International Journal of Future Engineering Innovations

Development, Testing, and Extraction Process Optimization of a Motorized Juice Extractor

Pius Aigbomeikhe Bawa [1], **Philip T Aondona** [2], **Emmanuel U Odeh** [3], **Joshua Nelson Antia** [4], **Ihom AP** [5*]
[1, 3-5] Department of Mechanical and Aerospace Engineering, University of Uyo, PMB 1017, Uyo, Nigeria
[2] Department of Industrial Engineering, Durban University of Technology (DUT), Durban, South Africa

* Corresponding Author: **Ihom AP**

Article Info

ISSN (online): 3049-1215
Impact Factor (RSIF): 8.25
Volume: 03
Issue: 02
March-April 2026
Received: 13-01-2026
Accepted: 11-02-2026
Published: 09-03-2026
Page No: 51-75

Abstract

The Development, Testing, and Extraction Process Optimization of a Motorized Juice Extractor, has been carried out. In this work a motorized juice extractor was designed using design software, design manuals and textbooks for design calculations and materials selection. The detailed component design was carried out, and this was followed by detail-components production and assembly process. This was facilitated by bolting, welding and the use of fixtures for holding during the assembly process. The fully assembled motorized juice extraction machine was then subjected to performance test and the result showed that, the developed fruit juice extraction machine was satisfactory as evident from the juice extraction efficiency and extraction capacity. The quadratic models were chosen to predict the EE and EC. It was ascertained that extraction processing parameters influence the EE and EC. For the range of variables considered in the performance analysis of the machine, maximum EE of 83.66% was obtained at the machine operating speed of 400 rpm, feed rate of 1.5 kg/min, blanching temperature of 80ºC and blanching time of 6 min, while the maximum EC of 3.89 L/min was obtained at the machine operating speed of 500 rpm, feed rate of 1.0 kg/min, blanching temperature of 60ºC and blanching time of 9 min. Predicted optimum EE and EC of 81.32% and 3.89 L/min respectively at operating speed of 525.23 rpm, feed rate of 2.13 kg/min, blanching temperature of 54.20ºC and blanching time of 8.73 min was obtained with a desirability of 0.977. Under these optimal juice extraction process conditions, the experimental values of 81.56% and 3.57 L/min were obtained for EE and EC respectively. The deviations between experimental and predicted values were low and statistically insignificant. The coefficient of determination (R^2) of 0.77 and 0.76 for EE and EC respectively, show that there is an excellent correlation between the juice extraction parameters (independent variables). Consequently, in view of the range of variables investigated, the chosen models have the adequacy to predict the extraction efficiency and extraction capacity for fruit juice using the developed machine. In conclusion the developed fruit juice extraction machine serves as a viable option for the small scale fruit juice processors.

DOI: https://doi.org/10.54660/IJFEI.2026.3.2.51-75

Keywords: Development, Testing, Optimization, Juice Extractor, RSM, ANOVA

1. Introduction

Enhanced productivity in the agro-economy of a nation will greatly depend on their high level of mechanization. However, mechanization has been difficult in Nigeria because of the high cost of imported machines and equipment and lack of indigenously designed, developed and built technologically advanced agricultural machines (Ekerete, 2000) [16]. Mechanized juice extractor can save time during processing, improve efficiency, increase capacity, and reduce spoilage and waste faced by small scale farmers. Bhatia (1989) [11] listed the important steps in fruit juice processing process to include selection, extraction, de-aeration, filtration, preservation and packaging. To achieve this, researchers have developed mechanized machines for extracting juice from fruits (Olowonibi and Ozumba, 1999; Bites, Morris and Grand, 2001; Ishiwu and Oluka, 2005; Badmus and Adeyemi, 2006) [10, 14, 20, 30]. Majority of the juice extractors are for medium and large-scale fruit juice extraction.

Traditional or manual juice extractors have been developed for home use due to their limited output (Eyeowa *et al.*, 2017) [19]. The rapid growth in population of Nigeria with the discovery of the nutritional (Kintinga and Kader, 1995) and medicinal (Ashurt, 1991) [6] importance of fruits in the human body has led to a high demand for fruits and allied products, and this made it necessary to evolve a means of preserving as well as satisfying the need of domestic and industrial users of fruits. Thus, the conventional or manual methods used for juice extraction cannot be employed for small or medium scale production to meet local commercial needs.

The effectiveness and efficiency of juice extraction process is a function of yield of juice extracted and the time taken in the extraction process. This will depend on factors such as viscosity of juice to be removed, resistance of the formation of solid phase of pulp, porosity of pulp and pressure or force applied. These factors are influenced by the physical characteristics of the pulp to be extracted and are subject to change in the course of extraction (Simmonds, 2000) [34]. In most local communities in the world, especially in the under-developed world, juice extraction from fruit has been found to be very unique. This involves crushing and pulping with mortar and pestle or blender and then sieving through muslin cloth or plastic sieve (Adewumi and Ukwenya, 2012) [4]. The problems with this processing method is concerned with high energy sapping, time consuming, low quantity of juice and are unhygienic. For these reasons, different types of juice extractors have been studied by researchers, depending on the kind of fruit or vegetable to be extracted (Kitinga and Kader, 1996) [24]. Some of these extractors are manually operated (Oguntuyi, 2013; Aremu and Ogunlade, 2016; Abulude *et al.*, 2007) [5, 25, 1] while others are motorized (Olaniyan, 2010; Olabisi and Adelegan, 2015) [27, 29].

Adejuyigbe and Bolaji (2005) [3], Bolaji *et al.*, (2008) [15], and Adejuyigbe and Bolaji (2012) [2] reported that one way to achieve improved agricultural mechanization in Nigeria is to encourage indigenous design, development and fabrication of majority of the required machines and equipment, this is to ensure their compatibility and sustainability for the farm produce as well as the incorporation of farmers technical and financial consideration.

The present study is aimed at designing and producing a motorized orange juice extractor for optimum performance using locally available raw materials that will be affordable for use by both home users and small scale juice processing plants in Nigeria at a preferred cost compared to that of an imported extractor of similar capacity. The study as well improved the machine efficiency of the produced motorized orange juice extractor. Therefore, this work presents the design, construction and performance evaluation of a locally fabricated motorized orange juice extractor both for home users, small and medium scale orange juice producers in Nigeria.

2. Materials and Method

2.1. Materials

2.1.1. Material Selection for Construction

The knowledge of materials and their properties is very important before design and consequently construction must take place. The machine members and/or elements was selected based on the physical and mechanical properties and are presented in Table 2.1.

- Physical properties: This includes properties such as density, co-efficient of linear expansion, thermal conductivity, melting point etc.
- Mechanical properties: This includes properties such as strength, stiffness, elasticity, ductility, shear stress, toughness, yield strength etc.

Table 1: Machine parts and material selection

S/N	Machine Parts	Recommended Material	Reasons
1	Pulley	Mild steel	• Cheap • Easily Machined
2	Bolts and nuts	Mild steel	• Can withstand bending and shear forces
3	Shaft	Stainless Steel	• Does not discolour food • High strength and rigidity • Resistance to pitting • Easily machined
4	Flight/auger	Stainless Steel	• Corrosion resistance • Does not discolour food • High Strength
5	Cylindrical main housing	Stainless Steel	• Does not discolour • Non-toxic metal • Good Corrosion • Resistance to pitting
6	Juice collector	Plastic Bowl	• Does not discolour food • Good Corrosion resistance
7	Perforated screen (filter)	Stainless Steel	• does not discolour food • good corrosion resistance • resistance to pitting
8	Machine base	Mild steel	• rigidity • high load bearing capacity
9	Hopper	Stainless steel sheet	
10	Pillow bearing		
11	Cast iron pulley		
12	V-belt		

2.2. Design Concept

The motorized fruit juice extraction machine is a robust design aiming at achieving optimal operating and extraction operation. The extraction chamber and juice outlet was designed and constructed with stainless steel to ensure the quality and safety of juice. The extraction chamber was also designed to accommodate the required quantity of fruit. The screw conveyor was designed to ensure maximum conveyance, abrasion, and maceration of the fruit mesocarp for smooth processing.

2.3. Design Consideration

The engineering properties of the fruits to be processed that are relevant to the design, development and performance evaluation were considered.

2.3.1. Design Factors Consideration

The following design factors considerations were employed in the design of the machine:

1. Strength, rigidity and simplicity of materials of construction.
2. The extraction pressure must be high enough to ensure acceptable level of extraction.
3. The transmission belt should be properly aligned such that it permits easy rotation of the shaft auger during extraction.
4. The power shaft should be rigid enough to withstand combined bending and tension stresses to which it will be subjected to while transmitting power under various operating and loading conditions.
5. Required force to expel out the juice.
6. Portability of the machine.
7. Easy inspection, serviceability, and maintenance of the machine.
8. Durability of the machine.
9. Functionality
10. Corrosion factor
11. Aesthetics

2.3.2. Economic Factors and Safety Considerations

Construction materials were selected based on economic factors and safety consideration. These factors are:

1. Availability and the cost of construction and materials
2. Durability and strength of materials
3. Manufacturing /fabrication methods that will be employed in construction.
4. Efficiency of extraction and minimizing juice contamination.
5. Corrosion resistant properties.

2.4. Method of Designing Machine Parts

The motorized juice extractor was designed, fabricated and assembled in the Mechanical Engineering Workshop, University of Uyo. The machine is so constructed that it will remain steady on the ground while in operation. The methods employed in the design and production of the major component parts of the machine include the methods of material selection, design of the respective component parts, as well as the selection of manufacturing processes. Also parts procured from the open market are specified. The following constructional operations were carried out on the components before the machine was finally assembled. These are: marking out, drilling of components, bending and folding of metal sheet, welding of components, machining – pulley and shaft, filling and smoothening, painting and assembly.

2.4.1. Machine Hopper

The hopper was constructed using stainless steel sheet of 8-gauge with 1.5 mm thickness. The inclination of the hopper was designed based on the angle of repose of fruits. This was determined by placing sample of oranges on an adjustable. The adjustable was inclined. This was done using 10 oranges and their corresponding coefficient of friction was analyzed. The results are shown in (Bawa, 2025) [13]. The cross-section of the feed hopper is composed of rectangular and trapezoidal shape in order to accommodate enough fruits and gradually introduce portions of the fruits by gravity into the chopping and extracting compartments. With the application of appropriate equations, the total surface area of cross-section of the hopper and capacity of the hopper were determined. The detailed calculations showing equations and calculation algorithms are presented in (Bawa, 2025) [13]. Fig 2.1 shows a depiction of the surface and cross-sectional areas of the feed hopper.

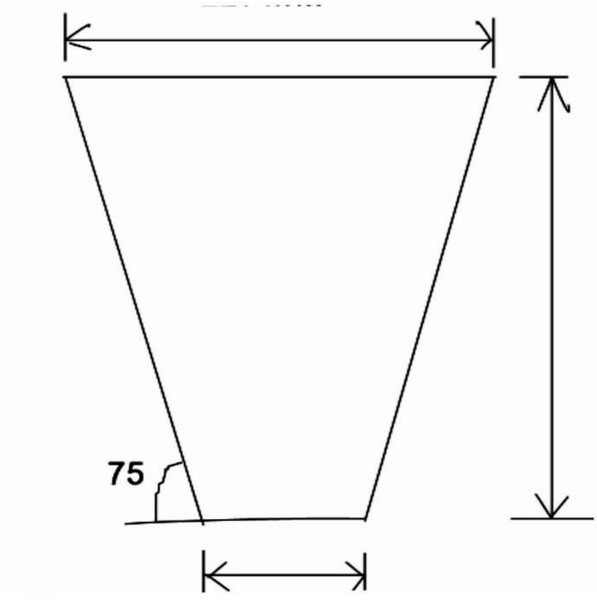


Fig1: Schematic diagram of surface and cross-sectional areas of the feed hopper

2.4.2. Shredder

The shredder attached to the feed hopper was constructed by attaching a-2 mm thick rectangular cut-away stainless steel blade as shown in Fig 2.2.

A 90.0 mm (4 inch) diameter stainless steel hollow pipe of 5.49 mm thickness was marked at regular intervals along its length. Twelve blades of 120 g each was attached to the cylindrical drum in seven row (Fig 3.2). The detailed design calculations are shown in (Bawa, 2025) [13].

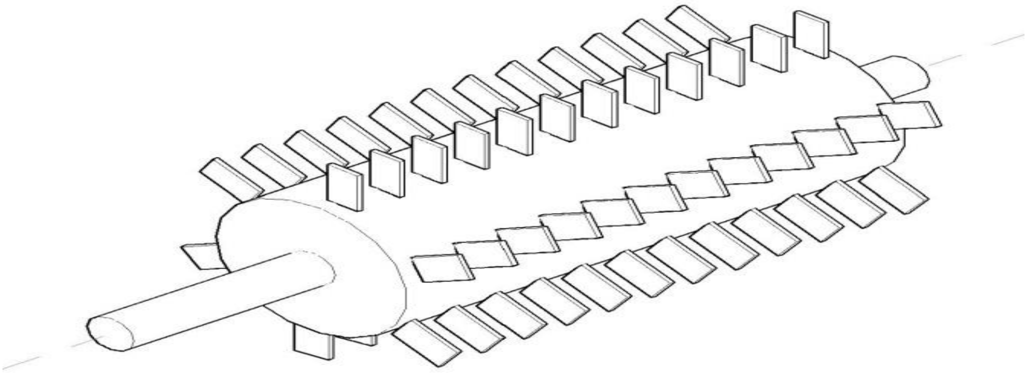


Fig 2: Schematic diagram of the shredder

2.4.3. Extraction Chamber

The juice extraction chamber (Fig 3.3) of the machine comprises the cylindrical barrel which houses a screw conveyor, and the pulley with bearing. The extraction chamber is made of 1.5mm thick stainless plate. The upper chamber will withstand pressure from the shaft and presser while the lower chamber (perforated sheet) will not; it will only act as the juice sieve. The lower chamber is situated below the upper chamber and it is almost exactly of the same size with the upper chamber except that it is perforated to allow passage of the extracted juice.

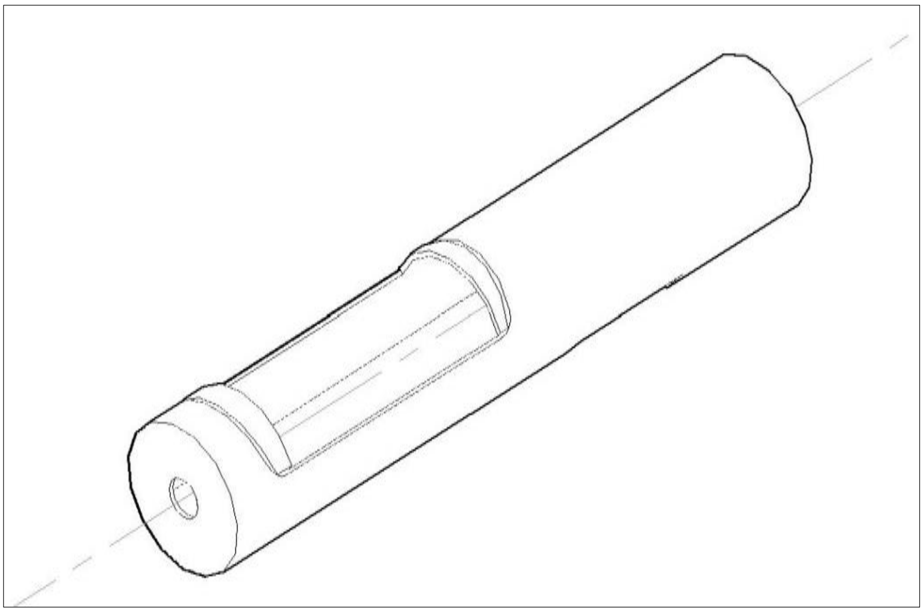


Fig 3: Juice Extraction Barrel

The accompanying detailed calculations of mass of juice extracted per batch, volume of the Orange required, volume of the juice extractor, volume of the extraction unit and volume of the shaft in the extraction chamber are shown in (Bawa, 2025) [13].

2.4.4. Screw Conveyor

The screw shaft is the squeezing and conveying component of the machine. The screw conveyor and housing provide the shear and compressive forces needed to crush the fruit and squeeze out the juice. As the screw conveyor rotates within the conveyor housing the screw collects the sliced fruit from the base of the hopper and moves them through the extraction chamber toward the collection point. During this movement, the sliced fruit is crushed and juice is squeezed out due to the gradual reduction of gap between the conveyor housing and screw conveyor.

2.4.5. Power Required to Drive the Juice Extractor

The machine was designed to be driven by an electric motor through the belt and pulley power transmission system. The electric motor was sized using the required power and speed range capacities. The power unit consist of a-2 hp variable geared electric motor which powers the machine via a belt and pulleys and gear box arrangement. The motor is mounted on a seating located at the base of the tool frame. The gear box is powered by a shaft on which a pulley of 60 mm diameter is mounted and driven by a belt which receives power from a pulley mounted on the motor shaft.

2.4.6. The Pulley

Fig 2.6 show the pulley and belt arrangement of the extraction machine for motor-machine and machine-shredder drive transmissions. The pulley is a two-way V-grooved type. The pulley is made of cast iron of diameter 60 mm and thickness of 40mm.The readymade type was obtained for this construction.

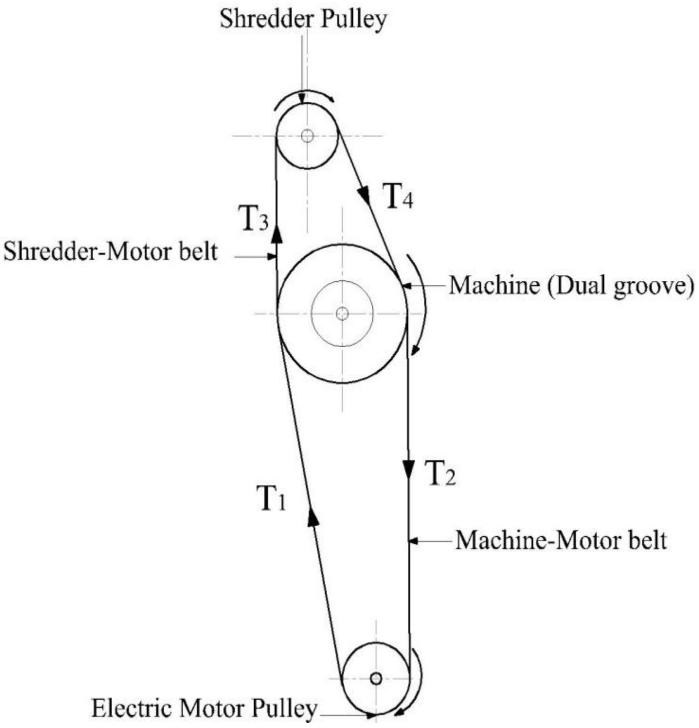


Fig 4: Pulley and belt drive system

2.4.7. V-Belt Drive

Based on the power required to drive the machine, and according to Indian standards (IS: 2494-1974), belt type A was selected for the drive (Table 2.2).

Table 2: Dimensions of standard V-belts

Types of belt	Power range in *kW*	Minimum pitch diameter of pulley (D) mm	Top width (b) *mm*	Thickness (t) *mm*	Weight per meter Length (*N*)
A	0.7-3.7	75	13	8	1.06
B	2-15	125	17	11	1.89
C	7.5-75	200	22	14	3.43
D	20-150	355	32	19	5.96
E	30-350	500	38	23	---

Source: Khurmi and Gupta (2008) [23]

V-belt drive systems (Fig 2.5), also called friction drives (because power is transmitted as a result of the belt's adherence to the pulley) are an economical option for industrial, automotive, commercial, agricultural, and home appliance applications. V-belt drives are also easy to install, require no lubrication, and dampen shock load.

Fig 5: V-belt drive system

The detailed calculations showing equations and calculation algorithms for V-belt consideration are presented in (Bawa, 2025) [13].

2.4.8. Shredder Shaft

The shredder shaft was designed on the basis that it would be subjected to combined twisting and bending moments. Fig 2.6 show loads, forces and reactions on shredder shaft. The machine element that exerts forces on shredder shaft is the belt, pulley (driven pulley) and the drum (cylinder and blade). The shaft with forces acting on it is represented schematically as shown in Fig 2.7. The shredder shaft was designed on the basis of strength, rigidity and stiffness. When designing the shaft, it was considered that it would be subjected to twisting and bending moments.

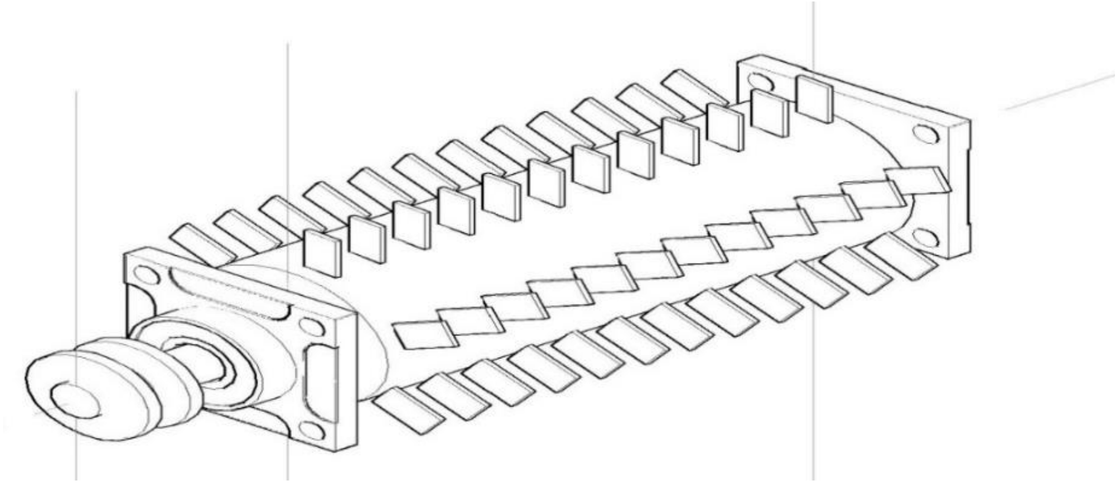
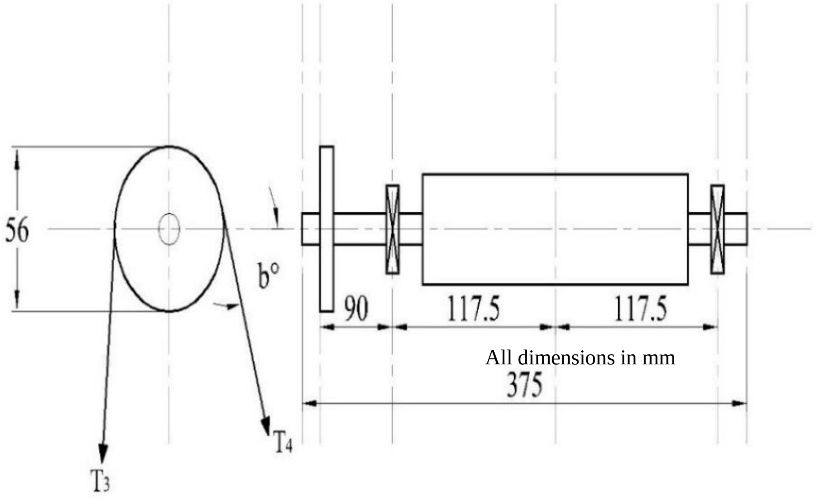


Fig 6: Shredder shaft carrying the cylinder and blades with a single groove pulley and two bearings (A and B)



All dimensions in mm

Fig 7: Space diagram of shredder shaft

The detailed calculations showing equations and calculation algorithms for the design of shredder shaft for the fabricated motorized juice extractor are presented in (Bawa, 2025) [13].

2.4.9. Machine Shaft

The drive shaft was designed on the basis that it would be subjected to combined twisting and bending moments. Fig 2.8 show loads, forces and reactions on drive shaft. The machine element that exerts forces on the drive shaft is the cone, the worms, the belt and pulley (driven pulley). The shaft with forces acting on it is represented schematically as shown in Figs 2.9 and 2.10. The detailed design calculations are shown in (Bawa, 2025) [13].

Forces acting on the drive shaft (Vertical and Horizontal)

The forces acting on the drive shaft are loads due to:

a. Weight of the shredded fruit (distributed force)
b. Weight of worms (also considered a distributed force)
c. Weight of cone and locknut (also considered a distributed force)
d. Weight of pulley (concentrated force)
e. Reactions at the bearings

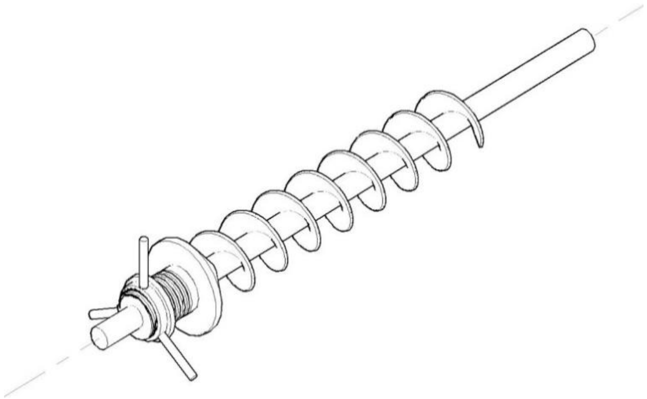


Fig 8: Extractor main shaft carrying the locknut, cone and worms with a dual groove pulley and two bearings

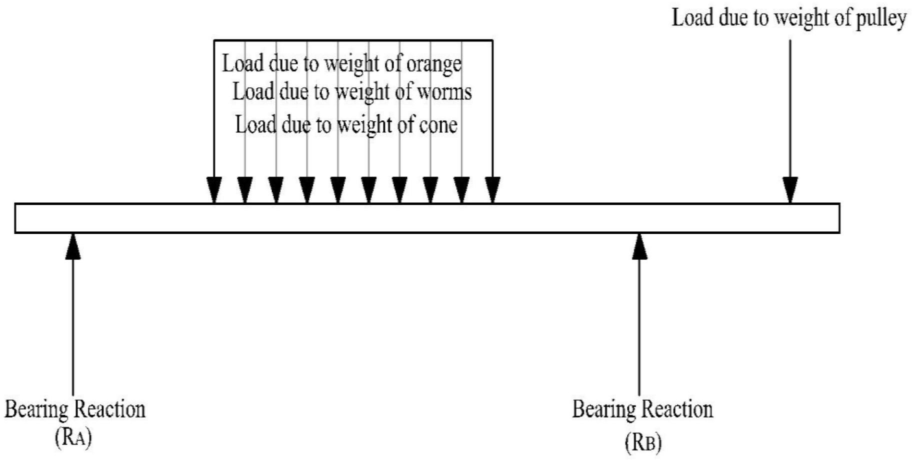
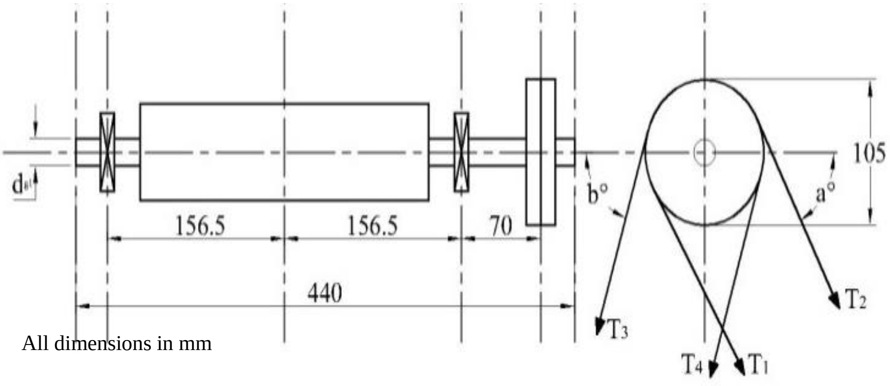


Fig 9: Forces acting on the shaft with bearing reaction



All dimensions in mm

Fig 10: Space diagram of machine shaft

2.4.10. Shredder Shaft and Main Shaft Bearings

Due to high centrifugal force in the machine shaft, the radial and thrust or axial loads on shredder shaft is supported by two (2) deep groove ball bearings. Deep groove ball bearing (Fig 2.11) has comparatively high load-carrying capacity. It is designed to carry a radial, and it can also perform well under combined radial and axial loads (Harris and Kotzalas, 2006) [18].

The bearing number 6204 having 10 kN dynamic load capacity (C) was selected for the shredder shaft while bearing number 6203 having 8.33 kN dynamic load capacity (C) was selected for the main shaft. The S-type bearings are used for highly contaminated environment, shaft deflection and misalignment. It is mostly applicable in agricultural machines, conveyor systems. (FAG Catalogue WL 41 520EA, 2006).

Therefore, a single row deep groove ball bearing with codes S6204.W303B and S6203.W303B was selected to support the load on shredder shaft and load on grater-1 shaft respectively based on the bearing numbers as calculated in (Bawa, 2025) [13].

Fig 11: Deep groove ball bearing

2.4.11. Design of the Frames

The frames were made of mild steel bars of rectangular cross-section. The frames carry the weights of two extraction drum, the variable geared electric motor and the hopper with shredder in it. It was built with a series of upright and horizontal members to support and bear the load of the entire machine. These members were set at right angles to each other to provide support for the floors, walls and top of the structure. The uprights are called columns and the horizontal members are called beams. Bawa, (2025) [13] presents the equations used in the determination of thickness of the frame and for bolts selection for the frames.

2.5. Production of the Designed Components

Various manufacturing processes were employed during the design, fabrication, and assembling of the component parts of the machine. These processes are marking out operations or procedures, cutting operations or procedures, assembling operations, welding operation and machining operation. The marking out operation was used to achieve the required shape and size of the design according to dimensions. This was done with aid of tapes, marker, squares, Vernier caliper etc. The hopper was constructed using stainless steel sheet of 8-gauge with 1.5 mm thickness (Bawa, 2025) [13]. Hammer, arc welding and grinding machines were used during the production of the hopper. Power saw was used in cutting of thick cylindrical stainless pipes used in the construction of the shredder. The blades attached to the cylindrical drum were cut from the work piece and welded on the shaft after machining to required dimensions. Milling machine, welding machine and grinding machine was used during the production of the shredder (Bawa, 2025) [13]. A hollow stainless pipe of required diameter and thickness was cut and used as the extraction barrel. Drilling machine, filing machine, and milling machine were employed in the finishing operation of the barrel. The work piece used in the fabrication of the auger conveyor was stainless steel and this was made into a helix of five circular discs and welded together to form the screw blade in a helical form (Bawa, 2025) [13]. To achieve this, arc welding machine, grinding machine, hammer, electric cutter and hand saw were used. Mild steel angle iron was cut to the required dimensions with the aid of a power hacksaw and welded together to form the main frame and electric motor stand (Bawa, 2025) [13]. Bawa (2025) [13] shows both the juice and chaff outlets while the fruit inlet side cover can also be seen in the reference.. The engineering drawings of the fruit juice extraction machine is depicted in (Bawa, 2025) [13]. Table 2.4 depicts the summary of materials and standard components selected for the production of the machine after the design.

Table 3: Summary of materials and standard components

S/N	Material / Standard Component	Designed or Standard	Design Criteria	Specification
1	Belt drive	Standard	Cheap and rigid	Belt type A (IS: 2494-1974)
2	Hopper	Designed	Non-toxic, good corrosion and wear resistance	Steel sheet of 8-gauge with 1.5 mm thickness
3	Electric motor	Standard	Ease of machinability, cheap	2 hp electric motor (single phase)
4	Pulley	Standard	Rigidity, supports for both the juice extractor and the electric motor, cheap and ease of machinability	60 mm and 100 mm
5	Frame	Designed	Shear stress on the machine and resistance to galvanic corrosion	50 × 50 mm standard length
6	Bolts, nuts and washers	Standard	–	M8, M10, M12, M14
7	Bearings	Standard	Minimum hourly life for bearings	S6204.W303B
8	Shredder shaft	Designed	–	20 mm diameter and 430 mm length
9	Machine shaft	Designed	–	30 mm diameter and 430 mm length

2.6. Assembly Process

The feed hopper was welded to the top of the juice extraction barrel using arc welding process. The extraction unit of the machine comprises the cylindrical barrel which houses a screw conveyor, and the pulley with bearing and is mounted on the tool frame with the aid of bolts and nuts. This made it easy for the machine to be disassembled and reassembled during maintenance. The screw shaft is supported by the bearings at both ends. The auger (screw) conveyor and the barrel were both fabricated from stainless steel, and the pulley, fabricated from mild-steel is mounted on the screw shaft (made of stainless steel). The pulley transmits rotary power (torque) from the electric motor to the juice extracting machine via the V-belt connection. The V-belts provide a means of changing speed. The motor base located at the base of the main frame is equally made of angular bar of mild steel material. The bars were cut to required sizes and welded carefully to require shape. The 2 Hp variable geared electric motor which powers the machine via a belt and pulleys and gear box arrangement is mounted on the motor base located at the base of the main frame using bolts and nuts. The shredder is powered through a dual-groove pulley and V-belt from the machine shaft.

2.7. Description of the fruit Juice Extractor

The juice extractor was designed to work on the principle of compression and squeezing due to the gradual reduction of clearance between conveyor housing and screw conveyor. It is made up of five units, namely main frame, feed hopper, juice extraction unit, collecting unit, and power and transmission unit (Fig 2.12).

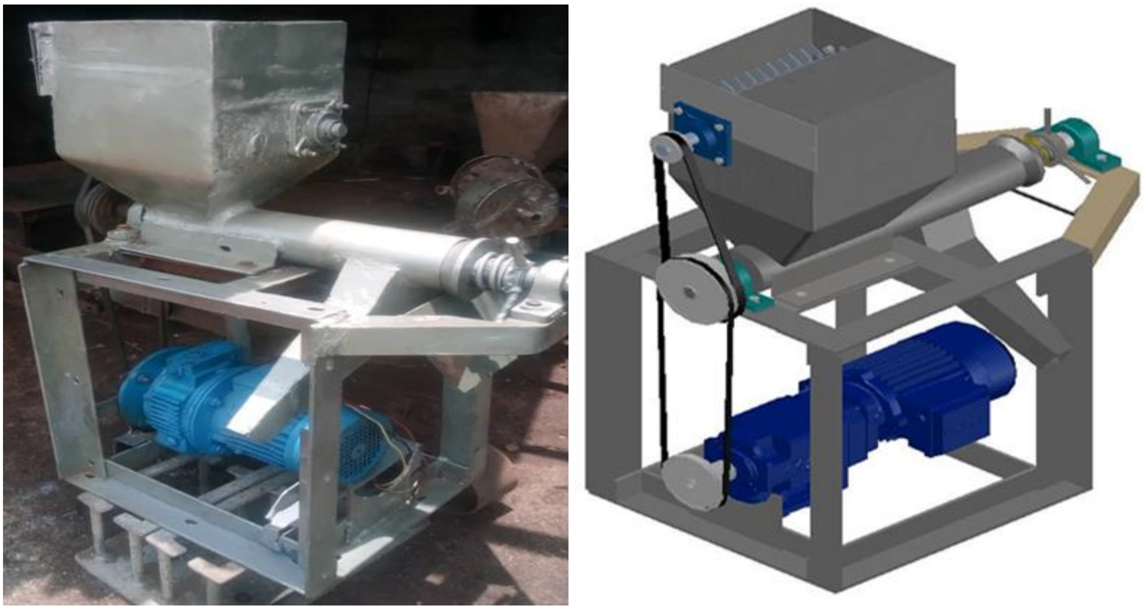

(a) (b)

Fig 12: (a) Photograph and, (b) 3D photo-rendering of the fruit juice Extraction Machine

Main frame: The main frame was made up of low carbon steel having an angle cross-section. The tool frames were form the supports and holds the machine components, and gives it a compact design and a sturdy outlook (Fig 2.13).

Hopper: The feed hopper, which was mounted on top of the juice extraction barrel, is a composite of rectangular and trapezoidal shape and inclined at an angle that enabled mass flow of feed into the extraction chamber to be achieved. It was made with cut-out stainless steel sheet of 1.5 mm thickness. Also embedded in the hopper unit is the shredder, which functions to reduce the size of the whole fruit introduced into the hopper (Fig 2.13).

Juice extraction unit: Below the feed hopper base and mounted on the tool frame, is the barrel like juice extraction unit that formed a conveyor housing where juice extraction takes place. Through this housing runs a shaft tapered from one end to the other end and rolled round it is a tapered screw. The shaft and screw assembly known as screw conveyor receives power through the geared motor and runs in a journal bearing. The screw on the conveyor is on the shaft and tapered at the feed entry point to the discharge end. The screw conveyor and housing provide the shear and compressive forces needed to crush the fruit and squeeze out the juice.

Collecting unit: At the bottom of the extraction chamber, is a perforated concave screen made of stainless steel. It permits the juice extracted from the fruit to be filtered from the crushed fibre. The filtered juice drops on an inclined juice collection channel and flows down through the collection chute into the juice collector. The waste discharge chute is located at the end of the extraction run (Fig 2.13).

Power and transmission unit: The power unit consist of a-2 Hp variable geared electric motor which powers the machine via a belt and pulleys and gear box arrangement. The motor is mounted on a seating located at the base of the main frame (Fig 2.13). The shredder is powered through a dual-groove pulley and V-belt from the machine shaft.

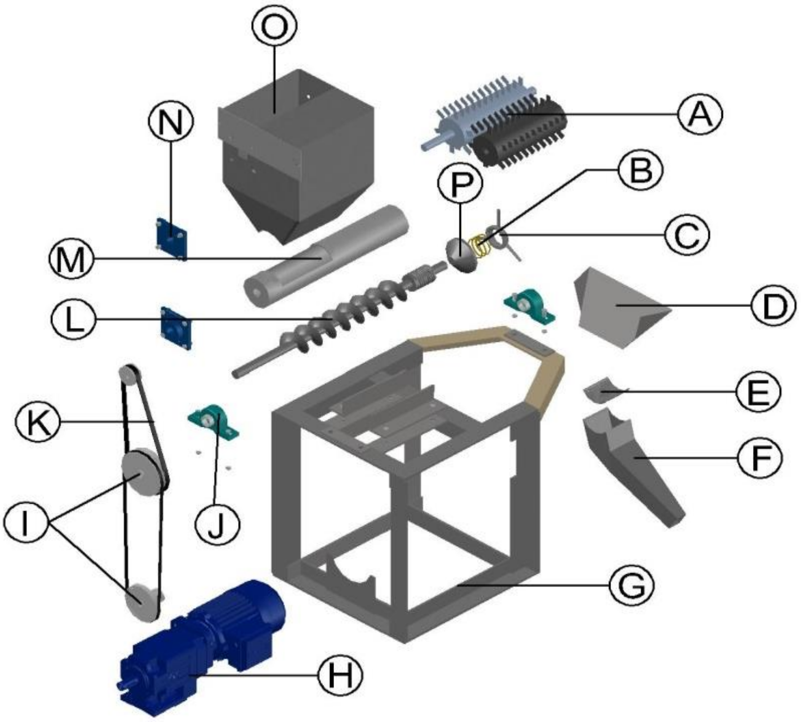


Fig 13: Exploded view of the juice extractor

2.8. Performance Test of the Machine

Performance testing and evolution were performed on the fabricated motorized fruit juice extraction machine at completion of the construction. The tests were carried out at the designed operation speed of 525.23 rpm. However, the tests were carried out so as to determine the following:

1. The rate of extraction and capacity of machine.
2. Possible leakage in the fabricated machine.
3. Hours or minute per hour the machine can operate.
4. The percentage and the efficiency of the machine.
5. Number of hours, the operator or engineer can operate on it, in order to know the accurate time to dismantle the conveyor or conical restriction section.

The machine performance test was carried out by pouring a known mass of orange fruit into the hopper. The power source was switch on to run the electric motor, which in turn powers the machine. The orange fruit in the hopper were then delivered in to the extraction chamber and the machine was allowed to operate until the material was completely fed and extracted. After that, mass of fruit fed into the machine, mass of juice extracted, mass of residual waste and juice constant of the fruit in decimal were recorded. The juice constant was obtained from the ratio of sum of masses of juice extracted and juice in chaff to the mass of fruit fed in. The mass of juice in chaff was determined using the method of ASAE (1983) as applied by Aviara *et al.* (2008) [7], and Oje (1993) [26]. This involved oven drying the chaff at 130°C until a constant weight was reached. Each experiment was replicated three times for the peeled oranges.

The performance evaluation of the juice extractor was carries out on the basis of the following indices used by Tressler and Joslyn (1961) [35]:

Juice yield,

$$J_y = \frac{100 \times W_{JE}}{W_{JE}+W_{RW}}\ \%$$

Equation 2.1

Extraction Efficiency,

$$EE = \frac{100 \times W_{JE}}{xW_{FS}}\ \%$$

Equation 2.2

Extraction loss,

$$El\ \% = \frac{100\,[W_{FS} - (W_{JE}+W_{RW})]}{W_{FS}}\%$$

Equation 2.3

Where W_{RW} = Residual waste/dry chaff (kg), EE = Extraction Efficiency, %; W_{JE} = mass of juice extracted, g; W_{FS} = mass of feed sample, g; x = juice constant of fruit, $decimal$

Extraction Capacity,

$$EC = \frac{V_J}{T}$$

Equation 2.4

Where EC = Extraction Capacity, $L/min.$; V_J = volume of juice extracted from fruit material, $litre$; T = juice extraction time, $min.$

2.9. Design of Experiment

Design Expert software (Version 6.0.6, Stat-Ease Inc, Minneapolis, MN 55413, USA) was used in this study to design the testing of the fruit juice extraction machine. The experimental design employed in this work was a five-level-four factor full factorial Central Composite Rotatable Design (CCRD) of response surface methodology (RSM) with 30 (i.e. $2^k + 2k + n$) test runs were perform for orange. Operating speed, feed rate, blanching temperature and blanching time were selected as independent factors for the machine performance test. The selection of the levels for the machine performance conditions was based on preliminary experiments and literature in which 5 levels each of operating speed, o_S (200, 300, 400, 500 and 600 rpm), feed rate, F_R (0.5, 1.0, 1.5, 2.0 and 2.5 kg/min), blanching temperature, B_T (0, 20, 40, 60 and 80^{0}C) and blanching time, B_t (0, 3, 6, 9 and 12 min) were adopted for the study.

Six replications of centre points were used in order to predict a good estimation of errors and testing were performed in a randomized order. The coded and actual values of the levels of the machine performance conditions is presented in Table 2.4, while the experimental setup for the independent variables is presented in Table 2.5. The coded values were designated by –2 (minimum), −1, 0 (centre), +1, +2 (maximum), −α and +α. Alpha is defined as a distance from the centre point which can be either inside or outside the range, with the maximum value of $2n/4$, where n is the number of factors. It is noteworthy to point out that the software uses the concept of the coded values for the investigation of the significant terms, thus equation in coded values is used to study the effect of the variables on the response. The empirical equation is represented in Equation 2.5 as:

$$Y = \beta_0 + \sum_{i=1}^{2}\beta_i X_i + \sum_{i=1}^{2}\beta_{ii} X^2{}_i + \sum_{i=1}^{2}\sum_{j=i+1}^{2}\beta_{ij} X_i X_j$$

Equation 3.5

Where Y = Response; β_0 = Constant term; $\sum_{i=1}^{2}\beta_i$ = Summation of coefficient of linear terms; $\sum_{i=1}^{2}\beta_{ii}$ = Summation of quadratic terms; $\sum_{i=1}^{2}\sum_{j=i+1}^{2}\beta_{ij}$ = summation of coefficient of interaction terms; X_iX_j = independent variables.

Table 4: Levels and Codes of Independent Variables for the performance test experiment

Factors	**Unit**	**Codes**	**-2**	**-1**	**0**	**1**	**2**
Operating Speed (OS)	rpm	X1	200	300	400	500	600
Feed Rate (FR)	L/min	X2	0.5	1.0	1.5	2.0	2.5
Blanching Temperature (BT)	°C	X3	0	20	40	60	80
Blanching Time (Bt)	min	X4	0	3	6	9	12

Table 5: Experimental design runs order and factors in coded and actual forms for the juice extraction process

Run	**Coded factors**				**Actual factors**			
	X_1	**X_2**	**X_3**	**X_4**	**OS (rpm)**	**FR (kg/min)**	**BT (°C)**	**Bt (min)**
1	0	0	0	-2	400.00	1.50	40.00	0.00
2	-1	-1	-1	-1	300.00	1.00	20.00	3.00
3	1	-1	-1	-1	500.00	1.00	20.00	3.00
4	-1	1	-1	-1	300.00	2.00	20.00	3.00
5	1	1	-1	-1	500.00	2.00	20.00	3.00
6	-1	-1	1	-1	300.00	1.00	60.00	3.00
7	1	-1	1	-1	500.00	1.00	60.00	3.00
8	-1	1	1	-1	300.00	2.00	60.00	3.00
9	1	1	1	-1	500.00	2.00	60.00	3.00
10	0	0	-2	0	400.00	1.50	0.00	6.00
11	0	-2	0	0	400.00	0.50	40.00	6.00
12	-2	0	0	0	200.00	1.50	40.00	6.00
13	0	0	0	0	400.00	1.50	40.00	6.00
14	0	0	0	0	400.00	1.50	40.00	6.00
15	0	0	0	0	400.00	1.50	40.00	6.00
16	0	0	0	0	400.00	1.50	40.00	6.00
17	0	0	0	0	400.00	1.50	40.00	6.00
18	0	0	0	0	400.00	1.50	40.00	6.00
19	2	0	0	0	600.00	1.50	40.00	6.00
20	0	2	0	0	400.00	2.50	40.00	6.00
21	0	0	2	0	400.00	1.50	80.00	6.00
22	-1	-1	-1	1	300.00	1.00	20.00	9.00
23	1	-1	-1	1	500.00	1.00	20.00	9.00
24	-1	1	-1	1	300.00	2.00	20.00	9.00
25	1	1	-1	1	500.00	2.00	20.00	9.00
26	-1	-1	1	1	300.00	1.00	60.00	9.00
27	1	-1	1	1	500.00	1.00	60.00	9.00
28	-1	1	1	1	300.00	2.00	60.00	9.00
29	1	1	1	1	500.00	2.00	60.00	9.00
30	0	0	0	2	400.00	1.50	40.00	12.00

OS = Operating Speed; FR = Feed Rate; BT = Blanching Temperature; Bt = Blanching Time

2.10. Model Selection for Optimization of Performance of the Juice Extractor

In the selection of a suitable model for the extraction efficiency and extraction capacity, the highest order polynomial where the additional terms are significant and the model is not aliased, insignificant lack-of-fit and the maximization of the "Adjusted R^2" and the "Predicted R^2" were considered. The cubic model is aliased and cannot be selected; and in terms of higher coefficient of determination (R^2) and lower standard deviation values (Oladejo and Ma, 2016; Umani *et al.*, 2019) [28, 36]. A Design Expert (version 6.0.6) software package for design of experiments was used to analyze and generate model equations for juice extraction efficiency (JEE) and extraction capacity (EC). Four different models namely linear, two factorial interactions (2FI), quadratic, and cubic were used to analyze the responses and the models were fitted to the experimental data using Design Expert software. The final regression model for juice extraction efficiency (EE) is given in Equation 2.6 as:

$$EE = -73.81 + 0.36O_S + 15.39F_R + 0.76B_T + 4.48B_t - 4.49 \times 10^{-4}{O_S}^2 - 8.16{F_R}^2 - 9.86 \times 10^{-3}{B_T}^2 - 0.33{B_t}^2 + 0.04O_SF_R - 2.18 \times 10^{-4}O_SB_T + 4.16 \times 10^{-3}O_SB_t + 0.11F_RB_T - 0.49F_RB_t + 9.95 \times 10^{-3}B_TB_t$$

Equation 2.6

Where EE = Extraction efficiency, % ; O_S = Operating speed, rpm; F_R = Feed rate, kg/min; B_T = Blanching temperature, °C; B_t = Blanching time, min.

While the final regression model for juice extraction capacity (EC) is given in Equation 2.7 as:

$$EC = -9.65 + 0.03O_S + 3.30F_R + 0.01B_T + 0.48B_t - 3.65 \times 10^{-5}{O_S}^2 - 1.30{F_R}^2 - 5.07 \times 10^{-4}{B_T}^2 - 0.04{B_t}^2 + 3.53 \times 10^{-3}O_SF_R - 2.25 \times 10^{-5}O_SB_T + 1.92 \times 10^{-4}O_SB_t + 0.01F_RB_T - 0.08F_RB_t + 4.27 \times 10^{-3}B_TB_t$$

Equation 2.7

Where EC = Extraction capacity, kg/min ; O_S = Operating speed, rpm; F_R = Feed rate, kg/min; B_T = Blanching temperature, °C; B_t = Blanching time, min.

2.11. Optimization and Verification of the model

The dependent extraction variables (extraction efficiency and extraction capacity) were optimized based on the 3D surface plots and regression analysis of the independent variables (Operating speed, feed rate, blanching temperature and blanching time). This was done with the aim of obtaining the maximum juice extraction efficiency (EE) and maximum extraction capacity (EC) using Design-Expert software. Predictive models were used to graphically represent the systems. Response surface and ramp for optimization plots of the response variables were utilized to select optimum combinations of operating speed, feed rate, blanching temperature and blanching time for the extraction of fruit juice from the pulp.

The statistical models were validated with respect to the dependent variables within the design space. The experimental results obtained were compared statistically with the predicted values in order to determine the models' validity using parity plots.

The criteria variables were set such that the independent variables (operating speed, feed rate, blanching temperature and blanching time) would be within a range or minimum from an economical point of view (Jain *et al.*, 2011) [22]. The main criteria for constraints optimization were maximum possible extraction efficiency and extraction capacity. The desired goals for each process parameter and response is shown in Tables 3.6. In order to optimize the process parameters for the juice extraction process by numerical optimization which finds a point that maximize the desirability function; equal importance of `3' was given to all the four extraction process parameters and the responses (EE and EC).

Table 6: Criteria and output for numerical optimization of extraction process parameters for the performance analysis of the juice extraction

Extraction criteria	Unit	Lower limit	Upper limit	Optimization Goal	Relative Importance
Operating Speed	Rpm	200	600	Range	3
Feed rate	kg/min.	0.5	2.5	Range	3
Blanching Temperature	⁰C	0	80	Range	3
Blanching Time	Min	0	12	Range	3
Extraction Efficiency	%	32.63	83.66	Maximize	3
Extraction Capacity	L/min	0.08	3.89	Maximize	3

The ramp of the optimization process is shown in Fig 2.14 with optimal extraction process factors operating speed of 525.23 rpm, feed rate of 2.13 kg/min, blanching temperature of 54.20ºC and blanching time of 8.73 min.

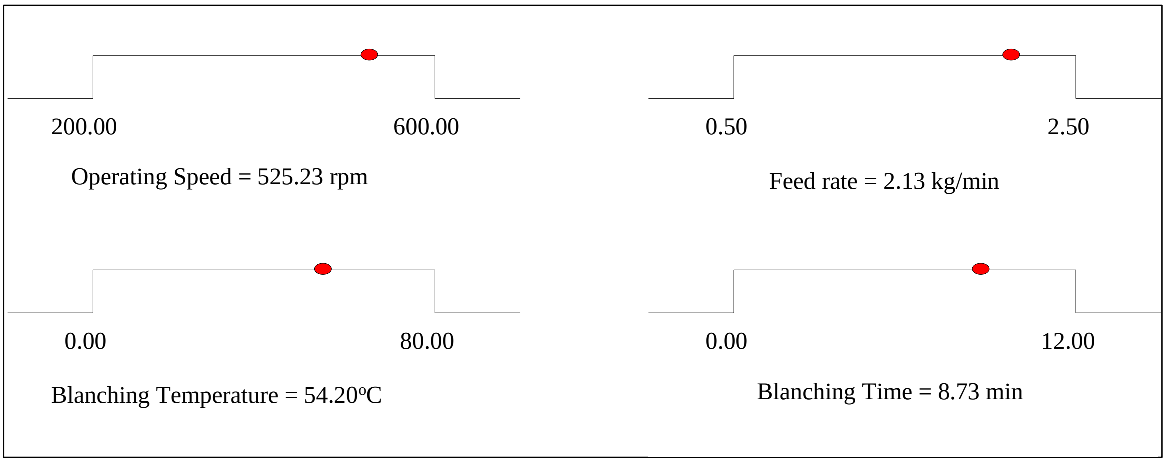


Fig 14: Ramp for optimization of juice extraction process conditions for extraction efficiency and extraction capacity

2.12. Response Surface Methodology (RSM)

A Design Expert (version 6.0.6) software package for design of experiments was adopted on order to analyze and generate model equations for the expression process. The data which was obtained through the experimental matrix was computed for the determination of regression coefficient of the second order multiple regression models. The analysis of regression and variance was performed by the Design Expert. In order to validate the optimal parameters, the experiment was repeated at the optimal conditions as suggested by Islau *et al.*, (2002) [21]. Thus, the obtained results were compared with predicted values.

2.13.Statistical Analysis

Data obtained from the experiments was analyzed using Response Surface Methodology so as to fit the quadratic polynomial equation generated by the Design-Expert software version 10.0.10 (Stat-Ease Inc., Minneapolis, USA). In order to correlate the response variable to the independent variables, multiple regressions were used to fit the coefficient of the polynomial model of the response. ANOVA was carried out to determine the significance and fitness of the model as well as the effect of significant individual terms and their interaction on the chosen responses. The *p*-value (probability of error value) was used as a tool to check the significance of each regression coefficient which also indicated the interaction effect of each cross product. Data obtained from the experiments was also be statistically analyzed to determine the significant difference in the extraction process and their interactions at 5% probability level using Minitab 17.0 software package.

2.14. Cost Analysis of the Motorized Fruit Juice Extraction Machine

The cost of the construction materials and other components of the juice extraction machine is presented in Table 2.7. A feasibility study was carried out based on the engineering materials selected for the construction of the machine. The total cost of the juice extraction machine is estimated to be ₦149,800 ($99.87). The various parts are easily affordable in case of failure of any part of the machine. The maintenance of the developed juice extraction system is easy and parts are readily available.

Table 7: Bill of Engineering Measurements and Evaluations (BEME) of the Juice Extraction Machine

S/N	Description	Size	Qty.	Unit Price (₦)	Total (₦)
1	Stainless steel Shaft	20 x 2100 mm	1	7,500	7,500
2	Stainless steel sheet (gauge-8, 4.18 mm)	609.6 x 609.6 mm	1	28,000	28,000
3	1-inch mild steel angle bar	5486.4 mm	1	1,800	1,200
4	Flange bearing	6204	2	2,200	4,400
5	Variable geared Electric motor (3- phase)	2 hp	1	50,000	50,000
6	Pulley	60 and 100 mm	2	1,000	2,000
7	Gear tooth		2	2,000	4,000
8	Bolts & Nuts	M8, M10, M12, M14			2,200
9	Panting & accessories				5,500
10	Labour				30,000
11	Miscellaneous				15,000
Total		$99.87			149,800

3. Results and Discussion

3.1. Results

3.1.1. Juice Extraction Machine Performance Analysis

Table 3.1 depicts the average summary of the juice extraction efficiency and juice extraction capacity at various extraction process condition combinations using 4 factors, 5 levels, factorial Central Composite Rotatable Design (CCRD) of Response Surface Methodology (RSM).

Table 8: Juice extraction efficiency and Extraction capacity at different processing condition combinations

Run	OS (rpm)	FR (kg/min)	BT (ºC)	Bt (min)	JEE (%)	JEC (L/min)
1	400.00	1.50	40.00	0.00	41.60	0.28
2	300.00	1.00	20.00	3.00	31.63	1.25
3	500.00	1.00	20.00	3.00	55.31	1.82
4	300.00	2.00	20.00	3.00	46.00	0.97
5	500.00	2.00	20.00	3.00	72.37	3.55
6	300.00	1.00	60.00	3.00	41.31	0.08
7	500.00	1.00	60.00	3.00	57.71	1.55
8	300.00	2.00	60.00	3.00	53.94	1.07
9	500.00	2.00	60.00	3.00	74.74	3.11
10	400.00	1.50	0.00	6.00	40.66	0.95
11	400.00	0.50	40.00	6.00	49.89	0.76
12	200.00	1.50	40.00	6.00	39.09	0.26
13	400.00	1.50	40.00	6.00	69.54	2.58
14	400.00	1.50	40.00	6.00	68.83	2.73
15	400.00	1.50	40.00	6.00	68.80	2.63
16	400.00	1.50	40.00	6.00	69.14	3.83
17	400.00	1.50	40.00	6.00	69.26	3.48
18	400.00	1.50	40.00	6.00	69.43	3.26
19	600.00	1.50	40.00	6.00	49.34	1.42
20	400.00	2.50	40.00	6.00	58.11	2.24
21	400.00	1.50	80.00	6.00	83.66	2.53
22	300.00	1.00	20.00	9.00	46.63	1.21
23	500.00	1.00	20.00	9.00	66.46	3.00
24	300.00	2.00	20.00	9.00	48.57	1.13
25	500.00	2.00	20.00	9.00	79.40	3.67
26	300.00	1.00	60.00	9.00	49.14	1.52
27	500.00	1.00	60.00	9.00	70.14	3.89
28	300.00	2.00	60.00	9.00	59.09	2.52
29	500.00	2.00	60.00	9.00	52.09	3.40
30	400.00	1.50	40.00	12.00	67.60	2.02

3.1.2 Juice Extraction Efficiency

Figs (3.1 - 3.6) shows the effects of juice extraction factors on the juice extraction efficiency.

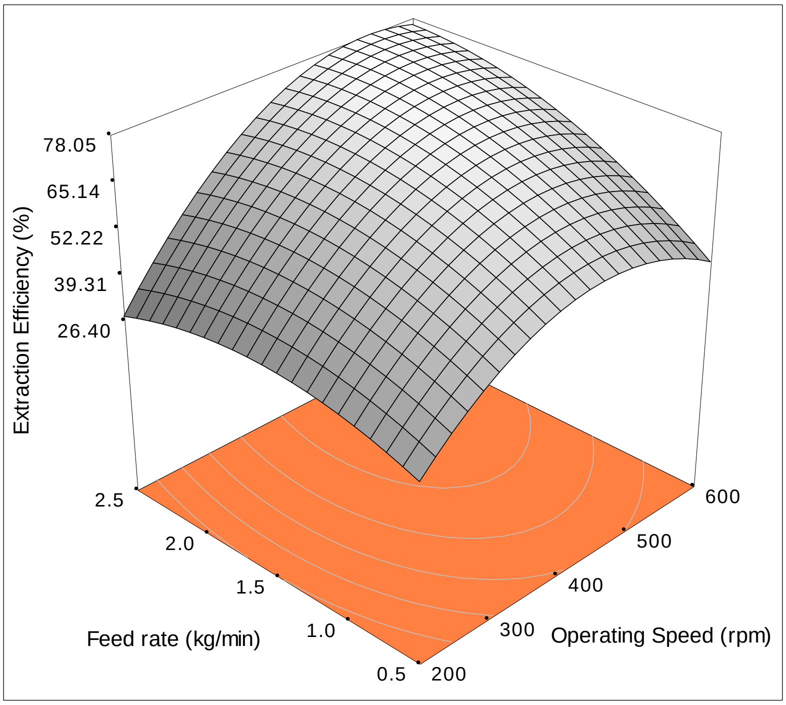


Fig 14: Response surface plot of the interactive effects of feed rate and operating speed on juice extraction efficiency

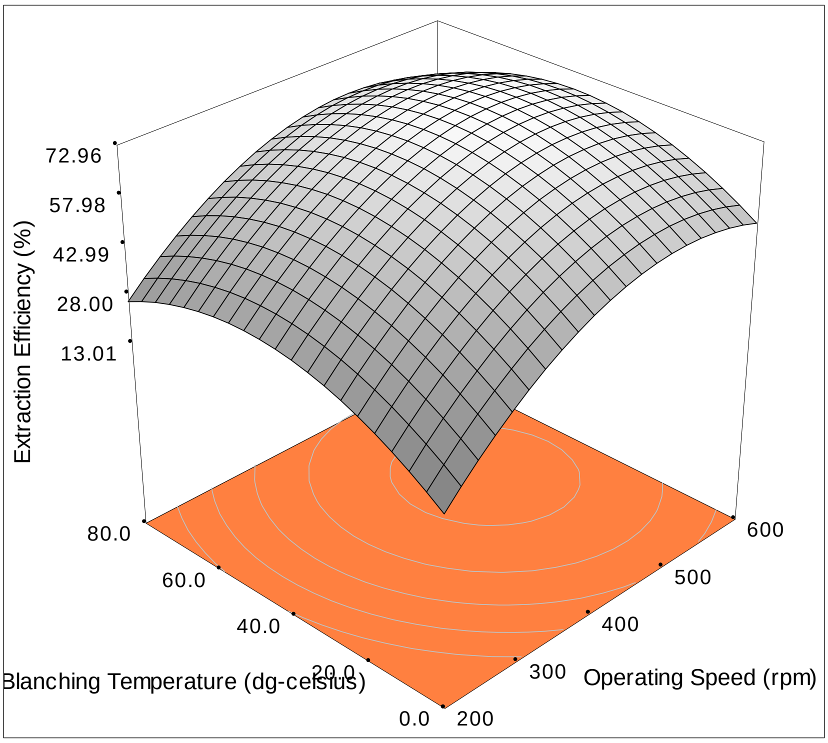


Fig 15: Response surface plot of the interactive effects of blanching temperature and operating speed on juice extraction efficiency

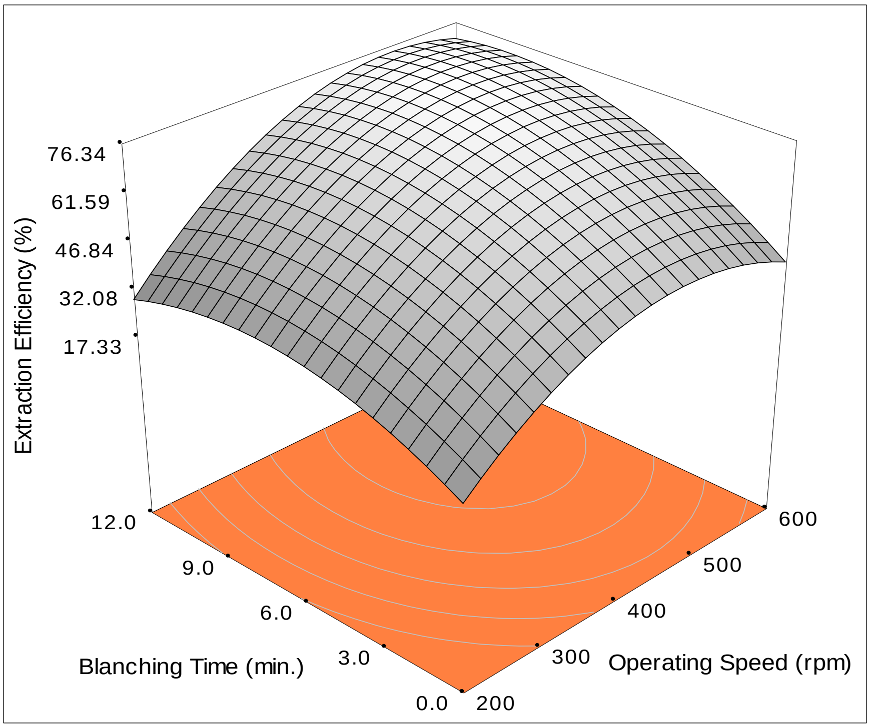


Fig 16: Response surface plot of the interactive effects of blanching time and operating speed on juice extraction efficiency

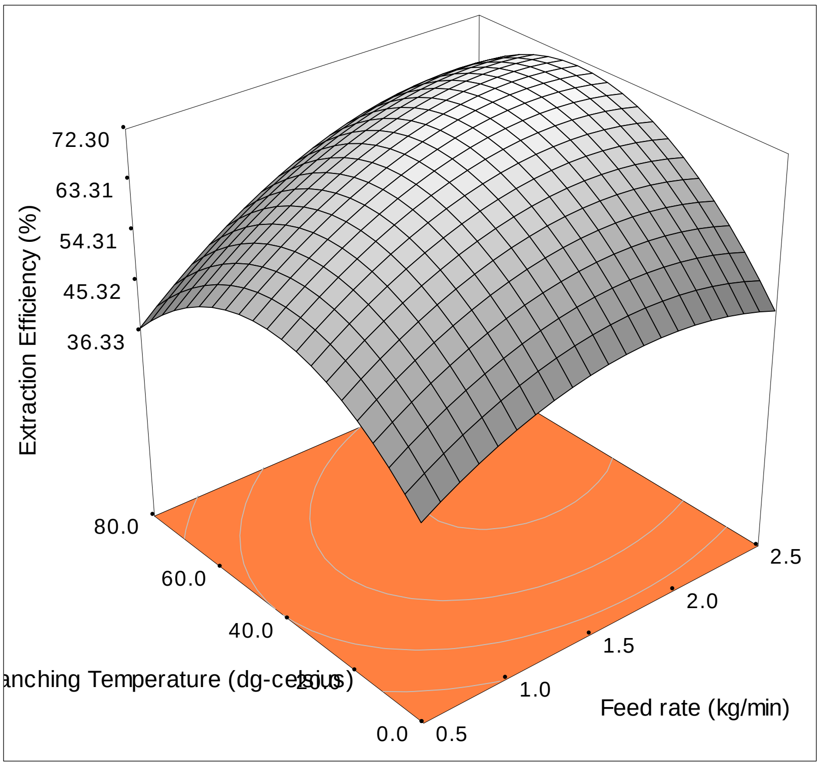


Fig 17: Response surface plot of the interactive effects of blanching temperature and feed rate on juice extraction efficiency

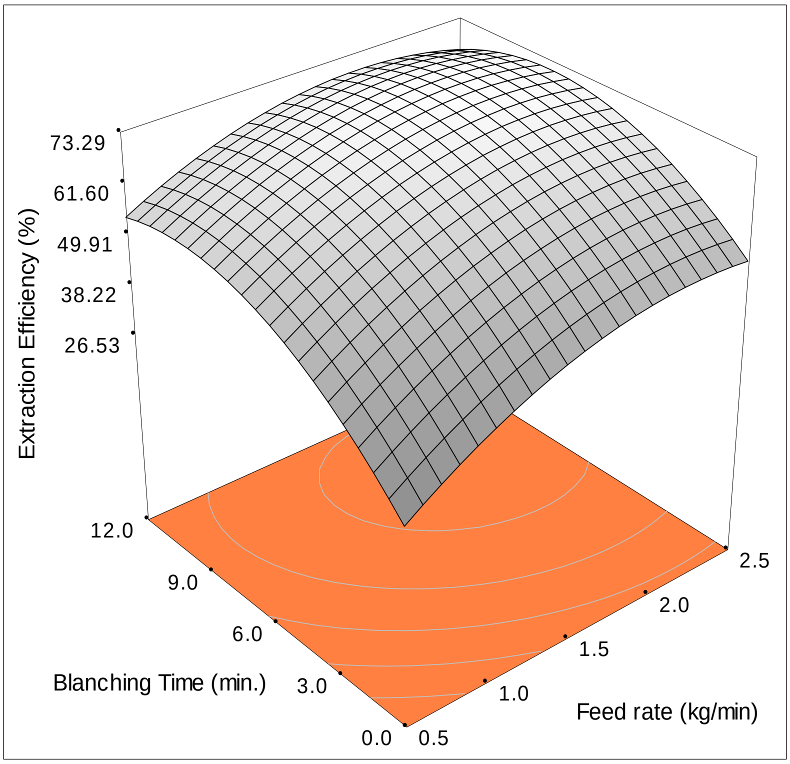


Fig 16: Response surface plot of the interactive effects of blanching time and feed rate on juice extraction efficiency

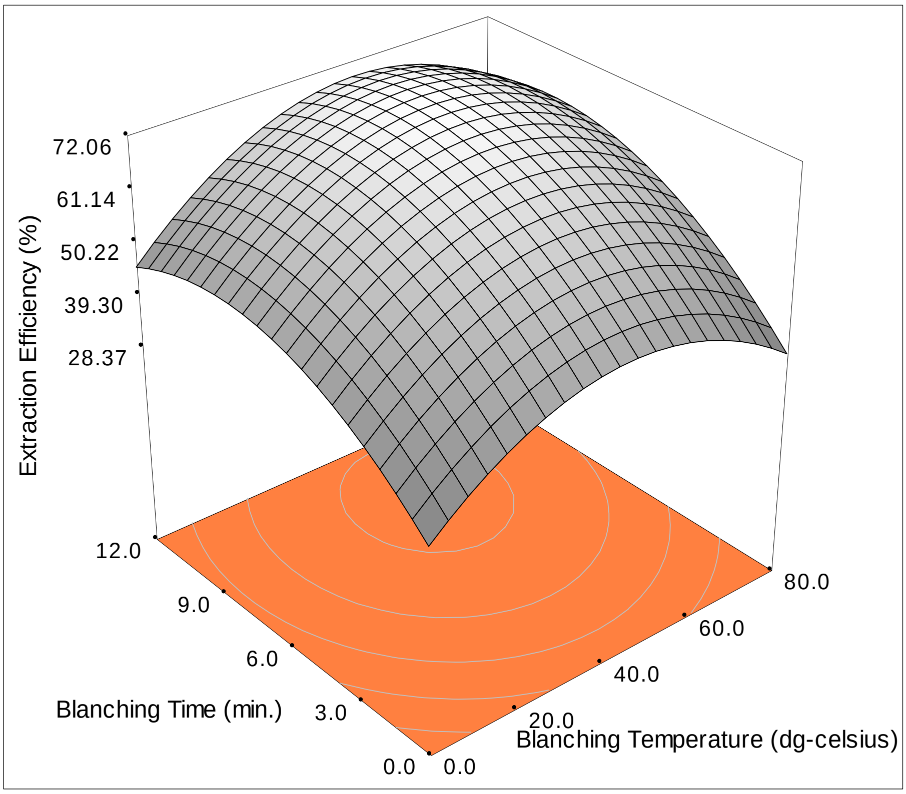


Fig 17: Response surface plot of the interactive effects of blanching time and blanching temperature on juice extraction efficiency

3.1.3 Juice Extraction Capacity

Figs (3.7 - 3.12) shows the effects of juice extraction process conditions on the juice extraction capacity.

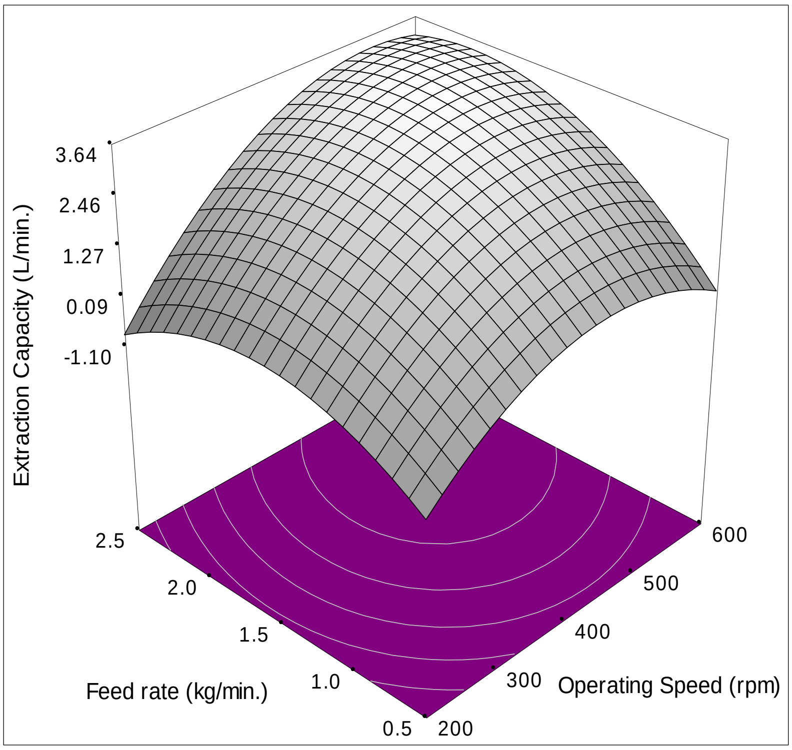


Fig 18 : Response surface plot of the interactive effects of feed rate and operating speed on juice extraction capacity

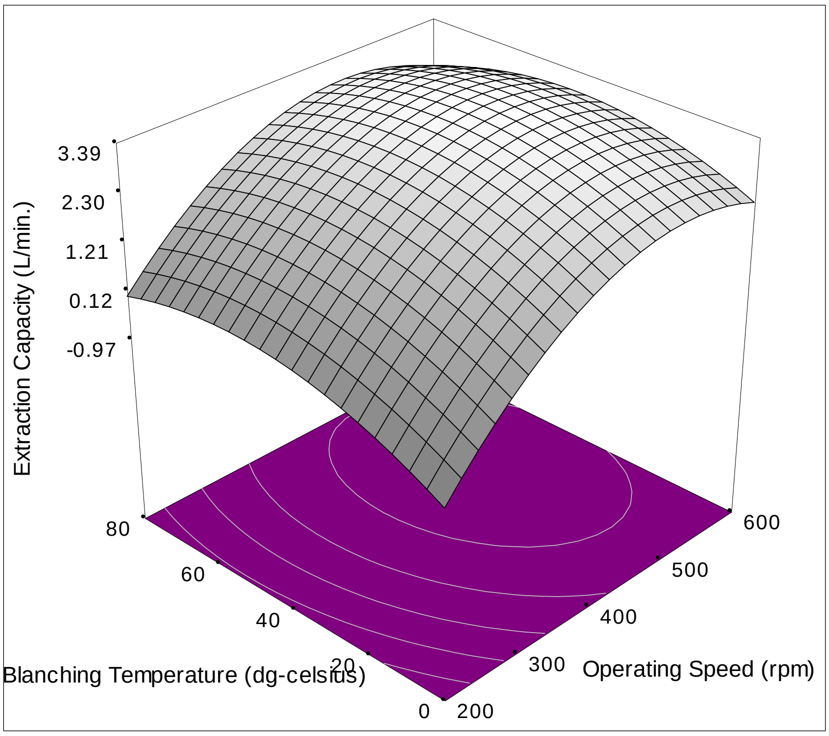


Fig 18 : Response surface plot of the interactive effects of blanching temperature and operating speed on juice extraction capacity

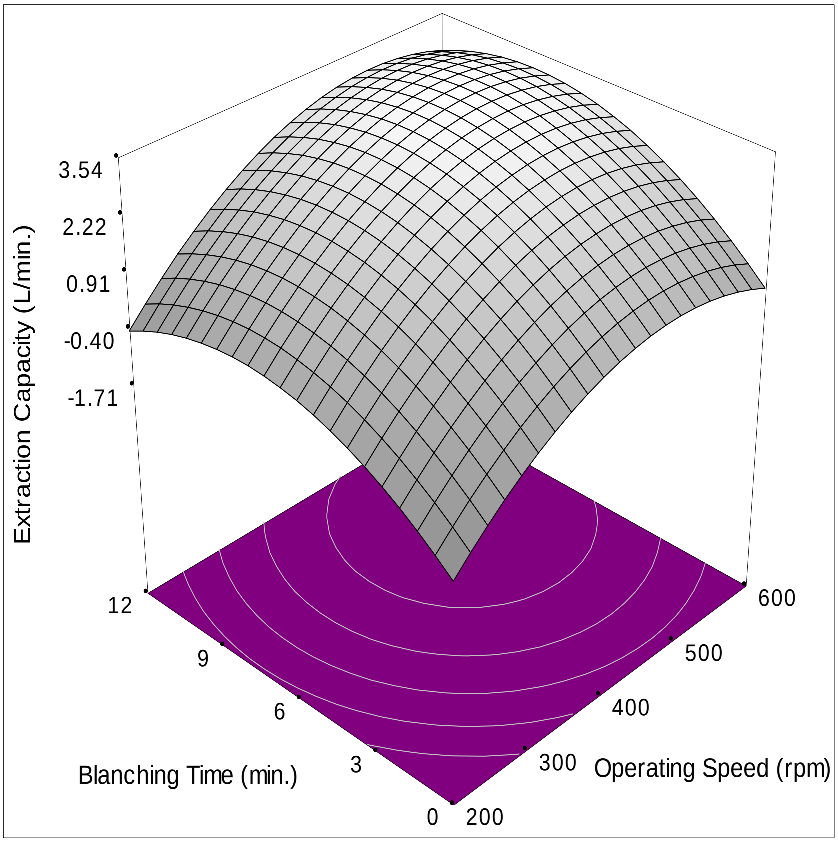


Fig 19 : Response surface plot of the interactive effects of blanching time and operating speed on juice extraction capacity

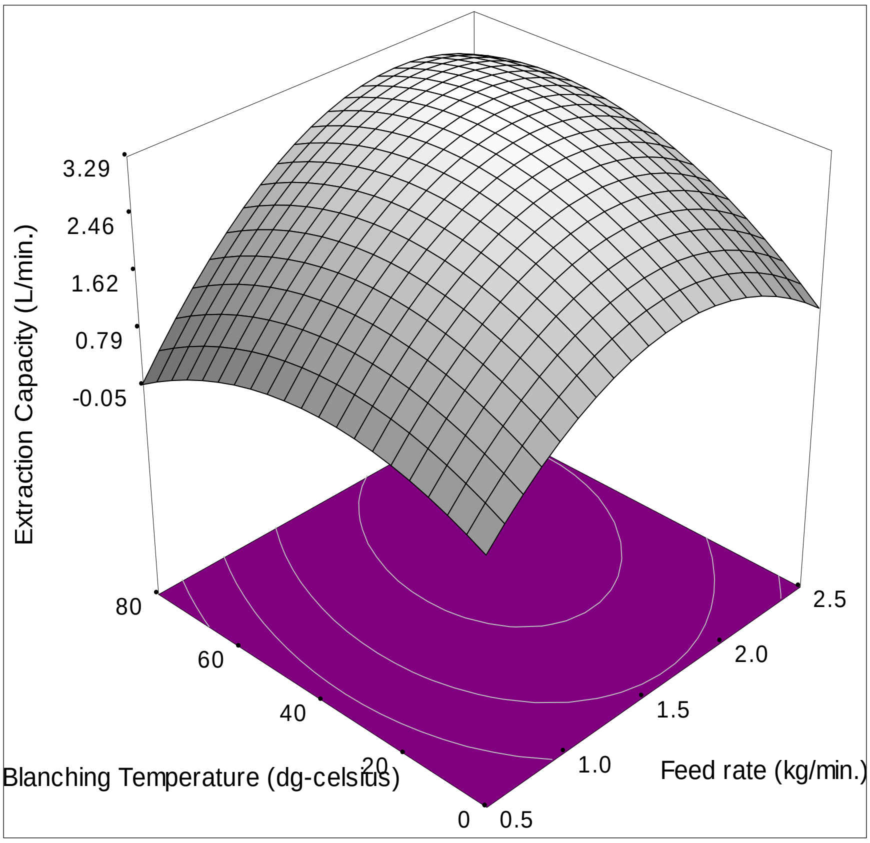


Fig 20 : Response surface plot of the interactive effects of blanching temperature and Feed rate on juice extraction capacity

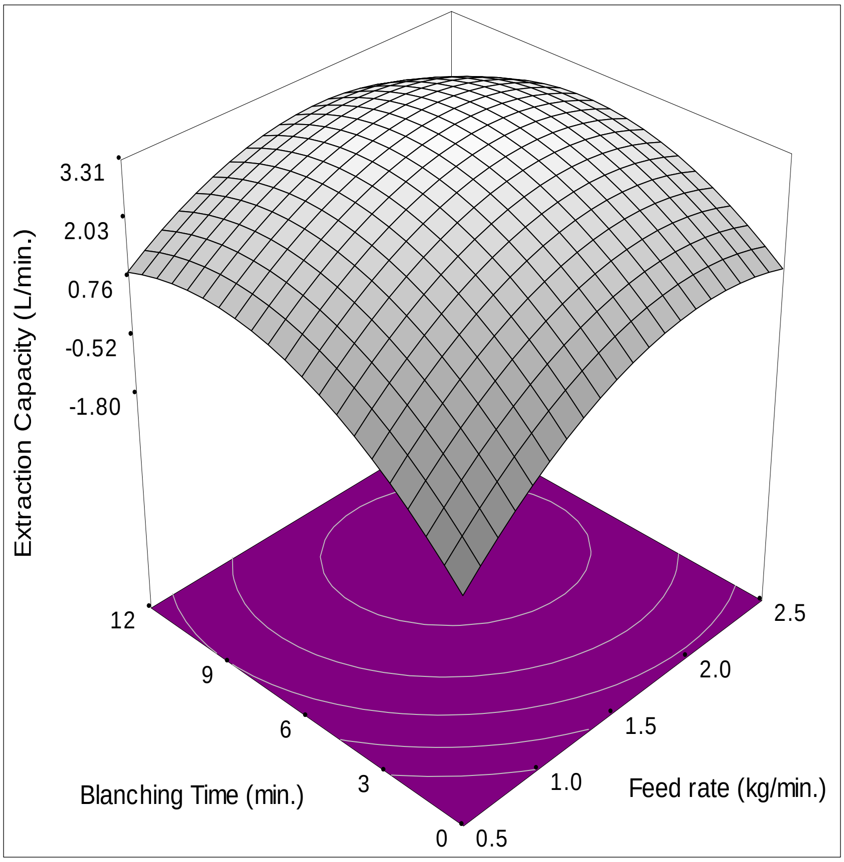


Fig 21: Response surface plot of the interactive effects of blanching time and feed rat on juice extraction capacity

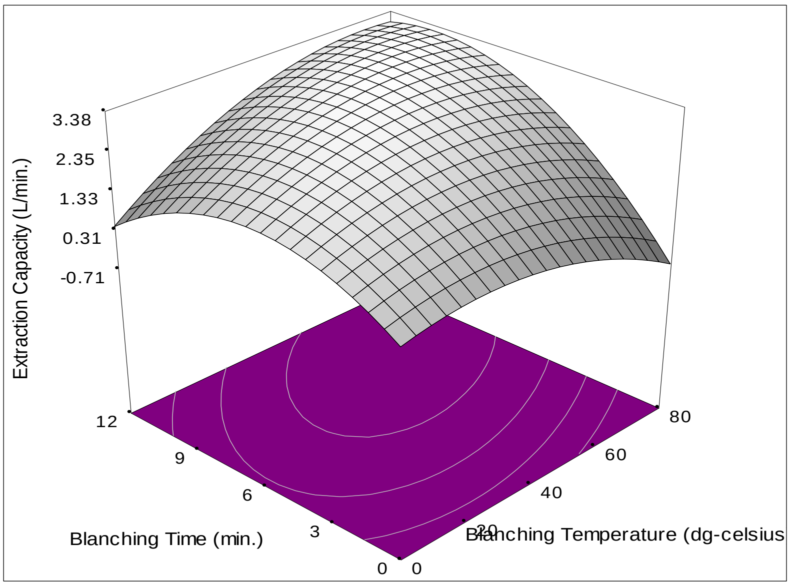


Fig 22 : Response surface plot of the interactive effects of blanching time and blanching temperature on juice extraction capacity

3.1.4 Model Selection for Optimization of Machine Performance Using Juice Extraction Efficiency

The comparison of four models (linear, 2FI, quadratic and cubic) for juice extraction efficiency during the performance analysis the juice extractor is shown in Tables (3.2 – 3.3).

Table 9: Model comparison for juice extraction efficiency

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	9.56	10.65	8.85	9.18
Mean	58.38	58.38	58.38	58.38
C.V.	16.38	18.25	15.15	15.37
PRESS	3227.47	3891.35	6757.75	84955.00
R^2	0.5534	0.5785	0.7707	0.8846
Adjusted R^2	0.4819	0.3567	0.5566	0.5220
Predicted R^2	0.3693	0.2396	-0.3205	-15.6009
Adequate precision	10.295	6.228	7.104	5.238

Table 10: ANOVA for response surface quadratic model for juice extraction efficiency

Source of Variation	Sum of Squares	df	Mean Square	F-value	Prob > F
Model	3943.92	14	281.71	3.60	0.0095*
A	1552.20	1	1552.20	19.84	0.0005*
B	458.59	1	458.59	5.86	0.0286*
C	127.19	1	127.19	1.63	0.2217
D	693.91	1	693.91	8.87	0.0094*
A^2	551.81	1	551.81	7.05	0.0180*
B^2	114.04	1	114.04	1.46	0.2460
C^2	426.94	1	426.94	5.46	0.0338*
D^2	248.56	1	248.56	3.18	0.0949
AB	66.54	1	66.54	0.85	0.3710
AC	3.04	1	3.04	0.039	0.8465
AD	24.88	1	24.88	0.32	0.5812
BC	19.78	1	19.78	0.25	0.6224
BD	8.66	1	8.66	0.11	0.7440
CD	5.70	1	5.70	0.073	0.7909
Residual	1173.57	15	78.24	—	—
Lack of Fit	1173.10	10	117.31	1258.87	<0.0001*
Pure Error	0.47	5	0.093	—	—
Cor Total	5117.49	29	—	—	—

A represents operating speed
B represents feed rate
C represents blanching temperature
D represents blanching time.
*Significant.

3.1.5 Model Selection for Optimization of Machine Performance Using Juice Extraction Capacity

The comparison of four models (linear, 2FI, quadratic and cubic) for the extraction capacity during the performance analysis of the juice extractor is shown in Tables (3.4 – 3.5).

Table 11: Analysis of Variance for extraction capacity

Source Model	Sum of Square	DF	Mean Square	F Val	Prob >F
A	18.37	1	18.37	30.79	< 0.0001
B	2.86	1	2.86	4.79	0.0382
C	18.62	1	18.62	31.21	< 0.0001
D	0.20	1	0.20	0.33	0.5697
Residual	14.92	25	0.60		
Lack of Fit	14.86	20	0.74	63.25	0.0001
Pure Error	0.059	5	0.012		
Cor Total	54.97	29			

Table 12: ANOVA for response surface quadratic model for juice extraction capacity

Source of Variation	Sum of Squares	df	Mean Square	F-value	Prob > F
Model	29.420	14	2.100	3.41	0.0122*
A	10.090	1	10.090	16.37	0.0011*
B	4.180	1	4.180	6.79	0.0199*
C	0.570	1	0.570	0.93	0.3512
D	4.520	1	4.520	7.34	0.0161*
$\boldsymbol{A^2}$	3.660	1	3.660	5.94	0.0277*
$\boldsymbol{B^2}$	2.880	1	2.880	4.68	0.0471*
$\boldsymbol{C^2}$	1.130	1	1.130	1.83	0.1958
$\boldsymbol{D^2}$	3.370	1	3.370	5.47	0.0337*
AB	0.500	1	0.500	0.81	0.3833
AC	0.032	1	0.032	0.053	0.8217
AD	0.053	1	0.053	0.086	0.7735
BC	0.250	1	0.250	0.41	0.5337
BD	0.230	1	0.230	0.37	0.5500
CD	1.050	1	1.050	1.71	0.2113
Residual	9.240	15	0.620		
Lack of Fit	7.910	10	0.790	2.98	0.1202
Pure Error	1.330	5	0.270		
Cor Total	38.660	29			

A represents operating speed
B represents feed rate
C represents blanching temperature
D represents blanching time.
*Significant.

3.1.6 Optimization and Validation of Machine Performance for Extraction Efficiency

The optimization result for the goal of maximizing the optimum value of the extraction efficiency (EE) for the juice extraction process during the performance analysis of the developed juice extraction machine is shown in Fig 3.13.

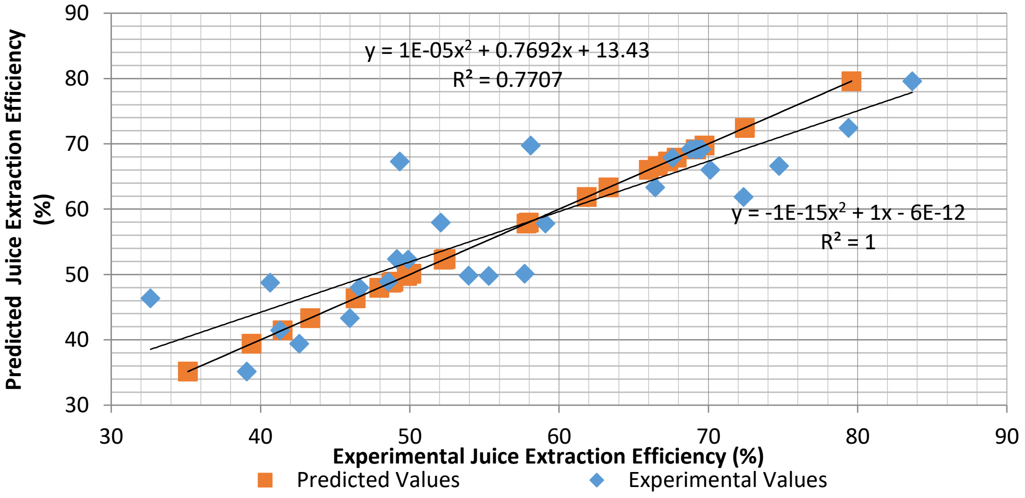


Fig 23: Comparison of the predicted and experimental values for the juice extraction efficiency

3.1.7. Optimization and Validation of Machine Performance for Extraction Capacity

The optimization result for the goal of maximizing the optimum value of the extraction capacity (EC) for the juice extraction process during the performance analysis of the developed juice extraction machine is shown in Fig 3.14.

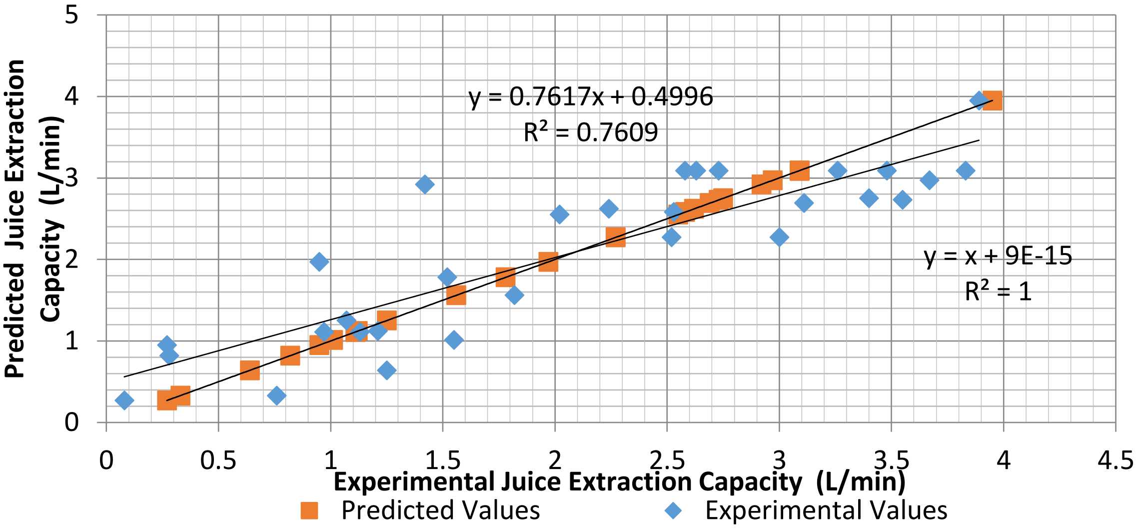


Fig 24: Comparison of the predicted and experimental values for the juice extraction capacity

4. Discussion

Table 3.1 shows result for the juice extraction efficiency and capacity at various levels combination of operating speed, feed rate, blanching temperature and blanching time. For the range of extraction process conditions considered in the expression process of juice from orange, the highest juice extraction efficiency of 83.66% was obtained at the machine operating speed of 400 rpm, feed rate of 1.5 kg/min, blanching temperature of 80ºC and blanching time of 6 min, while the lowest juice extraction efficiency of 31.63% was obtained at the machine operating speed of 300 rpm, feed rate of 1.0 kg/min, blanching temperature of 20ºC and blanching time of 3 min as shown in Table 3.1. Also, the highest extraction capacity of 3.89 L/min was obtained at the machine operating speed of 500 rpm, feed rate of 1.0 kg/min, blanching temperature of 60ºC and blanching time of 9 min, while the lowest extraction capacity of 0.26 L/min was obtained at the machine operating speed of 200 rpm, feed rate of 1.5 kg/min, blanching temperature of 40ºC and blanching time of 6 min as shown in Table 3.1. The juice extraction efficiency ranges from 31.63 to 83.66% while the juice extraction efficiency ranges from 0.26 to 3.89 L/min (Table 3.1). This compares favourably with the maximum juice extraction efficiencies of other developed machines for fruits.

In Fig 3.1, it was observed that an increase in operating speed and feed rate leads to increase in extraction efficiency after which there was a corresponding decrease in extraction efficiency at higher speed.

As presented in Fig 3.2, an increase in the machine operating speed with blanching temperature leads to increase in extraction efficiency, after which there was a decline. At high temperature, protein coagulation, increase in the liquid fluidity, liquid-cells breakdown and moisture content adjustment to the optimum level were achieved faster. This was in agreement with the findings of Oje (1993) [26], Oyeleke and Olaniyan (2007) [33], Aviara *et al*., (2008) [7], Olaniyan (2010), Adebayo *et al.*, (2014) [8], Olaniyan and Obajemihi (2014).

From Fig 3.3, an increase in operating speed with fruit blanching time resulted in an increase in the juice extraction efficiency and then a decrease in extraction efficiency. At lower temperature levels, evaporation causes the surface of the sample to harden, thus requiring a higher pressure or speed to overcome the hardened sample during extraction. This agrees with the findings of other researchers.

The results obtained for an increase in blanching temperature and feed rate as presented in Fig 3.4, leads to a corresponding increase in juice extraction efficiency. However, at higher temperatures and material feed rate, the extraction efficiency decreased. At higher blanching temperatures, protein coagulation and viscosity reduction take place at a faster rate leading to increase in the fluid flow at less feeding rate durations; while extending the increasing the feeding rate at higher blanching temperatures caused substantial moisture loss leading to hardening of samples which consequently leads to a decrease in extraction efficiency.

As depicted in Fig 3.5, an increase in feed rate and blanching time leads to a corresponding increase in juice extraction efficiency; however, at higher material feeding rate and blanching time, the extraction efficiency decreases. Heating the samples makes the mesocarp soft with a consequent reduction in the fluid viscosity. The softening of tissues weakens the cellular structure, making it highly liable to failure under applied pressures. However, according to Bargale *et al.*, (1999) [12], temperature decreases the viscosity of the juice thereby increasing its fluidity through the compressed medium, whereas an increase in pressure makes the fibre harder which restricts the flow of the liquid.

In Fig 3.6, an increase in fruit blanching time with blanching temperature leads to corresponding increase in the juice extraction efficiency, and then extraction efficiency decreases at higher temperature. Heating the samples at prolonged times makes the fruit brittle with a consequent reduction in liquid viscosity. The softening of fruit cells weakens the cellular structure, making it highly liable to failure under pressure.

The result obtained in Fig 3.7 showed that increase in operating speed and feed rate resulted in an increase in extraction capacity after which there was a corresponding decrease in extraction efficiency at higher speed. From Fig

3.8, it is clear that the extraction capacity of the machine increased with increase in the machine operating speed and blanching temperature, after which there was a decline in extraction capacity. This was in agreement with the findings of Aviara *et al.*, (2008) [7], Olaniyan (2010).

Fig 3.9 showed that an increase in operating speed with fruit blanching time leads to an increase in the juice extraction capacity and then a decrease in extraction capacity. At lower temperature levels, evaporation causes the surface of the sample to harden, thus requiring a higher pressure or speed to overcome the hardened sample during extraction.

In Fig 3.10, an increase in blanching temperature and feed rate leads to a corresponding increase in extraction capacity. However, at higher temperatures and material feed rate, the extraction machine capacity decreased. At higher blanching temperatures, protein coagulation and viscosity reduction take place at a faster rate leading to increase in the fluid flow at less feeding rate durations; while extending the increasing the feeding rate at higher blanching temperatures caused substantial moisture loss leading to hardening of samples which consequently leads to a decrease in extraction capacity.

The result in Fig 3.11 showed that an increase in feed rate with blanching time leads to a corresponding increase in juice extraction capacity; however, at higher material feeding rate and blanching time, the extraction capacity decreases. Heating the samples makes the mesocarp soft with a consequent reduction in the fluid viscosity. The softening of tissues weakens the cellular structure, making it highly liable to failure under applied pressures. However, according to Bargale *et al.*, (1999) [12], temperature decreases the viscosity of the juice thereby increasing its fluidity through the compressed medium, whereas an increase in pressure makes the fibre harder which restricts the flow of the liquid. This agrees with the findings of other researchers.

In Fig 3.12, an increase in fruit blanching time with blanching temperature leads to corresponding increase in the juice extraction capacity, and then extraction capacity decreases at higher temperature. Heating the samples at prolonged times makes the fruit brittle with a consequent reduction in liquid viscosity.

Considering the model with the highest R^2 value and lower standard deviation, quadratic model was selected to predict the percentage juice extraction efficiency and juice extraction capacity using the developed fruit juice extractor as depicted in Tables 3.2 and 3.4. The positive terms in the equation signify direct relationship between the extraction process conditions and their interactions with extraction efficiency (EE) and extraction capacity (EC), while the negative terms signify an inverse relationship between the extraction process conditions with extraction efficiency (EE) and extraction capacity (EC). It was observed that all the juice extraction process parameters have direct relationship with EE and EC. This implies that both EE and EC exhibited an increase with increase in the extraction process parameters. Feed rate was found to be the most significant parameter which affects EE and EC.

The Model F-values of 3.60 and 3.41 in Tables 3.3 and 3.5 respectively implies that the model is significant. Respectively, there are only 0.95% and 1.22% chances that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, D, A^2, C^2, D^2 are significant model terms, where A, B, C and D represent operating speed, feed rate, blanching temperature and blanching time respectively (Tables 3.3 and 3.5). This implies that the operating speed, feed rate, blanching temperature and blanching time all have significant effects on the juice extraction efficiency and extraction capacity with the operating speed having the greatest influence on the extraction efficiency and capacity. Therefore, the four juice extraction process conditions influenced the quantity of juice from the fruit using the developed juice extraction machine. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. However, that is not necessary for the selected model as there are several significant terms.

The "Lack of Fit F-values" of 1258.87 as represented in Table 4.3 implies the Lack of Fit is significant. There is only a 0.01% chance that a "Lack of Fit F-value" this large could occur due to noise. Significant lack of fit is bad as the aim is for the model to fit. ‘‘Adeq Precision’’ measures the signal-to-noise ratio. A ratio greater than 4 is desirable. Therefore, the ratio of 7.104 indicates an adequate signal (Table 3.2). This model can be used to navigate the design space. The model was significant with a very low probability value (0.0095) and a satisfactory coefficient of determination (R^2 = 0.77). The high coefficient of determination showed excellent correlations between the independent variables (dehydration parameters. This value indicates that the response (extraction efficiency) model can explain 77% of the total variability in the response.

The "Lack of Fit F-value" of 2.98 as depicted in Table 3.5 implies the Lack of Fit is not significant relative to the pure error. There is a 12.02% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good as the aim is for the model to fit. ‘‘Adeq Precision’’ measures the signal-to-noise ratio. A ratio greater than 4 is desirable. Therefore, the ratio of 6.617 indicates an adequate signal (Table 3.4). This model can be used to navigate the design space. The model was significant with a very low probability value of 0.0122 and a satisfactory coefficient of determination, R2 of 0.76. The high coefficient of determination showed excellent correlations between the independent variables (operating speed, feed rate, blanching temperature and blanching time). This value indicates that the response (extraction capacity) model can explain 76% of the total variability in the response.

From the optimization result as represented in Figs 3.13 and 3.14 for the maximum optimum predicted values in the range of 200 - 600 rpm for operating speed, 0.5 - 2.5 kg/min for feed rate, 0 - 80ºC for blanching temperature and 0 - 12 mins for blanching time, the predicted optimum extraction efficiency of 81.32 % and extraction capacity of 3.89 L/min with desirability of 97.7% at optimal operating speed of 525.23 rpm, feed rate of 2.13 kg/min, blanching temperature of 54.20ºC and blanching time of 8.73 min was obtained.

A test run under the obtained optimal juice extraction process conditions of operating speed of 525.23 rpm, feed rate of 2.13 kg/min, blanching temperature of 54.20ºC and blanching time of 8.73 min respectively, was carried out in order to validate the quadratic model for both the EE and EC of the developed fruit juice extraction machine, an experimental EE and EC values of 81.56% and 3.57% was obtained respectively.

In comparison of the predicted and experimental results for the optimum EE and EC, it can be seen that there was an excellent agreement between the experimental and predicted values for extraction efficiency and extraction capacity as obtained from the parity plot between the predicted and the actual values as shown in Figs 3.13 and 3.14. The correlation between the predicted and experimental values for the juice extraction efficiency and extraction capacity gave an R^2 values of 0.7707 and 0.7609 respectively which indicated that the predicted values and experimental values have a reasonable agreement. The deviation between predicted and experimental values were found to be low and ranged between 0.01- 0.40 for extraction efficiency and 0.01 - 0.82 for extraction capacity. Hence, the generated quadratic model has the accuracy to predict both the EE and EC of orange using the developed fruit juice extraction machine.

The cost analysis for the produced juice extractor machine shows that it costs $99.87 to produce, while the imported version costs $200. It is therefore more cost effective to produce the juice extractor locally than to import it into the country. This further strengthens the argument that mechanization can be enhanced through local production of machinery (Bawa, 2025) [13].

5. Conclusion

The following conclusions were drawn from this study on the ‘development, testing, and extraction process optimization of a motorized juice extractor’:

1. The performance of the developed fruit juice extraction machine was satisfactory as evident from the juice extraction efficiency and extraction capacity.

2. The quadratic models were chosen to predict the EE and EC. It was ascertained that extraction processing parameters influence the EE and EC.

3. For the range of variables considered in the performance analysis of the machine, maximum EE of 83.66% was obtained at the machine operating speed of 400 rpm, feed rate of 1.5 kg/min, blanching temperature of 80°C and blanching time of 6 min, while the maximum EC of 3.89 L/min was obtained at the machine operating speed of 500 rpm, feed rate of 1.0 kg/min, blanching temperature of 60°C and blanching time of 9 min.

4. Predicted optimum EE and EC of 81.32% and 3.89 L/min respectively at operating speed of 525.23 rpm, feed rate of 2.13 kg/min, blanching temperature of 54.20°C and blanching time of 8.73 min was obtained with a desirability of 0.977. Under these optimal juice extraction process conditions, the experimental values of 81.56% and 3.57 L/min were obtained for EE and EC respectively.

4. The deviations between experimental and predicted values were low and statistically insignificant.

5. The coefficient of determination (R^2) of 0.77 and 0.76 for EE and EC respectively, show that there is an excellent correlation between the juice extraction parameters (independent variables). 6. Consequently, in view of the range of variables investigated, the chosen models have the adequacy to predict the extraction efficiency and extraction capacity for fruit juice using the developed machine.

7. The developed fruit juice extraction machine serves as a viable option for the small scale fruit juice processors.

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How to Cite This Article

Bawa P A, Aondona P T, Odeh E U, Antia J N, Ihom A P. Development, testing, and extraction process optimization of a motorized juice extractor. Int J Future Eng Innov. 2026;3(2):51–75. doi:10.54660/IJFEI.2026.3.2.51-75

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