Mechanical shelling of Grenadian nutmeg seeds: Theoretical and experimental approaches

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Sankat, C.K. 1992. **Mechanical shelling of Grenadian nutmeg seeds: Theoretical and experimental approaches.** Can. Agric. Eng. **34**:157-165. Nutmeg seeds are round to ellipsoidal in shape and of variable minor diameter, normally ranging between 16 and 27 mm. Upon drying to 8% moisture content, the woody kernel shrinks within the thin, brittle shell and seeds are then cracked either manually or mechanically to liberate the nutmeg kernel. The manual method is slow and tedious, while the mechanical, impact type devices currently used produce high levels of kernel damage (14%) and leave many uncracked/partially cracked seeds (28%). The high levels of kernel damage may be attributed to multiple impacts between the kernel and the impacting surface. Alternative approaches to mechanical cracking which utilize a single cracking force were examined. From a semi-empirical model developed, a minimum of four pairs of fixed, counter-rotating cracking rolls each of 203 mm in diameter with sets or clearances of 15.2, 17.4, 20.2 and 23.4 mm can be used to crack nutmeg seeds previously graded into the diameter ranges of 16.0-18.1, 18.1-20.8, 20.8-24.1, and 24.1-27.9 mm. A centrifugal nutmeg seed cracker with a 0.60 m diameter rotor and a 1.39 m diameter cracker ring was also evaluated for cracking seeds of variable size. At the optimum rotor speed of 460 rpm the quantity of perfectly shelled kernels averaged 49.2% while that of damaged kernels was less than 1%. The quantity of partially cracked seeds averaged 21.8%, but can be reduced to 11.7% by a single recycling of seeds.

Les graines de noix de muscade ont une forme qui est entre l'ellepsoide et la sphère, la longueur du plus petit diamètre variant entre 16 et 27mm. Lors du séchage à 8% d'humidité, le noyau ligneux se rétrécit à l'intérieur de l'enveloppe mince et friable. Les graines sont ensuite brisées soit manuellement, soit mécaniquement pour libérer l'intérieur de la noix de muscade. La méthode manuelle est lente et hardue, tandis que la méthode mécanique, utilisant un système de type impacts (qui est le plus couramment utilisé), produit une grande quantité d'amandes endommagés (14%) et laisse beaucoup de graines non brisées ou partiellement brisées (28%). La grande quantité d'amandes endommagées peut être attribuée aux chocs multiples subis par ces dernieres. Nous avons donc examiné une méthode n'utilisant qu'une seule force de rupture. Pour cela, nous avons utilisé, à partir d'un modèle semi-empirique, un minimum de quatre paires de rouleaux de 205 mm de diamètre ayant un écart entre eux de 15.3, 17.4, 20.2 et 23.4 mm pour briser des noix de muscade classifieés selon leur diamètre en classe de 16.0-18.1, 18.1-20.8, 20.8-24.1 et 24.1-27.9 mm. Nous avons aussi évalué un appareil rotatif ayant un diamètre du rotor de 0.60 m et un diamètre de l'anneau de rupture de 1.39 m. A la vitesse optimum de rotation de 460 rpm, la quantité d'amandes parfaitement séparées étaient en moyenne de 49.2% tandis que les amandes endommagées étaient en moyenne inférieure à 1%. La quantité de graines partiellement brisées étaient en moyenne de 21.8% mais elle pouvait être réduite à 11.7% par un seul recyclage des graines.

INTRODUCTION

The nutmeg fruit *(Myristica fragrans)* is a fleshy drupe, with the yellow husk or pericarp usually splitting into two halves on maturing, exposing a dark, shiny, single seed surrounded by a crimson network, which is an arillus or outgrowth from the base of the seed (Purseglove 1974). Two spices are obtained from the nutmeg: the dried aril called mace, and the dried seed which contains commercial nutmeg. Harvested seeds have an initial moisture content of 30-35% (wet basis). At this time the nutmeg kernel fills the seed. On drying, usually to 8% moisture content, the woody nutmeg kernel shrinks within the thin, brittle shell and can be heard to rattle within. The nutmeg is removed by "cracking" or "splitting" of the shell.

Nutmegs, together with bananas and cocoa, are the leading export crops of the Island of Grenada in the Caribbean. In 1989, Grenada exported 1800 tonnes of nutmegs and 193 tonnes of mace, valued at US $10.6 and 2.4 millions respectively, principally to Europe, Canada and the USA. (Grenada Co-operative Nutmeg Association 1989).

Cracking of nutmeg seeds is a key operation in the processing of nutmegs as it liberates the kernel from the dried seeds. Ideally this is done without damage to the kernel. At the small nutmeg processing stations, cracking is done manually by workers who position each seed on a wooden block and strike it with a wooden mallet. This is an effective, but slow and tedious operation, but does provide considerable employment. At the two larger processing stations of Grenville and Gouyave in Grenada, cracking is achieved by two impact mechanical crackers, at least 30 years old, and whose origins are unclear.

The two machines currently used are robust but simple in design. They consist of a steel impeller of 0.21 m in diameter, keyed to a 50 mm diameter shaft which is supported on roller bearings bolted to the housing (Fig. 1). The wooden "jawbones" are lined with 3 mm thick steel. The impeller, which is 75 mm thick, rotates at 700 rpm in the cracker housing whose thickness just exceeds 75 mm. The position of the jawbones in the cracker housing is adjustable, thus allowing for a variable clearance between the impeller and the jawbones, with a clearance of 18-25 mm normally used. Nutmeg seeds are fed by gravity from a hopper into the machine's cracking zone. Cracking occurs through impact with the impeller or on striking the jawbones. The results are a mixture of perfect kernels, damaged kernels, uncracked and partially cracked seeds, and shell fragments. Partially cracked seeds are those seeds which show definite signs of shell damage or breakage, but whose shells are not completely removed. The machine's throughput and shelling characteristics were estimated by Peters (1982) at approximately 800 kg/h, producing fractions comprising of 58%, 14%, 7%, and 21% (by weight) of perfect kernels, damaged kernels, uncracked and partially cracked seeds, and shells respectively.

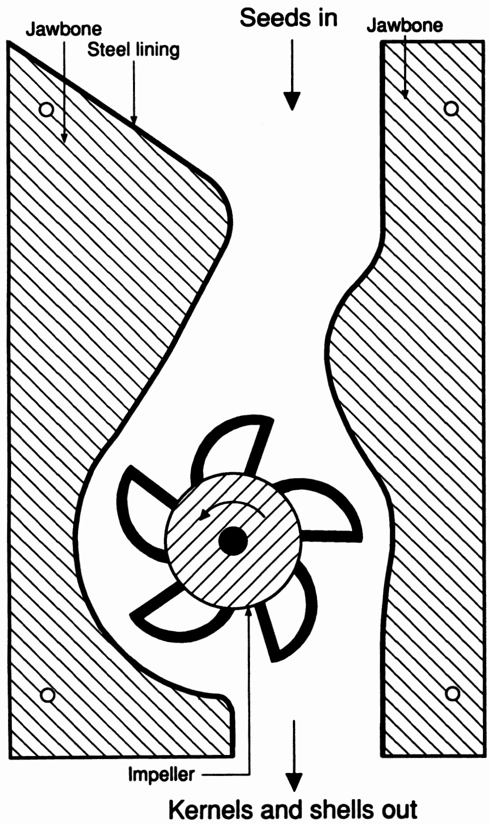

Fig. 1. A longitudinal section showing the functional features of the impact type nutmeg seed cracker used in Grenada.

OBJECTIVES OF THIS STUDY

The objectives of this study were to investigate alternative mechanical methods of cracking nutmeg seeds so as to improve on the performance of the impact type crackers currently used. Of prime importance was the need to reduce the damage occurring to kernels as such kernels called "defectives" are of reduced economic value. Another criterion for the design process was to design mechanical crackers which are of simple design and could be readily manufactured and maintained locally.

THEORETICAL APPROACHES TO MECHANICAL CRACKING

Mechanical cracking of seeds in the machines presently in use occurs by impact, with the force of the impeller on the seed being controlled by the speed of rotation and the ensuing peripheral velocity of the impeller. The principal cause of mechanical damage in such a machine is due to multiple impacts of the impeller with the seed or with the nutmeg. In considering alternatives, choices were limited to such mechanisms that were potentially capable of cracking the shell in a single event, then removing the nutmeg immediately from the cracking zone.

Seed size, kernel size and machine clearance

Nutmeg seeds vary in size and hence constitute a limiting factor in machine design. Tai (1969) reported that at the Gouyave processing station in Grenada, dried seed sizes varied between 18 and 40 mm in length and between 14 and 37 mm in diameter, with the corresponding kernels being 16 to 35 mm in length and 11 to 24 mm in diameter. At the Grenville processing station, seed sizes varied between 19 and 39 mm in length and between 16 and 29 mm in diameter, with the corresponding kernels being 17 to 36 mm in length and 14 to 26 mm in diameter. The relationship between dried seed size (S_D) and kernel size (K_D) is shown in Fig. 2 as developed from research data.

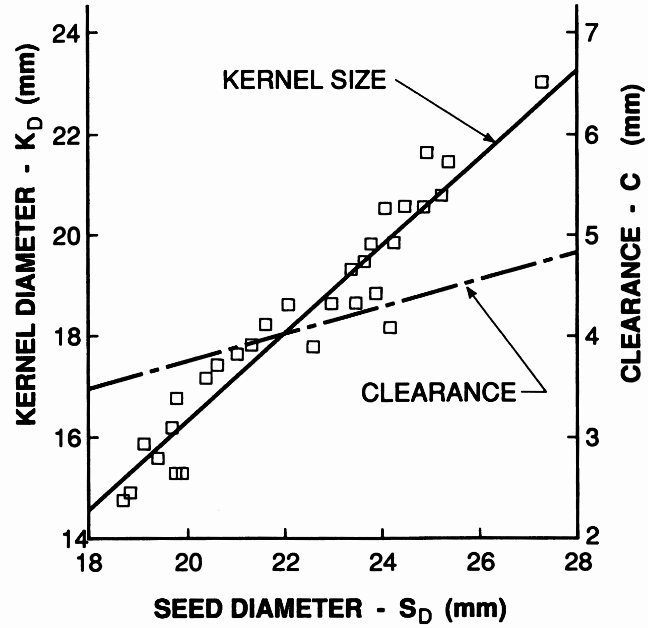

Fig. 2. The relationship between kernel size and seed size.

Noting the round to ellipsoidal shape of the seed and the kernel, S_D and K_D are mean diameters. From a regression analysis of the data:

$$K_D = 0.868\, S_D - 1.080 \qquad (r^2 = 0.92) \qquad (1)$$

Neglecting the thickness of the thin shell, the difference in seed and kernel diameters can be considered to be the clearance, C, between the kernel and shell, thus

$$C = S_D - K_D \qquad (2)$$

It is noted that the clearance is directly related to the moisture content of the nutmeg and Eq. 2 is therefore applicable at a specified moisture content. In this study, dried nutmeg seeds at a moisture content of approximately 8% (wet basis) are being considered for shelling.

Combining Eqs. 1 and 2, and as shown in Fig. 2, the predicted values of C also increase with seed size according to:

$$C = 1.080 + 0.132\, S_D \quad (3)$$

Forces to crack the shell and damage the kernel

The static compressive force required to crack the shell of dried nutmeg seeds when applied along the minor axis of the seed shows considerable variation. Using a Universal Testing Machine for compression loading, the average compressive force obtained when 25 nutmeg seeds were cracked was 271 N with a range of 76-565 N. The corresponding average value for damaging the kernel was higher at 369 N and ranged from 205-511 N.

The variation in the forces required to crack the shell or to damage the kernel may be attributed to the quality of the seeds delivered to the processing stations. Nutmeg seeds are collected from the ground after falling naturally from the trees. Often such seeds are immature, water logged, or may even be germinating. The kernels of all such seeds (called "defectives"), on drying, have a low specific gravity, less than 1, and are also of low apparent strength. On the other hand, sound nutmegs are those which are hard and dense with a specific gravity greater than 1.

Cracking rolls for nutmeg seeds

Dried nutmeg seeds may be cracked by passing them through a pair of cylindrical, counter-rotating, cracking rolls. By proper choice of roll diameters, and adjustment of the clearance between the rolls, seeds of different sizes may be nipped (gripped and compressed between the surface of the cracking rolls) and their outer shells cracked.

In Fig. 3, the normal (N), tangential (T), and resultant (R) forces on the seed as it is nipped or engaged by the rolls, are shown. The seed will be nipped when the resultant force R acts downwards. Under these conditions,

$$\tan(n/2) < \mu \quad (4)$$

where:

n = angle of nip as shown in Fig. 3, and

μ = coefficient of friction between seed and roll's surface.

The minimum roll diameter for cracking of the shell to occur may be obtained from the relationship (Taggart 1951):

$$\cos(n/2) = (d + s)/(d + S_D) \quad (5)$$

where:

d = roll diameter, and

s = set or clearance between rolls.

Using the values given by Tai (1969) for the largest seed and kernel sizes, with S_D = 37 mm, then s = 26 mm for no kernel damage. Using $\mu = \tan 18^\circ$ for nutmeg seeds on a smooth steel roller, and Eqs. 4 and 5, the minimum roll diameter for nipping of the largest seeds to occur is d = 187 mm. For the smallest seed size, S_D = 14 mm and s = 11 mm and using rolls of 187 mm in diameter, Eq. 5 gives $n = 19.8^\circ$ as the angle at which the smallest seeds can also be nipped and cracked. Thus a minimum roll diameter of 187 mm is theoretically necessary to nip seeds of varying sizes, from 14 to 37 mm in diameter.

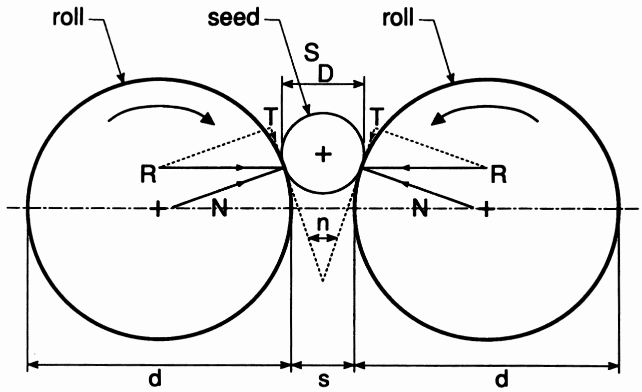

Fig. 3. The geometrical relationship and the forces on the nutmeg seed as it is nipped by a pair of cracking rolls.

A model for cracking nutmeg seeds of varying sizes

It is evident that to use fixed, cylindrical rolls for cracking seeds of varying sizes, sorting seeds in increasing sizes is necessary. To circumvent this limitation, a sorting and cracking system of roller pairs is proposed in which the roll diameters are fixed, but the clearances differ.

It is evident that for a given roll clearance, a range of seed sizes may be cracked with $S_{D\min}$ being the diameter of the smallest sized seeds and $S_{D\max}$ that of the largest sized seeds.

For seed cracking to occur at a particular clearance, s

$$S_{D\min} \geq s \quad (6)$$

For seed cracking to occur at a particular clearance, s, without kernel damage

$$S_{D\max} \leq s + C \quad (7)$$

Therefore, from Eqs. 3 and 7

$$S_{D\max} \leq 1.15s + 1.24 \quad (8)$$

The theoretical relationship between roll clearance and the range of seed sizes which may be cracked without kernel damage is shown in Fig. 4. From this relationship the minimum number of roller pairs, and their appropriate sets, may be derived to crack nutmeg seeds in the entire size range.

A centrifugal cracker for nutmeg seeds

The use of a centrifugal system for cracking the shell of the palm nut for palm kernel recovery has been reported (Anon 1963). The principle of operation of a centrifugal nut cracker is shown schematically in Fig. 5. In this machine, the rotor operates in a horizontal plane with the drive shaft being vertical. Nutmeg seeds are fed to the centre of the rotor, are accelerated along the radial slots by the centrifugal force, and

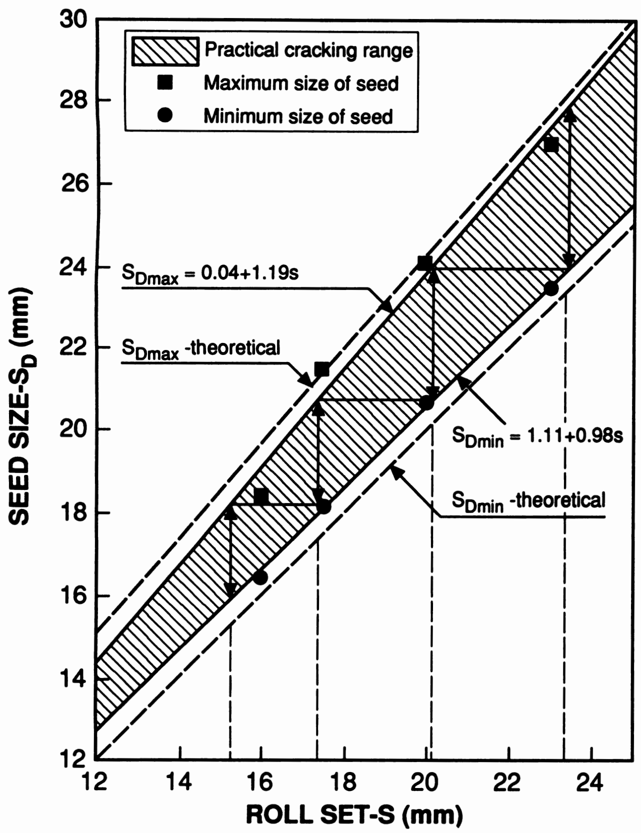

Fig. 4. Theoretical and experimental relationships between roll clearance, seed size and the cracking range.

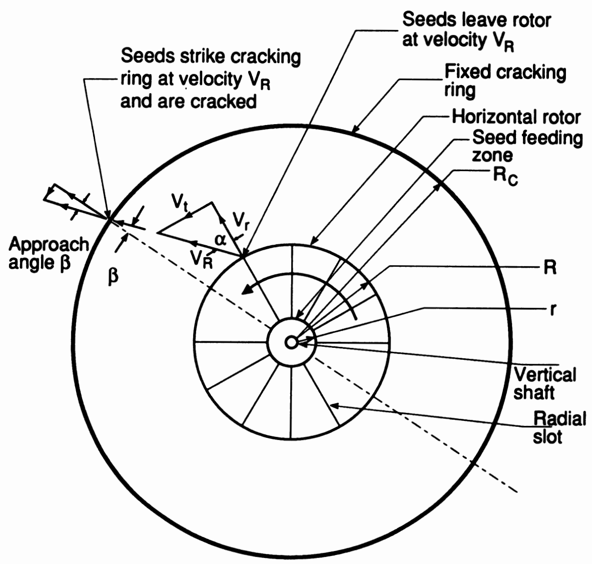

Fig. 5. Principle of operation of the centrifugal nutmeg seed cracker.

thrown onto the fixed, rigid cracking ring around the rotor. The impact breaks the shell, liberating the kernel. Kernels and shell fall away from the cracker ring into a conical hopper below.

Neglecting the frictional force between the seed and the rotor's surface, it can be shown that on leaving the rotor the resultant seed velocity is

$$V_R = (V_t2 + V_r2)^{1/2} \quad (9)$$

where:

$V_t = \omega R$ = tangential velocity component,
$V_r = \omega(R^2 - r^2)^{1/2}$ = radial velocity component,
ω = angular velocity of rotor
R = radius of rotor, and
r = radius of feeding zone.

Thus

$$V_R = \omega(2R^2 - r^2)^{1/2} \quad (10)$$

It can also be shown that the seed strikes the cracking ring at an angle, β, to the normal such that

$$\sin\beta = (R \sin\alpha)/R_C \quad (11)$$

where:

R_C = radius of cracking ring, and
$$\alpha = \tan^{-1} [R/(R^2 - r^2)^{1/2}] \quad (12)$$

It is noted from Eq. 11, that as R_C increases in size, the angle β reduces and the seeds tend to strike the cracking ring more normally, which appears desirable. This is illustrated in Fig. 6, for a rotor having dimensions of R = 0.30 m and r = 75 mm yielding α= 45.9°. Thus the cracking ring should be as large as possible but remain within practical limits.

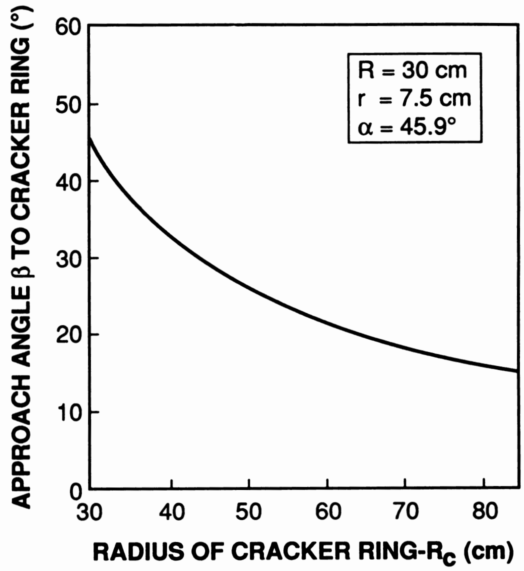

Fig. 6. The effect of cracker ring size on the seed approach angle, β.

NUTMEG SEED CRACKER DEVELOPMENT

Fixed, counter-rotating cracking rolls

An experimental seed cracker was built (Fig. 7). It consisted of:

(a) a pair of cylindrical rolls, 203 mm in diameter and 300 mm long, fabricated from steel tubing 10 mm thick. The two rollers were keyed to 25 mm diameter steel shafts.

(b) a wooden frame, on which the rolls were mounted. The roll shafts were supported on pillow block bearings, bolted to the frame. The clearance between the rolls could be varied by changing the position of the bearings of one roller, relative to the frame.
(c) a V-belt drive system, powered from a 0.75 kW variable speed, electric motor.
(d) a horizontal seed conveying system and hopper to feed the rolls.

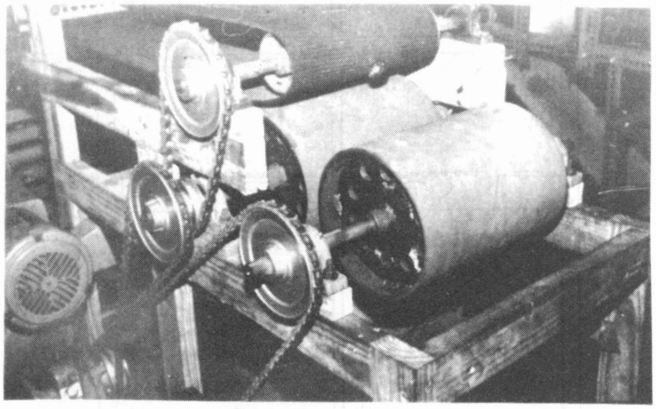

Fig. 7. The experimental nutmeg seed cracker using a pair of counter-rotating cracking rolls.

A series of experiments were performed to determine the range of nutmeg seed diameters for a particular roll clearance for cracking to take place. Dried nutmeg seeds, visually free of mechanical defects and which appeared to be sound were selected for these tests. The seeds were measured along their minor diameters, with seeds ranging between 16.1 and 27.0 mm chosen for the study. Seeds of increasing size were individually fed into the cracking rolls, with the roll clearance fixed at 16 mm. On passing through the counter-rotating rolls, which were operated at 20 rpm, the seeds were inspected and classified as: complete cracking (shell cracked and opened and liberating the kernel); partial cracking (some of the shell damaged or removed, but still enclosing the kernel); or no cracking (seeds passed through rolls unscathed). Liberated kernels were also inspected for kernel damage.

This experiment was repeated for roller clearances of 17.5 mm, 20 mm, and 23 mm. For each of the four clearances, the data were examined to determine the minimum seed diameter at which complete cracking began and the maximum seed diameter at which no kernel damage was found. These results are shown in Fig. 4 with the regression lines representing the limits of the desirable cracking range of nutmeg seeds.

The 203 mm diameter rolls used appeared satisfactory, as seeds in the size range used were nipped without slippage. The results show that for the normal range of seed sizes for cracking to occur, seeds with a diameter at least 0.5 - 0.7 mm larger than the roll set must be used. This is illustrated in Fig. 4 by the offset of the S_{Dmin} (theoretical) and S_{Dmin} (experimental) lines. The reason for this is that although the shell of the dried nutmeg at approximately 8% moisture content is thin and generally brittle, it does possess some elastic properties as deformation takes place prior to cracking. When the roll clearance is 16 mm, kernel damage begins when seeds 3.1 mm greater than this are used. However, when the roll clearance is 23 mm, kernel damage begins when seeds 4.4 mm larger than this are used. This variation is attributed to the increased clearance between the kernel and shell as seed size increases.

From these trials, and using the scheme shown in Fig. 4, it appears possible that a system could be designed for cracking nutmeg seeds of various sizes using a number of fixed cracking rolls spaced at various clearances. Seeds would first have to be graded on the basis of minimum seed diameter (i.e. diameter of the minor axis) into four categories; 16.0 - 18.1 mm, 18.1 - 20.8 mm, 20.8 - 24.1 mm, and 24.1 - 27. 9 mm and then be cracked by passing each category through fixed roller pairs having clearances of 15.2, 17.4, 20.2 and 23.4 mm, respectively. It is evident that if a larger number of roller pairs is used, and the cracking range is reduced for each pair of rolls, better overall performance is possible both through a reduction in kernel damage and in partially shelled nutmeg seeds.

Spring loaded, counter-rotating cracking rolls

To eliminate the need for a number of fixed cracking rolls of different clearances, the experimental seed cracker was modified. One of the rolls was supported in horizontally movable bearings, with movement restricted by compression springs (K = 9.8 kN/m) attached to each bearing (Fig. 8). The initial clearance between the rolls could be set by removing or adding spacers as needed.

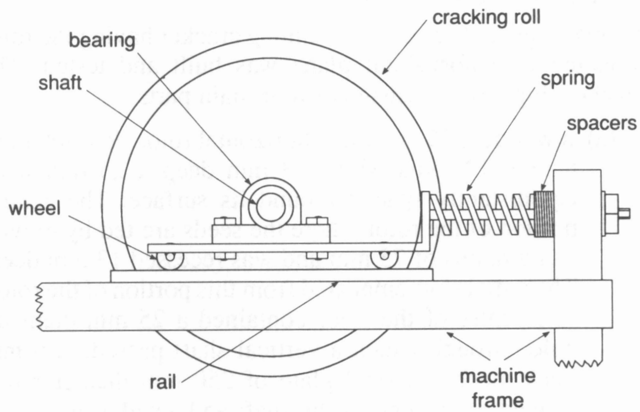

Fig. 8. The spring-loaded cracking roll.

In a series of trials, 150 nutmeg seeds having diameters between 16.0 - 27.0 mm were individually cracked between the rolls, which had been set at a clearance of 11 mm. On passing through the rolls, which were rotated at 24 rpm, seeds were examined for complete cracking, partial cracking, and no cracking, while liberated kernels were examined for kernel damage/bruising. This procedure was repeated with the initial roll clearance set to 12, 13, 14, 15 and 16.5 mm.

The results of these trials are shown in Fig. 9 with the performance indices given in per cent. The optimum roll clearance was found to be 13.5 mm. At clearances smaller than the optimum, the effective compressive forces on the seeds were large due to considerable spring displacement. The results were few uncracked seeds, a comparatively reduced level of partially cracked seeds, but also a high level of kernel damage. On increasing the roll clearance beyond

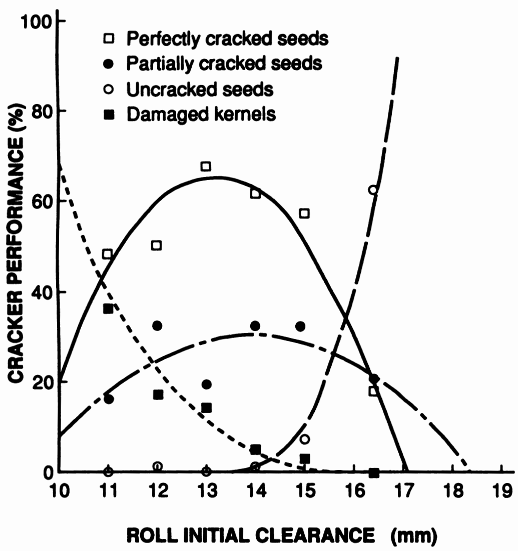

Fig. 9. The performance of the spring-loaded roller seed cracker at various initial roll clearances.

13.5 mm the quantity of perfectly shelled kernels decreased and kernel damage fell, while the quantity of uncracked seeds increased dramatically.

Centrifugal nutmeg cracking

An experimental centrifugal nutmeg cracker having the rotor mounted in a horizontal plane was built and tested. The cracker (Fig. 10) consisted of four main parts:

(a) a wooden, 25 mm thick horizontal rotor (R = 300 mm) having 12 radial slots, 13 mm deep x 25 mm wide equidistantly spaced around its surface. The central portion of the rotor where the seeds are fed by gravity had a radius of 75 mm and was recessed 13 mm deep. The radial slots emanated from this portion of the rotor. The centre of the rotor contained a 25 mm diameter hole, through which a vertical shaft passed. A 6 mm thick machined steel plate of 250 mm diameter was welded on the end of the shaft and acted as a support for the horizontal rotor.

(b) the cracking ring (R_C = 695 mm) was 100 mm high and was rolled from 8 mm thick steel. This ring provided an approach angle, β, of 18.5° (Fig. 6). On top of this ring, a 1.40 m diameter cover plate made of 13 mm thick plywood was bolted. This cover was made in halves and had a central opening of 150 mm in diameter to allow the vertical shaft and feeding of nutmeg seeds to take place.

(c) a conical steel collection chute, 500 mm high and 1.39 m in diameter at the top was bolted to the bottom of the cracking ring. The lower end of the chute had an opening 250 mm in diameter for the discharge of kernels and shells.

(d) a frame for supporting the vertical shaft and rotor assembly, the cracking ring and chute, and for mounting of the 0.75 kW electric motor.

Preliminary testing of this machine was undertaken in

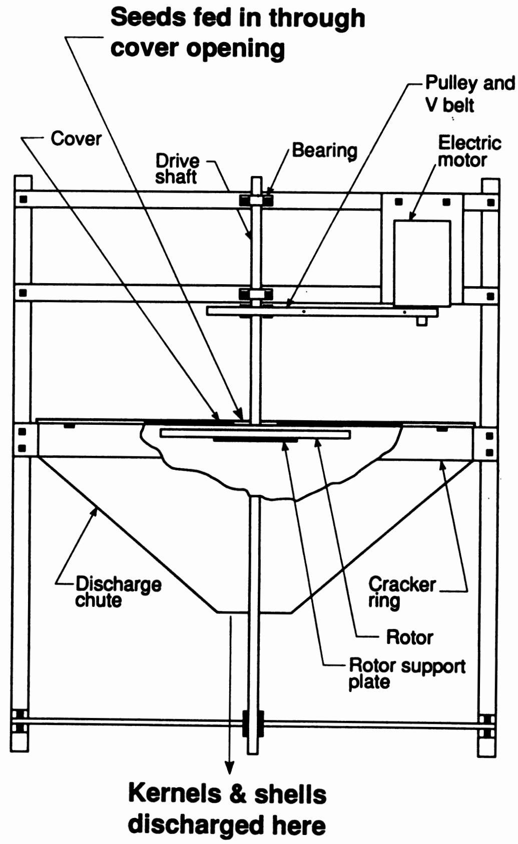

Fig. 10. The centrifugal nutmeg seed cracker.

Trinidad at the University of the West Indies. Speed of rotation of the rotor, as expected, was the critical factor affecting performance. Tests were carried out at rotor speeds ranging from 300 - 450 rpm using both individually fed nutmeg seeds and batches of 100. A typical set of results is shown in Table I. As the rotor's speed increased, shelling performance improved; however, the number of bruised/damaged nutmegs also increased.

Testing of the machine also took place at the Victoria nutmeg processing station in Grenada. Speed variation of the rotor was achieved through changes in pulley diameters. Fractions of perfectly shelled, partially shelled, and damaged

Table I: The effect of rotor speed on shelling performance of centrifugal nutmeg seed cracker.

Rotor speed (rpm)	Machine performance indicies (%)			
	Perfectly shelled seeds	Partially shelled seeds	Unshelled seeds	Damaged seeds
300	23	43	21	3
350	41	34	20	5
400	50	40	6	5
425	58	28	8	6
450	59	25	3	13

kernels were sorted and weighed, after 0.9 kg samples (approximately 180 seeds) of unassorted, dried seeds were poured into the cracker. Partially shelled nutmegs were recycled through the machine, and the resulting fractions again weighed. These tests were performed at two rotor speeds, 395 rpm and 460 rpm with the results shown in Table II. An improvement in the cracking efficiency was found at the higher speed while recycling of partial or unshelled seeds increased the risk of kernel damage.

Table II: The performance of the centrifugal nutmeg seed cracker at the Victoria processing station

Machine	Rotor speed	Weight fraction (%)	
	(rpm)	1st pass	2nd pass
Perfectly shelled kernels	395	39.8	57.8
Partially unshelled seeds	395	45.3	17.2
Damaged/bruised kernels	395	1.6	3.1
Perfectly shelled kernels	460	49.2	67.2
Partially unshelled seeds	460	21.8	11.7
Damaged/bruised kernel	460	0.8	3.9

The machine, operating at 460 rpm, was also tested as a single pass system at the Victoria processing station. This was considered to be a commercial run, as three bags of dried nutmeg seeds each having a mass of 68.2 kg were used. The results show that on a mass basis, 45.3% completely shelled kernels, 20.7% partial/unshelled seeds, and 3.9% damaged kernels were found. The partial/unshelled fraction was comprised of 17.8% partially shelled seeds, and 2.9% completely unshelled seeds. For these trials the machine's capacity was estimated at 40 kg of seeds per minute.

DISCUSSION AND CONCLUSION

Three approaches which utilize a single compressive or an impact force have been described for the mechanical shelling of dried nutmeg seeds. The first method envisages the sorting of nutmeg seeds in definite size ranges, with each range of seed sizes passed through a pair of counter-rotating rolls having a fixed clearance between them. A semi-empirical cracking model was described which predicts the need for a minimum of four rolls for effective cracking of seeds in the size range of 16 to 27 mm. Of the three methods described, this system appears to be the most promising in terms of shelling performance because of its precise nature. However, it is also the most expensive in terms of machinery, operator, and maintenance costs. Shelling performance can be improved in such a system if the range of seed sizes to be cracked by a particular roller pair is narrowed, and an increased number of roller pairs are used. This, however, adds to the capital cost of the system.

Using a pair of cracking rolls with one roller spring loaded showed promise for cracking nutmeg seeds of various sizes. The range of seed sizes obtained in practice, however, appears to be too large to expect very good shelling characteristics. Additionally, in a practical cracking system, unassorted seeds must be fed into the rolls in single file to prevent the possibility of seeds smaller than the instantaneous roller clearance falling through uncracked. This will limit the machine's throughput. However, if spring loaded rolls are used, instead of fixed rolls, in a sorting and cracking system as previously described, the number of pairs of cracking rolls may be reduced as there will be an extended range of seed sizes efficiently cracked by a particular pair of rolls.

The final method evaluated for cracking seeds of various sizes was a centrifugal cracker. This is a simple, low cost machine which appears suitable for manufacture and use in Grenada. The machine has an acceptable throughput, however its shelling performance requires improvement. While an increase in rotor speed will increase the amount of perfectly shelled seeds and reduce the amount of partial/unshelled seeds, kernel damage also increases. It appears that the machine's potential may be limited by the range of seed sizes to be shelled, as it is noted that the impact force of the seed on the cracking ring is directly proportional to the seed's mass. The mass ratio of the maximum to the minimum sized nutmeg seed found in Grenada is approximately 2:1. Hence, at a particular rotor speed, while large seeds may be perfectly shelled or even show kernel damage, smaller seeds will be uncracked or be partially cracked due to the reduced impact force. This method, therefore, also appears to require a seed sizing operation prior to cracking. The performance of a sizing and centrifugal cracking operation, with the rotor speed inversely proportional to seed size, needs further investigation.

Each of the three approaches described can reduce kernel damage compared to that of the impact type of mechanical sheller currently being used. The centrifugal cracker, however, shows considerable potential as a practical machine for shelling nutmeg seeds. Simplicity in design, adequate capacity, and the promise of good performance are the key attributes of this machine.

One of the difficulties associated with the shelling of unassorted nutmeg seeds, at the present time, is that there appears to be relatively high levels of "defective" seeds. Because of their low shell and kernel strengths, such seeds suffer considerable damage on cracking. Sorting and removal of defective seeds prior to cracking will prove to be beneficial in any processing operation.

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