The Development of a Manually operated Cashew Juice Extractor

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ABSTRACT

A manually operated cashew juice extractor operating on screw press principle was designed, constructed and tested. Apple crushing was by pressing a wooden piston against a steel reinforced end plate. Juice output was 1.02 litres/hr and the average juice extraction efficiency was 85.38 %. Three samples of the juice (fresh juice, juice stored under ambient conditions for 24hrs and refrigerated juice at 5^{o}C) were tested for sensory evaluation. The results indicated a significant difference ($p<0.05$) between the colour, taste and general acceptability of juice under ambient storage when compared with fresh juice; but there was no significant difference in the mouth feel. There was no significant difference between the colour, taste and mouth feel of the refrigerated juice and fresh juice; but the difference in general acceptability was significant. The refrigerated juice had the highest general acceptability by the panelists. The physico-chemical characteristics show that appearance, specific gravity, pH and total soluble solids of the juice are affected significantly ($p<0.05$) by storage under ambient conditions but only the specific gravity changed significantly ($p<0.05$) during refrigeration. The vitamin C content of the refrigerated juice was higher than juice stored under ambient conditions. A device of this nature can be manufactured in small machine shops in the cashew producing developing countries for village level applications.

Keywords: Cashew juice, extractor, fresh juice, stored juice, Nigeria

1. INTRODUCTION

The cashew tree (*Anacardium occidentale*) originated from Brazil and was introduced to Nigeria in the 16th century by the Portuguese explorers (Agnoloni and Giuliani, 1977; Ohler, 1979 and Olunloyo, 1996). Among most horticultural crops, cashew is known to provide high economic returns because of the foreign exchange earning obtainable from the raw or processed nuts, which is widely consumed in Europe, America and Asia. With a current annual cashew nut output of 636,000 tons (FAO report in Wikipedia, 2008), cashew apple production in Nigeria is estimated as 1.8 million tons per annum; of which only 6-10 % is consumed either as fresh fruit or in few cases processed into fruit drinks (Azam-Alli and Judge, 2001; Oduwole *et al*, 2001); the rest get wasted; cashew apple being highly perishable. (Olunloyo, 1996).

Ohler (1979) reported that cashew apple contains 85 % juice, 10 % of which is sugar. It is rich in ascorbic acid, thiamine, niacin and riboflavin and thrice as rich in vitamin C as sweet orange (Morton, 1987 and Akinwale, 1996). Agnoloni and Giuliani (1977) reported that raw cashew apple juice has some medicinal value. It is taken as a cure for stomach disorder and sore throat infections (Olunloyo, 1996). In Bolivia, it is taken as a brain stimulant because there, it is believed to enhance human memory (Agnoloni and Giuliani, 1977). These apart, cashew apple can be processed as wine, gin, brandy, syrup, vinegar and jam (Ohler, 1979; Morton, 1987; Aderiye *et al.*, 1991; Andrighetti *et al.*, 1994; Akinwale, 1996; Oduwole *et al.*, 2001; Ogunsina, 2005 and Wikipedia, 2008); some of which are produced in commercial scale in Brazil, India and Mozambique (Lopez *et al.*, 1985 and Olunloyo, 1996). Considering the fact that cashew apples are harvested over a period of 4 months during the year (Costa *et al*, 2003); its use as a resource for a variety of fruit based products can trigger revolution in the cashew industry. This apart from making cashew juice products available year round will equalize supply from one year to another and will improve earnings on cashew for rural farmers.

Extraction variables such as heat treatment and duration of treatment were reported to affect the colour, acidity and vitamin C content of cashew fruit juice however soluble solids, pH, and specific gravity of the juice are not affected by heat treatment (Akinwale *et al.,* 2001). Smoot and Naggy (1980) reported that storage temperature and duration affects the total vitamin content of grape fruit juice. Miguel *et al.,* (2004) investigated the effect of two extraction methods of pomegranate (*Punica granatum*) juice on its quality and stability during storage at $4^{o}C$ was evaluated. The first method consist seeds separation from fruits and centrifugation. The second method consist squeezing fruit halves with an electric lemon-squeezer. No significant difference was observed in the physico-chemical properties of the juices. Yusof (2000) found that sugar canes stored at 10°C was able to maintain the quality of juice for up to 9 days while those stored at 5°C last only 4 days .

Several juice extractors developed for fruits such as citrus, mango, and pineapple are unsuitable for cashew, because of their low efficiency of extraction and poor quality of the juice produced, when used for cashew juice extraction (Famuyiwa, 1983). The need for a special extractor for cashew apple stems from its total succulence, lack of distinct peel, absence of seed within the juicy pulp, high tannin content and corrosive action when in contact with mild steel. This paper reports the development of a manually operated cashew juice extractor.

2. MATERIAL AND METHOD

2.1 Materials Selection and Machine Description

Construction materials were selected based on their availability, durability, cost and corrosion resistant properties. Stainless steel was used for the hopper and cylinder because of the corrosiveness of cashew juice. Teak (*Tectona grandis*) was used as construction material for the piston, end plate and frame owing to its durability, strength, stability, availability and traditional use for domestic purposes. The juice collector was a plastic bowl. The component parts of the machine are: the hopper, cylinder, power-screw/piston assembly, handle, endplates, frame and juice collector/strainer.

2.2 Philosophy of Design

In this design the use of screw press to obtain a large mechanical advantage on a piston's face to crush cashew apples was adopted for juice extraction form cashew apples. The pressure that was made available on the piston's face was greater than the minimum pressure required to cause failure of the fruit so that it will be able to crush it and make the juice bearing cells release their contents. As the screw moves steadily along its horizontal axis, the piston's face drags the apple against the end plate and increases the pressure thereof to produce a squeezing effect on the apple.

2.3 Determination of the Pressure Required to Crush Cashew Apple

The method for determining oil point pressure documented by Sukuruman and Singh (1989), Ajibola *et al.* (2000) and Ajibola *et al.* (2002) using a laboratory press (Fig. 1) was adopted to determine the pressure required to crush cashew apple. In Fig. 1, the lever arm with dead weight of 90 kg and an effective length of 3000 mm transfers pressure. The weight of the loading drum was 30 kg. The pressure transferred from the lever arm to the sample in the test cylinder through the point load and compression piston was varied by moving the cylinder and its content along the lever arm. The test cylinder was a 100 mm long galvanized steel pipe with an internal diameter of 85 mm. The cylinder has one of its ends closed with a 12 mm thick metal base with 2 mm holes drilled at a pitch of 15 mm. The compression piston is a solid steel cylinder, 75 mm long and 70 mm in diameter. A 20 metric tons hydraulic jack was used to raise and lower the lever bar for applying pressure to the sample. The cylinder containing the sample was placed under the compression piston. Known weight was added to the loading drum while the lever arm was suspended by the hydraulic Jack. The jack was released gently to allow the suspended lever arm to lower down gradually to rest on the pressing ram and compression piston. The pressure generated was transferred through the cylinder onto the apple. The pressure at which there was failure of the fruit and discharge of juice through the holes on the cylinder was taken as the required pressure during each trial. The jack was then used to lift the lever arm in order to remove the cylinder and piston. The distance from this point to the support was measured and converted to pressure using the principle of moment of forces. This was repeated 10 times and the average value was calculated as 271.62 kPa (Table 1)

2.4 Design Considerations

i) The design load was taken as 300 kPa based on the results of compression test
ii) The average minimum axial force obtainable from an adult human being as a power unit was taken as 200 N, and this wasassumed to be sufficient to develop the torque needed at a screw length of 300 mm (Sanders and McCormicki, 1987)
iii) The power screw thread is square and in a single revolution, the charge of apples is advanced

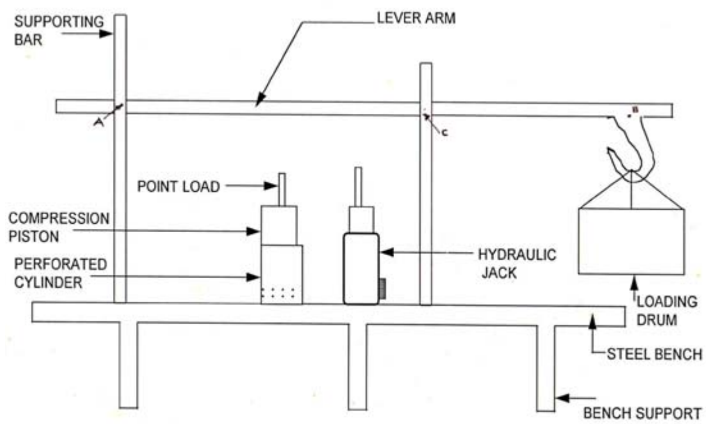

Fig. 1. Schematic diagram of the laboratory press
(Ajibola *et al.,* 2000, Ajibola *et al.,* 2002).

Table1: Determination of the pressure required to crush cashew apple

Trial/number	Pressure (kPa)
1	273.0
2	270.53
3	269.62
4	272.41
5	270.36
6	273.88
7	274.23
8	267.11

9	270.00
10	275.06
Average	271.62

by one pitch of the thread (Rothbart, 1985); the screw has a mean diameter of 13 mm, a thread thickness of 2 mm and pitch P_o of 4 mm.
v) In one stroke of the piston, juice is squeezed from 3 – 5 apples, the volume of which was determined to be 1.2 x 10^{-3} m^3.
vi) The density of steel is 7800 kg/m^3 and g = 10 m/s^2

2.4.1 The Hopper

The hopper was designed to accommodate the allowable volume of apples per stroke of the piston 1.2 x 10^{-3} m^3. At the base of the hopper was a square funnel with a shutter to discharge the apples into the cylinder by gravity. With a 1.6 mm stainless steel plate, the volume of the hopper occupied by steel was 1.4 x 10^{-4} m^3; therefore, its weight was obtained as 10.92 N.

2.4.2 The Cylinder

The cylinder was fabricated from a 1.6 mm stainless steel sheet to 85 mm diameter, and 400 mm length. The square feed funnel of the hopper sits on an 80 mm x 80 mm opening 150 mm from the drive end of the cylinder. The extraction chamber of the cylinder was perforated at the base to allow for juice extract to drain out. The volume of the cylinder was 2.09 x 10^{-4} m^3; therefore, its weight was calculated as 16.92 N.

2.4.3 The Power Screw

The power screw was considered as a long column with one end fixed when under stress as in Fig. 2. It was designed to bear a critical buckling load of 64.6 kN, which is far less than 1.2 kN; the required maximum load to crush cashew apple and express juice from it. Euler's equation for critical load for slender column of uniform cross-section was given by Hall *et al* (1987) as:

$$F_{cr} = \frac{c\pi^2 EA}{(L/k)^2} \qquad (1)$$

The solution for equation (1) therefore gives F_{cr} = 64.6 kN

With the power screw of diameter 13 mm, the buckling load is 64.6 kN, which is greater than 1200 N (the load required to crush cashew apple and express the juice in it) which proves the appropriateness of the chosen diameter.

The force required to overcome the load on the power screw (Rothbart, 1985) is as follows. The load Q opposes the direction of motion of the power screw from Fig. 3. By vector solution:

$$\tan\alpha = \frac{P_o}{Q} \tag{2}$$

From section 2.3(iii), P_o = 4 mm, and d = 13 mm, and Q=2π hence,

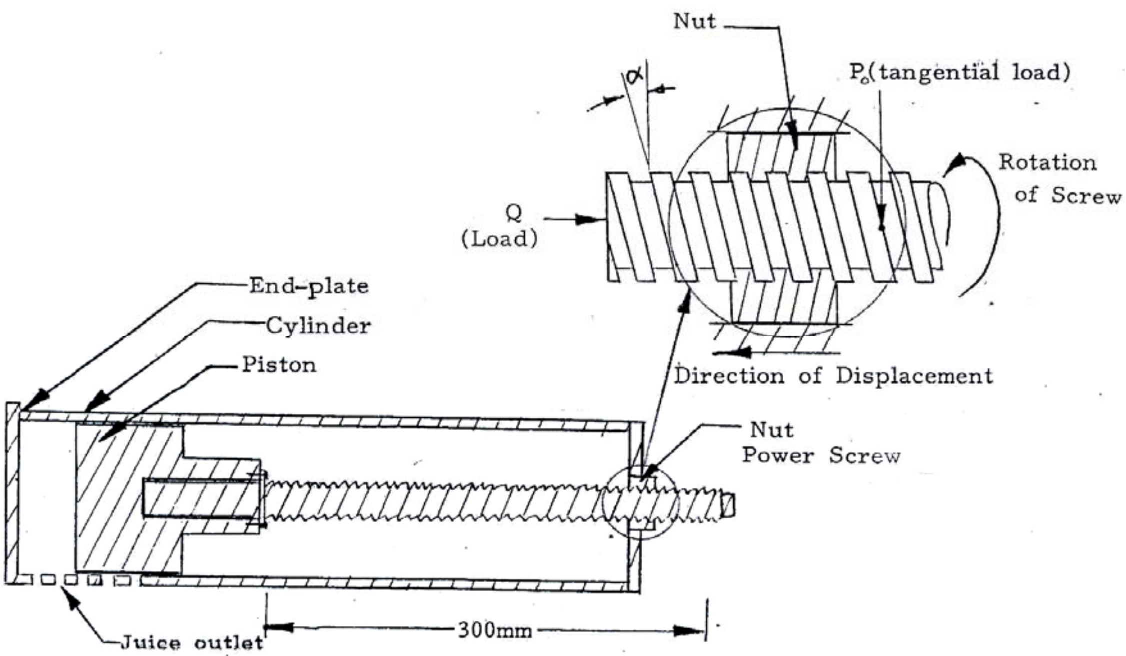

Figure 2. A section through the power screw/cylinder assembly showing the forces acting on the power screw

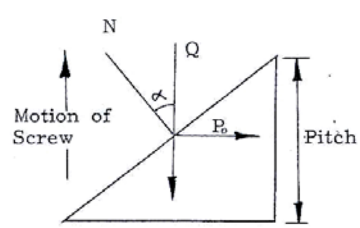

Figure 3. The vector solution of force P_o required for overcoming load Q neglecting friction

$$\tan\alpha = \frac{4}{2\pi}\left(\frac{13}{2}\right) = 0.0979$$

$$\text{i.e. } \alpha = 6^o$$

The Torque T to be developed is given by Hall *et al*., (1987) as:

$$T = w\left[r_m \left(\frac{\tan\alpha + \dfrac{f}{\cos\theta_n}}{1 - \dfrac{f\tan\alpha}{\cos\theta_n}} \right)\right] + f_c r_c \tag{3}$$

$$T = 1200\left[0.0065\left(\frac{0.09794 + \dfrac{0.15}{0.866}}{1 - \dfrac{0.15(0.09794)}{0.866}}\right)\right] + 0.25(0.0055) = 13.80 \text{ Nm.}$$

The volume of the power screw = $\pi r_m^2 L$ (4)

$= \pi(0.0065)^2\ 0.4$ m^3
$= 5.31 \times 10^{-5}$ m^3

taking $g = 10m/s^2$ and the density of steel as 7800 kg/m^3

Weight of the power screw = 7800 x 5.31 x 10^{-5} x 10 = 4.14 N

2.3.4 Design of the Turning Handle

The turning handle is made up of the hold and crank bar. The hold is a 25 mm wooden rod made of teak 120 mm in length (Fig. 4). The Torque T required to turn the screw can be expressed as:

$$T = F_h L_h \tag{5}$$

Therefore $$L_h = \frac{T}{F_h} = \frac{13.8Nm}{200N} \quad = \quad 69 \text{ mm}$$

However for ease of operation, a crank bar of length L_h = 130 mm was chosen. Considering the bar of length L_h as having breadth b_h and thickness h_h, the formula stated below can be applied.

$$S_b = \frac{Mc}{I} \tag{6}$$

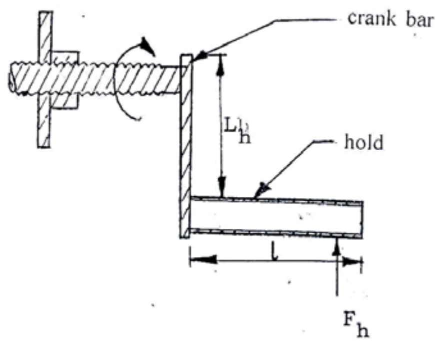

Figure 4. A section through the turning handle assembly

Substituting M, c and I as indicated in the list of notations, equation (6) becomes

$$S_b = \frac{M \times \frac{1}{2} h_h}{\frac{b_h h_h^{\,3}}{12}} = \frac{6M}{b_h h_h^{\,2}} \tag{7}$$

$$b_h h_h^{\,2} = \frac{6M}{S_b} = \frac{6 \times 13}{70 \times 10^6} = 1.11 \times 10^{-6} m^3$$

Taking b_h as 30 mm gives h_h = 6.1 mm.

The specification for the crank bar are L_h = 130 mm, b_h = 30 mm and h_h = 6 mm

The weight of the handle = weight of bar + weight of wooden hold.

$$= \left\{ [130 \times 30 \times 6 \times 7800] + \left[\pi/4 \left(25^2\right) \times 120 \times 640 \right] \right\} \times 10^{-8} = 2.2 \text{ N}$$

2.4.5 Design of the Piston

From the Nigerian Code of Practice 2 (1973), Teak (*Tectona grandis)* in the N_3 strength group of timbers (grade 80 %) was chosen for the piston due to its adequate strength and durability. Its specifications are: compression parallel to grain = 11.2 N/mm^2 (i.e. 11.2 kN/m^2); E = 9500 N/mm^2 (i.e. 9.5 MN/m^2) and density = 640 kg/m^3 (at 18 % moisture content). The dimensions of the piston are shown in Fig. 5.

The volume of the piston can be expressed as:

$$= \pi R^2 H + \pi r^2 h = \pi(0.0405^2 \times 0.06 + 0.020^2 \times 0.05) = 3.72 \times 10^{-4} m^3$$

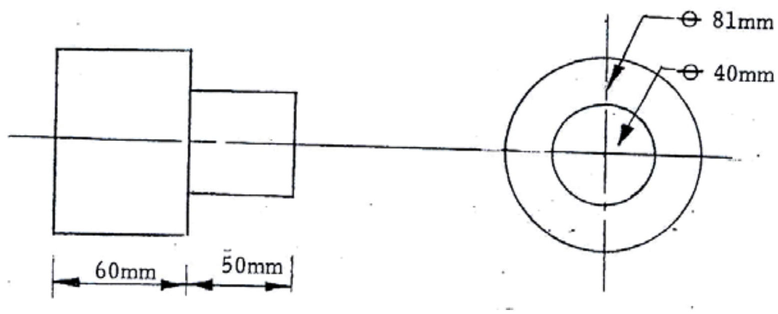

Figure 5. Front and end views of piston showing its dimension

Therefore, the weight of piston = $640 \times 3.72 \times 10^{-4} \times 10 = 2.38N$

2.4.6 Design of the End plate

The end plate reinforcement of mild steel was chosen so that it can withstand the stress due to the pressure available on the piston's face (300 kPa). The maximum stress of mild steel is 400 MPa (Howatson *et al*., 1991). This is greater than the stress on the end plate; the choice is therefore appropriate. Consider the end plate reinforcement as a square-shaped flat plate; the chosen dimension is 120 mm × 120 mm and a thickness of 3 mm. The plywood end plate has the same dimensions such that both can align and fit into the end-plate slot.

The volume of the end plate $= 0.12 \times 0.12 \times 0.003 = 4.32 \times 10^{-5} m^3$

Weight of end plate $= 3.37N$.

4. MACHINE TESTING

Fresh cashew apples were harvested by hand from the Cashew Nut Processing Industry Plc's plantation in Iwo, Osun state. The nuts were detached and the good apples sorted from the lot were washed with running water. Pressing occurred within two to three hours of harvesting because cashew is a highly perishable fruit (Costa *et al*, 2003). The apples were steamed for 10 minutes at 10 lb pressure to sterilize them and to remove astringency (Azam-Alli and Judge, 2001; Akinwale 2001). The steamed apples were cooled and washed with clean potable water and out of these; five apples of known weight were fed into the extractor. The piston was driven manually along the axis of the screw to exert pressure on the apples, crush it and press the juicy mass against the steel reinforced end plate to allow the juice to drain to the last drop. This took between 7-11 minutes. The power screw was loosened and the cake was removed from the end plate side. The process was repeated 10 times in batches. The weight of the juice and the cake

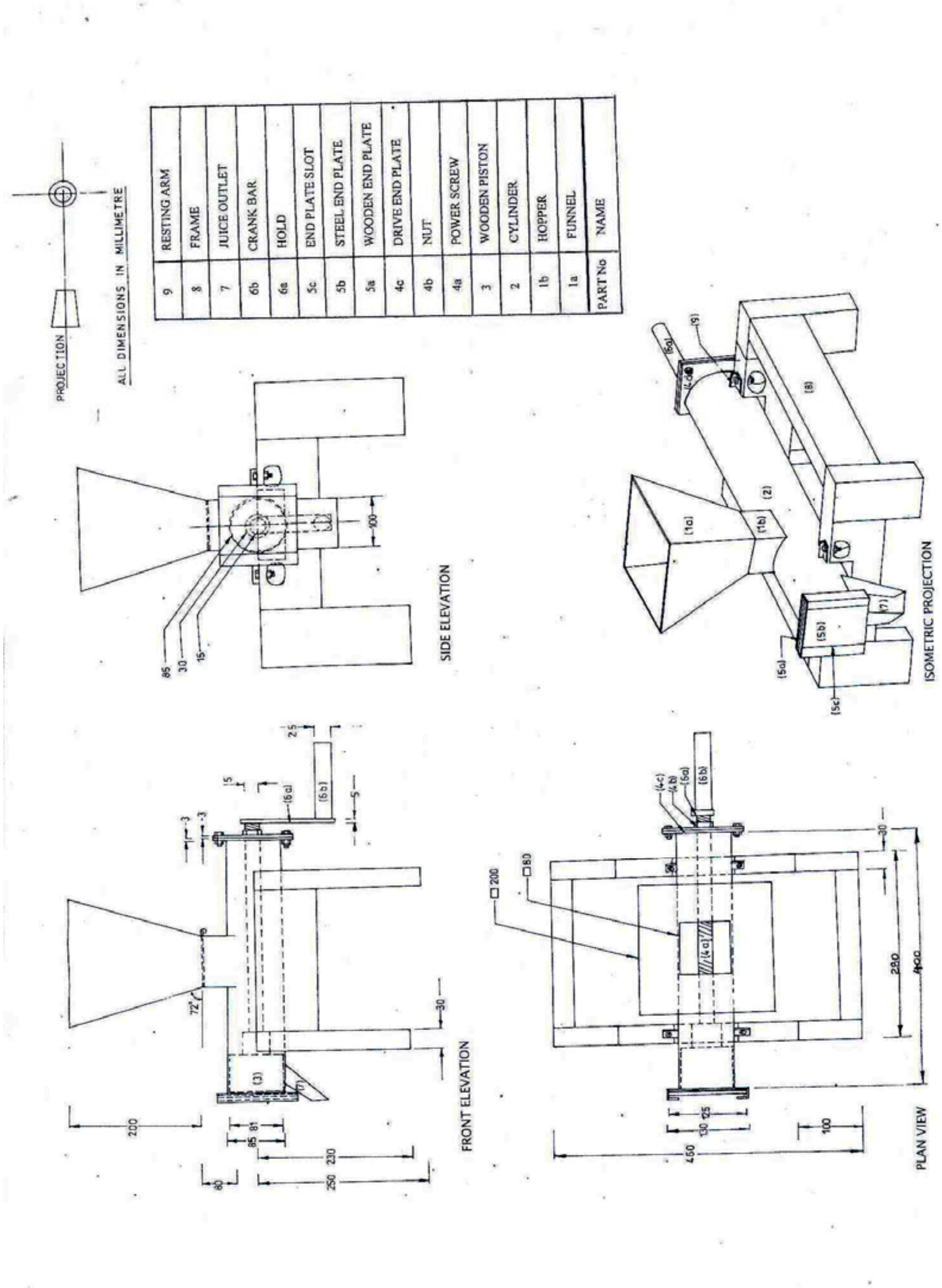

Figure 6. Orthographic and isometric projection of the cashew juice extractor

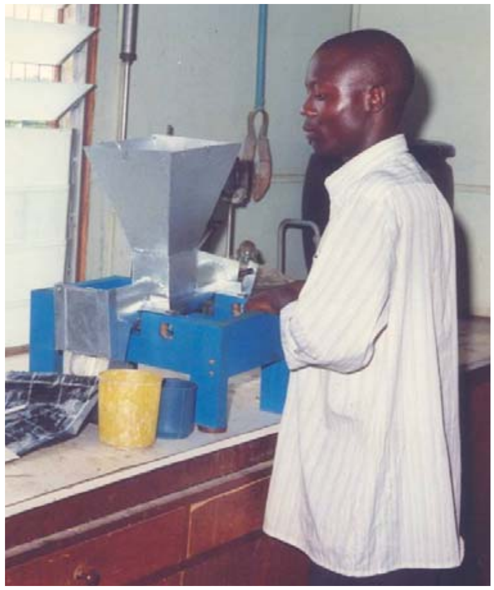

Figure 7. A view of the cashew juice extractor during testing

were determined. For each trial, the cake was oven-dried for 2 hrs at 103 ^{o}C and the oven dry weight was determined.

From Table 1, the average Juice Extraction Efficiency = 83.5 %

and from Table 2, the Average Juice Output = 16.54 g/minute (*i.e* 0.99 kg/hr)

But, the weight of 1litre of cashew juice wa determined as 0.97 kg

Therefore, the throughput = $\frac{0.99kg \times 1lit}{1hr \times 0.97kg}$ = 1.02 litres / hr

5. SENSORY TEST AND EVALUATION OF THE JUICE

Three samples of the juice in plastic bottles (fresh juice, juice stored under ambient conditions and refrigerated juice). Ambient storage duration was for 24 hrs and refrigerated storage was at 5 ^{o}C (Laguerre *et al.,* 2002) for 24 hrs were served to a 20-member trained taste panelist comprising 10 undergraduate students, 5 graduate students and 5 lecturers drawn from the Department of Food Science and Technology and crop processing and utilization unit of Agricultural Engineering Department of the University of Ibadan. With fresh juice as

Table 1. Cashew Juice Extraction Efficiency

Measurements (g)	Mean	Min	Max	SD
Weight (w_1) of fresh apple	234.2	182.0	276.0	32.7
Weight (w_2) of juice obtained	159.0	112.0	193.0	25.4
Weight (w_3) of wet cake	69.2	49.0	87.0	9.9
Weight (w_4) of oven-dried cake	45.2	26.0	68.0	13.5
Weight (w_5) of juice obtainable (w_5=w_1-w_4)	189.0	145.0	215.0	23.0
Juice Extraction Efficiency (E_j) in % ($E_j = \frac{w_2}{w_5} \times 100$)	83.9	76.4	91.4	5.5

Table 2. Thoroughput of the juice extractor

Measurements	Mean	Min	Max	SD
Weight of fresh apples fed to machine (g)	234.4	182.0	276.0	32.9
Weight of juice (g)	159.0	112.0	193.0	25.4
Duration of juice extraction (minutes)	9.6	10.0	11.0	1.4
Feed rate (capacity, g/minutes)	16.6	17.0	18.1	0.9

reference, the sensory attributes of juice under ambient storage was compared with juice under refrigerated storage. The results (Table 3) indicated a significant difference ($p<0.05$) between the colour, taste and acceptability of juice under ambient storage and the refrigerated juice.

Some physico-chemical properties of the juice under different storage conditions (fresh juice, juice stored under ambient condition and juice under refrigerated storage) were determined (Table 4). A significant difference ($p<0.05$) exists in the specific gravity, pH and vitamin C content of the juice stored under ambient storage. Past works on cashew juice did not vary the condition of juice storage, however this observation compare favourably with those of Akinwale *et al.* (2001); Akinwale and Aladesua (1999) and Aderiye *et al.*, (1991) for heat treated cashew juice.

Table 3. Sensory evaluation of cashew juices under ambient and refrigerated storage

Sensory attributes	J_s	J_r
Mouth feel	1.456^a	2.307^a
Colour	3.214^a	3.078^b
Taste	2.879^a	2.476^b
Acceptability	2.476^a	1.456^b

Js - juice stored under ambient conditions, J_r - refrigerated juice
a and b – means on the same row with different letters are significantly different ($p<0.05$)

Table 4. Some physico-chemical properties of cashew juice under different storage conditions

Sample	Appearance	Sp. Grav.	pH	% total soluble solids	vitamin C mg/100ml
J_f	whitish and cloudy	1.044^a	4.00^a	12.00^a	260.45^a
J_s	pale and cloudy	1.012^b	3.48^b	12.00^a	189.23^b
J_r	whitish and cloudy	1.042^b	4.00^a	12.00^a	257.60^a

J_f - fresh juice. J_s - juice stored under ambient conditions. J_r - refrigerated storage. Sp. Grav.-Specific Gravity
a and b – means on the same column with different letters are significantly different ($p<0.05$)

6. CONCLUSION

A machine was designed and constructed to extract fruit juice from cashew apples to forestall the usual wastage during peak harvest on most plantations in Nigeria. The average juice extraction efficiency and throughput were 83.85 % and 1.02 litres/hr respectively. The extracted juice was found acceptable based on the response of a trained taste panelist and chemical analysis. A machine of this nature can trigger and promote cottage processing of cashew apples into a commercially acceptable juice drink, thereby increasing income obtainable by local farmers from cashew.

Notations:

F_{cr} = critical load to cause buckling in Newtons (N)

c = constant depending upon end condition. For the purpose of this design (c = 2 is applicable)

E = modulus of elasticity in N/m^2 for steel E = 210 *GPa* (Howatson *et al* 1991)

A = cross – sectional area in m^2

L = length of column (power screw) in m (from fig 2, L=300 m).

k = minimum radius of gyration $k = \sqrt{\frac{I}{A,}}$ and for circular section $k = \frac{D}{4}$
where, D = diameter, D = 13 mm from section 3(iii); and I = minimum moment of inertia about the axis of bending.

T = Torque applied to turn the screw (Nm)

w = Load parallel to screw

r_m = mean thread radius (m)

r_c = collar radius (m)

f = coefficient of friction between the screw and nut thread (0.15)

f_c = coefficient of collar friction (according to Hall *et al* (1987), 0.25 is assumed)

α = helix angle of thread at mean radius

θ_n = angle between tangent to tooth profile (on the loaded side) and a radial line measured in the plane normal to the thread helix at mean radius. Since α is small, θ_n was taken as 30 ^{o} (Hall *et al*, 1987).

F_h = force applied to turn the handle. A man can apply a force of 200 N to the handle conveniently (Sanders and Cormicki, 1987)

L_h = hold length i.e. length of the crank bar.

T = Torque applied to the power screw. From section 3.3, T = 13.80 Nm.

S_b = bending stress and is assumed equal to the allowable stress for the material i..e. 70 MN/m^2

M = bending moment at the root of the handle given as $M = F_h \times I$, where $I = \frac{1}{2} L_h$
And $M = 200 \times \frac{1}{2} 0.13 = 13Nm$

c = distance from neutral axis to the outer surface, $c = \frac{1}{2} h_h$

I = rectangular moment of inertia, $I = \dfrac{b_h h_h^{\ 3}}{12}$

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