img48 = cv2.imread('/home/pi/images/p48.bmp')
img49 = cv2.imread('/home/pi/images/p49.bmp')
img50 = cv2.imread('/home/pi/images/p50.bmp')

img51 = cv2.imread('/home/pi/images/p51.bmp')
img52 = cv2.imread('/home/pi/images/p52.bmp')
img53 = cv2.imread('/home/pi/images/p53.bmp')
img54 = cv2.imread('/home/pi/images/p54.bmp')
img55 = cv2.imread('/home/pi/images/p55.bmp')
img56 = cv2.imread('/home/pi/images/p56.bmp')
img57 = cv2.imread('/home/pi/images/p57.bmp')
img58 = cv2.imread('/home/pi/images/p58.bmp')
img59 = cv2.imread('/home/pi/images/p59.bmp')
img60 = cv2.imread('/home/pi/images/p60.bmp')

img61 = cv2.imread('/home/pi/images/p61.bmp')
img62 = cv2.imread('/home/pi/images/p62.bmp')
img63 = cv2.imread('/home/pi/images/p63.bmp')
img64 = cv2.imread('/home/pi/images/p64.bmp')
img65 = cv2.imread('/home/pi/images/p65.bmp')
img66 = cv2.imread('/home/pi/images/p66.bmp')
img67 = cv2.imread('/home/pi/images/p67.bmp')
img68 = cv2.imread('/home/pi/images/p68.bmp')
img69 = cv2.imread('/home/pi/images/p69.bmp')
img70 = cv2.imread('/home/pi/images/p70.bmp')

img71 = cv2.imread('/home/pi/images/p71.bmp')
img72 = cv2.imread('/home/pi/images/p72.bmp')
img73 = cv2.imread('/home/pi/images/p73.bmp')
img74 = cv2.imread('/home/pi/images/p74.bmp')
img75 = cv2.imread('/home/pi/images/p75.bmp')
img76 = cv2.imread('/home/pi/images/p76.bmp')
img77 = cv2.imread('/home/pi/images/p77.bmp')
img78 = cv2.imread('/home/pi/images/p78.bmp')
img79 = cv2.imread('/home/pi/images/p79.bmp')
img80 = cv2.imread('/home/pi/images/p80.bmp')
```

```
img81 = cv2.imread('/home/pi/images/p81.bmp')
img82 = cv2.imread('/home/pi/images/p82.bmp')
img83 = cv2.imread('/home/pi/images/p83.bmp')
img84 = cv2.imread('/home/pi/images/p84.bmp')
img85 = cv2.imread('/home/pi/images/p85.bmp')
img86 = cv2.imread('/home/pi/images/p86.bmp')
img87 = cv2.imread('/home/pi/images/p87.bmp')
img88 = cv2.imread('/home/pi/images/p88.bmp')
img89 = cv2.imread('/home/pi/images/p89.bmp')
img90 = cv2.imread('/home/pi/images/p90.bmp')

img91 = cv2.imread('/home/pi/images/p91.bmp')
img92 = cv2.imread('/home/pi/images/p92.bmp')
img93 = cv2.imread('/home/pi/images/p93.bmp')
img94 = cv2.imread('/home/pi/images/p94.bmp')
img95 = cv2.imread('/home/pi/images/p95.bmp')
img96 = cv2.imread('/home/pi/images/p96.bmp')
img97 = cv2.imread('/home/pi/images/p97.bmp')
img98 = cv2.imread('/home/pi/images/p98.bmp')
img99 = cv2.imread('/home/pi/images/p99.bmp')
img100 = cv2.imread('/home/pi/images/p100.bmp')

img101 = cv2.imread('/home/pi/images/p101.bmp')
img102 = cv2.imread('/home/pi/images/p102.bmp')
img103 = cv2.imread('/home/pi/images/p103.bmp')
img104 = cv2.imread('/home/pi/images/p104.bmp')
img105 = cv2.imread('/home/pi/images/p105.bmp')
img106 = cv2.imread('/home/pi/images/p106.bmp')
img107 = cv2.imread('/home/pi/images/p107.bmp')
img108 = cv2.imread('/home/pi/images/p108.bmp')
img109 = cv2.imread('/home/pi/images/p109.bmp')
img110 = cv2.imread('/home/pi/images/p110.bmp')

img111 = cv2.imread('/home/pi/images/p111.bmp')
img112 = cv2.imread('/home/pi/images/p112.bmp')
img113 = cv2.imread('/home/pi/images/p113.bmp')
img114 = cv2.imread('/home/pi/images/p114.bmp')
img115 = cv2.imread('/home/pi/images/p115.bmp')
img116 = cv2.imread('/home/pi/images/p116.bmp')
img117 = cv2.imread('/home/pi/images/p117.bmp')
img118 = cv2.imread('/home/pi/images/p118.bmp')
img119 = cv2.imread('/home/pi/images/p119.bmp')
img120 = cv2.imread('/home/pi/images/p120.bmp')

img121 = cv2.imread('/home/pi/images/p121.bmp')
img122 = cv2.imread('/home/pi/images/p122.bmp')
img123 = cv2.imread('/home/pi/images/p123.bmp')
img124 = cv2.imread('/home/pi/images/p124.bmp')
img125 = cv2.imread('/home/pi/images/p125.bmp')
img126 = cv2.imread('/home/pi/images/p126.bmp')
img127= cv2.imread('/home/pi/images/p127.bmp')
img128= cv2.imread('/home/pi/images/p128.bmp')
img129= cv2.imread('/home/pi/images/p129.bmp')
img130= cv2.imread('/home/pi/images/p130.bmp')

img131= cv2.imread('/home/pi/images/p131.bmp')
img132= cv2.imread('/home/pi/images/p132.bmp')
```

```
img133= cv2.imread('/home/pi/images/p133.bmp')
img134= cv2.imread('/home/pi/images/p134.bmp')
img135= cv2.imread('/home/pi/images/p135.bmp')
img136= cv2.imread('/home/pi/images/p136.bmp')
img137= cv2.imread('/home/pi/images/p137.bmp')
img138= cv2.imread('/home/pi/images/p138.bmp')
img139= cv2.imread('/home/pi/images/p139.bmp')
img140= cv2.imread('/home/pi/images/p140.bmp')

img141= cv2.imread('/home/pi/images/p141.bmp')
img142= cv2.imread('/home/pi/images/p142.bmp')
img143= cv2.imread('/home/pi/images/p143.bmp')
img144= cv2.imread('/home/pi/images/p144.bmp')
img145= cv2.imread('/home/pi/images/p145.bmp')
img146= cv2.imread('/home/pi/images/p146.bmp')
img147= cv2.imread('/home/pi/images/p147.bmp')
img148= cv2.imread('/home/pi/images/p148.bmp')
img149= cv2.imread('/home/pi/images/p149.bmp')
img150= cv2.imread('/home/pi/images/p150.bmp')

try:
 while True:
  res = 0
  if GPIO.input(sensor):
   with picamera.PiCamera( ) as camera:
camera.resolution = (640, 480)
camera.start_preview( )
time.sleep(2)
camera.capture_sequence( [ '/home/pi/images/p.bmp', ])
camera.stop_preview( )
img = cv2.imread('/home/pi/images/p.bmp')
```

Then source code was inputed

See link for source code:https://pysource.com/object-detection-opencv-deep-learning-video-course/.. Accessept oct. 26 2019

```
   print (res)

p.ChangeDutyCycle(6)
time.sleep(1)
   if res <> 0:
q.ChangeDutyCycle(4.5)
GPIO.output(PIN3, 1)
GPIO.output(PIN4, 0)
   if res == 0:
q.ChangeDutyCycle(13.5)
GPIO.output(PIN4, 1)
GPIO.output(PIN3, 0)
time.sleep(0.5)

p.ChangeDutyCycle(2.5)
q.ChangeDutyCycle(9)
time.sleep(0.5)

except KeyboardInterrupt:
```

```
q.stop( )
p.stop( )
GPIO.cleanup( )
  cv2.waitKey(0)
  cv2.destroyAllWindows()
```

Appendix D1: Modeled Equations for Optical Properties of Cowpea Seeds

Variety	Parameter	Equation	Statistic Parameter: R-Squared	Statistic Parameter: Predicted R-Squared
055	L	$L = -3796.684 + 1329.096M - 168.321M^2 + 9.27M^3 - 0.188M^4$	0.996	0.905
	A	$a = -126.885 + 44.407M - 5.573M^2 + 0.204M^3 - 0.006M^4$	0.996	0.91
	B	$b = -1091.842 + 384.215M - 48.768M^2 + 2.691M^3 - 0.055M^4$	0.972	0.3331
	Absorbance	$A = -4.872 - 0.114M + 0.024W - 0.0006MW + 0.018M^2 - 0.00001W^2$	0.859	0.716
	Reflectance	$R = +3.937 + 0.003M - 0.014W + 0.00001W^2$	0.78	0.703
	Transmittance	$\sqrt{T} = +1.888 - 0.194M + 0.0006MW - 0.000007W^2$	0.527	0.281
063	L	$L = -3917.462 + 1378.158M - 173.166M^2 + 9.415M^3 - 0.188M^4$	0.996	0.905
	A	$a = -146.248 + 49.151M - 5.977M^2 + 0.315M^3 - 0.006M^4$	0.996	0.91
	B	$b = -1123.896 + 395.769M - 49.882M^2 + 2.724M^3 - 0.055M^4$	0.972	0.333
	Absorbance	$A = -4.961 - 0.114M + 0.024W - 0.0006MW + 0.016M^2 - 0.00001W^2$	0.859	0.716
	Reflectance	$R = +3.937 + 0.003M - 0.014W + 0.00001W^2$	0.78	0.703
	Transmittance	$\sqrt{T} = +1.657 - 0.194M + 0.0006MW - 0.000007W^2$	0.527	0.281

Variety	Parameter	Equation	Statistic Parameter R-Squared	Predicted R-Squared
033	L	$\boldsymbol{L = -314.226 + 1181.941M - 157.266M^2 + 8.998M^3 - 0.188M^4}$	0.996	0.905
	A	$\boldsymbol{a = -101.148 + 37.848M - 5.056M^2 + 0.291M^3 - 0.006M^4}$	0.996	0.91
	B	$\boldsymbol{b = -788.301 + 311.643M - 43.086M^2 + 2.546M^3 - 0.055M^4}$	0.972	0.3331
	Absorbance	$\boldsymbol{A = -4.819 - 0.114M + 0.024W - 0.0006MW + 0.017M^2 - 0.00001W^2}$	0.859	0.716
	Reflectance	$\boldsymbol{R = +3.937 + 0.003M - 0.014W + 0.00001W^2}$	0.78	0.703
	Transmittance	$\boldsymbol{\sqrt{T} = +2.282 - 0.194M + 0.0006MW - 0.000007W^2}$	0.527	0.281

Where: M = Moisture content (%), W = wavelength (nm)

Appendix D2: Model Equations for Electrical Properties of Cowpea Seeds.

Variety	Elec. Prop	Equation	R-Squared	Predicted R-Squared
055	R	$R = 43.19 - 5.869M - 0.002F + 0.229M^2$	0.501	0.151
	G	$1/\sqrt{C} = 10.01 - 1.218M - 0.0004F + 0.048M^2$	0.595	0.309
	ρ	$ln(\rho) = 6.424 - 1.079M - 0.0003F + 0.043M^2$	0.66	0.432
	σ	$\sigma = -11.622 + 1.986M + 0.002F - 0.077M^2 - 4.9x10^{-7}F^2$	0.815	0.625
	C	$C = 1.1x10^{-7} + 2.7x10^{-13}M - 1.8x10^{-10}F - 3.5x10^{-16}MF + 6.6x10^{-14}F^2$	0.771	0.555
	ε	$\in = 3740.129 - 0.012M - 6.264F + 0.002F^2$	0.772	0.611
	L	$L = -1.179x10^6 + 1280F - 0.75F^2$	0.785	-0.597
	X	$X = -6.5x10^6 + 2.3x10^6M + 6545.6F + 104.2MF - 98420M^2 - 5.1F^2$	0.5	-0.601
063	R	$R = 44.423 - 5.869M - 0.002F + 0.229M^2$	0.501	0.151
	G	$1/\sqrt{C} = 10.299 - 1.218M - 0.0004F + 0.048M^2$	0.595	0.309
	ρ	$ln(\rho) = 6.701 - 1.079M - 0.0003F + 0.043M^2$	0.66	0.432
	σ	$\sigma = -11.444 + 1.986M + 0.002F - 0.081M^2 - 4.9x10^{-7}F^2$	0.815	0.625
	C	$C = 1.05x10^{-7} + 6.9x10^{-13}M - 1.8x10^{-10}F - 3.5x10^{-16}MF + 6.6x10^{-14}F^2$	0.771	0.555
	ε	$\in = 3762.284 - 0.007M - 6.264F + 0.002F^2$	0.772	0.611
	L	$L = 1.123x10^{21} - 5.929x10^{18}F + 4.471x10^{15}F^2$	0.785	-0.597
	X	$X = -7.4x10^6 + 2.2x10^6M + 7473.9F + 104.2MF - 98420M^2 - 5.1F^2$	0.5	-0.601

Variety	Elec. Prop	Equation	R-Squared	Predicted R-Squared
033	R	$\boldsymbol{R = 41.56 - 5.869M - 0.002F + 0.229M^2}$	0.501	0.151
	G	$\boldsymbol{1/\sqrt{C} = 9.63 - 1.218M - 0.0004F + 0.048M^2}$	0.595	0.309
	ρ	$\boldsymbol{ln(\rho) = 6.036 - 1.079M - 0.0003F + 0.043M^2}$	0.66	0.432
	σ	$\boldsymbol{\sigma = -9.938 + 1.986M + 0.002F - 0.082M^2 - 4.9x10^{-7}F^2}$	0.815	0.625
	C	$\boldsymbol{C = 1.05x10^{-7} + 2.3x10^{-13}M - 1.8x10^{-10}F - 3.5x10^{-16}MF + 6.6x10^{-14}F^2}$	0.771	0.555
	ε	$\boldsymbol{\in = 3740.655 - 0.019M - 6.264F + 0.002F^2}$	0.772	0.611
	L	$\boldsymbol{L = 1.245x10^6 - 2816F + 0.75F^2}$	0.785	-0.597
	X	$\boldsymbol{X = -1.1x10^7 + 2.4x10^6M + 7253.9F + 104,2MF - 98420M^2 - 5.1F^2}$	0.5	-0.601

M = Moisture, F = frequency, R = Resistance, G = Conductance, ρ = Resistivity, σ = Conductivity, C = Capacitance, ε = Dielectric constant, L = Inductance, X = Capacitance reactance, Elec. Prop. Is Electrical Property.

Appendix D3: Optimization of cowpea varieties for Colour properties

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Moisture	is in range	8	16	1	1	3
Variety	is in range	0055	0033	1	1	3
L	is in range	38	92.2	1	1	3
a	is in range	0.722	9.708	1	1	3
b	is in range	13.648	27.308	1	1	3

Solutions for 3 combinations of categorical factor levels

Number	moisture	variety	L	a	b	Desirability
1	15.002	0033	68.157	1.824	20.187	1.000
2	8.000	0055	40.440	6.063	14.994	1.000
3	10.000	0055	53.902	9.382	18.751	1.000
4	16.000	063	58.311	1.333	17.590	1.000
5	16.000	0055	39.188	8.124	16.144	1.000
6	14.000	0055	41.064	7.444	15.941	1.000
7	14.000	0033	62.243	1.387	18.197	1.000
8	10.000	063	84.556	3.187	23.524	1.000
9	8.000	0033	91.990	3.775	27.170	1.000
10	10.000	0033	76.471	2.231	19.385	1.000
11	12.000	063	59.409	1.103	17.092	1.000
12	12.000	0055	38.018	6.680	14.444	1.000
13	12.000	0033	54.812	0.786	14.098	1.000
14	14.000	063	56.286	0.772	16.958	1.000
15	16.000	0033	61.866	1.175	17.606	1.000
16	10.876	0055	46.045	8.019	16.555	1.000
17	9.275	0055	57.181	9.809	19.699	1.000
18	10.713	0055	47.563	8.283	16.974	1.000
19	8.203	0055	46.046	7.132	16.582	1.000
20	9.043	0055	56.839	9.636	19.612	1.000
21	14.033	0055	41.241	7.484	16.005	1.000
22	11.429	0055	41.380	7.226	15.295	1.000
23	9.377	0055	57.071	9.827	19.664	1.000
24	10.752	0055	47.201	8.220	16.874	1.000
25	8.611	0055	53.471	8.743	18.675	1.000
26	8.234	0055	46.776	7.280	16.789	1.000
27	11.318	0055	42.232	7.368	15.521	1.000

Appendix D4: Optimization of cowpea varieties for Absorbance, Reflectance and Transmittance

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Moisture	is in range	10	14	1	1	3
Wavelength	is in range	420	620	1	1	3
Variety	is in range	NGB/OG/0055	NG/AD/11/08/0033	1	1	3
Absorbance	is in range	0	1.8364	1	1	3
Reflectance	is in range	0.0145793	1	1	1	3
Transmittance	is in range	0	12.04	1	1	3

Solutions for 3 combinations of categorical factor levels

Number	Moisture	Wavelength	Variety	Absorbance	Reflectance	Transmittance	Desirability
1	11.584	478.378	NG/AD/11/08/0033	1.290	0.112	4.211	1.000
2	12.000	520.000	NG/OA/11/08/063	1.060	0.024	2.518	1.000
3	14.000	420.000	NGB/OG/0055	1.171	0.310	5.213	1.000
4	10.000	420.000	NG/OA/11/08/063	0.701	0.298	0.581	1.000
5	12.000	520.000	NGB/OG/0055	1.473	0.024	3.256	1.000
6	10.000	420.000	NG/AD/11/08/0033	0.904	0.298	1.607	1.000
7	10.000	420.000	NGB/OG/0055	1.042	0.298	0.870	1.000
8	14.000	420.000	NG/OA/11/08/063	0.831	0.310	4.246	1.000
9	14.000	420.000	NG/AD/11/08/0033	1.034	0.310	7.111	1.000
10	11.826	520.462	NGB/OG/0055	1.480	0.023	3.184	1.000
11	10.316	468.535	NGB/OG/0055	1.327	0.135	1.837	1.000
12	11.481	447.505	NGB/OG/0055	1.173	0.203	2.374	1.000

13	10.207	452.688	NGB/OG/0055	1.243	0.182	1.509	1.000
14	12.274	463.767	NGB/OG/0055	1.257	0.154	3.244	1.000
15	12.834	467.529	NGB/OG/0055	1.288	0.145	3.772	1.000
16	11.362	523.306	NGB/OG/0055	1.510	0.017	3.010	1.000
17	13.672	495.351	NGB/OG/0055	1.420	0.077	4.342	1.000
18	13.085	527.278	NGB/OG/0055	1.483	0.016	3.655	1.000
19	13.339	505.104	NGB/OG/0055	1.432	0.055	4.013	1.000
20	13.587	497.484	NGB/OG/0055	1.422	0.072	4.257	1.000
21	10.377	473.903	NGB/OG/0055	1.352	0.120	1.960	1.000
22	12.288	484.111	NGB/OG/0055	1.343	0.099	3.360	1.000
23	11.039	497.131	NGB/OG/0055	1.426	0.065	2.658	1.000
24	12.851	463.782	NGB/OG/0055	1.274	0.156	3.781	1.000

Appendix D5: Optimization of cowpea varieties for Electrical properties

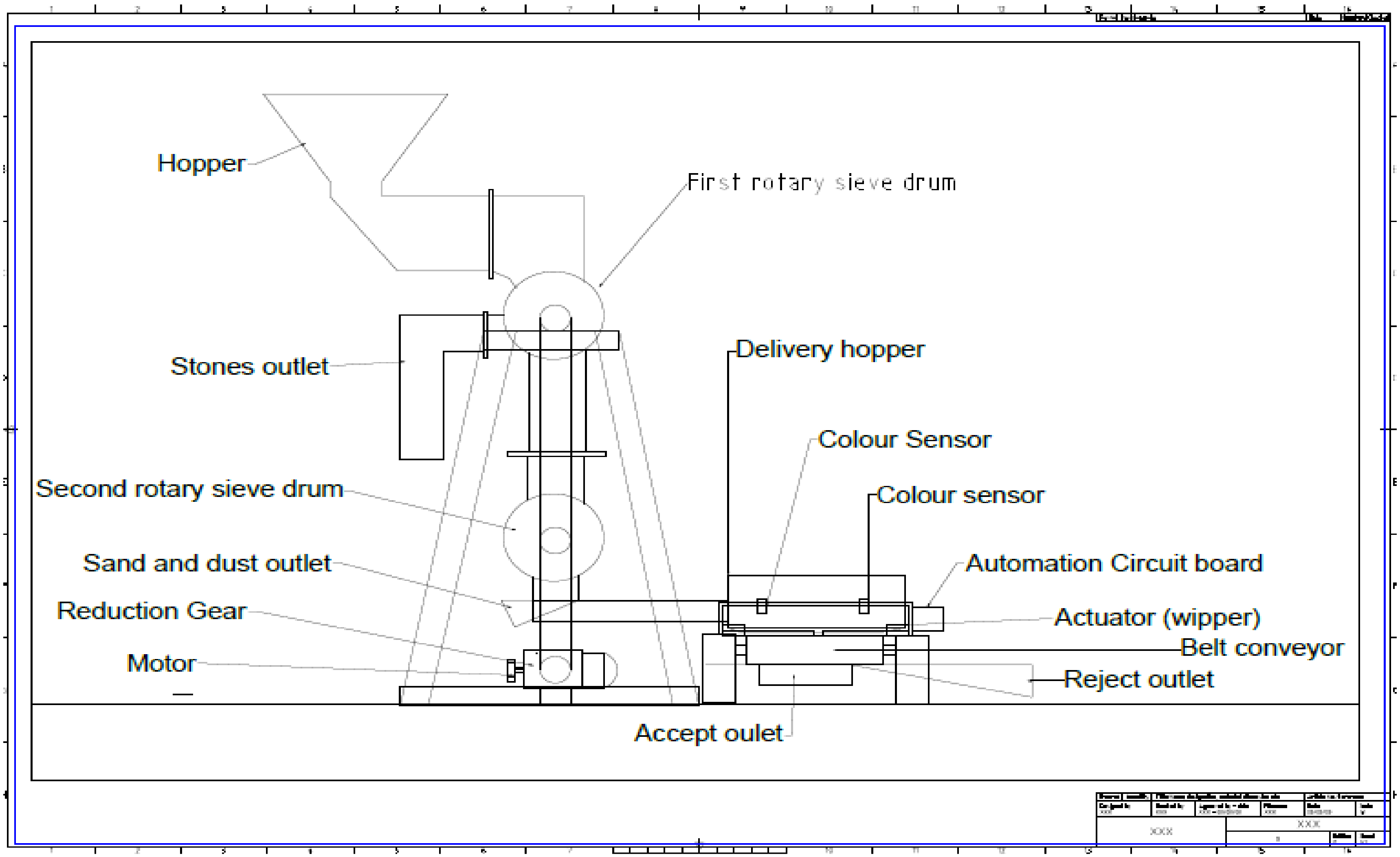
Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Moisture	is in range	10	14	1	1	3
B: frequency	is in range	500	1500	1	1	3
C: variety	is in range	NGB/OG/0055	NG/OA/11/08/063	1	1	3
Resistance	is in range	1.9263	15.625	1	1	3
Conductance	is in range	0.064	0.51913	1	1	3
Resistivity	is in range	0.272379	2.20938	1	1	3
Conductivity	is in range	0.452617	3.67136	1	1	3
Capacitance	is in range	1.8E-011	1.38E-007	1	1	3
Dielectric constant	is in range	0.5	4928.57	1	1	3
Inductance	is in range	6.02203E-007	9.04419E+021	1	1	3
Capacitance reactance	is in range	1.15315E+006	1.44668E+007	1	1	3

Solutions for 3 combinations of categoric factor levels

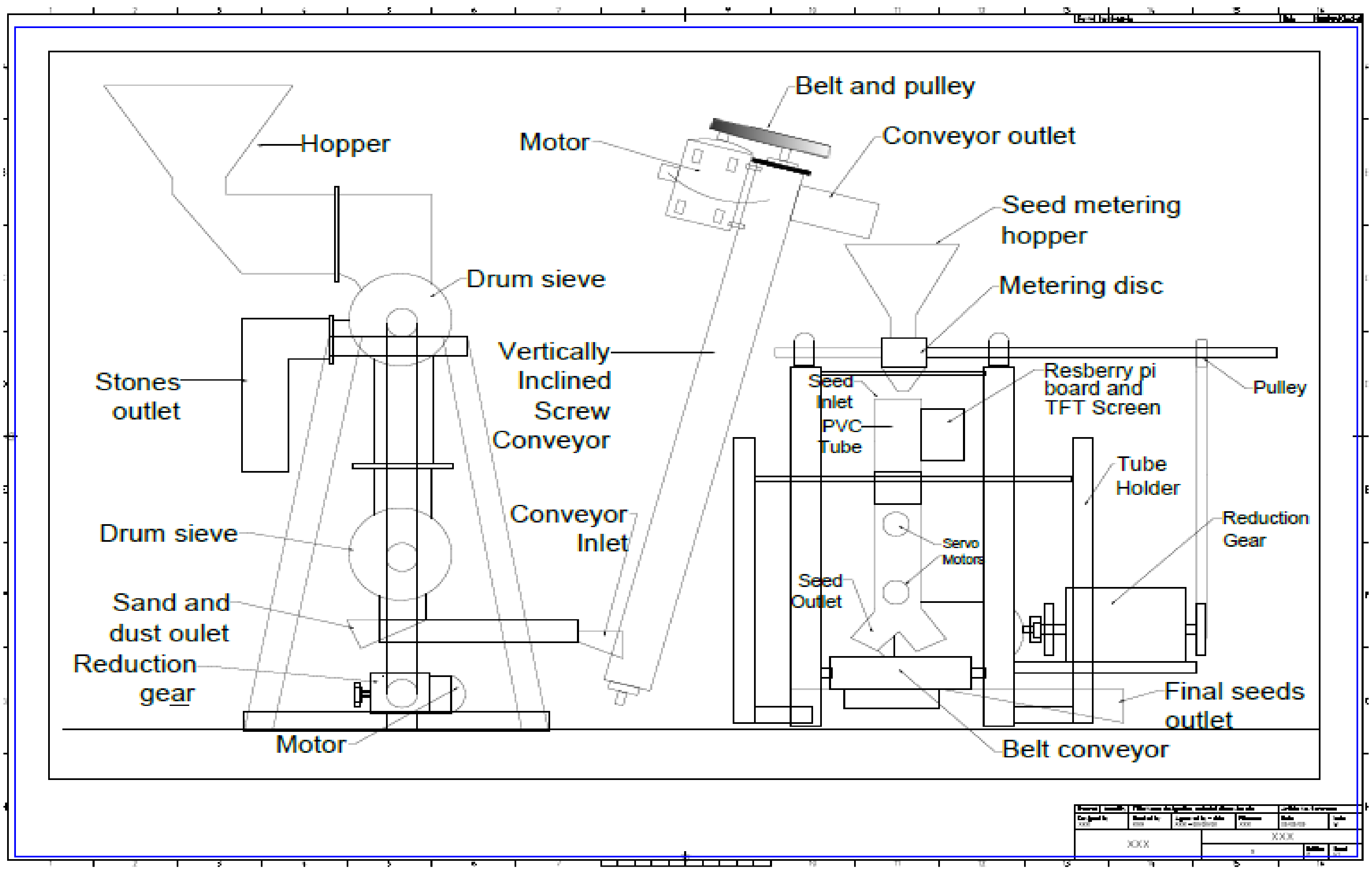
S/N	M	F	variety	R	C	ρ	σ	C	ε	L	X	Desirability	
1	10.00	500.00	oo55	6.57	0.18	0.84	1.34	3.4E-08	1,215.62	393,216.00	8,653,074.73	1	Selected
2	14.00	500.00	oo55	5.09	0.22	0.70	1.59	3.4E-08	1,215.60	393,216.00	8,401,707.67	1	
3	12.40	800.00	oo55	4.30	0.27	0.58	2.01	7E-09	249.69	196,608.00	9,246,303.67	1	
4	10.63	652.18	oo55	5.60	0.21	0.71	1.66	1.88E-08	672.95	196,608.00	9,093,920.71	1	
5	10.11	807.25	oo55	5.92	0.20	0.75	1.64	6.49E-09	231.58	163,840.00	8,978,426.31	1	
6	13.01	874.74	oo55	4.15	0.28	0.57	2.04	2.09E-09	74.63	147,456.00	9,095,636.75	1	
7	12.21	529.77	oo55	4.80	0.24	0.63	1.77	3.08E-08	1,100.91	327,680.00	8,980,343.05	1	
8	11.57	663.54	oo55	4.84	0.24	0.63	1.85	1.78E-08	636.80	262,144.00	9,229,013.38	1	
9	11.25	751.94	oo55	4.90	0.24	0.63	1.87	1.05E-08	376.07	196,608.00	9,251,980.44	1	
10	11.36	823.36	oo55	4.71	0.25	0.61	1.94	5.39E-09	192.17	163,840.00	9,241,811.93	1	
11	10.28	785.91	oo55	5.75	0.21	0.73	1.68	8E-09	285.63	196,608.00	9,045,233.33	1	
12	11.93	527.37	oo55	4.90	0.24	0.64	1.75	3.11E-08	1,110.01	262,144.00	8,995,184.28	1	
13	13.35	529.93	oo55	4.78	0.24	0.65	1.72	3.08E-08	1,100.29	327,680.00	8,737,795.70	1	
14	12.01	851.76	oo55	4.32	0.27	0.58	2.03	3.52E-09	125.67	163,840.00	9,242,766.56	1	
15	10.22	609.44	oo55	6.12	0.19	0.78	1.51	2.28E-08	814.42	196,608.00	8,934,661.47	1	
16	12.25	553.78	oo55	4.75	0.25	0.63	1.80	2.83E-08	1,011.42	327,680.00	9,031,417.85	1	
17	11.08	789.88	oo55	4.97	0.24	0.64	1.87	7.72E-09	275.41	131,072.00	9,223,957.34	1	
18	12.83	602.58	oo55	4.59	0.25	0.62	1.84	2.35E-08	837.91	327,680.00	9,033,196.68	1	
19	11.93	857.85	oo55	4.35	0.27	0.58	2.03	3.14E-09	111.90	131,072.00	9,238,842.97	1	
20	10.35	801.81	oo55	5.65	0.21	0.71	1.71	6.87E-09	245.16	229,376.00	9,058,149.87	1	

M = Moisture, F = frequency, R=Resistance, G=Conductance, ρ=Resistivity, σ=Conductivity, C=Capacitance, ε=Dielectric constant, L=Inductance, X=Capacitance reactance

Appendix D6 First Design of the Separating System



Appendix C7: Second Design of the Separating System



Appendix D8: Sample Information used for Evaluation

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Weight before Experiment (kg)					
Run	sped of sieve drums	speeds of bucket conveyor	speed of seed metering disc	grade	variety	Good seeds	Broken seeds	Damaged seeds	Foreign bodies	Total Bad portion	Total weight of sample
1	60	300	12	3	055	1.52	0.14	0.3	0.04	0.48	2
2	80	250	12	2	055	1.68	0.1	0.2	0.02	0.32	2
3	40	250	16	3	063	1.52	0.14	0.3	0.04	0.48	2
4	80	350	20	2	055	1.68	0.1	0.2	0.02	0.32	2
5	40	350	20	2	033	1.68	0.1	0.2	0.02	0.32	2
6	80	350	16	3	033	1.52	0.14	0.3	0.04	0.48	2
7	40	300	20	2	063	1.68	0.1	0.2	0.02	0.32	2
8	80	350	16	1	063	1.804	0.06	0.12	0.016	0.196	2
9	80	250	12	1	033	1.804	0.06	0.12	0.016	0.196	2
10	80	250	20	2	063	1.68	0.1	0.2	0.02	0.32	2
11	40	250	20	1	033	1.804	0.06	0.12	0.016	0.196	2
12	80	350	20	1	033	1.804	0.06	0.12	0.016	0.196	2
13	80	350	12	1	055	1.804	0.06	0.12	0.016	0.196	2
14	60	350	16	2	063	1.68	0.1	0.2	0.02	0.32	2
15	40	300	16	1	033	1.804	0.06	0.12	0.016	0.196	2
16	40	350	12	2	055	1.68	0.1	0.2	0.02	0.32	2
17	40	250	20	3	055	1.52	0.14	0.3	0.04	0.48	2
18	60	300	16	1	063	1.804	0.06	0.12	0.016	0.196	2
19	80	250	20	1	055	1.804	0.06	0.12	0.016	0.196	2
20	40	250	12	1	055	1.804	0.06	0.12	0.016	0.196	2
21	80	300	16	2	033	1.68	0.1	0.2	0.02	0.32	2
22	40	350	12	1	063	1.804	0.06	0.12	0.016	0.196	2
23	60	250	20	2	055	1.68	0.1	0.2	0.02	0.32	2
24	60	250	16	2	063	1.68	0.1	0.2	0.02	0.32	2
25	40	250	12	2	033	1.68	0.1	0.2	0.02	0.32	2
26	60	300	12	2	063	1.68	0.1	0.2	0.02	0.32	2
27	40	300	12	3	033	1.52	0.14	0.3	0.04	0.48	2
28	60	350	16	3	055	1.52	0.14	0.3	0.04	0.48	2
29	60	350	16	2	063	1.68	0.1	0.2	0.02	0.32	2
30	40	350	20	1	055	1.804	0.06	0.12	0.016	0.196	2
31	60	250	20	3	033	1.52	0.14	0.3	0.04	0.48	2
32	80	250	12	3	055	1.52	0.14	0.3	0.04	0.48	2
33	60	300	16	1	063	1.804	0.06	0.12	0.016	0.196	2
34	80	250	20	2	033	1.68	0.1	0.2	0.02	0.32	2
35	60	250	20	2	055	1.68	0.1	0.2	0.02	0.32	2
36	60	350	12	2	033	1.68	0.1	0.2	0.02	0.32	2
37	40	300	12	2	063	1.68	0.1	0.2	0.02	0.32	2
38	40	300	16	1	033	1.804	0.06	0.12	0.016	0.196	2
39	80	350	20	3	063	1.52	0.14	0.3	0.04	0.48	2
40	40	250	16	3	063	1.52	0.14	0.3	0.04	0.48	2

Appendix D9: Experimental Processing Time for the System

Run	Factor 1 sped of sieve drums	Factor 2 speeds of bucket conveyor	Factor 3 speed of seed metering disc	Factor 4 grade	Factor 5 variety	Time to finished processing (hours) First drum	Second drum	Bucket Conveyor	Sensing unit	Entire system
1	60	300	12	3	055	0.03	0.067	0.022	0.31	0.429
2	80	250	12	2	055	0.04	0.088	0.03	0.33	0.488
3	40	250	16	3	063	0.017	0.03	0.032	0.2	0.279
4	80	350	20	2	055	0.04	0.075	0.01	0.1	0.225
5	40	350	20	2	033	0.02	0.041	0.013	0.12	0.194
6	80	350	16	3	033	0.04	0.077	0.014	0.22	0.351
7	40	300	20	2	063	0.016	0.027	0.021	0.12	0.184
8	80	350	16	1	063	0.042	0.08	0.012	0.2	0.334
9	80	250	12	1	033	0.045	0.074	0.031	0.28	0.43
10	80	250	20	2	063	0.041	0.072	0.03	0.122	0.265
11	40	250	20	1	033	0.021	0.038	0.031	0.125	0.215
12	80	350	20	1	033	0.041	0.079	0.012	0.13	0.262
13	80	350	12	1	055	0.043	0.085	0.0125	0.3	0.4405
14	60	350	16	2	063	0.031	0.07	0.014	0.22	0.335
15	40	300	16	1	033	0.02	0.04	0.024	0.25	0.334
16	40	350	12	2	055	0.019	0.035	0.0127	0.29	0.3567
17	40	250	20	3	055	0.02	0.039	0.029	0.14	0.228
18	60	300	16	1	063	0.037	0.073	0.024	0.25	0.384
19	80	250	20	1	055	0.044	0.083	0.032	0.13	0.289
20	40	250	12	1	055	0.19	0.041	0.03	0.28	0.541
21	80	300	16	2	033	0.041	0.081	0.021	0.21	0.353
22	40	350	12	1	063	0.017	0.035	0.04	0.26	0.352
23	60	250	20	2	055	0.03	0.065	0.029	0.13	0.254
24	60	250	16	2	063	0.031	0.063	0.027	0.23	0.351
25	40	250	12	2	033	0.021	0.04	0.031	0.32	0.412
26	60	300	12	2	063	0.032	0.073	0.032	0.27	0.407
27	40	300	12	3	033	0.021	0.042	0.023	0.3	0.386
28	60	350	16	3	055	0.032	0.064	0.015	0.24	0.351
29	60	350	16	2	063	0.031	0.068	0.013	0.24	0.352
30	40	350	20	1	055	0.018	0.04	0.012	0.15	0.22
31	60	250	20	3	033	0.032	0.064	0.031	0.17	0.297
32	80	250	12	3	055	0.035	0.08	0.03	0.28	0.425
33	60	300	16	1	063	0.037	0.071	0.025	0.026	0.159
34	80	250	20	2	033	0.04	0.078	0.03	0.013	0.161
35	60	250	20	2	055	0.03	0.063	0.03	0.14	0.263
36	60	350	12	2	033	0.032	0.064	0.014	0.28	0.39
37	40	300	12	2	063	0.017	0.028	0.02	0.26	0.325
38	40	300	16	1	033	0.021	0.042	0.023	0.24	0.326
39	80	350	20	3	063	0.035	0.075	0.016	0.17	0.296
40	40	250	16	3	063	0.016	0.03	0.032	0.2	0.278

Appendix D10: Information on Sample Foreign Body Content before and after Experiment

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Weight foreign bodies before Experiment (kg)				Weight foreign bodies out of the system after Experiment (kg)			
Run	sped of sieve drums	speeds of bucket conveyor	speed of seed metering disc	grade	variety	Impurity greater than 12mm	Impurity lesser than 2mm	Plant part	Total	Impurity greater than 12mm	Impurity lesser than 2mm	Plant part	Total
1	60	300	12	3	055	0.02	0.015	0.005	0.04	0.018	0.015	0.004	0.039
2	80	250	12	2	055	0.01	0.007	0.003	0.02	0.008	0.007	0.0023	0.0193
3	40	250	16	3	063	0.02	0.015	0.005	0.04	0.019	0.015	0.004	0.039
4	80	350	20	2	055	0.01	0.007	0.003	0.02	0.008	0.007	0.002	0.019
5	40	350	20	2	033	0.01	0.007	0.003	0.02	0.009	0.007	0.0027	0.0197
6	80	350	16	3	033	0.02	0.015	0.005	0.04	0.016	0.015	0.0045	0.0395
7	40	300	20	2	063	0.01	0.007	0.003	0.02	0.009	0.007	0.0024	0.0194
8	80	350	16	1	063	0.009	0.005	0.002	0.016	0.007	0.005	0.0016	0.0156
9	80	250	12	1	033	0.009	0.005	0.002	0.016	0.007	0.005	0.0018	0.0158
10	80	250	20	2	063	0.01	0.007	0.003	0.02	0.005	0.007	0.0024	0.0194
11	40	250	20	1	033	0.009	0.005	0.002	0.016	0.008	0.005	0.0018	0.0158
12	80	350	20	1	033	0.009	0.005	0.002	0.016	0.007	0.005	0.0017	0.0157
13	80	350	12	1	055	0.009	0.005	0.002	0.016	0.007	0.005	0.00175	0.01575
14	60	350	16	2	063	0.01	0.007	0.003	0.02	0.009	0.007	0.0026	0.0196
15	40	300	16	1	033	0.009	0.005	0.002	0.016	0.008	0.005	0.0016	0.0156
16	40	350	12	2	055	0.01	0.007	0.003	0.02	0.009	0.007	0.0022	0.0192
17	40	250	20	3	055	0.02	0.015	0.005	0.04	0.018	0.015	0.004	0.039
18	60	300	16	1	063	0.009	0.005	0.002	0.016	0.008	0.005	0.0016	0.0156
19	80	250	20	1	055	0.009	0.005	0.002	0.016	0.007	0.005	0.0014	0.0154
20	40	250	12	1	055	0.009	0.005	0.002	0.016	0.008	0.005	0.0015	0.0155
21	80	300	16	2	033	0.01	0.007	0.003	0.02	0.008	0.007	0.00228	0.01928
22	40	350	12	1	063	0.009	0.005	0.002	0.016	0.008	0.005	0.0015	0.0155
23	60	250	20	2	055	0.01	0.007	0.003	0.02	0.008	0.007	0.0022	0.0192

Run	Factor 1 sped of sieve drums	Factor 2 speeds of bucket conveyor	Factor 3 speed of seed metering disc	Factor 4 grade	Factor 5 variety	Weight foreign bodies before Experiment (kg) Impurity greater than 12mm	Impurity lesser than 2mm	Plant part	Total	Weight foreign bodies out of the system after Experiment (kg) Impurity greater than 12mm	Impurity lesser than 2mm	Plant part	Total
24	60	250	16	2	063	0.01	0.007	0.003	0.02	0.009	0.007	0.0026	0.0196
25	40	250	12	2	033	0.01	0.007	0.003	0.02	0.009	0.007	0.0027	0.0197
26	60	300	12	2	063	0.01	0.007	0.003	0.02	0.009	0.007	0.023	0.04
27	40	300	12	3	033	0.02	0.015	0.005	0.04	0.018	0.015	0.0045	0.0395
28	60	350	16	3	055	0.02	0.015	0.005	0.04	0.017	0.015	0.0036	0.0386
29	60	350	16	2	063	0.01	0.007	0.003	0.02	0.008	0.007	0.0021	0.0191
30	40	350	20	1	055	0.009	0.005	0.002	0.016	0.008	0.005	0.0013	0.0153
31	60	250	20	3	033	0.02	0.015	0.005	0.04	0.016	0.015	0.046	0.081
32	80	250	12	3	055	0.02	0.015	0.005	0.04	0.015	0.015	0.0031	0.0381
33	60	300	16	1	063	0.009	0.005	0.002	0.016	0.008	0.005	0.0021	0.0161
34	80	250	20	2	033	0.01	0.007	0.003	0.02	0.008	0.007	0.0027	0.0197
35	60	250	20	2	055	0.01	0.007	0.003	0.02	0.008	0.007	0.0021	0.0191
36	60	350	12	2	033	0.01	0.007	0.003	0.02	0.009	0.007	0.0026	0.0196
37	40	300	12	2	063	0.01	0.007	0.003	0.02	0.009	0.007	0.0024	0.0194
38	40	300	16	1	033	0.009	0.005	0.002	0.016	0.008	0.005	0.0017	0.0157
39	80	350	20	3	063	0.02	0.015	0.005	0.04	0.015	0.015	0.003	0.038
40	40	250	16	3	063	0.02	0.015	0.005	0.04	0.018	0.015	0.0041	0.0391

Appendix D11: weights of samples collected from outlets of system and metering flowrate

Run	Factor 1 sped of sieve drums	Factor 2 speeds of bucket conveyor	Factor 3 speed of seed metering disc	Factor 4 grade	Factor 5 variety	Weight of materials collected from the system outlets (kg) First drum	Second drum	Belt conveyor for accepted Good	Belt conveyor for accepted Bad	Belt Conveyor for rejected Good	Belt Conveyor for rejected Bad	Total	Design flow rate (L/s)	Actual Metering Disc Flow Rate (L/S)
1	60	300	12	3	055	0.03	0.02	1.1	0.1	0.3	0.35	1.9	4.125E-12	8.088E-13
2	80	250	12	2	055	0.04	0.025	1.3	0.09	0.3	0.2	1.955	4.125E-12	8.088E-13
3	40	250	16	3	063	0.021	0.016	1	0.09	0.4	0.42	1.947	4.125E-12	1.078E-12
4	80	350	20	2	055	0.042	0.03	1.2	0.09	0.3	0.3	1.962	4.125E-12	1.348E-12
5	40	350	20	2	033	0.017	0.01	1.4	0.04	0.168	0.33	1.965	4.125E-12	1.348E-12
6	80	350	16	3	033	0.042	0.03	1.3	0.04	0.1	0.4	1.912	4.125E-12	1.078E-12
7	40	300	20	2	063	0.018	0.01	1	0.07	0.52	0.31	1.928	4.125E-12	1.348E-12
8	80	350	16	1	063	0.054	0.033	1.26	0.03	0.41	0.14	1.927	4.125E-12	1.078E-12
9	80	250	12	1	033	0.052	0.03	1.6	0.01	0.1	0.16	1.952	4.125E-12	8.088E-13
10	80	250	20	2	063	0.045	0.027	1.1	0.06	0.5	0.24	1.972	4.125E-12	1.348E-12
11	40	250	20	1	033	0.022	0.015	1.5	0.02	0.2	0.2	1.957	4.125E-12	1.348E-12
12	80	350	20	1	033	0.05	0.031	1.54	0.013	0.16	0.16	1.954	4.125E-12	1.348E-12
13	80	350	12	1	055	0.054	0.034	1.57	0.055	0.04	0.15	1.903	4.125E-12	8.088E-13
14	60	350	16	2	063	0.034	0.024	1.15	0.05	0.4	0.25	1.908	4.125E-12	1.078E-12
15	40	300	16	1	033	0.025	0.017	1.54	0.015	0.18	0.17	1.947	4.125E-12	1.078E-12
16	40	350	12	2	055	0.02	0.017	1.31	0.092	0.336	0.2	1.975	4.125E-12	8.088E-13
17	40	250	20	3	055	0.029	0.02	1	0.12	0.35	0.4	1.919	4.125E-12	1.348E-12
18	60	300	16	1	063	0.037	0.024	1.22	0.034	0.5	0.13	1.945	4.125E-12	1.078E-12
19	80	250	20	1	055	0.05	0.03	1.35	0.047	0.32	0.16	1.957	4.125E-12	1.348E-12
20	40	250	12	1	055	0.024	0.018	1.45	0.035	0.3	0.12	1.947	4.125E-12	8.088E-13
21	80	300	16	2	033	0.04	0.02	1.5	0.03	0.12	0.25	1.96	4.125E-12	1.078E-12
22	40	350	12	1	063	0.025	0.016	1.26	0.036	0.5	0.15	1.987	4.125E-12	8.088E-13
23	60	250	20	2	055	0.034	0.022	1.25	0.096	0.3	0.24	1.942	4.125E-12	1.348E-12

Run	Factor 1 sped of sieve drums	Factor 2 speeds of bucket conveyor	Factor 3 speed of seed metering disc	Factor 4 grade	Factor 5 variety	Weight of materials collected from the system outlets (kg) First drum	Second drum	Belt conveyor for accepted Good	Belt conveyor for accepted Bad	Belt Conveyor for rejected Good	Belt Conveyor for rejected Bad	Total	Design flow rate (L/s)	Actual Metering Disc Flow Rate (L/S)
24	60	250	16	2	063	0.033	0.026	1.16	0.062	0.43	0.25	1.961	4.125E-12	1.078E-12
25	40	250	12	2	033	0.02	0.012	1.5	0.029	0.15	0.28	1.991	4.125E-12	8.088E-13
26	60	300	12	2	063	0.02	0.018	1.18	0.05	0.5	0.23	1.998	4.125E-12	8.088E-13
27	40	300	12	3	033	0.026	0.021	1.35	0.044	0.152	0.4	1.993	4.125E-12	8.088E-13
28	60	350	16	3	055	0.031	0.02	1.21	0.12	0.29	0.32	1.991	4.125E-12	1.078E-12
29	60	350	16	2	063	0.021	0.015	1.15	0.064	0.49	0.25	1.99	4.125E-12	1.078E-12
30	40	350	20	1	055	0.025	0.017	1.3	0.07	0.34	0.2	1.952	4.125E-12	1.348E-12
31	60	250	20	3	033	0.032	0.023	1.28	0.05	0.13	0.45	1.965	4.125E-12	1.348E-12
32	80	250	12	3	055	0.04	0.028	1.2	0.1	0.31	0.32	1.998	4.125E-12	8.088E-13
33	60	300	16	1	063	0.036	0.025	1.25	0.032	0.45	0.15	1.943	4.125E-12	1.078E-12
34	80	250	20	2	033	0.041	0.022	1.4	0.033	0.15	0.3	1.946	4.125E-12	1.348E-12
35	60	250	20	2	055	0.033	0.02	1.26	0.098	0.29	0.25	1.951	4.125E-12	1.348E-12
36	60	350	12	2	033	0.035	0.02	1.5	0.03	0.13	0.27	1.985	4.125E-12	8.088E-13
37	40	300	12	2	063	0.019	0.012	1.12	0.062	0.5	0.25	1.963	4.125E-12	8.088E-13
38	40	300	16	1	033	0.024	0.018	1.53	0.017	0.18	0.18	1.949	4.125E-12	1.078E-12
39	80	350	20	3	063	0.041	0.03	0.98	0.1	0.31	0.45	1.911	4.125E-12	1.348E-12
40	40	250	16	3	063	0.021	0.017	1	0.09	0.4	0.42	1.948	4.125E-12	1.078E-12

APENDIX D12: Modeled Equations for Operational Efficiencies and their Statistical parameters

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
		63		Std. Dev.	3.423
		33		Mean	76.596
	1		$E_1 = 108.549 - 051\ S_D$		
		55		C.V. %	4.469
		63		PRESS	554.163
Efficiency of 1st Sieve Drum (E_1)	2	33	$E_1 = 106.822 - 051\ S_D$	-2 Log Likelihood	205.453
		55		R-Squared	0.883
		63		Adj R-Squared	0.866
		33		Pred R-Squared	0.837
	3		$E_1 = 104.096 - 051\ S_D$		
		55		Adeq Precision	19.358
				BIC	227.586
				AICc	219.998
	1	63	$Logit\ (E_2) = Ln\left[\frac{(E_2 - 40)}{(100 - E_2)}\right] = 4.575\ - 0.061\ S_D$	Std. Dev.	4.188
		33		Mean	85.338
		55		C.V. %	4.908
Efficiency of 2nd Sieve Drum (E_2)	2	63	$Logit\ (E_2) = Ln\left[\frac{(E_2 - 40)}{(100 - E_2)}\right] = 5.229\ - 0.061\ S_D$	PRESS	843.083
		33		-2 Log Likelihood	221.599
		55		R-Squared	0.877
	3	63	$Logit\ (E_2) = Ln\left[\frac{(E_2 - 40)}{(100 - E_2)}\right] = 5.229\ - 0.061\ S_D$	Adj R-Squared	0.858
		33		Pred R-Squared	0.826
		55		Adeq Precision	20.059

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
				BIC	243.733
				AICc	236.145
Efficiency of Bucket Conveyor (E_3)	1	63	$Logit\ (E_3) = Ln\left[\frac{(E_3 - 90)}{(100 - E_3)}\right] = 3.473\ - 0.127\ S_M$	Std. Dev.	0.001
		33		Mean	0.101
		55		C.V. %	0.710
	2	63		PRESS	2.5E-05
		33		-2 Log Likelihood	-472.052
		55		R-Squared	0.108
	3	63		Adj R-Squared	-0.023
		33		Pred R-Squared	-0.253
		55		Adeq Precision	2.905
				BIC	-449.918
				AICc	-457.506
Efficiency of Metering Device (E_4)	1	63	$\sqrt{E_4} = 2.520 + 0.161S_M$	Std. Dev.	0.000
		33	$\sqrt{E_4} = 2.51 + 0.161S_M$	Mean	26.307
		55	$\sqrt{E_4} = 2.5 + 0.161S_M$	C.V. %	0.000
	2	63	$\sqrt{E_4} = 2.520 + 0.161S_M$	PRESS	4.50E-28
		33	$\sqrt{E_4} = 2.51 + 0.161S_M$	-2 Log Likelihood	1.000
		55	$\sqrt{E_4} = 2.5 + 0.161S_M$	R-Squared	1.000
	3	63	$\sqrt{E_4} = 2.520 + 0.161S_M$	Adj R-Squared	1.000
		33	$\sqrt{E_4} = 2.51 + 0.161S_M$	Pred R-Squared	
		55	$\sqrt{E_4} = 2.5 + 0.161S_M$	Adeq Precision	
			$E_5 =$ [illegible]	BIC	
				AICc	

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
Efficiency of Automation Unit (E_5)	1	63	$E_5 = 81.6 + 0.049S_M$	Std. Dev.	0.018
		33	$E_5 = 90.875 + 0.049S_M$	Mean	5.100
		55	$E_5 = 74.146 + 0.049S_M$	C.V. %	0.360
	2	63	$E_5 = 79.475 + 0.049S_M$	PRESS	0.015
		33	$E_5 = 88.765 + 0.049S_M$	-2 Log Likelihood	-213.810
		55	$E_5 = 72.036 + 0.049S_M$	R-Squared	0.999
	3	63	$E_5 = 81.524 + 0.049S_M$	Adj R-Squared	0.999
		33	$E_5 = 91.14 + 0.049S_M$	Pred R-Squared	0.999
		55	$E_5 = 74.085 + 0.049S_M$	Adeq Precision	187.740
				BIC	-191.670
				AICc	-199.260
System Efficiency (E_5)	***1***	***63***	$\mathbf{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.712 - 0.018S_D - 2.33 \times 10^{-4}S_B + 0.024S_M}$	***Std. Dev.***	***1.073***
		33	$\boldsymbol{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.442 - 0.018S_D - 2.33\ x\ 10^{-4}S_B + 0.024S_M}$	***Mean***	***73.585***
		55	$\mathbf{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.562 - 0.018S_D - 2.33 \times 10^{-4}S_B + 0.024S_M}$	***C.V. %***	***1.458***

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
	2	*63*	$\mathbf{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.649 - 0.018S_D - 2.33 \times 10^{-4}S_B + 0.024S_M}$	***PRESS***	***58.147***
		33	$\mathbf{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.8 - 0.018S_D - 2.33 \times 10^{-4}S_B + 0.024S_M}$	***-2 Log Likelihood***	***110.209***
		55	$\mathbf{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.509 - 0.018S_D - 2.33 \times 10^{-4}S_B + 0.024S_M}$	***R-Squared***	***0.946***
	3	*63*	$\mathbf{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.6 - 0.018S_D - 2.33 \times 10^{-4}S_B + 0.024S_M}$	***Adj R-Squared***	***0.935***
		33	$\mathbf{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.75 - 0.018S_D - 2.33 \times 10^{-4}S_B + 0.024S_M}$	***Pred R-Squared***	***0.915***
		55	$\boldsymbol{logit(E_S) = \left[\frac{(E_S - 50)}{(100 - E_S)}\right] = 0.46 - 0.018S_D - 2.33\ x\ 10^{-4}S_B + 0.024S_M}$	***Adeq Precision***	***32.292***

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
				BIC	***139.720***
				AICc	***130.854***

S_D = Speed of drum, S_B = Speed of Bucket Conveyor, S_M = Speed of Metering Device

APENDIX D13: Modeling Equation for Operational Throughput and their Statistical parameters

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
Throughput of 1st Sieve Drum (T1)	1	63	$\text{logit}(T_1) = ln\left[\frac{(T_1+0)}{0.7-T_1}\right] = -8.303 - 0.084S_D + 0.032S_B + 0.573S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	Std. Dev.	0.045
		33	$\text{logit}(T_1) = ln\left[\frac{(T_1+0)}{0.7-T_1}\right] = -8.795 - 0.084S_D + 0.032S_B + 0.573S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	Mean	0.220
		55	$\text{logit}(T_1) = ln\left[\frac{(T_1+0)}{0.7-T_1}\right] = -12.886 - 0.084S_D + 0.032S_B + 0.573S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	C.V. %	20.600
	2	63	$\text{logit}(T_1) = ln\left[\frac{(T_1+0)}{0.7-T_1}\right] = -4.725 - 0.084S_D + 0.025S_B + 0.499S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	PRESS	0.160
		33	$\text{logit}(T_1) = ln\left[\frac{(T_1+0)}{0.7-T_1}\right] = -5.583 - 0.084S_D + 0.028S_B + 0.471S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	-2 Log Likelihood	-152.650
		55	$\text{logit}(T_1) = ln\left[\frac{(T_1+0)}{0.7-T_1}\right] = -8.849 - 0.084S_D + 0.033S_B + 0.592S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	R-Squared	0.932
	3	63	$\text{logit}(T_1) = ln\left[\frac{(T_1+0)}{0.7-T_1}\right] = -4.367 - 0.084S_D + 0.02S_B + 0.44S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	Adj R-Squared	0.894

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
		33	$\text{logit}(T_1) = ln\left[\frac{(T_1 + 0)}{0.7 - T_1}\right] = -2.366 - 0.084S_D + 0.024S_B + 0.412S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	Pred R-Squared	0.788
		55	$\text{logit}(T_1) = ln\left[\frac{(T_1 + 0)}{0.7 - T_1}\right] = -5.626 - 0.084S_D + 0.028S_B + 0.533S_M - 1.351\ x\ 10^{-4}S_DS_B - 0.003S_DS_M - 0.001S_BS_M + 0.001{S_D}^2$	Adeq Precision	19.454
				BIC	-97.325
				AICc	-102.658
Throughput of 2nd Sieve Drum (T2)	1	63	$\frac{1}{T_2} = -36.750 + 0.681S_D + 0.025S_B + 1.5S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	Std. Dev.	0.015
		33	$\frac{1}{T_2} = -33.179 + 0.632S_D + 0.014S_B + 1.71S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	Mean	0.144
		55	$\frac{1}{T_2} = -26.503 + 0.674S_D + 0.001S_B + 1.454S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	C.V. %	10.373
	2	63	$\frac{1}{T_2} = -23.287 + 0.483S_D + 0.01S_B + 1.303S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	PRESS	0.020
		33	$\frac{1}{T_2} = -19.752 + 0.434S_D + 0.002S_B + 1.509S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	-2 Log Likelihood	-241.353
		55	$\frac{1}{T_2} = -14.111 + 0.477S_D + 0.014S_B + 1.257S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	R-Squared	0.988
	3	63	$\frac{1}{T_2} = -23.715 + 0.313S_D + 0.021S_B + 1.427S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	Adj R-Squared	0.982
		33	$\frac{1}{T_2} = -19.906 + 0.264S_D + 0.009S_B + 1.633S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	Pred R-Squared	0.959

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
		55	$\frac{1}{T_2} = -15.248 + 0.3071S_D + 0.003S_B + 1.381S_m - 0.004S_DS_M - 0.001{S_D}^2 - 0.039{S_M}^2$	Adeq Precision	48.980
				BIC	-186.020
				AICc	-191.353
Throughput of sensing Unit (T3)	1	63	$\frac{1}{\sqrt{T_3}} = -0.63 + 0.016S_D + 0.007S_B + 0.108S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	Std. Dev.	0.286
		33	$\frac{1}{\sqrt{T_3}} = -0.508 + 0.016S_D + 0.007S_B + 0.094S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	Mean	0.921
		55	$\frac{1}{\sqrt{T_3}} = -0.136 + 0.016S_D + 0.007S_B + 0.077S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	C.V. %	31.006
	2	63	$\frac{1}{\sqrt{T_3}} = -0.995 + 0.016S_D + 0.007S_B + 0.109S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	PRESS	3.787
		33	$\frac{1}{\sqrt{T_3}} = -0.784 + 0.016S_D + 0.007S_B + 0.095S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	-2 Log Likelihood	6.763
		55	$\frac{1}{\sqrt{T_3}} = -0.391 + 0.016S_D + 0.007S_B + 0.078S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	R-Squared	0.760
	3	63	$\frac{1}{\sqrt{T_3}} = -1.679 + 0.016S_D + 0.007S_B + 0.139S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	Adj R-Squared	0.725
		33	$\frac{1}{\sqrt{T_3}} = -0.398 + 0.016S_D + 0.007S_B + 0.125S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	Pred R-Squared	0.673
		55	$\frac{1}{\sqrt{T_3}} = -1.08 + 0.016S_D + 0.007S_B + 0.108S_M - 1.275x10^{-4}{S_D}^2 - 1.198x10^{-5}{S_B}^2 - 0.005{S_M}^2$	Adeq Precision	16.384
				BIC	28.896

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
				AICc	21.308
	1	*63*	$\frac{1}{\sqrt{T_S}} = 0.473 + 0.026S_D - 0.002S_B + 0.056S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***Std. Dev.***	***0.229***
		33	$\frac{1}{\sqrt{T_S}} = 0.574 + 0.025S_D - 0.002S_B + 0.049S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***Mean***	***0.699***
		55	$\frac{1}{\sqrt{T_S}} = 1.29 + 0.024S_D - 0.003S_B + 0.03S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***C.V. %***	***32.758***
	2	*63*	$\frac{1}{\sqrt{T_S}} = 0.238 + 0.025S_D - 0.003S_B + 0.058S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***PRESS***	***2.479***
System Throughput (Ts)		*33*	$\frac{1}{\sqrt{T_S}} = 0.397 + 0.024S_D - 0.003S_B + 0.051S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***-2 Log Likelihood***	***-13.322***
			$\frac{1}{\sqrt{T_S}} = 0.397 + 0.024S_D - 0.003S_B + 0.051S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$		
		55	$\frac{1}{\sqrt{T_S}} = 1.073 + 0.023S_D - 0.003S_B + 0.032S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***R-Squared***	***0.724***
	3	*63*	$\frac{1}{\sqrt{T_S}} = 0.416 + 0.023S_D - 0.002S_B + 0.082S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***Adj R-Squared***	***0.663***
		33	$\frac{1}{\sqrt{T_S}} = 0.179 + 0.022S_D - 0.002S_B + 0.075S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***Pred R-Squared***	***0.592***
		55	$\frac{1}{\sqrt{T_S}} = 0.445 + 0.021S_D - 0.003S_B + 0.056S_M - 1.355x10^{-4}S_BS_M - 1.845x10^{-4}{S_D}^2 - 0.004{S_M}^2$	***Adeq Precision***	***13.181***

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
				BIC	***16.189***
				AICc	***7.323***

S_D = Speed of drum, S_B = Speed of Bucket Conveyor, S_M = Speed of Metering Device

APENDIX D14: Modeling Equation for Operational Maximum Capacity and their Statistical parameters

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
Maximum Capacity of 1st Sieve Drum (MC1)	1	63	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = -2.383 - 0.023S_D + 0.008S_B - 3.972x10^{-6}S_DS_B$	Std. Dev.	0.561
		33	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = -1.956 - 0.023S_D + 0.008S_B - 3.972x10^{-6}S_DS_B$	Mean	2.645
		55	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = -2.714 - 0.023S_D + 0.008S_B - 3.972x10^{-6}S_DS_B$	C.V. %	21.213
	2	63	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = +1.419 - 0.031S_D - 0.002S_B - 3.972x10^{-6}S_DS_B$	PRESS	18.556
		33	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = +2.239 - 0.031S_D - 0.002S_B - 3.972x10^{-6}S_DS_B$	-2 Log Likelihood	54.418
		55	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = +1.276 - 0.031S_D - 0.002S_B - 3.972x10^{-6}S_DS_B$	R-Squared	0.916
	3	63	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = +6.502 - 0.054S_D - 0.007S_B - 3.972x10^{-6}S_DS_B$	Adj R-Squared	0.887
		33	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = +5.088 - 0.054S_D - 0.007S_B - 3.972x10^{-6}S_DS_B$	Pred R-Squared	0.829
		55	$logit(MC_1) = ln\left[\frac{(MC_1+0)}{(8-MC_1)}\right] = +5.147 - 0.054S_D - 0.007S_B - 3.972x10^{-6}S_DS_B$	Adeq Precision	20.723

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
				BIC	94.996
				AICc	85.847
Maximum Capacity of 2nd Sieve Drum (MC2)	1	63	$\frac{1}{MC_2} = -3.063 + 0.057S_D + 0.002S_B + 0.125S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	Std. Dev.	0.180
		33	$\frac{1}{MC_2} = -2.765 + 0.053S_D + 0.001S_B + 0.142S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	Mean	1.733
		55	$\frac{1}{MC_2} = -2.209 + 0.056S_D + 0.0001S_B + 0.121S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	C.V. %	10.373
	2	63	$\frac{1}{MC_2} = -1.941 + 0.04S_D + 0.001S_B + 0.109S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	PRESS	2.859
		33	$\frac{1}{MC_2} = -1.646 + 0.036S_D - 0.0001S_B + 0.126S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	-2 Log Likelihood	-42.560
		55	$\frac{1}{MC_2} = -1.176 + 0.04S_D - 0.001S_B + 0.105S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	R-Squared	0.988
	3	63	$\frac{1}{MC_2} = -1.976 + 0.026S_D + 0.002S_B + 0.119S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	Adj R-Squared	0.982
		33	$\frac{1}{MC_2} = -1.659 + 0.022S_D + 0.0008S_B + 0.136S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	Pred R-Squared	0.959
		55	$\frac{1}{MC_2} = -1.271 + 0.026S_D - 0.0003S_B + 0.115S_M - 3.533\ x\ 10^{-4}\ S_D S_M - 1.093 \text{ x } 10^{-4} {S_D}^2 - 0.003\ x\ {S_M}^2$	Adeq Precision	48.980
				BIC	12.773
				AICc	7.440
Maximum Capacity	1	63	$\frac{1}{\sqrt{MC_3}} = 0.182 - 1.211\ x\ 10^{-4} S_B + 0.041S_m + 3.724\ x\ 10^{-7} {S_D}^2 - 0.002{S_M}^2$	Std. Dev.	0.024

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
of sensing Unit (MC3)		33	$\frac{1}{\sqrt{MC_3}} = 0.209 - 1.211\ x\ 10^{-4}S_B + 0.037S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	Mean	0.077
		55	$\frac{1}{\sqrt{MC_3}} = 0.309 - 1.211\ x\ 10^{-4}S_B + 0.032S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	C.V. %	31.006
		63	$\frac{1}{\sqrt{MC_3}} = 0.085 - 1.211\ x\ 10^{-4}S_B + 0.041S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	PRESS	0.026
	2	33	$\frac{1}{\sqrt{MC_3}} = 0.138 - 1.211\ x\ 10^{-4}S_B + 0.037S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	-2 Log Likelihood	-192.030
		55	$\frac{1}{\sqrt{MC_3}} = 0.248 - 1.211\ x\ 10^{-4}S_B + 0.032S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	R-Squared	0.760
		63	$\frac{1}{\sqrt{MC_3}} = -0.125 - 1.211\ x\ 10^{-4}S_B + 0.049S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	Adj R-Squared	0.725
	3	33	$\frac{1}{\sqrt{MC_3}} = -0.036 - 1.211\ x\ 10^{-4}S_B + 0.045S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	Pred R-Squared	0.673
		55	$\frac{1}{\sqrt{MC_3}} = 0.052 - 1.211\ x\ 10^{-4}S_B + 0.041S_m + 3.724\ x\ 10^{-7}{S_D}^2 - 0.002{S_M}^2$	Adeq Precision	16.384
				BIC	-169.897
				AICc	-177.485
System Maximum Capacity (MCS)	***1***	***63***	$\frac{1}{\sqrt{MC_S}} = -0.095 + 0.007S_D + 7.732\ x10^{-4}S_B + 0.017S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$		
				Std. Dev.	***0.019***
		33	$\frac{1}{\sqrt{MC_S}} = -0.056 + 0.007S_D + 7.732\ x10^{-4}S_B + 0.015S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***Mean***	***0.058***

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
		55	$\frac{1}{\sqrt{MC_S}} = 0.142 + 0.007S_D + 5.541\,x10^{-4}S_B + 0.01S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***C.V. %***	***32.758***
	2	***63***	$\frac{1}{\sqrt{MC_S}} = -0.173 + 0.007S_D + 7.732\,x10^{-4}S_B + 0.018S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***PRESS***	***0.017***
		33	$\frac{1}{\sqrt{MC_S}} = -0.117 + 0.007S_D + 7.732\,x10^{-4}S_B + 0.016S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***-2 Log Likelihood***	***-212.115***
		55	$\frac{1}{\sqrt{MC_S}} = 0.073 + 0.007S_D + 5.451\,x10^{-4}S_B + 0.011S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***R-Squared***	***0.724***
	3	***63***	$\frac{1}{\sqrt{MC_S}} = -0.319 + 0.007S_D + 7.732\,x10^{-4}S_B + 0.025S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***Adj R-Squared***	***0.663***
		33	$\frac{1}{\sqrt{MC_S}} = -0.245 + 0.007S_D + 7.737\,x10^{-4}S_B + 0.023S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***Pred R-Squared***	***0.592***
		55	$\frac{1}{\sqrt{MC_S}} = -0.072 + 0.007S_D + 5.451\,x10^{-4}S_B + 0.018S_M + 4x10^{-5}S_BS_M - 5x10^{-5}{S_D}^2 - 2x10^{-6}{S_B}^2 - 0.001{S_M}^2$	***Adeq Precision***	***13.181***

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
				BIC	***-182.604***
				AICc	***-191.470***

S_D = Speed of drum, S_B = Speed of Bucket Conveyor, S_M = Speed of Metering Device

APENDIX D15: Modeling Equation for Operational Actual Utilization and their Statistical parameters

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
		63		Std. Dev.	2.77E-17
	1	33		Mean	0.083
		55	$AU_1 = 0.083 + 2.89\ x\ 10^{-19} S_D - 1.234\ x\ 10^{-19} S_B + 1.393\ x 10^{-18} S_M$	C.V. %	3.32E-14
Actual Utilization of 1st Sieve Drum (AU1)		63		PRESS	6.01E-32
	2	33		-2 Log Likelihood	
		55		R-Squared	0.789
		63		Adj R-Squared	0.758
	3	33		Pred R-Squared	0.513
		55		Adeq Precision	
				BIC	
				AICc	
		63		Std. Dev.	2.77E-17
	1	33		Mean	0.083
		55	$AU_2 = 0.083 + 2.89\ x\ 10^{-19} S_D - 1.234\ x\ 10^{-19} S_B + 1.393\ x 10^{-18} S_M$	C.V. %	3.32E-14
Actual Utilization of 2nd Sieve Drum (AU2)		63		PRESS	6.01E-32
	2	33		-2 Log Likelihood	
		55		R-Squared	0.789
		63		Adj R-Squared	0.758
	3	33		Pred R-Squared	0.513
		55		Adeq Precision	
				BIC	
				AICc	
		63		Std. Dev.	2.75E-17
	1	33		Mean	0.083
		55		C.V. %	3.30E-14
Actual Utilization of sensing Unit (AU3)		63		PRESS	5.94E-32
	2	33	$AU_3 = 0.083 + 2.89\ x\ 10^{-19} S_D - 1.234\ x\ 10^{-19} S_B + 1.393\ x 10^{-18} S_M$	-2 Log Likelihood	
		55		R-Squared	0.791
		63		Adj R-Squared	0.761
	3	33		Pred R-Squared	0.518
		55		Adeq Precision	
				BIC	
				AICc	
	1	**63**		***Std. Dev.***	4.05E-17

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
		33		***Mean***	0.083
		55		***C.V. %***	4.86E-14
		63		***PRESS***	1.06E-31
System Actual Utilization (AUs)	***2***		$AU_S = 0.083 + 3.81\ x\ 10^{-20} S_D - 1.368\ x\ 10^{-19} S_B - 7.122\ x 10^{-20} S_M$		
		33		***-2 Log Likelihood***	
		55		***R-Squared***	***0.566***
		63		***Adj R-Squared***	***0.471***
	3	***33***		***Pred R-Squared***	***0.119***
		55		***Adeq Precision***	
				BIC	
				AICc	

S_D = Speed of drum, S_B = Speed of Bucket Conveyor, S_M = Speed of Metering Device

APENDIX D16: Modeling Equation for Operational Backlog and their Statistical parameters

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
Backlog of 1st Sieve Drum (B1)	1	63	$\log_{10} B_1 = -3.566 + 0.011 S_D$	Std. Dev.	6.18E-04
		33		Mean	0.0018493
		55		C.V. %	3.34E+01
	2	63	$\log_{10} B_1 = -3.496 + 0.011 S_D$	PRESS	1.81E-05
				-2 Log	-
		33		Likelihood	484.07752
		55		R-Squared	0.761
	3	63	$\log_{10} B_1 = -3.176 + 0.011 S_D$	Adj R-Squared	0.726
		33		Pred R-Squared	0.668
		55		Adeq Precision	15.823
				BIC	-461.944
				AICc	-469.532
Backlog of 2nd Sieve Drum (B2)	1	63	$\log_{10} B_2 = -4.347 + 0.02 S_D$	Std. Dev.	4.19E-04
		33		Mean	1.15E-03
		55		C.V. %	3.64E+01
	2	63	$\log_{10} B_2 = -4.375 + 0.02 S_D$	PRESS	8.62E-06
				-2 Log	
		33		Likelihood	-515.110
		55		R-Squared	0.832
	3	63	$\log_{10} B_2 = -4.062 + 0.02 S_D$	Adj R-Squared	0.807
		33		Pred R-Squared	0.757
		55		Adeq Precision	18.837
				BIC	-492.980
				AICc	-500.570
Backlog of bucket conveyor (B3)	1	63	$\log_{10} B_3 = -2.126 + 0.051 S_M$	Std. Dev.	2.66E-03
		33		Mean	2.81E-03
		55		C.V. %	9.47E+01
	2	63	$\log_{10} B_3 = -2.363 + 0.051 S_M$	PRESS	3.39E-04
				-2 Log	
		33		Likelihood	-367.440
		55		R-Squared	0.168
	3	63	$\log_{10} B_3 = -2.323 + 0.051 S_M$	Adj R-Squared	0.045
		33		Pred R-Squared	-0.176
		55		Adeq Precision	4.364

Modeling Parameter	Grade	Variety	Modeling Equations	Model Statistic Parameters	
				BIC	-345.310
				AICc	-352.900
Backlog materials other than stones and sand (B4)	1	63	$\log_{10} B_4 = -0.006 + 0.001S_D$	Std. Dev.	0.006
		33		Mean	0.041
		55		C.V. %	14.010
	2	63	$\log_{10} B_4 = -0.02 + 0.001S_D$	PRESS	0.002
				-2 Log	
		33		Likelihood	-305.430
		55		R-Squared	0.921
	3	63	$\log_{10} B_4 = -0.025 + 0.001S_D$	Adj R-Squared	0.910
		33		Pred R-Squared	0.894
		55		Adeq Precision	27.295
				BIC	-283.300
				AICc	-290.880
System Backlog (Bs)	***1***	***63***	$\sqrt{B_S} = 0.123 + 0.002S_D + 0.005S_M$	***Std. Dev.***	***0.006***
		33		***Mean***	***9.51E-03***
		55		***C.V. %***	***58.96***
	2	***63***	$\sqrt{B_S} = 0.072 + 0.002S_D + 0.005S_M$	***PRESS***	***1.59E-03***
				-2 Log	***-***
		33		***Likelihood***	***3.10E+02***
		55		***R-Squared***	***0.525***
	3	***63***	$\sqrt{B_S} = 0.091 + 0.002S_D + 0.005S_M$	***Adj R-Squared***	***0.421***
		33		***Pred R-Squared***	***0.248***
		55		***Adeq Precision***	***8.580***
				BIC	***-280.570***
				AICc	***-289.440***

S_D = Speed of drum, S_B = Speed of Bucket Conveyor, S_M = Speed of Metering Device

Appendix D17: Optimized solutions for the system efficiencies

S/N	speed of sieve drums	speeds of bucket conveyor	speed of metering disc	Grade	Variety	E1	E2	E3	E4	E5	Es	Desirability
1	40	250.015	19.771	3	033	83.685	96.326	96.767	32.398	91.776	80.645	0.919
2	40	250.6	19.784	3	033	83.685	96.326	96.764	32.421	91.777	80.648	0.919
3	40	251.289	19.799	3	033	83.685	96.326	96.761	32.448	91.777	80.65	0.919
4	40	251.76	19.809	3	033	83.685	96.326	96.759	32.467	91.778	80.652	0.919
5	40	254.951	19.876	3	033	83.685	96.326	96.743	32.59	91.781	80.662	0.919
6	40.001	255.701	19.891	3	033	83.685	96.326	96.74	32.618	91.782	80.664	0.919
7	40	256.136	19.899	3	033	83.685	96.326	96.738	32.633	91.782	80.666	0.919
8	40.002	250.004	19.899	3	033	83.684	96.325	96.738	32.633	91.782	80.682	0.919
9	40	256.442	19.905	3	033	83.685	96.326	96.737	32.645	91.783	80.667	0.919
10	40.232	250.017	19.809	3	033	83.566	96.277	96.759	32.467	91.778	80.607	0.919
11	40.001	258.698	19.95	3	033	83.684	96.326	96.727	32.727	91.785	80.673	0.918
12	40.076	250.05	19.934	3	033	83.646	96.31	96.73	32.697	91.784	80.676	0.918
13	40	260.015	19.975	3	033	83.685	96.326	96.721	32.773	91.786	80.677	0.918
14	40	250.744	19.983	3	033	83.685	96.326	96.719	32.788	91.786	80.705	0.918
15	40	250.048	19.988	3	033	83.685	96.326	96.718	32.797	91.787	80.708	0.918
16	40	260.823	19.991	3	033	83.685	96.326	96.718	32.801	91.787	80.679	0.918
17	40	253.306	19.991	3	033	83.685	96.326	96.717	32.802	91.787	80.7	0.918
18	40	256.759	19.997	3	033	83.685	96.326	96.716	32.813	91.787	80.692	0.918
19	40.748	250.004	19.888	3	033	83.303	96.166	96.741	32.612	91.782	80.521	0.917
20	40	250.001	19.735	3	033	83.685	96.326	96.775	32.331	91.774	80.635	0.916
21	41.566	250	20	3	033	82.886	95.984	96.715	32.819	91.787	80.38	0.913
22	40	263.446	19.96	3	033	83.685	96.326	96.724	32.745	91.785	80.663	0.913
23	40.009	250.027	20	2	033	86.407	96.325	96.715	32.819	89.738	81.288	0.911
24	40	250.752	19.998	2	033	86.411	96.327	96.716	32.815	89.738	81.288	0.91
25	40	251.578	20	2	033	86.411	96.327	96.715	32.819	89.738	81.286	0.909
26	40	252.476	20	2	033	86.411	96.327	96.715	32.819	89.738	81.283	0.907
27	40.223	250.001	20	2	033	86.297	96.28	96.715	32.818	89.738	81.244	0.906
28	40.23	250.618	20	2	033	86.294	96.278	96.715	32.819	89.738	81.24	0.905
29	40	254.917	20	2	033	86.411	96.327	96.715	32.819	89.738	81.277	0.904
30	40	271.313	20	3	033	83.685	96.326	96.715	32.819	91.787	80.653	0.903
31	40.523	250	20	2	033	86.145	96.216	96.715	32.819	89.738	81.181	0.9
32	40	258.356	20	2	033	86.411	96.327	96.715	32.818	89.738	81.267	0.9
33	40	259.118	20	2	033	86.411	96.327	96.715	32.819	89.738	81.265	0.899
34	40	250.013	17.991	3	063	83.685	96.326	97.161	29.335	82.4	78.31	0.898
35	40	250.025	17.988	3	063	83.685	96.326	97.162	29.329	82.4	78.309	0.898
36	40	250.753	18.01	3	063	83.685	96.326	97.157	29.368	82.401	78.314	0.898
37	40	250.017	18.254	3	063	83.685	96.326	97.104	29.794	82.413	78.389	0.898
38	40.001	250	18.464	3	063	83.685	96.326	97.058	30.165	82.423	78.452	0.898
39	40	252.827	18.072	3	063	83.685	96.326	97.144	29.476	82.404	78.326	0.898
40	40	253.203	18.165	3	063	83.685	96.326	97.123	29.639	82.408	78.353	0.898
41	40	254.366	18.115	3	063	83.685	96.326	97.134	29.551	82.406	78.335	0.898
42	40	250.013	18.765	3	063	83.685	96.326	96.992	30.699	82.437	78.541	0.898
43	40.02	250.003	18.661	3	063	83.675	96.322	97.015	30.515	82.432	78.506	0.898
44	40	250.607	18.904	3	063	83.685	96.326	96.961	30.947	82.444	78.581	0.898
45	40	254.134	18.702	3	063	83.685	96.326	97.006	30.587	82.434	78.511	0.898
46	40	256.284	18.474	3	063	83.685	96.326	97.056	30.182	82.423	78.437	0.898
47	40	258.158	18.215	3	063	83.685	96.326	97.113	29.726	82.411	78.354	0.898
48	40	250.014	19.299	3	063	83.685	96.326	96.873	31.658	82.463	78.701	0.898
49	40	250.029	19.385	3	063	83.685	96.326	96.854	31.815	82.468	78.726	0.898
50	40	261.558	18.314	3	063	83.685	96.326	97.091	29.901	82.415	78.374	0.898
51	40	250.009	19.504	3	063	83.685	96.326	96.827	32.032	82.473	78.762	0.898
52	40.001	265.281	18.388	3	063	83.684	96.326	97.075	30.03	82.419	78.385	0.897
53	40	250	19.854	3	063	83.685	96.326	96.748	32.673	82.49	78.866	0.897

S/N	speed of sieve drums	speeds of bucket conveyor	speed of metering disc	Grade	Variety	E1	E2	E3	E4	E5	Es	Desirability
54	40.072	250.014	19.216	3	063	83.648	96.311	96.892	31.509	82.459	78.66	0.897
55	40	250.019	19.919	3	063	83.685	96.326	96.734	32.792	82.494	78.885	0.897
56	40	274.931	18.582	3	063	83.685	96.326	97.032	30.373	82.428	78.416	0.897
57	40	260.666	20	2	033	86.411	96.327	96.715	32.819	89.738	81.261	0.897
58	40	279.328	18.656	3	063	83.685	96.326	97.016	30.506	82.432	78.426	0.897
59	40	279.795	18.664	3	063	83.685	96.326	97.014	30.519	82.432	78.426	0.897
60	40	274.335	19.361	3	063	83.685	96.326	96.859	31.772	82.466	78.65	0.897
61	40	265.781	19.973	3	063	83.685	96.326	96.722	32.891	82.496	78.857	0.897
62	40	277.503	19.459	3	063	83.685	96.326	96.837	31.949	82.471	78.67	0.896
63	40.034	250	19.908	2	033	86.394	96.32	96.736	32.65	89.733	81.257	0.896
64	40	272.82	19.904	3	063	83.685	96.326	96.737	32.764	82.493	78.816	0.896
65	40	286.904	18.898	3	063	83.685	96.326	96.962	30.938	82.444	78.476	0.896
66	40	287.649	18.819	3	063	83.685	96.326	96.98	30.796	82.44	78.451	0.896
67	40	291.161	18.825	3	063	83.685	96.326	96.979	30.806	82.44	78.442	0.896
68	40.002	294.085	18.842	3	063	83.684	96.325	96.975	30.836	82.441	78.438	0.896
69	40	296.039	18.878	3	063	83.685	96.326	96.967	30.902	82.443	78.444	0.896
70	40	298.419	18.932	3	063	83.685	96.326	96.955	30.998	82.446	78.454	0.896
71	40	261.554	20	2	033	86.411	96.327	96.715	32.819	89.738	81.259	0.896
72	40	275.913	20	3	033	83.685	96.326	96.715	32.819	91.787	80.64	0.896
73	40	299.745	18.96	3	063	83.685	96.326	96.948	31.048	82.447	78.458	0.896
74	40	300.633	18.98	3	063	83.685	96.326	96.944	31.084	82.448	78.462	0.896
75	40	303.242	19.043	3	063	83.685	96.326	96.93	31.197	82.451	78.473	0.896
76	40	304.514	19.067	3	063	83.685	96.326	96.925	31.241	82.452	78.477	0.895
77	40	300.14	19.565	3	063	83.685	96.326	96.813	32.142	82.476	78.638	0.895
78	40	306.135	19.181	3	063	83.685	96.326	96.899	31.446	82.458	78.506	0.895
79	40	295.466	19.974	3	063	83.685	96.326	96.721	32.894	82.496	78.773	0.895
80	40	307.051	19.155	3	063	83.685	96.326	96.905	31.398	82.456	78.495	0.895
81	40	307.648	19.139	3	063	83.685	96.326	96.909	31.37	82.456	78.489	0.895
82	40	309.891	19.189	3	063	83.685	96.326	96.897	31.461	82.458	78.498	0.895
83	40	311.915	19.236	3	063	83.685	96.326	96.887	31.545	82.46	78.506	0.895
84	40	308.396	20	3	063	83.685	96.326	96.715	32.941	82.497	78.744	0.895
85	40	323.656	19.51	3	063	83.685	96.326	96.826	32.042	82.474	78.554	0.894
86	40	262.673	20	2	033	86.411	96.327	96.715	32.819	89.738	81.256	0.894
87	40	250	19.51	3	033	83.685	96.326	96.826	31.921	91.763	80.57	0.894
88	42.592	250.001	20	3	033	82.362	95.744	96.715	32.819	91.787	80.161	0.894
89	40	263.081	20	2	033	86.411	96.327	96.715	32.819	89.738	81.255	0.894
90	40	332.336	19.722	3	063	83.685	96.326	96.778	32.429	82.484	78.593	0.894
91	40	277.068	20	3	033	83.685	96.326	96.715	32.819	91.787	80.637	0.894
92	40	337.784	19.914	3	063	83.685	96.326	96.735	32.783	82.493	78.635	0.894
93	40.833	250	20	2	033	85.987	96.149	96.715	32.819	89.738	81.116	0.894
94	40	277.879	20	3	033	83.685	96.326	96.715	32.819	91.787	80.635	0.893
95	40	265.397	20	2	033	86.411	96.327	96.715	32.819	89.738	81.248	0.891
96	40	250	19.867	2	033	86.411	96.327	96.745	32.574	89.731	81.252	0.891
97	40	265.881	20	2	033	86.411	96.327	96.715	32.819	89.738	81.247	0.891
98	40.999	250	20	2	033	85.901	96.112	96.715	32.819	89.738	81.081	0.89
99	40	348.463	20	3	063	83.685	96.326	96.715	32.941	82.497	78.63	0.889
100	42.951	250	20	3	033	82.179	95.657	96.715	32.819	91.787	80.085	0.887

E1= Efficiency of 1st drum, E2=Efficiency of 2nd drum, E3=Efficiency of bucket conveyor, E4=Efficiency of metering device, E5= efficiency of automation unit, Es=System Efficiency

Appendix D18: Optimized solutions for the system throughputs

S/N	speed of sieve drums	speeds of bucket conveyor	speed of metering disc	Grade	Variety	T1	T2	T3	Ts	Desirability
1	40	250.015	19.771	3	033	0.44	0.234	2.699	3.74	0.919
2	40	250.6	19.784	3	033	0.439	0.233	2.702	3.743	0.919
3	40	251.289	19.799	3	033	0.439	0.233	2.705	3.746	0.919
4	40	251.76	19.809	3	033	0.438	0.233	2.707	3.748	0.919
5	40	254.951	19.876	3	033	0.434	0.232	2.723	3.759	0.919
6	40.001	255.701	19.891	3	033	0.434	0.231	2.727	3.761	0.919
7	40	256.136	19.899	3	033	0.433	0.231	2.729	3.763	0.919
8	40.002	250.004	19.899	3	033	0.44	0.234	2.771	3.838	0.919
9	40	256.442	19.905	3	033	0.433	0.231	2.731	3.763	0.919
10	40.232	250.017	19.809	3	033	0.437	0.233	2.708	3.743	0.919
11	40.001	258.698	19.95	3	033	0.43	0.23	2.744	3.77	0.918
12	40.076	250.05	19.934	3	033	0.439	0.234	2.787	3.856	0.918
13	40	260.015	19.975	3	033	0.428	0.23	2.751	3.772	0.918
14	40	250.744	19.983	3	033	0.439	0.235	2.815	3.896	0.918
15	40	250.048	19.988	3	033	0.44	0.235	2.823	3.909	0.918
16	40	260.823	19.991	3	033	0.427	0.23	2.756	3.774	0.918
17	40	253.306	19.991	3	033	0.436	0.233	2.801	3.869	0.918
18	40	256.759	19.997	3	033	0.432	0.232	2.782	3.83	0.918
19	40.748	250.004	19.888	3	033	0.431	0.231	2.727	3.748	0.917
20	40	250.001	19.735	3	033	0.44	0.233	2.68	3.714	0.916
21	41.566	250	20	3	033	0.42	0.229	2.753	3.749	0.913
22	40	263.446	19.96	3	033	0.425	0.228	2.726	3.719	0.913
23	40.009	250.027	20	2	033	0.271	0.165	2.711	3.47	0.911
24	40	250.752	19.998	2	033	0.271	0.165	2.705	3.467	0.91
25	40	251.578	20	2	033	0.27	0.165	2.701	3.467	0.909
26	40	252.476	20	2	033	0.27	0.165	2.695	3.464	0.907
27	40.223	250.001	20	2	033	0.268	0.164	2.701	3.444	0.906
28	40.23	250.618	20	2	033	0.268	0.164	2.696	3.442	0.905
29	40	254.917	20	2	033	0.269	0.165	2.679	3.457	0.904
30	40	271.313	20	3	033	0.415	0.225	2.72	3.654	0.903
31	40.523	250	20	2	033	0.265	0.162	2.687	3.409	0.9
32	40	258.356	20	2	033	0.267	0.166	2.659	3.446	0.9
33	40	259.118	20	2	033	0.267	0.166	2.655	3.444	0.899
34	40	250.013	17.991	3	063	0.625	0.604	2.25	3.752	0.898
35	40	250.025	17.988	3	063	0.625	0.604	2.249	3.751	0.898
36	40	250.753	18.01	3	063	0.625	0.599	2.25	3.755	0.898
37	40	250.017	18.254	3	063	0.626	0.622	2.307	3.873	0.898
38	40.001	250	18.464	3	063	0.626	0.64	2.358	3.98	0.898
39	40	252.827	18.072	3	063	0.624	0.587	2.252	3.765	0.898
40	40	253.203	18.165	3	063	0.624	0.59	2.27	3.803	0.898
41	40	254.366	18.115	3	063	0.623	0.578	2.253	3.771	0.898
42	40	250.013	18.765	3	063	0.626	0.669	2.439	4.151	0.898
43	40.02	250.003	18.661	3	063	0.626	0.657	2.409	4.087	0.898
44	40	250.607	18.904	3	063	0.626	0.678	2.477	4.232	0.898
45	40	254.134	18.702	3	063	0.624	0.624	2.398	4.069	0.898
46	40	256.284	18.474	3	063	0.623	0.588	2.327	3.924	0.898
47	40	258.158	18.215	3	063	0.621	0.557	2.258	3.783	0.898
48	40	250.014	19.299	3	063	0.627	0.738	2.612	4.519	0.898
49	40	250.029	19.385	3	063	0.627	0.752	2.644	4.587	0.898
50	40	261.558	18.314	3	063	0.619	0.54	2.267	3.798	0.898

S/N	speed of sieve drums	speeds of bucket conveyor	speed of metering disc	Grade	Variety	T1	T2	T3	Ts	Desirability
51	40	250.009	19.504	3	063	0.627	0.773	2.69	4.687	0.898
52	40.001	265.281	18.388	3	063	0.617	0.521	2.272	3.799	0.897
53	40	250	19.854	3	063	0.628	0.847	2.84	5.011	0.897
54	40.072	250.014	19.216	3	063	0.627	0.72	2.579	4.445	0.897
55	40	250.019	19.919	3	063	0.628	0.862	2.87	5.077	0.897
56	40	274.931	18.582	3	063	0.611	0.478	2.297	3.799	0.897
57	40	260.666	20	2	033	0.266	0.166	2.648	3.44	0.897
58	40	279.328	18.656	3	063	0.608	0.461	2.311	3.792	0.897
59	40	279.795	18.664	3	063	0.608	0.459	2.313	3.791	0.897
60	40	274.335	19.361	3	063	0.611	0.531	2.53	4.236	0.897
61	40	265.781	19.973	3	063	0.617	0.667	2.801	4.845	0.897
62	40	277.503	19.459	3	063	0.608	0.52	2.56	4.259	0.896
63	40.034	250	19.908	2	033	0.27	0.164	2.635	3.379	0.896
64	40	272.82	19.904	3	063	0.612	0.595	2.747	4.664	0.896
65	40	286.904	18.898	3	063	0.602	0.439	2.376	3.832	0.896
66	40	287.649	18.819	3	063	0.602	0.432	2.354	3.787	0.896
67	40	291.161	18.825	3	063	0.599	0.418	2.359	3.755	0.896
68	40.002	294.085	18.842	3	063	0.597	0.408	2.368	3.734	0.896
69	40	296.039	18.878	3	063	0.595	0.403	2.383	3.732	0.896
70	40	298.419	18.932	3	063	0.593	0.396	2.404	3.732	0.896
71	40	261.554	20	2	033	0.266	0.166	2.643	3.437	0.896
72	40	275.913	20	3	033	0.41	0.223	2.71	3.6	0.896
73	40	299.745	18.96	3	063	0.592	0.393	2.416	3.732	0.896
74	40	300.633	18.98	3	063	0.591	0.391	2.425	3.732	0.896
75	40	303.242	19.043	3	063	0.589	0.385	2.452	3.734	0.896
76	40	304.514	19.067	3	063	0.588	0.382	2.465	3.732	0.895
77	40	300.14	19.565	3	063	0.589	0.419	2.623	4.035	0.895
78	40	306.135	19.181	3	063	0.586	0.381	2.508	3.767	0.895
79	40	295.466	19.974	3	063	0.592	0.463	2.781	4.364	0.895
80	40	307.051	19.155	3	063	0.585	0.377	2.504	3.745	0.895
81	40	307.648	19.139	3	063	0.585	0.375	2.501	3.732	0.895
82	40	309.891	19.189	3	063	0.582	0.37	2.529	3.732	0.895
83	40	311.915	19.236	3	063	0.58	0.365	2.555	3.732	0.895
84	40	308.396	20	3	063	0.579	0.411	2.846	4.193	0.895
85	40	323.656	19.51	3	063	0.567	0.343	2.741	3.732	0.894
86	40	262.673	20	2	033	0.265	0.166	2.638	3.434	0.894
87	40	250	19.51	3	033	0.44	0.232	2.566	3.558	0.894
88	42.592	250.001	20	3	033	0.408	0.225	2.707	3.651	0.894
89	40	263.081	20	2	033	0.265	0.166	2.637	3.432	0.894
90	40	332.336	19.722	3	063	0.556	0.329	2.922	3.734	0.894
91	40	277.068	20	3	033	0.409	0.222	2.708	3.586	0.894
92	40	337.784	19.914	3	063	0.548	0.323	3.089	3.762	0.894
93	40.833	250	20	2	033	0.261	0.16	2.672	3.373	0.894
94	40	277.879	20	3	033	0.408	0.222	2.707	3.577	0.893
95	40	265.397	20	2	033	0.264	0.166	2.627	3.425	0.891
96	40	250	19.867	2	033	0.27	0.164	2.605	3.344	0.891
97	40	265.881	20	2	033	0.264	0.166	2.625	3.424	0.891
98	40.999	250	20	2	033	0.259	0.159	2.664	3.354	0.89
99	40	348.463	20	3	063	0.533	0.304	3.313	3.677	0.889
100	42.951	250	20	3	033	0.404	0.224	2.691	3.618	0.887

T1=Throughput of 1st drum, T2=Throughput of 2nd drum, T3=Throughput of sensing unit, Ts=system Throughput

Appendix D19: Optimized solutions for the system maximum capacities

S/N	Speed of Sieve Drums	Speeds of Bucket Conveyor	Speed of Metering Disc	Grade	Variety	MC1	MC2	MC3	MCs	Desirability
1	40	250.015	19.771	3	033	5.953	2.804	31.673	44.778	0.919
2	40	250.6	19.784	3	033	5.952	2.801	31.782	44.779	0.919
3	40	251.289	19.799	3	033	5.95	2.798	31.91	44.778	0.919
4	40	251.76	19.809	3	033	5.949	2.796	31.998	44.779	0.919
5	40	254.951	19.876	3	033	5.943	2.781	32.596	44.781	0.919
6	40.001	255.701	19.891	3	033	5.941	2.778	32.736	44.78	0.919
7	40	256.136	19.899	3	033	5.94	2.776	32.815	44.778	0.919
8	40.002	250.004	19.899	3	033	5.953	2.813	32.553	45.959	0.919
9	40	256.442	19.905	3	033	5.94	2.775	32.873	44.779	0.919
10	40.232	250.017	19.809	3	033	5.937	2.795	31.797	44.783	0.919
11	40.001	258.698	19.95	3	033	5.935	2.764	33.298	44.783	0.918
12	40.076	250.05	19.934	3	033	5.948	2.811	32.758	46.167	0.918
13	40	260.015	19.975	3	033	5.933	2.758	33.541	44.779	0.918
14	40	250.744	19.983	3	033	5.951	2.814	33.194	46.617	0.918
15	40	250.048	19.988	3	033	5.953	2.819	33.2	46.814	0.918
16	40	260.823	19.991	3	033	5.931	2.755	33.693	44.781	0.918
17	40	253.306	19.991	3	033	5.946	2.8	33.362	46.166	0.918
18	40	256.759	19.997	3	033	5.939	2.779	33.559	45.558	0.918
19	40.748	250.004	19.888	3	033	5.902	2.776	32.058	44.779	0.917
20	40	250.001	19.735	3	033	5.953	2.802	31.432	44.459	0.916
21	41.566	250	20	3	033	5.846	2.746	32.415	44.701	0.913
22	40	263.446	19.96	3	033	5.926	2.738	33.581	44.085	0.913
23	40.009	250.027	20	2	033	2.745	1.981	31.466	43.519	0.911
24	40	250.752	19.998	2	033	2.749	1.982	31.48	43.37	0.91
25	40	251.578	20	2	033	2.753	1.982	31.534	43.241	0.909
26	40	252.476	20	2	033	2.758	1.983	31.57	43.076	0.907
27	40.223	250.001	20	2	033	2.737	1.963	31.349	43.19	0.906
28	40.23	250.618	20	2	033	2.74	1.963	31.371	43.064	0.905
29	40	254.917	20	2	033	2.769	1.984	31.67	42.643	0.904
30	40	271.313	20	3	033	5.91	2.696	34.24	43.288	0.903
31	40.523	250	20	2	033	2.726	1.94	31.193	42.736	0.9
32	40	258.356	20	2	033	2.786	1.986	31.806	42.066	0.9
33	40	259.118	20	2	033	2.79	1.986	31.841	41.949	0.899
34	40	250.013	17.991	3	063	7.442	7.251	26.647	44.806	0.898
35	40	250.025	17.988	3	063	7.442	7.248	26.639	44.786	0.898
36	40	250.753	18.01	3	063	7.442	7.194	26.719	44.788	0.898
37	40	250.017	18.254	3	063	7.442	7.468	27.361	46.23	0.898
38	40.001	250	18.464	3	063	7.442	7.675	27.996	47.505	0.898
39	40	252.827	18.072	3	063	7.44	7.045	26.948	44.795	0.898
40	40	253.203	18.165	3	063	7.44	7.08	27.214	45.229	0.898
41	40	254.366	18.115	3	063	7.439	6.936	27.112	44.79	0.898
42	40	250.013	18.765	3	063	7.442	8.023	29.011	49.541	0.898
43	40.02	250.003	18.661	3	063	7.442	7.882	28.638	48.774	0.898
44	40	250.607	18.904	3	063	7.442	8.136	29.548	50.455	0.898
45	40	254.134	18.702	3	063	7.439	7.485	28.934	48.321	0.898
46	40	256.284	18.474	3	063	7.438	7.051	28.241	46.507	0.898
47	40	258.158	18.215	3	063	7.437	6.683	27.517	44.779	0.898
48	40	250.014	19.299	3	063	7.442	8.855	31.172	53.915	0.898
49	40	250.029	19.385	3	063	7.442	9.02	31.572	54.726	0.898
50	40	261.558	18.314	3	063	7.434	6.48	27.923	44.853	0.898

S/N	Speed of Sieve Drums	Speeds of Bucket Conveyor	Speed of Metering Disc	Grade	Variety	MC1	MC2	MC3	MCs	Desirability
51	40	250.009	19.504	3	063	7.442	9.273	32.147	55.911	0.898
52	40.001	265.281	18.388	3	063	7.431	6.251	28.275	44.779	0.897
53	40	250	19.854	3	063	7.442	10.159	34.024	59.783	0.897
54	40.072	250.014	19.216	3	063	7.441	8.642	30.767	53.014	0.897
55	40	250.019	19.919	3	063	7.442	10.35	34.406	60.569	0.897
56	40	274.931	18.582	3	063	7.425	5.739	29.258	44.778	0.897
57	40	260.666	20	2	033	2.797	1.987	31.905	41.71	0.897
58	40	279.328	18.656	3	063	7.421	5.527	29.683	44.779	0.897
59	40	279.795	18.664	3	063	7.421	5.506	29.728	44.781	0.897
60	40	274.335	19.361	3	063	7.425	6.376	32.464	49.894	0.897
61	40	265.781	19.973	3	063	7.431	8.001	35.48	57.017	0.897
62	40	277.503	19.459	3	063	7.423	6.237	33.087	50.229	0.896
63	40.034	250	19.908	2	033	2.744	1.972	30.582	42.342	0.896
64	40	272.82	19.904	3	063	7.426	7.139	35.388	54.889	0.896
65	40	286.904	18.898	3	063	7.416	5.263	30.904	45.531	0.896
66	40	287.649	18.819	3	063	7.415	5.183	30.614	45.035	0.896
67	40	291.161	18.825	3	063	7.413	5.02	30.772	44.85	0.896
68	40.002	294.085	18.842	3	063	7.41	4.897	30.954	44.786	0.896
69	40	296.039	18.878	3	063	7.409	4.831	31.182	44.897	0.896
70	40	298.419	18.932	3	063	7.407	4.758	31.503	45.091	0.896
71	40	261.554	20	2	033	2.802	1.988	31.941	41.575	0.896
72	40	275.913	20	3	033	5.9	2.67	34.451	42.714	0.896
73	40	299.745	18.96	3	063	7.406	4.717	31.676	45.195	0.896
74	40	300.633	18.98	3	063	7.406	4.69	31.798	45.274	0.896
75	40	303.242	19.043	3	063	7.404	4.617	32.183	45.542	0.896
76	40	304.514	19.067	3	063	7.403	4.579	32.347	45.647	0.895
77	40	300.14	19.565	3	063	7.406	5.024	34.677	48.966	0.895
78	40	306.135	19.181	3	063	7.402	4.569	32.949	46.26	0.895
79	40	295.466	19.974	3	063	7.409	5.561	36.97	52.548	0.895
80	40	307.051	19.155	3	063	7.401	4.523	32.862	46.089	0.895
81	40	307.648	19.139	3	063	7.4	4.494	32.813	45.989	0.895
82	40	309.891	19.189	3	063	7.399	4.436	33.152	46.246	0.895
83	40	311.915	19.236	3	063	7.397	4.385	33.47	46.499	0.895
84	40	308.396	20	3	063	7.4	4.936	37.821	51.933	0.895
85	40	323.656	19.51	3	063	7.388	4.119	35.48	48.26	0.894
86	40	262.673	20	2	033	2.807	1.989	31.988	41.41	0.894
87	40	250	19.51	3	033	5.953	2.789	30.031	42.58	0.894
88	42.592	250.001	20	3	033	5.774	2.702	31.9	43.402	0.894
89	40	263.081	20	2	033	2.809	1.989	32.005	41.351	0.894
90	40	332.336	19.722	3	063	7.382	3.951	37.209	49.962	0.894
91	40	277.068	20	3	033	5.898	2.664	34.505	42.581	0.894
92	40	337.784	19.914	3	063	7.377	3.879	38.81	51.629	0.894
93	40.833	250	20	2	033	2.715	1.917	31.033	42.278	0.894
94	40	277.879	20	3	033	5.896	2.66	34.542	42.49	0.893
95	40	265.397	20	2	033	2.82	1.99	32.101	41.026	0.891
96	40	250	19.867	2	033	2.746	1.971	30.223	41.896	0.891
97	40	265.881	20	2	033	2.823	1.99	32.121	40.96	0.891
98	40.999	250	20	2	033	2.708	1.904	30.949	42.037	0.89
99	40	348.463	20	3	063	7.369	3.643	40.05	53.174	0.889
100	42.951	250	20	3	033	5.748	2.687	31.73	42.975	0.887

MC1= Maximum Capacity of 1st drum, MC2= Maximum Capacity of 2nd drum, MC3= Maximum Capacity of sensing unit, MCs=System Maximum Capacity

Appendix D20: Optimized solutions for the system actual utilizations

S/N	Speed of Sieve Drums	Speeds of Bucket Conveyor	Speed of Metering Disc	Grade	Variety	AU1	AU2	AU3	AUs	Desirability
1	40	250.015	19.771	3	033	0.083	0.083	0.083	0.083	0.919
2	40	250.6	19.784	3	033	0.083	0.083	0.083	0.083	0.919
3	40	251.289	19.799	3	033	0.083	0.083	0.083	0.083	0.919
4	40	251.76	19.809	3	033	0.083	0.083	0.083	0.083	0.919
5	40	254.951	19.876	3	033	0.083	0.083	0.083	0.083	0.919
6	40.001	255.701	19.891	3	033	0.083	0.083	0.083	0.083	0.919
7	40	256.136	19.899	3	033	0.083	0.083	0.083	0.083	0.919
8	40.002	250.004	19.899	3	033	0.083	0.083	0.083	0.083	0.919
9	40	256.442	19.905	3	033	0.083	0.083	0.083	0.083	0.919
10	40.232	250.017	19.809	3	033	0.083	0.083	0.083	0.083	0.919
11	40.001	258.698	19.95	3	033	0.083	0.083	0.083	0.083	0.918
12	40.076	250.05	19.934	3	033	0.083	0.083	0.083	0.083	0.918
13	40	260.015	19.975	3	033	0.083	0.083	0.083	0.083	0.918
14	40	250.744	19.983	3	033	0.083	0.083	0.083	0.083	0.918
15	40	250.048	19.988	3	033	0.083	0.083	0.083	0.083	0.918
16	40	260.823	19.991	3	033	0.083	0.083	0.083	0.083	0.918
17	40	253.306	19.991	3	033	0.083	0.083	0.083	0.083	0.918
18	40	256.759	19.997	3	033	0.083	0.083	0.083	0.083	0.918
19	40.748	250.004	19.888	3	033	0.083	0.083	0.083	0.083	0.917
20	40	250.001	19.735	3	033	0.083	0.083	0.083	0.083	0.916
21	41.566	250	20	3	033	0.083	0.083	0.083	0.083	0.913
22	40	263.446	19.96	3	033	0.083	0.083	0.083	0.083	0.913
23	40.009	250.027	20	2	033	0.083	0.083	0.083	0.083	0.911
24	40	250.752	19.998	2	033	0.083	0.083	0.083	0.083	0.91
25	40	251.578	20	2	033	0.083	0.083	0.083	0.083	0.909
26	40	252.476	20	2	033	0.083	0.083	0.083	0.083	0.907
27	40.223	250.001	20	2	033	0.083	0.083	0.083	0.083	0.906
28	40.23	250.618	20	2	033	0.083	0.083	0.083	0.083	0.905
29	40	254.917	20	2	033	0.083	0.083	0.083	0.083	0.904
30	40	271.313	20	3	033	0.083	0.083	0.083	0.083	0.903
31	40.523	250	20	2	033	0.083	0.083	0.083	0.083	0.9
32	40	258.356	20	2	033	0.083	0.083	0.083	0.083	0.9
33	40	259.118	20	2	033	0.083	0.083	0.083	0.083	0.899
34	40	250.013	17.991	3	063	0.083	0.083	0.083	0.083	0.898
35	40	250.025	17.988	3	063	0.083	0.083	0.083	0.083	0.898
36	40	250.753	18.01	3	063	0.083	0.083	0.083	0.083	0.898
37	40	250.017	18.254	3	063	0.083	0.083	0.083	0.083	0.898
38	40.001	250	18.464	3	063	0.083	0.083	0.083	0.083	0.898
39	40	252.827	18.072	3	063	0.083	0.083	0.083	0.083	0.898
40	40	253.203	18.165	3	063	0.083	0.083	0.083	0.083	0.898
41	40	254.366	18.115	3	063	0.083	0.083	0.083	0.083	0.898
42	40	250.013	18.765	3	063	0.083	0.083	0.083	0.083	0.898
43	40.02	250.003	18.661	3	063	0.083	0.083	0.083	0.083	0.898
44	40	250.607	18.904	3	063	0.083	0.083	0.083	0.083	0.898
45	40	254.134	18.702	3	063	0.083	0.083	0.083	0.083	0.898
46	40	256.284	18.474	3	063	0.083	0.083	0.083	0.083	0.898
47	40	258.158	18.215	3	063	0.083	0.083	0.083	0.083	0.898
48	40	250.014	19.299	3	063	0.083	0.083	0.083	0.083	0.898
49	40	250.029	19.385	3	063	0.083	0.083	0.083	0.083	0.898
50	40	261.558	18.314	3	063	0.083	0.083	0.083	0.083	0.898

S/N	Speed of Sieve Drums	Speeds of Bucket Conveyor	Speed of Metering Disc	Grade	Variety	AU1	AU2	AU3	AUs	Desirability
51	40	250.009	19.504	3	063	0.083	0.083	0.083	0.083	0.898
52	40.001	265.281	18.388	3	063	0.083	0.083	0.083	0.083	0.897
53	40	250	19.854	3	063	0.083	0.083	0.083	0.083	0.897
54	40.072	250.014	19.216	3	063	0.083	0.083	0.083	0.083	0.897
55	40	250.019	19.919	3	063	0.083	0.083	0.083	0.083	0.897
56	40	274.931	18.582	3	063	0.083	0.083	0.083	0.083	0.897
57	40	260.666	20	2	033	0.083	0.083	0.083	0.083	0.897
58	40	279.328	18.656	3	063	0.083	0.083	0.083	0.083	0.897
59	40	279.795	18.664	3	063	0.083	0.083	0.083	0.083	0.897
60	40	274.335	19.361	3	063	0.083	0.083	0.083	0.083	0.897
61	40	265.781	19.973	3	063	0.083	0.083	0.083	0.083	0.897
62	40	277.503	19.459	3	063	0.083	0.083	0.083	0.083	0.896
63	40.034	250	19.908	2	033	0.083	0.083	0.083	0.083	0.896
64	40	272.82	19.904	3	063	0.083	0.083	0.083	0.083	0.896
65	40	286.904	18.898	3	063	0.083	0.083	0.083	0.083	0.896
66	40	287.649	18.819	3	063	0.083	0.083	0.083	0.083	0.896
67	40	291.161	18.825	3	063	0.083	0.083	0.083	0.083	0.896
68	40.002	294.085	18.842	3	063	0.083	0.083	0.083	0.083	0.896
69	40	296.039	18.878	3	063	0.083	0.083	0.083	0.083	0.896
70	40	298.419	18.932	3	063	0.083	0.083	0.083	0.083	0.896
71	40	261.554	20	2	033	0.083	0.083	0.083	0.083	0.896
72	40	275.913	20	3	033	0.083	0.083	0.083	0.083	0.896
73	40	299.745	18.96	3	063	0.083	0.083	0.083	0.083	0.896
74	40	300.633	18.98	3	063	0.083	0.083	0.083	0.083	0.896
75	40	303.242	19.043	3	063	0.083	0.083	0.083	0.083	0.896
76	40	304.514	19.067	3	063	0.083	0.083	0.083	0.083	0.895
77	40	300.14	19.565	3	063	0.083	0.083	0.083	0.083	0.895
78	40	306.135	19.181	3	063	0.083	0.083	0.083	0.083	0.895
79	40	295.466	19.974	3	063	0.083	0.083	0.083	0.083	0.895
80	40	307.051	19.155	3	063	0.083	0.083	0.083	0.083	0.895
81	40	307.648	19.139	3	063	0.083	0.083	0.083	0.083	0.895
82	40	309.891	19.189	3	063	0.083	0.083	0.083	0.083	0.895
83	40	311.915	19.236	3	063	0.083	0.083	0.083	0.083	0.895
84	40	308.396	20	3	063	0.083	0.083	0.083	0.083	0.895
85	40	323.656	19.51	3	063	0.083	0.083	0.083	0.083	0.894
86	40	262.673	20	2	033	0.083	0.083	0.083	0.083	0.894
87	40	250	19.51	3	033	0.083	0.083	0.083	0.083	0.894
88	42.592	250.001	20	3	033	0.083	0.083	0.083	0.083	0.894
89	40	263.081	20	2	033	0.083	0.083	0.083	0.083	0.894
90	40	332.336	19.722	3	063	0.083	0.083	0.083	0.083	0.894
91	40	277.068	20	3	033	0.083	0.083	0.083	0.083	0.894
92	40	337.784	19.914	3	063	0.083	0.083	0.083	0.083	0.894
93	40.833	250	20	2	033	0.083	0.083	0.083	0.083	0.894
94	40	277.879	20	3	033	0.083	0.083	0.083	0.083	0.893
95	40	265.397	20	2	033	0.083	0.083	0.083	0.083	0.891
96	40	250	19.867	2	033	0.083	0.083	0.083	0.083	0.891
97	40	265.881	20	2	033	0.083	0.083	0.083	0.083	0.891
98	40.999	250	20	2	033	0.083	0.083	0.083	0.083	0.89
99	40	348.463	20	3	063	0.083	0.083	0.083	0.083	0.889
100	42.951	250	20	3	033	0.083	0.083	0.083	0.083	0.887

AU1= Actual Utilization of 1st drum, AU2= Actual Utilization of 2nd drum, AU3= Actual Utilization of sensing Unit, AUs= System Actual Utilization

Appendix D21: Optimized solutions for the system backlogs

S/N	Speed of Sieve Drums	Speeds of Bucket Conveyor	Speed of Metering Disc	Grade	Variety	B1	B2	B3	B4	Bs	Desirability
1	40	250.015	19.771	3	033	0.002	0.001	0.066	0.014	0.074	0.919
2	40	250.6	19.784	3	033	0.002	0.001	0.066	0.014	0.074	0.919
3	40	251.289	19.799	3	033	0.002	0.001	0.066	0.014	0.074	0.919
4	40	251.76	19.809	3	033	0.002	0.001	0.066	0.014	0.074	0.919
5	40	254.951	19.876	3	033	0.002	0.001	0.067	0.014	0.074	0.919
6	40.001	255.701	19.891	3	033	0.002	0.001	0.067	0.014	0.074	0.919
7	40	256.136	19.899	3	033	0.002	0.001	0.067	0.014	0.074	0.919
8	40.002	250.004	19.899	3	033	0.002	0.001	0.067	0.014	0.074	0.919
9	40	256.442	19.905	3	033	0.002	0.001	0.067	0.014	0.074	0.919
10	40.232	250.017	19.809	3	033	0.002	0.001	0.066	0.014	0.074	0.919
11	40.001	258.698	19.95	3	033	0.002	0.001	0.067	0.014	0.074	0.918
12	40.076	250.05	19.934	3	033	0.002	0.001	0.067	0.014	0.074	0.918
13	40	260.015	19.975	3	033	0.002	0.001	0.067	0.014	0.074	0.918
14	40	250.744	19.983	3	033	0.002	0.001	0.067	0.014	0.074	0.918
15	40	250.048	19.988	3	033	0.002	0.001	0.067	0.014	0.074	0.918
16	40	260.823	19.991	3	033	0.002	0.001	0.067	0.014	0.074	0.918
17	40	253.306	19.991	3	033	0.002	0.001	0.067	0.014	0.074	0.918
18	40	256.759	19.997	3	033	0.002	0.001	0.067	0.014	0.074	0.918
19	40.748	250.004	19.888	3	033	0.002	0.001	0.067	0.015	0.075	0.917
20	40	250.001	19.735	3	033	0.002	0.001	0.065	0.014	0.073	0.916
21	41.566	250	20	3	033	0.002	0.001	0.068	0.016	0.076	0.913
22	40	263.446	19.96	3	033	0.002	0.001	0.067	0.014	0.074	0.913
23	40.009	250.027	20	2	033	0.001	0	0.061	0.019	0.064	0.911
24	40	250.752	19.998	2	033	0.001	0	0.061	0.019	0.064	0.91
25	40	251.578	20	2	033	0.001	0	0.061	0.019	0.064	0.909
26	40	252.476	20	2	033	0.001	0	0.061	0.019	0.064	0.907
27	40.223	250.001	20	2	033	0.001	0	0.061	0.019	0.065	0.906
28	40.23	250.618	20	2	033	0.001	0	0.061	0.019	0.065	0.905
29	40	254.917	20	2	033	0.001	0	0.061	0.019	0.064	0.904
30	40	271.313	20	3	033	0.002	0.001	0.068	0.014	0.074	0.903
31	40.523	250	20	2	033	0.001	0	0.061	0.019	0.065	0.9
32	40	258.356	20	2	033	0.001	0	0.061	0.019	0.064	0.9
33	40	259.118	20	2	033	0.001	0	0.061	0.019	0.064	0.899
34	40	250.013	17.991	3	063	0.002	0.001	0.053	0.014	0.069	0.898
35	40	250.025	17.988	3	063	0.002	0.001	0.053	0.014	0.069	0.898
36	40	250.753	18.01	3	063	0.002	0.001	0.054	0.014	0.069	0.898
37	40	250.017	18.254	3	063	0.002	0.001	0.055	0.014	0.07	0.898
38	40.001	250	18.464	3	063	0.002	0.001	0.056	0.014	0.07	0.898
39	40	252.827	18.072	3	063	0.002	0.001	0.054	0.014	0.07	0.898
40	40	253.203	18.165	3	063	0.002	0.001	0.054	0.014	0.07	0.898
41	40	254.366	18.115	3	063	0.002	0.001	0.054	0.014	0.07	0.898
42	40	250.013	18.765	3	063	0.002	0.001	0.058	0.014	0.071	0.898
43	40.02	250.003	18.661	3	063	0.002	0.001	0.058	0.014	0.071	0.898
44	40	250.607	18.904	3	063	0.002	0.001	0.059	0.014	0.072	0.898
45	40	254.134	18.702	3	063	0.002	0.001	0.058	0.014	0.071	0.898
46	40	256.284	18.474	3	063	0.002	0.001	0.056	0.014	0.07	0.898
47	40	258.158	18.215	3	063	0.002	0.001	0.055	0.014	0.07	0.898
48	40	250.014	19.299	3	063	0.002	0.001	0.062	0.014	0.072	0.898
49	40	250.029	19.385	3	063	0.002	0.001	0.063	0.014	0.073	0.898
50	40	261.558	18.314	3	063	0.002	0.001	0.055	0.014	0.07	0.898

S/N	Speed of Sieve Drums	Speeds of Bucket Conveyor	Speed of Metering Disc	Grade	Variety	B1	B2	B3	B4	Bs	Desirability
51	40	250.009	19.504	3	063	0.002	0.001	0.064	0.014	0.073	0.898
52	40.001	265.281	18.388	3	063	0.002	0.001	0.056	0.014	0.07	0.897
53	40	250	19.854	3	063	0.002	0.001	0.066	0.014	0.074	0.897
54	40.072	250.014	19.216	3	063	0.002	0.001	0.062	0.014	0.072	0.897
55	40	250.019	19.919	3	063	0.002	0.001	0.067	0.014	0.074	0.897
56	40	274.931	18.582	3	063	0.002	0.001	0.057	0.014	0.071	0.897
57	40	260.666	20	2	033	0.001	0	0.061	0.019	0.064	0.897
58	40	279.328	18.656	3	063	0.002	0.001	0.058	0.014	0.071	0.897
59	40	279.795	18.664	3	063	0.002	0.001	0.058	0.014	0.071	0.897
60	40	274.335	19.361	3	063	0.002	0.001	0.063	0.014	0.073	0.897
61	40	265.781	19.973	3	063	0.002	0.001	0.067	0.014	0.074	0.897
62	40	277.503	19.459	3	063	0.002	0.001	0.063	0.014	0.073	0.896
63	40.034	250	19.908	2	033	0.001	0	0.061	0.019	0.064	0.896
64	40	272.82	19.904	3	063	0.002	0.001	0.067	0.014	0.074	0.896
65	40	286.904	18.898	3	063	0.002	0.001	0.059	0.014	0.071	0.896
66	40	287.649	18.819	3	063	0.002	0.001	0.059	0.014	0.071	0.896
67	40	291.161	18.825	3	063	0.002	0.001	0.059	0.014	0.071	0.896
68	40.002	294.085	18.842	3	063	0.002	0.001	0.059	0.014	0.071	0.896
69	40	296.039	18.878	3	063	0.002	0.001	0.059	0.014	0.071	0.896
70	40	298.419	18.932	3	063	0.002	0.001	0.06	0.014	0.072	0.896
71	40	261.554	20	2	033	0.001	0	0.061	0.019	0.064	0.896
72	40	275.913	20	3	033	0.002	0.001	0.068	0.014	0.074	0.896
73	40	299.745	18.96	3	063	0.002	0.001	0.06	0.014	0.072	0.896
74	40	300.633	18.98	3	063	0.002	0.001	0.06	0.014	0.072	0.896
75	40	303.242	19.043	3	063	0.002	0.001	0.06	0.014	0.072	0.896
76	40	304.514	19.067	3	063	0.002	0.001	0.061	0.014	0.072	0.895
77	40	300.14	19.565	3	063	0.002	0.001	0.064	0.014	0.073	0.895
78	40	306.135	19.181	3	063	0.002	0.001	0.061	0.014	0.072	0.895
79	40	295.466	19.974	3	063	0.002	0.001	0.067	0.014	0.074	0.895
80	40	307.051	19.155	3	063	0.002	0.001	0.061	0.014	0.072	0.895
81	40	307.648	19.139	3	063	0.002	0.001	0.061	0.014	0.072	0.895
82	40	309.891	19.189	3	063	0.002	0.001	0.061	0.014	0.072	0.895
83	40	311.915	19.236	3	063	0.002	0.001	0.062	0.014	0.072	0.895
84	40	308.396	20	3	063	0.002	0.001	0.067	0.014	0.074	0.895
85	40	323.656	19.51	3	063	0.002	0.001	0.064	0.014	0.073	0.894
86	40	262.673	20	2	033	0.001	0	0.061	0.019	0.064	0.894
87	40	250	19.51	3	033	0.002	0.001	0.064	0.014	0.073	0.894
88	42.592	250.001	20	3	033	0.002	0.001	0.068	0.017	0.077	0.894
89	40	263.081	20	2	033	0.001	0	0.061	0.019	0.064	0.894
90	40	332.336	19.722	3	063	0.002	0.001	0.065	0.014	0.073	0.894
91	40	277.068	20	3	033	0.002	0.001	0.068	0.014	0.074	0.894
92	40	337.784	19.914	3	063	0.002	0.001	0.067	0.014	0.074	0.894
93	40.833	250	20	2	033	0.001	0	0.061	0.02	0.065	0.894
94	40	277.879	20	3	033	0.002	0.001	0.068	0.014	0.074	0.893
95	40	265.397	20	2	033	0.001	0	0.061	0.019	0.064	0.891
96	40	250	19.867	2	033	0.001	0	0.061	0.019	0.064	0.891
97	40	265.881	20	2	033	0.001	0	0.061	0.019	0.064	0.891
98	40.999	250	20	2	033	0.001	0	0.061	0.02	0.065	0.89
99	40	348.463	20	3	063	0.002	0.001	0.068	0.014	0.074	0.889
100	42.951	250	20	3	033	0.002	0.001	0.068	0.017	0.078	0.887

B1= Backlog of 1st drum, B2= Backlog of 2nd drum, B3= Backlog of bucket conveyor, B4= Backlog materials other than stones and sand, Bs= System Backlog

Appendix D22: Confirmation (Validation) Experimental Result

Validation parameter	Replication 1	Replication 2	Replication 3	Mean
E1 (%)	90.296	91.194	90.197	90.5623
E2 (%)	96.341	97.35	96.24	96.6437
E3 (%)	96.542	97.382	96.242	96.722
E4 (%)	32.059	32.037	32.049	32.0483
E5 (%)	90.641	91.251	91.816	91.236
Es (%)	81.325	81.908	80.969	81.4007
T1 (kg/hr)	0.37	0.35	0.36	0.36
T2 (kg/hr)	0.2	0.199	0.197	0.19867
T3 (kg/hr)	2.976	2.975	3.03	2.99367
Ts (kg/hr)	3.711	3.232	3.71	3.551
MC1 (kg/12hrs)	3.424	3.147	3.229	3.26667
MC2 (kg/12hrs)	2.011	1.874	1.972	1.95233
MC3 (kg/12hrs)	40.181	41.393	40.98	40.8513
MCs (kg/12hrs)	45.101	47.112	46.001	46.0713
AU1	0.083	0.083	0.083	0.083
AU2	0.083	0.083	0.083	0.083
AU3	0.083	0.083	0.083	0.083
AUs	0.083	0.083	0.083	0.083
B1 (kg)	0.00088	0.00073	0.00081	0.00081
B2 (kg)	0.0002	0.00015	0.00017	0.00017
B3 (kg)	0.0611	0.06121	0.0554	0.05924
B4 (kg)	0.00798	0.00855	0.00878	0.00844
Bs (kg)	0.06399	0.07151	0.06999	0.0685

E1= Efficiency of 1st drum, E2 = Efficiency of 2nd drum, E3 = Efficiency of bucket conveyor, E4 = Efficiency of metering device, E5 = efficiency of automation unit, Es = System Efficiency, T1 = Throughput of 1st drum, T2 = Throughput of 2nd drum, T3 = Throughput of sensing unit, Ts = system Throughput, MC1 = Maximum Capacity of 1st drum, MC2 = Maximum Capacity of 2nd drum, MC3 = Maximum Capacity of sensing unit, MCs = System Maximum Capacity, AU1= Actual Utilization of 1st drum, AU2= Actual Utilization of