EFFECTS OF EXPRESSION PRESSURES AND DISC SHAPES ON THE EXTRACTION EFFICIENCY aOF A FRUIT JUICE EXTRACTOR

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ABSTRACT

A developed fruit juice extractor was studied for its performance. Some parameters like, expression pressures and pressure disc shapes diameters were varied to determine their effects on its extraction efficiency using Response Surface Methodology (RSM). Three levels of expression pressures (80 ,100 and 120 N/mm^2) and three different diameters of its concave and convex discs pressure plates (60,80 and 100 mm) were investigated. The highest extraction efficiency of 71.95 % was obtained when the convex disc diameter was 100 mm and the expression pressure was 120 N/mm^2. Further RSM analysis showed that the linear effects of expression pressures and convex disc diameter of the juice extractor were significant to its extraction efficiency at 5% probability ($P \leq 0.05$). Also significant are the quadratic effects of concave and convex disc diameters, interactions of expression pressures and concave disc diameters, interactions of expression pressures and convex disc diameters and interactions of concave and convex disc diameters. These factors accounted for about 98.58 % of the variations in the extraction efficiency of the machine.

Keywords: juice extractor, concave and convex discs, expression pressure, extraction efficiency, response surface methodology.

INTRODUCTION

Production of fruits in Nigeria can be estimated at hundreds of thousands of metric tons per year, unfortunately, over 50 % are lost due to perishable nature of fruits occasioned by high moisture content and poor post-harvest handling and marketing strategies (Otterloo, 1997). This shows that fruits juice is the next best thing to fresh fruits, and can be packaged in aseptic, easily transported containers that are less susceptible to damage and have a relatively long storage life. Juice extraction and separation therefore open up new market opportunities for tailoring fruit products to modern consumers. Hygienic problems due to local methods of preservation and juice extraction, time and energy wastage in hand- squeezing the fruit singly or manually and economic losses due to lack of affordable extracting and processing machines will be something of past with introduction of a semi-mechanized fruit juice extractors to the market at affordable prices to average farmers or medium scale industrialists (Bamigbade, 2002).

Oranges, lemon, limes, grape fruits and tangerines are member of the class of fruits known as citrus fruits (Olife *et al.*, 2015). It is universally acknowledged that citrus fruits emanated from North Eastern India Ortese *et al.*, (2012). The Federal Department of Agriculture and Missionaries in the 1930s introduced citrus fruits to Nigeria. Since its introduction, the cultivation of citrus fruit has spread to every part of the country (Oyedele and Yahaya 2010).

The market available for citrus fruits is the fresh fruit market and the processed citrus fruits market chiefly for orange juice (Olife *et al*., 2015).Sweet orange (*citrus sinensis*) accounts for the most produced citrus fruit with a global production forecast for 2016/2017 at 2.4 million metric tons (USDA, 2017). Citrus and citrus products contain very high nutritional contents; they are rich and cheap sources of vitamins (particularly vitamin C), minerals and dietary fibre which are essential for healthy living. In 2007, Nigeria was ranked 9th in the world citrus production; producing about 3,325,000 tons (Oyedele and Yahaya 2010). Orange (hesperidia) is a specialized type of berry and the structure consists of a soft, pithy central axis surrounded by 10-15 segments which contains the pulp and juice. The segment is enveloped in the oily rind leathery mesocarp which exposes a white spongy inner part and a harder, orange coloured outer part that contains many glands which secrete oil. Contained in the segment juice are sugar, organic acid (mainly citric acid) and several other components that give the orange its unique taste. Orange is a rich source of vitamins A, B and C (Sylvester and Abugh, 2012).

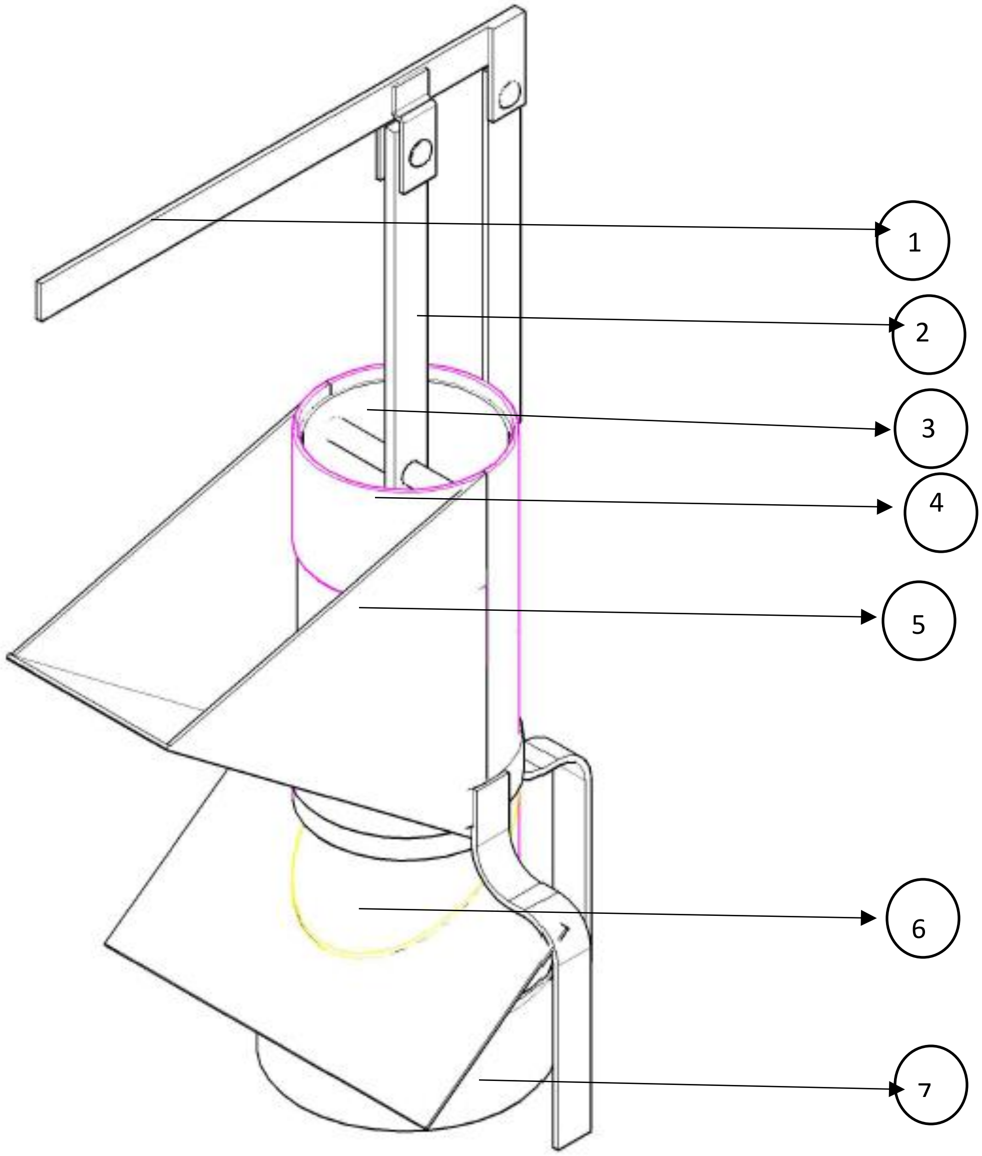
Fruit juices are categorized as those with and without pulp. Other classification includes natural juice (product obtainable from a fruit) and mixed juice (obtainable from the mixing of two or more fruits of different fruit species or by adding sugar). Juice obtained by removal of a major part of their water content by vacuum evaporator or fractional freezing are defined as concentrated juice (Wills *et al.*, 1998).

Fruit cell wall is made of cellulose, hemicelluloses, peptic substance and proteins (Ashurt, 1991). Fruit juice extractor is a postharvest machine that is used in pressing of citrus fruit in order to get juice. Fruit juice extraction involves the process of crushing, squeezing and pressing of whole fruit in order to obtain the juice and reduce the bulkiness of the fruit to liquid and pulp. Hand extraction of juice is slow and tedious and also not hygienic enough. The merits of using machine for extraction are: time saving, improved efficiency, increased capacity and reduction in spoilage and waste (Tressler and Joslyn, 2005).According to (Etoamaihe *et al.,* 2018),the machine parameters likely to affect the extraction efficiency of a juice extractor are the expression pressures and diameters of its concave and convex pressure discs. Hence the need for this research work. Response Surface Methodology using Central Composite Design was used to design the experiments (NIST/SEMATECH, 2012). Three factors, namely expression pressures, the concave and convex pressure disc diameters of the juice extractor were investigated as they affected the juice extraction efficiencies of the machine.

MATERIALS AND METHODS

Description of the Semi-mechanized Juice Extractor

A semi mechanized citrus juice extractor was developed (Etoamaihe *et al.,* 2018). The semi-mechanized citrus juice extractor comprises a perforated convex cup, where the half cut citrus is placed face down. Directly beneath the convex cup is the collector cup for the extracted juice. Above the convex cup is a concave cup designed to press the citrus on the perforated convex cup. The concave cup is directly attached on its top to the screw press mechanism, controlled by a handle designed to manually exert the desired expression pressure on the concave cup that depresses the citrus on the convex cup so that juice can be extracted. A hopper for stocking the half cut citrus (orange) is located by the side of the convex cup. The whole mechanism is linked to a solid steel frame. The collector cup, convex and concave cups are made of stainless steel materials, while other parts of the machine are made of mild steel. The isometric drawing of the machine is shown in Figs. 1. The picture of the developed machine is shown in



1=Handle

2 = Main Shaft

3=Pressing Shaft

4= Convex Cup

5= Hopper

6 = Concave Cup

7= Collector Cup

Fig 2.

Fig.1: Isometric Drawing of the Semi-mechanized Citrus Juice Extractor

Fig 2: The Developed Semi-mechanized Citrus Juice Extractor

Experimental Design and Research Methodology

After the development of the machine, tests were carried out to determine its extraction efficiencies as they relate to the expression pressures developed by the machine, the concave and convex disc sizes of the machine using Response Surface Methodology. The extraction efficiency was obtained by using the expression given by Olaniyan and Oje 2011, as;

$$Ef = {}^{100Wj}\!/_{xWh} \quad \% \qquad (1)$$

Where;

Ef= Extraction efficiency (%)

Wj= Weight of juice expressed (g)

x =Juice content of citrus in decimals, experimentally determined as 0.56 (Olaniyan and Oje 2011).

Wh=Weight of whole citrus (g)

For the RSM analysis, the regression analysis was carried out with Minitab 16 software, while the response surface graphs were plotted with Matlab R2015a software.

In the design the linear, interactive and quadratic effects of the factors (independent variables) as they affect the response (juice extraction efficiency) were studied (Etoamaihe,2015,Agriga, 2008). Three levels of each of the factors were shown in Table 1.

Table 1: Experimental Variables Used in the Design

Independent Variables	Variable Levels		
Expression Pressures, X1	80 N/mm^2	100 N/mm^2	120 N/mm^2
Concave Disc diameters, X2	60 mm	80 mm	100 mm
Convex Disc diameters, X3	60 mm	80 mm	100 mm
Code Designation	1	0	-1
Dependent Variable (Response)			
Juice Extraction Efficiency (%) Y			

RESULTS AND DISCUSSIONS

The experimental variables and coding are shown in Table 1, while the experimental results with the independent variables (in coded terms) are shown in Table 2. The estimated regression coefficients for extraction efficiency versus expression pressures, concave and convex disc diameters of the juice extractor are shown in Table 3, while the analysis of variance associated with the regression are shown in Table 4. From Table 3, the linear effects of expression pressures and convex disc diameter of the juice extractor were significant to its extraction efficiency at 5 % probability ($P \leq 0.05$). Also significant are the quadratic effects of concave and convex disc diameters, interactions of expression pressures and concave disc diameters, interactions of expression pressures and convex disc diameters and interactions of concave and convex disc diameters. These factors accounted for about 98.58 % of the variations in the extraction efficiency of the juice extractor.

Table 2: Experimental Results of Independent Variables and Response in Coded Terms

Runs	X1	X2	X3	Y
1	0	0	-1	65
2	0	0	0	60
3	0	0	0	61
4	0	0	0	59
5	0	0	0	60
6	0	-1	0	53
7	-1	-1	-1	50
8	-1	1	1	51
9	-1	1	-1	49
10	1	1	-1	72
11	-1	0	0	56
12	1	-1	-1	62
13	0	0	0	59
14	1	1	1	65
15	1	-1	1	66
16	0	0	1	67
17	0	0	0	60
18	1	0	0	67
19	-1	-1	1	62
20	0	1	0	55

Table 3 : Response Surface Regression: Y versus X1, X2, X3

Term	Coef	SE Coef	T	P
Constant	60.1545	0.3499	171.903	0.000
X1	6.4000	0.3219	19.883	0.000
X2	-0.1000	0.3219	-0.311	0.762
X3	1.3000	0.3219	4.039	0.002
X1*X1	0.8636	0.6138	1.407	0.190
X2*X2	-6.6364	0.6138	-10.812	0.000
X3*X3	5.3636	0.6138	8.738	0.000
X1*X2	2.6250	0.3599	7.294	0.000
X1*X3	-2.1250	0.3599	-5.905	0.000
X2*X3	-2.6250	0.3599	-7.294	0.000

S = 1.01791
R-Sq = 98.58%

The regression equation is given as;

Y= 60.16+6.40X1-0.10X2+1.30X3+0.86X1^2-6.64X2^2+5.36X3^2+2.63X1X2-2.13X1X3-2.63X2X3
(2)

Where Coef = regression coefficients, SE Coef = Standard error of regression coefficient
T = Tabulated values of the regression parameters, P = Probability values of the regression terms, S = Standard error , R = R-squared (A standardized measure of the goodness of fit of the regression model).
The regression equation (16) was generated by the software and shows the actual numerical values of the independent variables as they affected the response.

Table 4: Analysis of Variance for Y

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	720.589	720.589	80.065	77.27	0.000
Linear	3	426.600	426.600	142.200	137.24	0.000
X1	1	409.600	409.600	409.600	395.31	0.000
X2	1	0.100	0.100	0.100	0.10	0.762
X3	1	16.900	16.900	16.900	16.31	0.002
Square	3	147.614	147.614	49.205	47.49	0.000
X1*X1	1	0.050	2.051	2.051	1.98	0.190
X2*X2	1	68.450	121.114	121.114	116.89	0.000
X3*X3	1	79.114	79.114	79.114	76.35	0.000
Interaction	3	146.375	146.375	48.792	47.09	0.000
X1*X2	1	55.125	55.125	55.125	53.20	0.000
X1*X3	1	36.125	36.125	36.125	34.87	0.000
X2*X3	1	55.125	55.125	55.125	53.20	0.000
Residual Error	10	10.361	10.361	1.036		
Lack-of-Fit	5	7.528	7.528	1.506	2.66	0.154
Pure Error	5	2.833	2.833	0.567		
Total	19	730.950				

Where,DF =Degrees of freedom . Seq SS = Sum of squares. Adj SS = Adjusted sum of squares. Adj MS = Adjusted mean squares. F = Value of the restriction test on the regression model. P = Probability values of the regression terms.

The analysis of variance Table 4, also confirmed the stated results. From the response surface curve in Fig. 3, the highest extraction efficiency of 63.31 % was obtained when the concave disc diameter was 100 mm and the expression pressure was 120 N/mm^2 while in Fig. 4 the overall highest extraction efficiency of 71.95 % was obtained when the convex disc diameter was 100 mm and the expression pressure was 120 N/mm^2. In Fig 5, the highest extraction efficiency of 67.02 % was obtained when the convex disc diameter was 82 mm and concave disc diameter was 100 mm. These findings are in line with the observations of Olaniyan and Oje 2011.

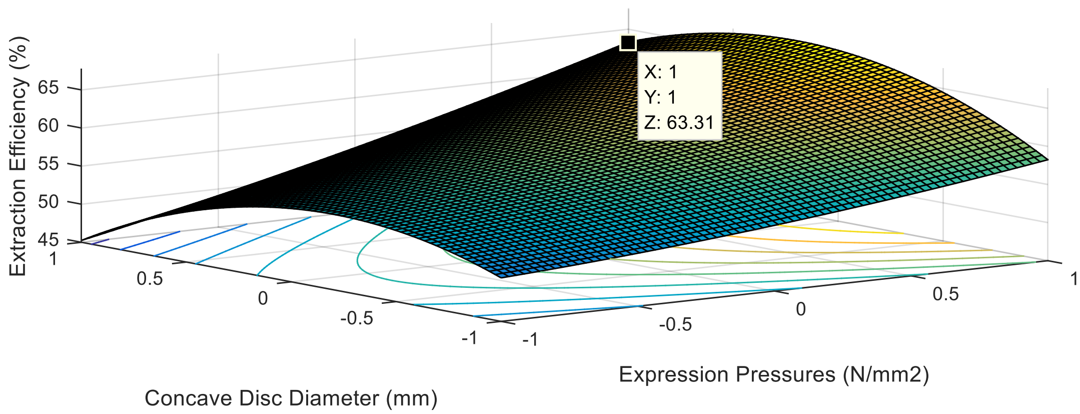


Fig 3: Response Surface Curve of the Effect of Concave Disc Diameter and Expression Pressures on the Extraction Efficiency of the Machine

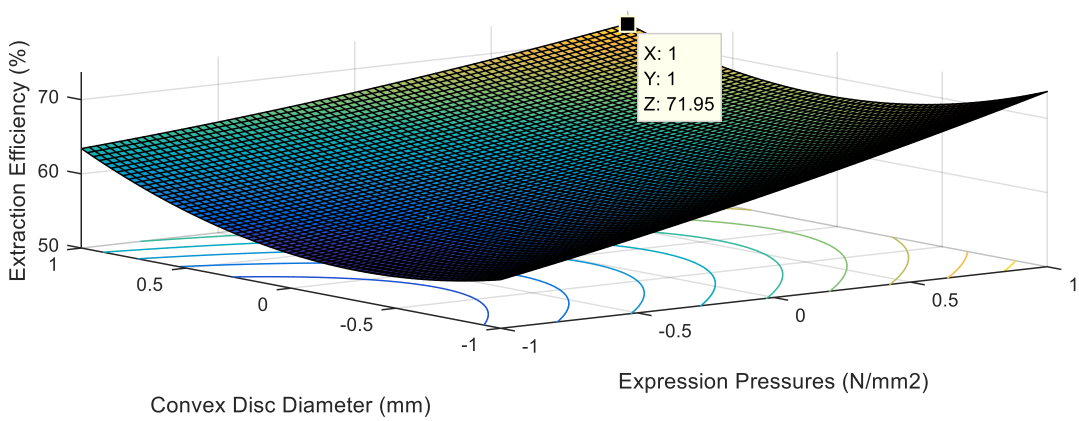


Fig 4: Response Surface Curve of the Effect of Convex Disc Diameter and Expression Pressures on the Extraction Efficiency of the Machine

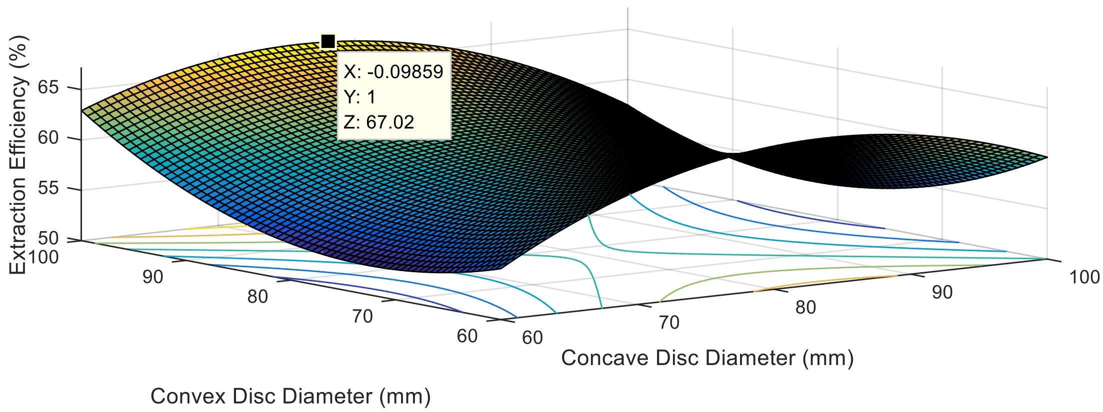


Fig 5: Response Surface Curve of the Effect of Convex Disc Diameter and Concave Disc Diameter on the Extraction Efficiency of the Machine

CONCLUSIONS

Three machine parameters (expression pressures, concave and convex pressure discs' diameters) were studied as they affected the extraction efficiency of a fruit juice extractor. From results and analysis, it was observed that the extraction efficiency increased with the expression pressures and diameters of the concave and convex pressure discs' diameters. The highest extraction efficiency of 71.95 % was obtained when the convex disc diameter was 100 mm and the expression pressure was 120 N/mm^2.

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