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Development of a semi-automatic macadamia cracking machine

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Abstract

Macadamia is the king of nuts and popular around the world. Cracking is vital to extract the whole nut and increases the commercial value of the product. Therefore, a semi-automatic macadamia cracking machine was designed and assessed. It was modified from a manual nut cracker. Such a machine was expected to have a higher throughput and produce a higher quality output. The key part of this machine consisted of a drive blade set and a nut discharge set, which were both upgraded so that they were driven by an electric motor. In extant machines, both these tasks are manual. We tested blade speeds of up to 22 rpm, macadamia nut diameters from 21 to 27 mm and the method to feed the nuts into the cracking section. The optimum cracking condition was found to be a 19 rpm blade speed or 19 cracking strokes per minute. The feeder handled 99% of the nuts successfully leading to a nut throughput of 10.6 kg/h, with 88% whole kernels. The best cracking performance was found on nut diameters in the range of 25 to 27 mm with a blade compression depth of 2.5 mm.

Keywords: Macadamia, Shelling, Cracking, Semi-automatic

1. Introduction

Macadamia nuts are a popular edible nut - packed with healthy nutrients, notably oleic acid. Botanically, macadamia belongs to the family Proteaceae, genus *Macadamia*. Some alternative common names include Australia nut, Queensland nut and bush nut. Macadamia nuts are produced in many countries, Australia (40%), USA (24%), South Africa (15%), South and Central America (12%) and others (9%). In Thailand, macadamia plantations are found mainly in the northern and northeastern regions. Since macadamia nuts are recognized for their health benefits, the price of macadamia nuts is always high [1].

Generally, macadamia nuts are processed by harvesting, dehusking, drying, cracking, separating, grading, roasting, salting and packaging. After macadamia nuts are harvested, the husk must be removed within twenty-four hours to prevent heating of the nut from its respiration, metabolic and enzymatic action, all of which can degrade nut quality. In this process, the operation of cracking Macadamia nuts is the most critical and delicate step for achieving high-quality kernels [2-3].

In Thailand, laborers used a simple manual hammer to crack nut for shelling. This process is slow and many nuts are broken. Additionally, husking by hand is a tedious, laborious process and the workers earn little money. The traditional cracker's impact head was modified by the Chiangmai Agricultural Engineering Research Center (CAERC), adding a counter weight. Their machine had a capacity (measured as rate of cracked nuts in kg/h) of 5.2 kg/h of cracked macadamia nuts, yielding 90% whole kernels and 10% broken kernels, which, in turn, yielded 68% full kernels and 32% broken kernels. This was an increase from the traditional method using a hammer at a capacity of 3.7 kg/h, yielding 63% full kernels and 37% broken [4]. The machine used can be seen in Figure 1.

Figure 1 Macadamia nut cracking using the CAERC manual impact system, taken from Krissanasrani (2017) [5]

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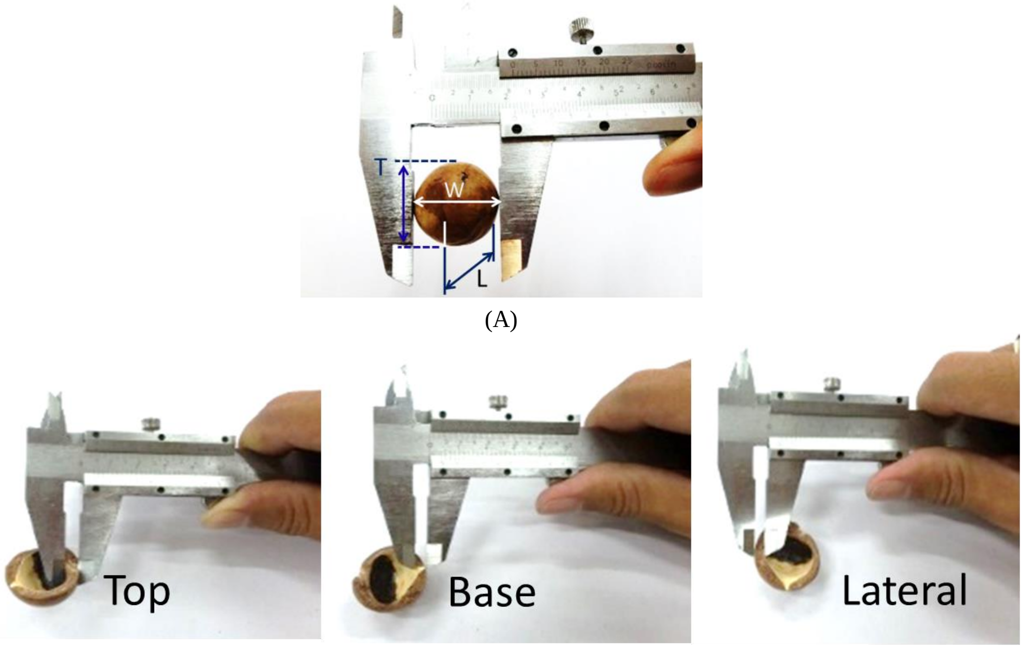

(A)

(B)

Figure 2 Measurement of nut dimensions: (A) length, width and thickness and (B) shell thickness, measured on the top, base and lateral sides

However, the CAERC machine still requires an operator to control all steps of the process, which starts by taking the nut into the nut cracking section, rolling the counter balance wheel to drive the hammer and then extracting the shelled nut and husk from the machine. It is still a tedious and laborious process. Thus, we developed a semi-automatic macadamia cracking machine, called the MSU-MAC, based on the manual cracker, to reduce the human effort to work and control the machine. This increases the cracking capacity and it is expected that this cracker will run faster and produce a higher quality output. Although much larger plants are available, the capital costs for the machinery and its installation are not justified by the typical small Thai business. Thus we aimed to design a simple, inexpensive, system that would increase the efficiency of existing small holders. The MSU-MAC can be used to upgrade existing machines or in manual practices requiring no additional space and minimal operator training.

2. Materials and methods

The main idea to develop the semi-automatic macadamia cracking machine (MSU-MAC) is to reduce operator activities needed to control the machine. Then, the cracking capacity will be increased. It is expected that the nut cracker will run faster and have a greater output quality. The key parameters that required control of our machine were the settings of drive blades and the nut discharge. Both were upgraded so that they are driven by electric motors. The design steps are described in the following sections.

2.1 Physical properties of nuts

Macadamia nuts (*M. integrifolia*), were harvested in the 2015 season in Chiang Mai Province in the north of Thailand, and used as raw material to assess our machine. The nuts were dehusked within 24 hours of harvest and then dried in a conventional batch type hot air dryer at 50 – 55 ºC [6] until the moisture content was reduced to about 3% (wet basis). After that, the shells were stored in nylon sacks at ambient temperature (typically 25-30 ºC) prior to the experiment.

The physical properties of the nuts were determined so that the required clearance between the blades and nuts in the shelling unit could be set. Moreover, this data also illustrated their characteristic behavior. The length, L (major diameter), width, W (intermediate diameter) and thickness, T (minor diameter), as well as shell thickness were measured using vernier calipers and seed mass was measured with a digital balance.

Before making the measurements, nuts were separated into three groups by diameter (small, 21-23 mm, medium, >23-25mm, and large, >25-27 mm), to design the compression range of blade. The nuts were found to be almost spherical. Variations between the length (L), width (W) and thickness (T) are reported in the next section. The thickness of the nut shell was measured on the top, base and lateral sides. Their physical dimensions were determined from 20 randomly chosen nuts with 3 replications of each measurement (Figure 2 A). Equivalent diameters (D_g) were calculated as the geometric mean of the three dimensions [3, 7-8]:

$$D_g = (LWT)^{1/3} \tag{1}$$

The nuts are characterized by a sphericity measure, computed following [9]:

$$S_p = (D_g/L) \times 100 \tag{2}$$

The physical properties of the nuts used for determining the design parameters are shown in Table 1. The computed equivalent diameters (Dg) were 22.48 + 0.25 mm, 24.22 + 0.39 mm. and 26.12 +0.45 for small, medium and large size nuts, respectively. Sphericity coefficients (Sp) for small, medium and large nuts were 99.5%, 99.3%, and 99.6%, respectively. Careful analysis of the nut sphericity shows that

Table 1 Macadamia nut dimensions

Physical properties	Small size nut (Diameter between 21-23 mm.)	Medium size nut (Diameter between 23-25 mm.)	Large size nut (Diameter between 25-27 mm.)
Length, L (mm)	22.4 ± 0.40	24.4 ± 0.40	26.2 ± 0.53
Width, W (mm)	22.4 ± 0.41	24.1 ± 0.45	25.9 ± 0.55
Thickness, T (mm)	22.6 ± 0.37	24.2 ± 0.51	26.2 ± 0.49
Equivalent diameter, Dg (mm)	22.5 ± 0.25	24.2 ± 0.39	26.1 ± 0.45
Sphericity (Sp) %	99.5	99.3	99.6
Mass (g)	6.2 ± 0.34	7.6 ± 0.34	9.7 ± 0.34
Nuts/Kg	160	130	103
Shell thickness on top side (mm)	4.7 ± 0.52	5.0 ± 0.52	5.2 ± 0.60
Shell thickness on Base side (mm)	4.1 ± 0.50	3.9 ± 0.43	4.4 ± 0.50
Shell thickness on lateral side (mm)	2.8 ± 0.38	2.7 ± 0.37	3.1 ± 0.56

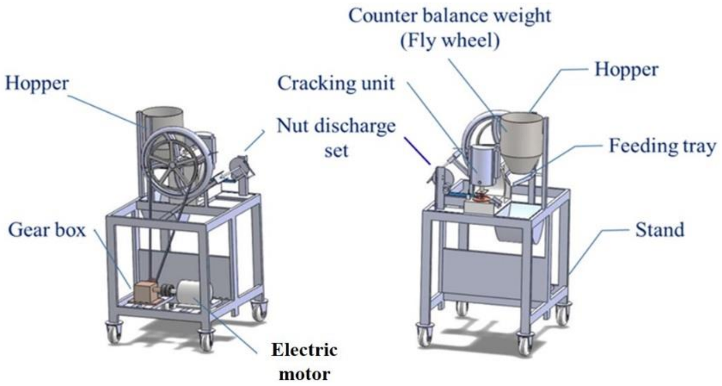

Figure 3 Two views of the MSU-MAC machine

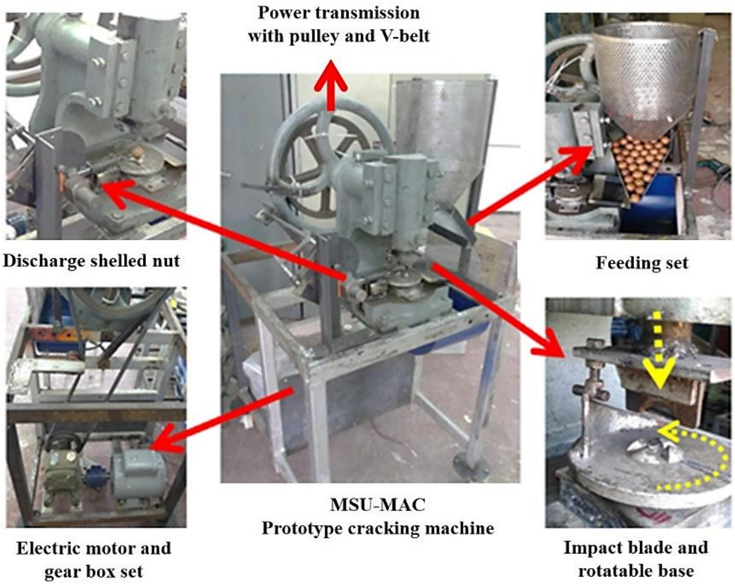

Figure 4 Main operation of MSU-MAC

these values were not significantly different from 100%, i.e., the nuts were essentially spheres. However, the shell thickness was used to set the blade stroke distance. This parameter is important to design the blade curvature and nut feed direction into the cracking unit. For the shell thickness, we found that the top base sides of the grain had similar thicknesses, but the lateral sides were about 60% thinner. Moreover, natural cracks were often observed along the top to the base, through the lateral side. This made it was easier for the blade to crack the shell. For the blade compression depth, we found that the stroke length should not exceed 2.7 mm, so that the blade is not in contact with the nut and no damage occurs. Figure 5 shows setting the stroke length by adjusting the distance between cracking case and the horizontal bar attached to the blade.

2.2 MSU-MAC machine description

The MSU-MAC is a simple device. The major components are readily assembled. It consists of a cracker, which is fixed in the center of the stand, a hopper fitted with a feeding tray, installed on the bottom of the hopper, a cracking unit, counter balance weight, nut discharge and a power system which includes a 373 kW electric motor and a 50:1 gear box, driven by a flexible V-belt, as shown in Figures 3 and 4.

The main workings of the machine are shown in Figure 4. First, the nuts were sorted by size using a sieve (promoted by their almost spherical shape). The blade was set for the current nut size (see Figure 5). Nuts were fed into the hopper with a feeding tray installed on the bottom of the hopper. Then, the operator simply puts a nut into the nut cracking section. In this step, cracking the nut, the vertical ‘cracking rod’ fitted with a blade on the lower end was moved up. Then, the rod is forced down so that the blade strikes the nut and cuts into the shell. Next, a steel rod mounted on the cracking rod, moves down to force the sloping steel plate to turn, so that the cracked nut is twisted. Then, the cracking rod is moved up to the top again and the discharge rod moves into the cracking section and sweeps both the cracked nut and the shell into a bin. The cycle starts again as the operator feeds a nut into the nut cracking section, as shown in Figure 6.

2.3 Performance testing

2.3.1 Operator feeding capacity

The cracking machine was run by a single operator who randomly selects a nut from the tray under the hopper, and moves it into the cracking section. Performance testing measured the ability of the operator to successfully feed nuts at various cracker stroke rates from 16 to 22 strokes/minute.

2.3.2 Performance testing

The macadamia nut cracker in this study was first configured with the cracking speed and blade compression depth from our early testing. The experiment was started by the operator placing a nut into the cracking section. After testing, both the cracked nut and shell were discharged into a bin. The nuts were classified as unshelled seeds (A), whole kernels (B), half kernels (C), small damaged kernels (D), large damaged kernels (E) and total grain testing (T). Shelling capacities, efficiencies and qualities of each class were recorded on a weight basis [10]. The quantitative and qualitative indicators were shelling efficiency (SE), percentage of whole kernels (WK), and broken kernels (BK) (include of half kernels, small damaged kernels and large damaged kernels). Examples are shown in Figure 7 and definitions of the metrics are:

$$SE = [(B+C+D+E)/T] \times 100\ \% \quad (3)$$

$$WK = [(B) / (B+C+D+E)] \times 100\ \% \quad (4)$$

$$BK = [(C + D + E)/ (B+C+D+E)] \times 100\ \% \quad (5)$$

Three replicates were made under all experimental conditions.

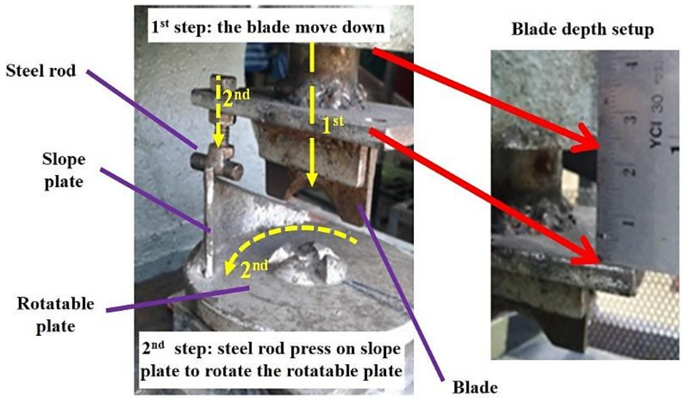

Figure 5 Blade compression depth setting

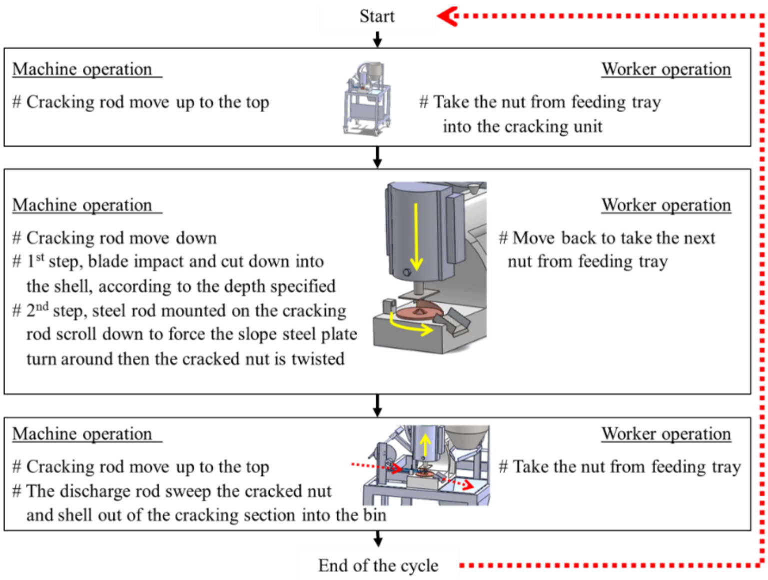

Figure 6 Operation of the MSU-MAC. The operator’s only task is to move nuts into the cracking section

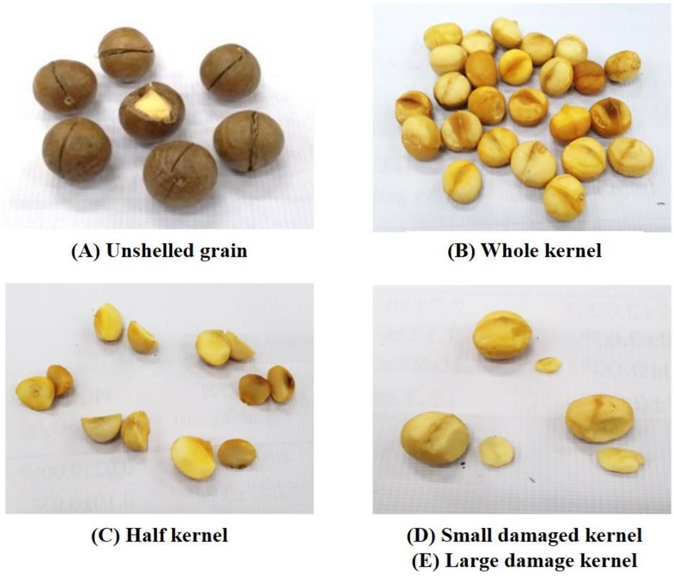

Figure 7 Classes of macadamia nuts after cracking

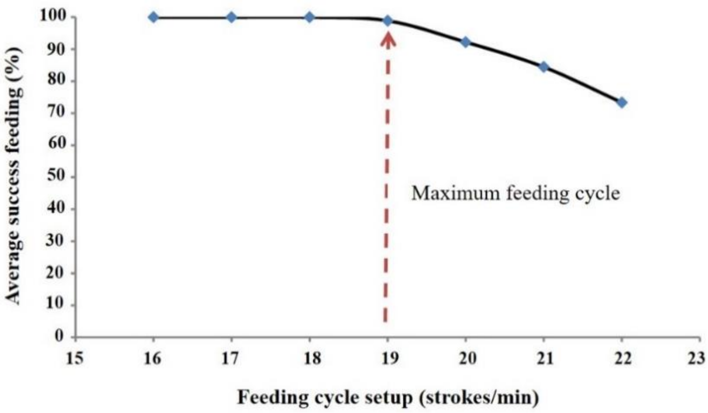

Figure 8 Successful feeding versus feeding cycle setup (strokes/min)

3. Results

3.1 Performance testing

3.1.1 Operator feeding capacity

Operator feeding capacity was tested at various cracker stroke rates and feeding success rates (see Figure 8). At rates less than 19 strokes/min, almost all nuts can be moved into the cracking section and put on the rotatable base. However, at higher rates, the operator could not feed nuts into the cracking section fast enough and missed strokes causing the success rate to drop. Thus, the cracking capacity was estimated as the feeding rate of 19 strokes/minute which led to ~1140 nuts per hour.

3.1.2 Machine performance testing

The metrics, shelling efficiency (SE), percentage of whole kernel (WK) and broken kernel (BK) (including half kernels, small damaged kernels and large damaged kernels) were compared with conventional shelling methods and shown in Table 2. The performance of the MSU-MAC machine was compared to that of conventional methods, tested by Thongjan et al. [4]. The cracking capacity of the MSU-MAC was higher than conventional cracking and shelling methods for all nut sizes at 6.6 kg/h (small), 7.5 kg/h (medium) and 10.6 kg/h (large). For shelling efficiency, Conventional methods can achieve 100% shelling efficiency because workers try to crack every nut, in order to get every kernel. Alternatively, the MSU-MAC operator only has to put nuts into the cracking section and some nuts are not cracked. However, shelling efficiency was still high level at 94 % (small), 87% (medium) and 97% (large).

4. Discussion

The MSU-MAC machine was able to crack nuts to free whole kernels with higher success rates (88%) than hammer or pressing techniques and with similar success rates to the CAERC cracking machine (90%) [5] as shown in Table 2. The cracking capacity of the MSU-MAC machine was higher than all other conventional tools. For different sized nuts, the MSU-MAC machine was able to increase the capacity relative to the CAERC machine by 58%, to the hammer by 64% and with pressing by 120%. The MSU-MAC showed the best performance with large nuts ~88% of whole kernels, not significantly different from the whole kernel production of the CAERC machine. However, small and medium size nuts showed lower whole kernel success because the high compression force from blade

Table 2 Performance testing

Results	Cracking methods					
				Conventional tools		
	 MSU-MAC cracking machine			 CAERC cracking machine	 Hammer	 Pressing
	Small size nut (21-23 mm)	Medium size nut (23-25 mm)	Large size nut (25-27 mm)	All nut sizes	All nut sizes	All nut sizes
Capacity (kg/hr)	6.6	7.5	10.6	5.2	5.0	3.7
Shelling efficiency (SE) %	94	87	97	na*	na*	na*
Whole kernel (WK) %	80.5	78.2	87.7	89.9	67.7	62.9
Broken kernel (BK) %	19.5	21.8	12.3	10.1	32.3	37.1

* Normally, shells are removed from all nuts if workers operate the cracking machine.

was dissipated inside the kernel and led to higher broken kernel rates, similar to results of hammer and pressing methods.

5. Conclusions

The semi-automatic macadamia cracking machine (MSU-MAC), modified from a manual nut cracker, ran approximately twice as fast as the best previous machine and with higher quality output than manual methods and with a similar quality to the CAERC machine. The key parts of our machine were a blade set and a nut discharge set, both were driven by an electric motor. Then, an operator just has to release a nut into the nut cracking section. The optimum cracking condition was encountered with a blade speed set at 19 strokes/min. The feeding success was 99%, the maximum nut cracking capacity was 10.6 kg/h., with 88% whole kernels. Following that, the best cracking performance was found with 25 - 27 mm diameter nuts with a blade compression depth of 2.5 mm. Finally, in line with our aim to enhance small farm efficiency, we note that MSU-MAC can replace existing machines and manual practices while requiring minimal additional space and operator training.

6. Acknowledgements

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7. References

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