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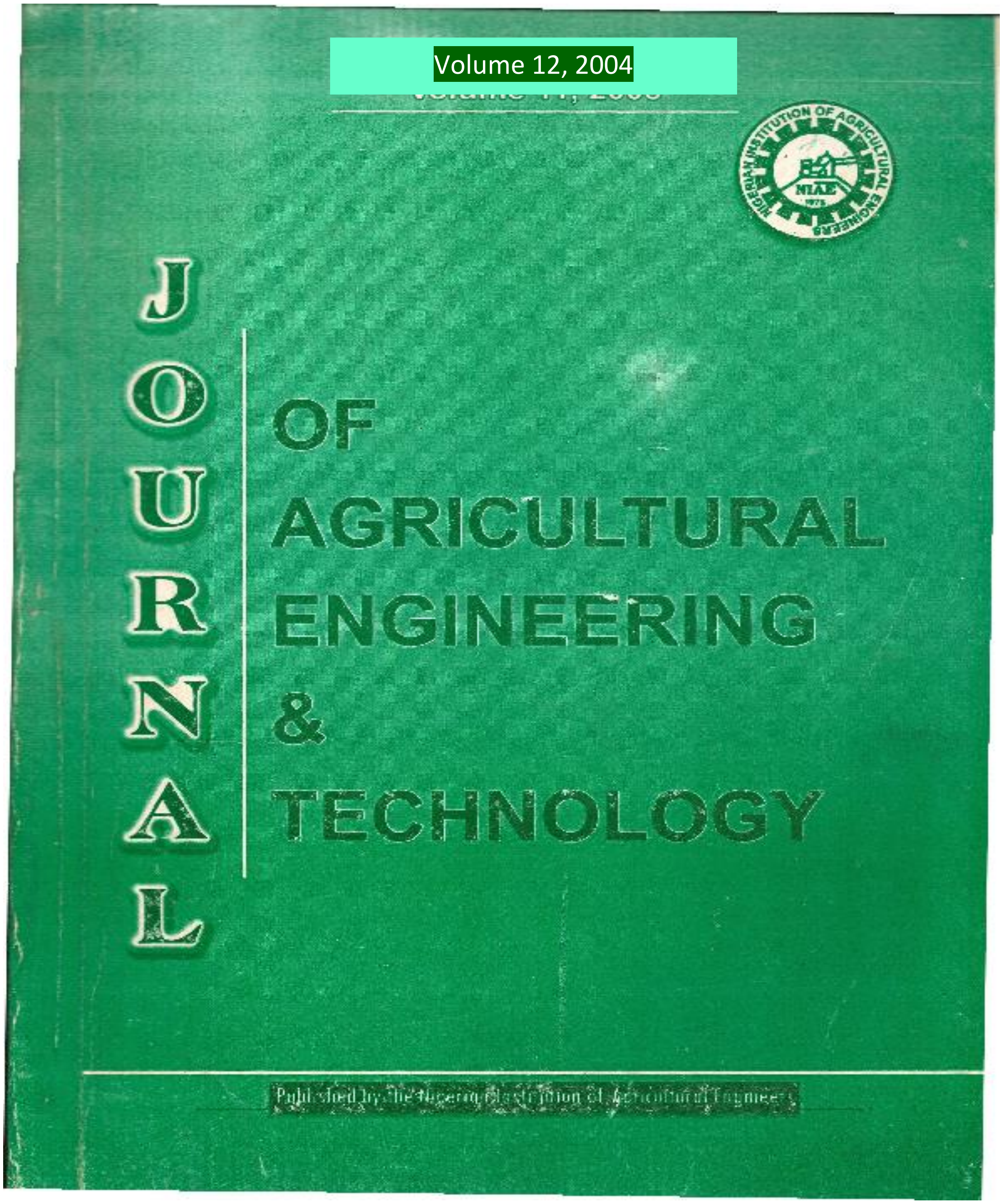

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DESIGN, DEVELOPMENT AND EVALUATION OF A BENISEED OIL EXPELLER

T.M.A. Ọlayanju
Department of Agricultural Engineering, College of Engineering, University of Agriculture,
Abeokuta, Ogun state, Nigeria.
Email: tiyanju@yahoo.com

ABSTRACT

Based on the results of some determined physical and mechanical properties of two beniseed accessions (Yandev 55 and E8), a prototype oil expeller was designed and fabricated. It has a barrel of 60mm diameter and a special worm shaft length of 600mm rotating at a speed of 45rpm through a 0.75kW electric gear reduction motor. The throughput was estimated as 10kg beniseed per hour. It can be used for other oil-bearing seeds such as groundnuts, caster beans and melon seeds.

The efficiency of the expeller in terms of oil recovery from the seed as influenced by worm shaft speed and seed moisture content was evaluated. The maximum filtered oil recoveries of 79.63 and 74.28% and minimum oil-in-cake of 14.43 and 17.73% were obtained for Yandev-55 and E8 respectively from a – one pass crushing. These values were obtained at worm shaft speed of 45rpm and moisture content of 5.3% and are in agreement with what obtained for other oilseeds.

KEYWORDS: Beniseed, expeller, evaluation, efficiency

1. INTRODUCTION

Beniseed (*Sesamum indicum L.*) is housed in an axial capsule, which is 3 to 4cm long, with 4 segments each containing 20 to 25 small flat seeds (Olayanju, *et al.* 2000). The seed is very small and tender with the weight of about 1,000 seeds being 2.0 to 3.5g. Beniseeds have been classified into three main varieties based on their characteristics. These are white, black, and red or brown varieties. The white variety is rich in oil (50 to 60%) and contains lower levels of hull than the black and red varieties. It is found in some parts of Nigeria. The black variety has an oil content of about 48%, but yields the best quality oil while the red yields about 46% oil. Both varieties are found in India but not so popular in Nigeria (Oresanya and Koleoso, 1990).

Although, the seed is edible, the oil is the major component of the crop that is of general demand. The oil is a valuable, high-grade stable oil usually referred to as "Queen of oils" and is used as a substitute for olive oil in cooking and medicine (Johnson *et al.*, 1979; and Inyang and Ekanem, 1996). The usual method of beniseed oil extraction at domestic level involves pounding the seeds in a wooden mortar and treating them with hot water, which makes the oil to float to the surface from where it is skimmed off. This method is slow, with low oil yield, gives rise to unpleasant odour and bitter taste (UNIFEM, 1987).

Commercially, beniseed oil is produced either by extraction or expression. Extraction method is not suitable for cottage scale level because of the expensive solvent involved; the problem of separating the chemical used from the oil; and the fact that extraction might result in devaluation of the seed (Davies and Vincent, 1980). Therefore, expression method is preferred. Khan and Hannah (1983) described expression as the process of mechanically removing liquid out of solid containing liquid by the use of equipment such as plate presses, hydraulic presses and expellers. Plate and hydraulic presses are much more laborious, time consuming and less effective than screw presses/expellers (Oresanya and Koleoso, 1990; NCRI, 1995). An expeller is therefore preferred. However, most available expellers could not perform effectively with beniseed because of their small size (Olayanju, 2002). Hence, the objective of this work is to design and fabricate an expeller that will be suitable for household and cottage-scale production of beniseed oil.

2. MATERIALS AND METHODS

2.1 Design Assumptions

For simplicity of design, the following assumptions were made:

- In one revolution of screw, the charge of beniseed is advanced by one pitch of thread.
- There are negligible air spaces between beniseeds on entering the chamber.
- The maceration of oilseed was complete in the feed section leaving the homogenous mixture of oil and solids in the ram section.
- No pressure development would take place in the feed section. The pressure development and the expression of oil start at the beginning of the ram section.
- The temperature of oilseed mass remained constant in the ram section. In reality, the temperature would increase along the ram section due to shearing action of the shaft.

2.2 Design Specifications

Based on the above assumptions, determination of some physical and mechanical properties of the seed and analysis of information received on the existing oil expellers (Olayanju, 2002), the following specifications were obtained and used in the fabrication of the screwed shaft conveying and compressing the oilseeds:

Length of chamber, L = 300mm; Number of worms, n = 6; Pitch of screw, P = 2 x 25, 37.5, 37.5, 37.5, 37.5, 37.5mm; Depth of worm, H = 6.25mm; Flight width, e = 6.25mm; Helix angle, $\alpha = 10^0$; Mean diameter, D_m = 54mm; and Wormshaft rotational speed, N = 45rpm

The screw is a variable type at the entry point.

2.3 Design Capacity

The theoretical capacity of an expeller with single flight in feed section was given by Varma (1998) as:

$$Q = \pi DN \cos\alpha\, (P\cos\alpha - e)\, H$$

A computer program in basic language was written to evaluate the design capacity based on the above equation as follows:

```
10    INPUT "PI ="; PI
20    INPUT "INNER DIAMETER OF BARREL (IN MILLEMETRES) ="; D
30    INPUT "WORMSHAFT SPEED (IN REVOLUTIONS PER MINUTES) ="; N
40    INPUT "HELIX ANGLE (IN DEGREES) ="; ALPHA
50    INPUT "PITCH (IN MILLEMETRES) ="; P
60    INPUT "WORM THICKNESS (IN MILLEMETRES) ="; e
70    INPUT "WORM DEPTH (IN MILLEMETRES) ="; H
80    REM
90    REM ---------CALCULATION OF DATA QUANTITIES ---------------------------
100 . REM
110   Q1 = PI * D * N
120   Q2 = COS (ALPHA)
130   Q3 = Q1 * Q2
140   Q4 = P * Q2
150   Q5 = Q4 – E
160   Q6 = Q5 * H
170   Q = Q3 * Q6
180   PRINT
190   PRINT "OUTPUT DERIVABLES
200   PRINT
210   PRINT "CAPACITY, Q (CUBIC MILLIMETRES PER MINUTE) ="; Q: "mm³/min"
220   END
```

In order to run the program, the following iterative values were used:

PI = 3.142
D = 54mm
ALPHA = 10degrees
N = 45rpm
$P = \pi D \tan \alpha = 3.142 * 54 * \tan 10 = 29.92$
$H = 0.2P - 0.25mm = 0.5 * 29.9 + 0.25 = 6.23mm$
$e = 0.5H = 0.5 * 12.75 = 3.2mm$

Output Derivable

$Q = 3.142 \times 54 \times 45 \times \cos 10\,(29.9\cos 10 - 3.2)\,6.23$
$= 11.29 \times 10^5\ mm^3/min$
$= 0.06774 m^3/h$ for single start in 3 passes
$= 46.13kg/h$ for average bulk density of $681kg/m^3$ (Olayanju, 2002)
$= 15.38kg/h$ in a single pass

This can be approximated to 10kg/h considering all loses in material and machine operation, which translates to 0.25 metric tonne/day.

2.4 Forces Acting on Screw Thread

The two main forces acting on the screw thread are those required to translate and compress the beniseed charge and the frictional force resulting from the screw's motion.

The worm shaft has six worms, each of which is subjected to pressure due to compression of beniseed kernels. This pressure increases from a minimum value at the feed end to a maximum at the discharge end. Consider a portion of the worm screw as shown in Figure 1, under the static condition, the direction of elemental load, K on the unit length of the thread will be normal to the thread surface along line AO. When the screw is rotated so that the load is moved, the line of action AO will be rotated through the angle of friction, ϕ to BO. For equilibrium of forces, resolving the force BO vertical and horizontally, the component parallel to the axis of the screw, is given as

$$W = K\cos(\alpha + \phi) \qquad (2)$$

Similarly, the component perpendicular to the axis of the screw.

$$F = K\sin(\alpha + \phi) \qquad (3)$$

$$\text{then, } \frac{F}{W} = \frac{K\sin(\alpha + \phi)}{K\cos(\alpha + \phi)}$$

$$\Rightarrow F = W\tan(\alpha + \phi) \qquad (4)$$

The friction angle,

$$\phi = \tan^{-1}\mu_s \qquad (5)$$

where:

μ_s = coefficient of static friction = 0.486 (Olayanju, 2002)

$\therefore \quad \phi = \tan^{-1}(0.486) \equiv 25^{\circ}$

W is the axial force required to expel a great deal of the oil at the oil-point and has been determined to be 28.8N on the average. Based on the average size of beniseed (1.70mm) about 100 seeds are crushed at the considered feed end portion. Therefore a force of 2.88KN will be required to express the oil.

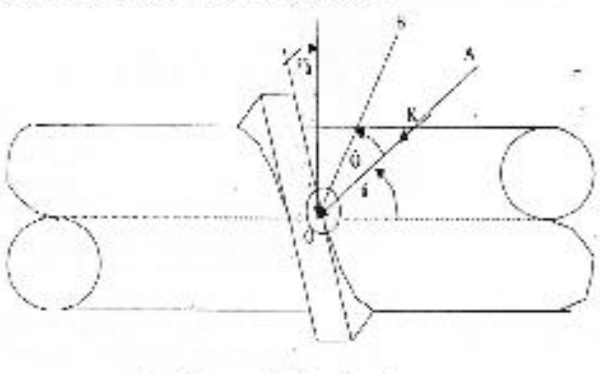

Figure 1: Forces acting on screw thread

2.5 Torque on Screw Thread

Torque, T and axial load. W are related to each other through the following equation for advance against load (Hall, *et al.*, 1980):

$$T = W\left(R\tan(\alpha+\phi) + f_c r_c\right) \tag{6}$$

With the use of a well-lubricated bearing, the frictional force, fc at the collar will be neglected, thus, the quantity $f_c r_c$ will be zero. Hence, the equation becomes;

$$T = WR\tan(\alpha+\phi) \tag{7}$$

From equation (4), $F = W\tan(\alpha+\phi)$

$$\Rightarrow \quad T = FR \tag{8}$$

where: R = Mean radius = 27mm (9)

2.6 Power Requirement

The power input to the expeller is used to convey and heat the material for oil expression. The power drive mechanism incorporates the use of a reduction gear motor of ratio 12 to 1. This is coupled to the expeller shaft by pulley and belts arrangement. The chosen speed for the expeller N, is 45rpm

$$\text{the angular speed, } \omega_e = \frac{2\pi N}{60} \tag{10}$$

The power input to the expeller can be computed as given below:

$$P_e = T\omega_e \tag{11}$$

A computer program was also written to obtain the above parameters as follows:

```
10        INPUT "PI=" ; PI
20        INPUT "AXIAL FORCE (IN NEWTON UNIT) ="; W
30        INPUT "WORMSHAFT SPEED (IN REVOLUTION PER MINUTE) ="; N
40        INPUT "FRICTION ANGLE (IN DEGREES) ="; TETHA
50        INPUT "HELIX ANGLE (IN DEGREES) ="; ALPHA
60        INPUT "MEAN RADIUS (IN METRES) ="; R
70        REM
80        REM --------------- CALCULATION OF DATA QUANTITIES ----------------
90        REM
```

```
100 F = W * (TAN ((TETHA) + (ALPHA)))
110 T = F * R
120 OMEGA = (2 * PI * N) / 60
130 P = T * OMEGA
140        PRINT
150 PRINT "**********************"
160 PRINT "OUTPUT DERIVABLES"
170 PRINT "**********************"
180 PRINT
190 PRINT "EXPULSION FORCE (IN NEWTON UNIT) =" ; F; "N"
200  PRINT "TORQUE (IN NEWTON METRE) =" ; T; "Nm"
210 PRINT "ANGULAR VELOCITY (IN RAD PER SEC) =" ; OMEGA; "rad/s"
220 PRINT "POWER REQUIREMENT (IN WATT UNIT) =" ; P; "W"
230 PRINT "EXPULSION FORCE (IN NEWTON UNIT) =" ; F; "N"
240 PRINT
250 END
```

Input Parameters

PI = 3.142
W = 28800N
N = 45rpm
θ = 25degrees
α = 10degrees
R = 0.07m

Output Derivables

EXPULSION FORCE, F = 13.65KN
TORQUE, T = 368.44Nm
ANGULAR VELOCITY, OMEGA = 4.71rad/s
POWER REQUIREMENT, P = 1.75KW

This power input to the expeller is utilized to heat the material, to convey the material for oil expression. In order to give allowance for power used in driving worm shaft and pulleys, a 2KW (1.5hp) electric reduction gear motor with a speed of about 140rpm is chosen.

2.7 Belt Selection

A 2 B33 - synchronous (toothed) belt arrangement that combines the characteristics of belts and chains was selected. This will guide against slippage, hence maintaining a constant speed ratio between the driving and the driven shafts

2.8 Machine Features

The oil expeller consists of seven main parts namely: the feeding assembly, the expression barrel, the worms and worm shaft assembly, the cone mechanism, the power transmission unit, the oil and cake troughs and the main frame (Fig.2). The expression chamber is made of twenty wear resistant bars arranged longitudinally to form a circular barrel with slots between them for oil drainage. The chamber is split into two halves. The top carries the hopper at the extreme right while the bottom part is welded to the frame for rigidity. The split parts are bolted together.

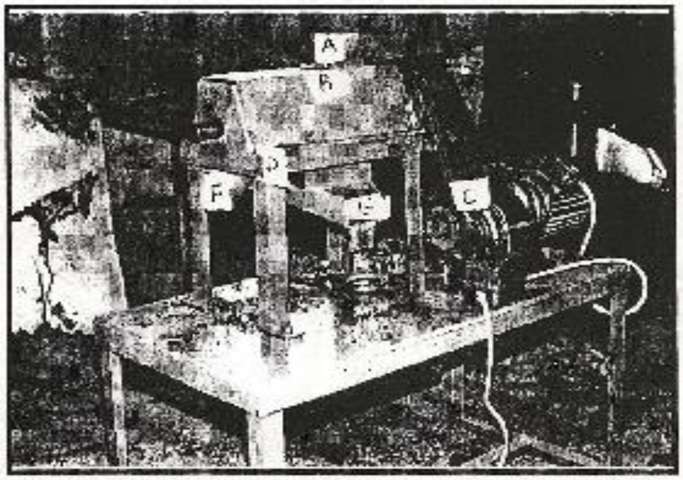

Fig. 2. The fabricated beniseed oil expeller
A. The hopper; B. The expression chamber; C. The power drive;

Six worms of different pitches were fitted on the main shaft. The fifth worm is in the reverse direction to enable proper squeezing of the cake before discharge. The worm flight design, along pressure and discharge section is such that the material does not wrap around more than 320°. This leaves an axial gap in the flight that enables the compressed material to slide in either direction relative to velocity generated by worm pitch. This balances the pressure over a group of worm section and reduces the tendency of material to lock in, individual section and rotate with the shaft. The unit is driven by a 0.75kW electric motor.

2.9 Machine Performance Evaluation

Two kilograms each of dehulled beniseed samples was expressed in the oil expeller. The filtered oil and residual cake are as shown in Fig. 3. The operation was performed at 4.1, 5.3, 7.7 and 10.3 % seed moisture contents (wb) and machine worm shaft speeds of 30, 45, 60, and 75rpm. The volumes of the expressed and filtered oil were measured by using a graduated cylinder while the weight of the cake obtained after expression was measured on a chemical balance. The expression efficiency, E in terms of the oil recovery was evaluated as the ratio of the expressed and filtered oil to that of the expressible oil, which is equivalent to the initial oil content of the seed. The oil content of the seed and residual oil in the cake were determined by soxhlet extraction apparatus with normal hexane as solvent.

3. RESULTS AND DISCUSSION

Table 1 gives the data on the performance operational tests in terms of the machine throughput, oil recovery and residual oil in cake at different worm shaft speeds and moisture content levels. The maximum machine throughputs of [illegible] and 12.08kg/hour; maximum filtered oil recovery of 79.63 and 74.28% and minimum oil-in-cake of 14.43 and [illegible]% were obtained for Yandev-55 and E8 respectively from a one pass crushing. These values were obtained at worm shaft speed of 45rpm and moisture content of 5.3% and are in agreement with what obtained for other oilseeds.

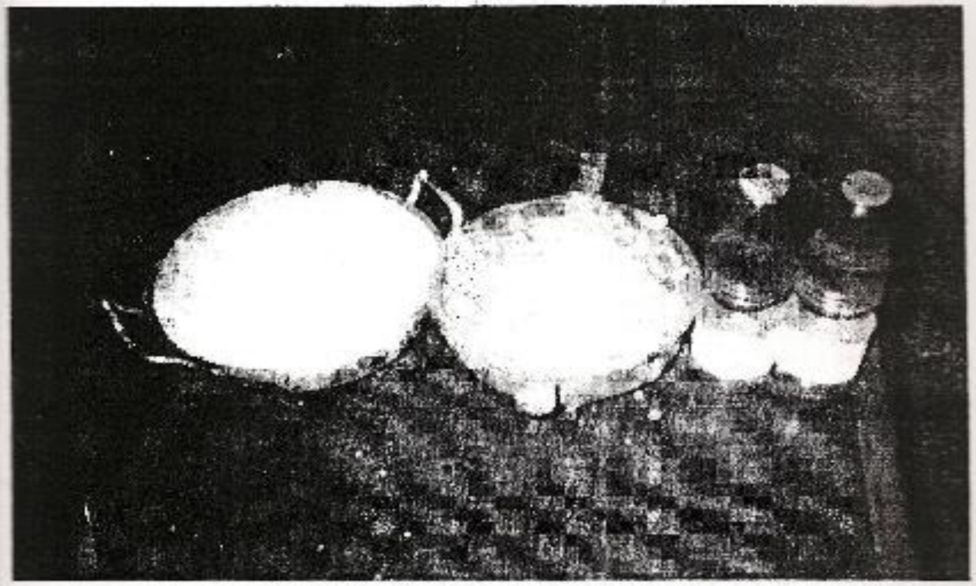

Fig. 3. The oil and cake produced by the expeller

The result may be attributed to the fact that at 5.3% moisture level, the shear and compression are relatively better than at the other moisture levels. This is because moisture works as heat transfer medium. So the total heat generated by wormshaft during pressing might be fully transferred to the individual fat globules, which results in breakdown of the emulsion form of the fat and helps in releasing more oil droplets. While low moisture causes britleness, higher moisture content causes plasticising effect, which reduces the level of compression and gives poor recovery.

Further oil can be recovered from the expressed cake in multiple passes/crushing of the cake in the expeller. However, this choice depends on the economics of the process and end use of the cake. According to ewant and Shukla (1991), high pressure can be used to express more oil from the seed in a single pass, but the quality of the oil and the nutritional value of the cake may be affected. It will also reduce the capacity of the expeller.

Alternatively, the press solvent extraction technique can be used. In this case the oil is first expelled at low pressure from the seed, the cake, which contain more than 8% oil, is then extracted in a solvent extraction plant. This technique is advantageous as more oil is expelled using less energy. The quality of the oil is good from nutritional and consumption point of view.

Table 1: Performance evaluation of the fabricated beniseed oil expeller

Wormshaft speed, rpm	Moisture content, %, wb	Machine throughput, kg/h		Oil recovery, %		Residual oil-in-cake, %	
		Yandev 55	E8	Yandev 55	E8	Yandev 55	E8
30	4.1	9.97	9.06	37.56	33.70	40.39	42.77
30	5.3	11.88	11.22	42.57	44.48	37.30	36.12
30	7.7	10.59	10.14	41.57	42.02	37.92	37.64
30	10.3	10.49	9.42	34.64	34.55	42.19	42.25
45	4.1	11.33	9.88	70.62	64.85	19.98	23.55
45	5.3	12.81	11.96	79.63	74.28	4.43	17.73
45	7.7	11.71	11.50	66.19	61.43	22.72	25.64
45	10.3	11.63	10.79	59.13	59.08	27.08	27.11
60	4.1	11.39	10.75	50.92	49.91	32.15	32.77
60	5.3	12.99	12.08	54.84	52.72	29.73	31.08
60	7.7	11.84	11.54	43.32	43.12	36.84	36.96
60	10.3	11.67	11.34	42.99	39.13	37.04	39.43
75	4.1	11.56	10.46	40.23	38.79	38.75	39.64
75	5.3	12.23	11.85	41.40	40.58	38.02	38.53
75	7.7	11.98	11.50	32.88	32.51	43.28	43.51
75	10.3	11.90	11.18	32.47	31.92	43.54	43.88

4. CONCLUSIONS

Based on the results of the performance evaluation, the following conclusions are drawn: the machine performs adequately for expressing oil from oilseeds, beniseeds in particular; the oil expression efficiency is comparable to what obtained for other oilseeds; the throughput of the expeller should be increased so that larger quantities can be handled per unit time and the modified machine should be commercialised so as to meet the oil demand of the people.

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