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CRACKED-MIXTURE SIEVING RATES AND EFFICIENCIES IN SMALL-SCALE PALM NUT PROCESSING IN GHANA

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Abstract

A number of innovations, including the inclined manual rotary sieve or trommel, have been introduced by small-scale process equipment manufacturers and are being used in palm-nut cracked mixture separation. But the proficiency of these innovations has not been officially established. The study measures the sieving rates and efficiencies of the manual trommel in small-scale cleaning of palm nut-cracked mixture with a view to further upgrading the technology of separating kernels from the cracked mixture. Over a sample of 24 field trials, observed minimum, maximum and average through-put rates are 298.6, 1927.5 and 733.6 kg/h, respectively. The average rate is 936.1 kg/h for separately installed sieves that are not directly fed from a motorized palm nut cracker. However, with a cleaning efficiency or dirt content reduction of 26 per cent the overflow dirt content of 54.7 per cent compares poorly with 15-17 per cent reported for large scale mills after preliminary winnowing before hydro-cycloning or separation in the claybath.

Résumé

Amoah, J. Y., Aggey, M. & Annumu, S.: *Les vitesses de criblage de cassé-mélangé et l'efficacité de séparation de l'amande de palme dans la petite entreprise au Ghana*. Un nombre d'innovations, y compris le trommel ou le crible rotatif manuel incliné, ont été introduites par les constructeurs de machines de traitement dans la petite entreprise et elle sont utilisée dans la séparation de l'amande de palme cassé-mélangé. Mais la qualité de ces innovations n'a pas été officiellement assurée. Cette étude mesure la vitesse de criblage et l'efficacité du trommel manuel dans la petite entreprise de nettoyage de l'amande de palme cassé-mélangé en vue d' améliorer de plus la technologie de séparation d' amande du cassé-mélangé. Sur un échantillon de 24 d'essais sur le terrain les vitesses de la capacité de production minimum, maximum et moyenne observées respectivement sont 298.6, 1927.5 et 733.6 kg/h. La vitesse moyenne est 936.1 kg/h pour les criblage séparément installé qui ne sont pas directement fournis par un casse-noix motorisé. Cependant, avec une efficacité de nettoyage ou la réduction du contenu de saleté de 26%, le débordement du contenu de saleté de 54.7% se compare mal avec 15-17% mentionné pour les moulins à grande échelle après le vannage préliminaire avant le hydrocyclone ou la séparation dans le bain argileux.

Introduction

Separating palm kernels from the cracked mixture before oil extraction involves the removal of undecorticated kernels, pieces of shell, stones, debris and other extraneous material. All these abrasive materials, excluding any kernels (whole or pieces) attached constitute dirt which, if not separated, may result in rates of wear, tear and breakage in grinding mills, expellers and other milling equipment. Internationally accepted dirt levels in commercially traded palm kernels are 4 per cent (Unilever, Undated) but Head (1988) reports a dirt content of 5.4-5.6 per cent for palm kernels from palm oil mills in Cameroun (Ekona) while large scale mills in Ghana achieve between 15-17 per cent dirt levels after preliminary winnowing, reducing to between 3.5 and 9 per cent after hydro-cycloning, and also targeting levels of 4 per cent kernel content in trash from the cleaning operation (Aggey & Amoah, 2003).

In Ghana, separating kernels from cracked-mixture in small-scale processing remains arduous, involving manual sieving, clay-bath separation and hand-picking for the numerous women in traditional kernel oil production (Aggey, 1990). Direct hand picking is employed at the micro level of processing involving only small quantities of kernels. In many areas in Ghana kernel separation begins with winnowing, which invariably involves a woman fetching about 10-20 kg batches of cracked-mixture in a basin which she carries on her head. The mixture is then poured out gradually onto a pile on the floor as the wind is allowed to blow away pieces of debris. An average of 9 woman hours could be expended in winnowing cracked-mixture from 256 kg of palm nuts (Aggey, 1990). The winnowed mixture is subsequently separated in a clay-bath into kernels and shells.

A number of innovations have been introduced by small-scale process equipment manufacturers and are being used in the palm nut cracked-mixture separation operation but the proficiency of these innovations has not been officially established. In some places a mechanical blower is used to generate the draft of wind in which the cracked-mixture is winnowed. Some women too use a rectangular screen nailed to the base of a wooden frame. Another innovation is the use of inclined rotating sieves which are either operated manually or coupled to an engine or electric motor to remove the debris from the cracked mixture. The objective of this study is to measure the sieving rates and efficiency of the inclined rotating sieve in cleaning palm nut cracked mixture prior to the design of a downstream palm kernel-shell separating system.

Screen effectiveness and cleaning efficiency

Simple material balance equations have been useful in calculating the ratios of material in feed to a screen as well as oversize and underflow from a screen through analyzing these three streams and knowledge of the desired cut diameter. For example, if F = mass flow rate of feed, D = mass flow rate of overflow, B = mass flow rate of underflow, x_F = mass fraction of material A in feed, x_D = mass fraction of material A in overflow, x_B = mass fraction of material A in underflow.

Assuming the feed comprises of only materials A and B then the mass fractions of material B in the feed, overflow, and underflow are $1-x_F$, $1-x_D$, and $1-x_B$. Under these conditions the following material balance equations have been useful:

An overall balance;

$$F = D + B \quad \text{...(1)}$$

And a component balance;

$$Fx_F = Dx_D + Bx_B \quad \text{...(2)}$$

On this basis, McCabe & Smith (1976) define a common measure of screen effectiveness or screen efficiency based on the oversize, E_A, that is a measure of the success of a screen in closely separating materials A and B as the ratio of oversize material A that is actually in the overflow, to the amount of A entering in the feed, where

$$E_A = \frac{Dx_D}{Fx_F} = \frac{x_F - x_B}{x_D - x_B} \cdot \frac{x_D}{x_F} \quad \text{..........................(3)}$$

On the bases of the undersize material, screen efficiency is:

$$E_B = \frac{B(1-x_B)}{F(1-x_F)} = \frac{x_D - x_F}{x_D - x_B} \cdot \frac{(1-x_B)}{(1-x_F)} \quad \text{...............(4)}$$

Noting, however, that there is confusion concerning the meaning of screen efficiency as a uniform method for figuring efficiency has never been established, Perry & Green (1984) recommended graphical methods and the method given by Tyler (1973). In the Tyler formula, when material put through the screen is the desired product, “efficiency” E is the ratio of the amount of undersize obtained to the amount of undersize in the feed:

$$E = (R \, . \, d)/b \quad \ldots \quad (5)$$

Where R is percent of fines through the screen, d is percent finer than designated size in screen fines, and b is percent finer than designated fines in the screen feed. When the object is to recover an oversize product from the screen, efficiency may be expressed as a ratio of the amount of oversize obtained to the amount of true oversize:

$$E - (O \, .c)/a \quad \ldots \quad (6)$$

where O is percent of oversize over the screen, c is percent coarser than the designated size in screen oversize, and a is percent coarser than designated size in screen feed.

In addition to the analytical difficulty presented by the unavailability of a uniform method for defining screen efficiency, cleaning palm nut cracked mixture by screening raises further issues. The operation is not a simple matter of separating material into two well defined size ranges. Results from a screen analysis of cracked mixture in the present study showed the following compositions on a screen of mesh number -1.51+2.86; whole kernels 22.39 per cent, kernel pieces 3.43 per cent, undecorticated nuts 1.75 per cent, shells and debris 26.82 per cent totaling 54.38 per cent. Respectively, the corresponding compositions on the lower screen mesh number -2.86+3.82 are 0. 19, 1.39, 0.01, 19.25 and 20.38 per cent. While the first three components of the mixture are retained on only these two screen meshes, the size distribution of shells and debris (the forth component) spreads to as low as mesh number -41.65, making the balance of 25.24 per cent.

The critical point to note here is that the percentage of total kernels, including pieces, on the top screen (25.82%) is extremely close to the percentage of shells and debris (26.82%). This indicates that particles of similar size which may not be separated easily by the screening operation only aids in cleaning the kernel by concentrating the larger size shells and debris in the material retained by the top screen, as suggested by Head (1988). In fact although more than 95 per cent of kernels in the cracked mixture may be found in the rotating screen, oversize, suggesting a very satisfactory screening efficiency, the actual percentages of kernels (42.8%) and shells, and undecorticated nuts (42.1%) in this stream remain close, which is completely undesirable in the cleaning operation. Thus, the above methods may not be ideal and standard in describing kernel cleaning efficiencies.

Aggey & Amoah (2003) found two dimensions of kernel cleaning efficiency in use by oil palm millers in Ghana; a dirt content of kernels and the percentage kernel loss to shells. In this method the cracked mixture, the cleaned kernel and the discarded shells streams are considered as comprising of whole kernels, kernel pieces, whole nuts, partially cracked nuts, shells and debris. The dirt content D is determined for the cracked mixture and the cleaned kernel streams as:

$$D = \{(S_{WN} + S_{CN} + S_{L})(100)/W\} \% \quad \ldots (7)$$

where S_{WN} is weight of shells from whole nuts in the sample, S_{CN} is weight of shells from partially cracked nuts in the sample, S_L is weight of loose shells in the sample, and W is weight of sample from cracked mixture or oversize. Percentage reduction in dirt content between cracked mixture and oversize streams may then be interpreted as cleaning efficiency. Similarly, percent kernel loss to shell stream is determined by

$$L = \{(K_{WN} + K_{CN} + K_{P} + K_{L})(100)/W\} \% \quad \ldots (8)$$

where K_{WN} is weight of kernels from whole nuts in the sample, K_{CN} is weight of kernels from partially cracked nuts in the sample, K_P is free kernel pieces in the sample, K_L is weight of loose whole kernels in the sample, and W is weight of sample of shells or undersize stream. This approach is combined with material balance equations in calculating the screening efficiencies in the paper.

Experimental

Source of palm nuts and cracked-mixture

Palm nut samples were obtained from small-scale palm oil processing krammer mills in the Kade-Kusi-Takorase area of Ghana. These mills obtain mixed oil palm fruits comprising traditional *dura* and the hybrid *tenera* from farms in the locality. Seedlings of the hybrid *tenera* fruit originate from the nearby research institutes and local seed developers. Palm nut samples from respective krammer oil mills were cracked at eight different cracking sites spread over the three towns; Kade, Kusi and Takorase. At each sampling site, three samples of between 100-120 kg of nuts were weighed on a 250-kg capacity platform scale into separate heaps; each sample being drawn from the consignment of a different customer to the site. The heaps of nuts are cracked with the operation carefully timed while the operator and assistants are observed. The resulting cracked mixture from each lot was carefully mixed and batch samples of up to 3 kg were drawn.

Sampling from the manual rotating screens or sieves

The rotating screen or sieve (Fig. 1) has been widely adopted in the project area by the traditional palm kernel oil processing industry. Essentially, the innovation is a *trommel* screen (Perry & Green, 1984) consisting of a cylindrical frame surrounded by wire cloth, open at both ends and inclined at less than 5^{o} to the horizontal. The wire thickness is about 2 mm and the screen aperture is 20 mm by 8-10 mm. The palm nut cracked mixture to be screened is fed at the upper

Fig. 1. Timing the palm nut cracked-mixture sieving operation

end, and the oversize is discharged at the lower end. Debris, as well as smaller shell and kernel pieces, fall through the wire cloth openings to the floor to be discarded. One person manually cranks the *trommel* while another pours in the cracked mixture. Elsewhere in Ghana, the screen is coupled through speed reducing gears to the prime mover driving the palm nut cracker but this was not found in the project area.

Having been weighed again after sampling, the various batches of cracked mixture are then fed into the rotating sieves and the cleaning operation is carefully timed. Where a rotating sieve is fed directly from the nut cracking machine, the end-time of cracking and sifting are distinguished. After screening, the oversize and undersize materials are weighed and then sampled. Three samples each of cracked mixture, oversize and undersize were obtained from each site resulting in 24 samples from the eight sites sampled. These are later subjected to a sieve analysis using standard analytical screen series ranging in mesh size from -0.61+0.80 to -27.68+41.65. The screens were fitted to a *Fritsch Gmb* mechanical *autosieve* shaker (*Analysette 3PRO*) set at 10 min sieving time and an amplitude of 2.5 mm.

Results

The raw data for calculating sieving rates observed for small-scale manual rotating sieves in the project area are presented in Table 1. The Table also gives the fruit varieties in each sample, the dimensions of each sieve and an indication of whether the sieve is fed directly from the palm nut cracker egress chute or not.

Except for samples from site 1 which consisted of either pure *tenera* or *dura* varieties, all the remaining samples were a mixture of the two varieties. The sieves sampled ranged from 1100 to 1520 mm in length and 350 to 500 mm in diameter. At three of the sites sampled the sieves are linked directly to motorized palm nut crackers although they are not coupled to the prime movers. The sieves are linked at all the two sites sampled at Kade and also at one of the four sites at Takorase.

Table 2 summarizes average sieving rates by site, location and whether the sieve is directly linked to the motorized palm nut cracker or not. The results of a statistical test of the difference of means of cracking rates between locations at Kade, Kusi and Takorase are presented in Tables 3A and 3B. Observed average sieving rates are highest in Kusi (average, 1132.4 kg/h) followed by Takorase (708.7 kg/h) and Kade (384.5 kg/h).

Table 2 also shows that operating the rotating sieve on its own without direct linkage with a cracker gives higher sieving rates (average 936.1 kg/h) than when it is linked up (averaged 432.7 kg/h), receiving cracked mixture directly from the egress chute of a motorized cracker. Pearson's coefficients of correlation between sieving rates and sieve length (0.684) and diameter (-0.403) are in Table 4. Tables 5, 6 and 7 provide data for calculating the cleaning efficiency of the manual rotating sieves as summarized in Table 8. Table 5 profiles the cracked mixture before it is cleaned in the sieve while Tables 6 and 7 describe the outputs from the sieve. The undersize (Table 7) is discarded as chaff or trash and the oversize (Table 6), which is the portion of interest, is collected and further separated in a clay-bath.

The dirt level in the cracked mixture ranges from 60.7 to 81.4 per cent with an average of 74.3 per cent (Table 5). In the chaff, the dirt level is between 100 (0.0% kernel) and 96.8 per cent (3.2% kernel), averaging 98.6 per cent (Table 7) while the sieve oversize dirt level is 44.7-63.6 per cent with an average of 54.7 per cent (Table 6). An average reduction in dirt level (or cleaning efficiency) of 26.0 per cent is obtained in the manual rotating sieve corresponding to an output dirt level of 54.7 per cent (Table 8). The correlation between cleaning efficiency and sieving rate, sieve length and diameter are summarized in Table 9.

Discussion

The average throughput and maximum rates (936.1 kg/h and 1927.5 kg/h) observed for the manual

TABLE 1

Observed sieving rates of trommels in the project area

Location	*Trial*	*Mass of cracked mixture (kg)*	*Sieving time (min)*	*Sieving rate (kg/h)*	*Fruit variety*	*Linked to cracker*	*Sieve length* (mm)	*Sieve dia.* (mm)
Kusi	1	107.1	3.52	1825.6	Dura	No	1500	400
	2	117.9	3.67	1927.5	Dura	No	1500	400
	3	93.8	7.70	730.9	Tenera	No	1500	400
Takorase	1	108.4	6.12	1062.7	Dura/Tenera mixed	No	1300	350
	2	105.2	8.46	746.1	Dura/Tenera mixed	No	1300	350
	3	100.7	7.13	847.4	Dura/Tenera mixed	No	1300	350
Takorase	1	106.2	11.21	568.4	Mixed/More Dura	No	1300	350
	2	101.9	9.73	628.4	Mixed/More Dura	No	1300	350
	3	99.2	9.83	605.5	Mixed/More Dura	No	1300	350
Takorase	1	108.8	17.87	365.3	Mixed/More Tenera	Yes[1]	1100	500
	2	115.3	15.75	439.2	Mixed/More Tenera	Yes[1]	1100	500
	3	114.8	15.24	452.0	Mixed/More Tenera	Yes[1]	1100	500
Takorase	1	113.8	9.17	744.6	Dura/Tenera mixed	No	1300	350
	2	110.4	6.76	979.9	Dura/Tenera mixed	No	1300	350
	3	103.1	5.81	1064.7	Dura/Tenera mixed	No	1300	350
Kade	1	107	21.5	298.6	Dura/Tenera mixed	Yes[2]	1100	480
	2	103.9	18.3	340.7	Dura/Tenera mixed	Yes[2]	1100	480
	3	108.9	19.9	328.3	Dura/Tenera mixed	Yes[2]	1100	480
Kade	1	103.3	12.8	484.2	Dura/Tenera mixed	Yes	1200	390
	2	108.8	14.7	444.1	Dura/Tenera mixed	Yes	1200	390
	3	102.1	14.9	411.1	Dura/Tenera mixed	Yes	1200	390
Kusi	1	96.1	7.81	738.3	Mixed/More Tenera/ Wet	No	1520	380
	2	108.4	8.32	781.7	Mixed/More Tenera/ Wet	No	1520	380
	3	113.7	8.63	790.5	Mixed/More Tenera/ Wet	No	1520	380

[1] Manually cranked but fed directly from the cracker egress chute.
[2] Linked to cracker with extra time required for cleaning spillovers.

rotating screens are 43.4 and 68.9 per cent, respectively, higher than cracking rates in the small scale motorized palm nut cracker from which the feed material to the screens are obtained. Aggey (2004) reports average and maximum rates of 652.7 kg/h and 1141.2 kg/h, respectively, for such crackers in Ghana. Relative to the cracking rates these screening rates are acceptable as they permit linking the screens directly to the crackers without any risk of expensive hold-ups during processing as the principle of increasing capacity in matching machines in a process system stipulates that each machine involved in succeeding steps in a system needs to provide greater capacity than the preceding machine to avoid expensive hold-ups (Bowers, 1981).

TABLE 2

Average sieving rates by site, location and linkage to palm nut cracker

		Observed rate (kg/h)		
Location or Site	*Minimum*	*Maximum*	*Average*	*Standard deviation*
All	298.6	1927.5	733.6	418.6
Site 1	730.9	1927.5	1494.7	663.4
Site 2	746.1	1062.7	885.4	161.7
Site 3	568.4	628.4	600.8	30.3
Site 4	365.3	452.0	418.8	46.8
Site 5	298.6	1064.7	929.7	165.8
Site 6	298.6	340.7	322.5	21.6
Site 7	411.1	484.2	446.5	36.6
Site 8	738.3	790.5	770.2	28.0
Kusi	730.9	1927.5	1132.4	577.8
Takorase	365.3	1064.7	708.7	241.4
Kade	298.6	484.2	384.5	73.0
Not linked	568.4	1927.5	936.1	410.1
Linked	365.3	484.2	432.7	40.5
Extra cleaning	298.6	340.7	322.5	21.6

TABLE 3A

Difference of mean sieving rates at Kade compared to Takorase and Kusi

	Takorase rates	*Kade rates*	*Kusi rates*
Mean	708.7	384.5	1132.4
Variance	58253.3	5331.5	333817.3
Observations	12	6	6
Hypothesized mean difference	0		0
Df	14		5
t Stat	4.3		3.1
P(T<=t) two-tail	0.0		0.0
t Critical two-tail	2.1		2.6

Since the manual trommel is faster than the motorized cracker, it is, therefore, expected that trommels fed directly from crackers should be slower than the independently operated ones. However, that average (432.7 kg/h) and maximum (484.2 kg/h) sieving rates are far lower than corresponding average and maximum (652.7 kg/h and 1141.2 kg/h) cracking rates is unexpected and may be due to operators consciously controlling cracking rate in the erroneous belief that the

TABLE 3B

Difference of mean sieving rates at Takorase compared to Kusi

	Takorase rates	*Kusi rates*
Mean	708.7	1132.4
Variance	58253.3	333817.3
Observations	12	6
Hypothesized mean difference	0	
Df	6	
t Stat	-1.7	
P(T<=t) two-tail	0.1	
t Critical two-tail	2.4	

TABLE 4

Correlation between sieving rates and sieve dimensions (Pearson's correlation coefficient)

	Sieving rate (kg/h)
Sieve length (mm)	0.684
Sieve diameter (mm)	-0.403

motorized cracker may be faster than the manually operated trommel linked to it.

Comparing the sieving rates at Kusi and Takorase to those observed at Kade (Table 3A and B), using corresponding *t* values of 3.1 and 4.3 compared to respective critical *t* values of 2.6 and 2.1, suggests Kade rates are significantly different from rates at the former two locations. By the same reasoning no significant differences were found between Kusi and Takorase rates probably because all the Kade trommels sampled are linked directly to crackers resulting in significantly lower rates.

The results confirmed Head's (1988) observation that sieving provides an aid to seed cleaning as it concentrates both trash and kernels in separate portions of output though it does not effectively separate kernels from the cracked mixture. The kernel mass fraction in the trommel oversize is on average 72.6 per cent more than the mass fraction in the cracked mixture (Tables 6 and 8), and the trash level in the undersize is an average of 98.5 per cent (Table 7) compared to 73.9 per cent in the cracked mixture (Table 5). The effective removal of debris and smaller pieces of shells from the cracked mixture prevents contamination of kernels in the traditional clay bath operation as debris normally rises with kernel to the top of the clay slurry. However, with a cleaning efficiency or reduction in dirt content of 26 per cent (Table 8) the overflow dirt content of 54.7 per cent achieved compares poorly with 15-17 per cent reported by large scale palm oil mills in Ghana during preliminary winnowing of cracked mixture before hydro-cycloning or separation in the clay bath (Aggey & Amoah, 2003).

Conclusion

Aggey, Amoah & Annum (2004) concluded that equipment interventions directly after the cracking operation in small-scale palm nut processing in Ghana should target average design through-put rates of more than 1300 kg/h which is the maximum through-put cracking rate of available small-scale motorized palm nut crackers. The authors, however, added that care must be taken that the intervention performs better than the proficiency of techniques currently being used by processors immediately after the cracking operation. Since the proposed palm kernel separator is aimed at replacing both the trommel and claybath process units in small-scale palm kernel processing, design through-put rates of the intervention may still have to be higher than the maximum 1927.5 kg/h of the tromme.

The maximum cleaning efficiency of the trommel is 39.0 per cent equivalent to 44.7 per cent dirt level in the oversize which compares poorly with preliminary winnowing results of 15-17 per cent, and hydrocycloning outputs of 3.5-9.0 per cent in large-scale process mills. While observing these operational figures as guidelines for the target design efficiency of the proposed

TABLE 5

Mass fraction of kernels and dirt levels in cracked mixture from small-scale palm nut cracked mixture

Site No.	Location	Trial	Mass of kernels (g)			Mass fractions of kernels			Mass of whole nuts (g)	Mass of shells on whole nuts (g)	Mass of shells and debris (g)	Total dirt (g)	Dirt level (%)	Total mass of sample
			Whole	Broken	Total	Whole	Broken	Total						
1	Kusi	Sample 2	158	43.0	201.0	0.15	0.04	0.19	24.00	19.38	844	863	80.8	1069
		Sample 1 & 3	189	33.0	222.0	0.18	0.03	0.21	16.00	12.65	839	852	79.1	1077
2	Takorase	Sample 2	292	45.0	337.0	0.27	0.04	0.32	21.00	14.58	766	781	69.4	1124
		Sample 1 & 3	285	44.0	329.0	0.27	0.04	0.31	26.00	18.08	751	769	69.5	1106
3	Takorase	Sample 2	152	36.0	188.0	0.14	0.03	0.18	11.00	8.95	821	830	81.4	1020
		Sample 1 & 3	148	51.0	199.0	0.14	0.05	0.19	24.00	19.11	778	797	79.6	1001
4	Takorase	Sample 2	346	76.0	422.0	0.32	0.07	0.39	13.00	7.90	653	661	60.7	1088
		Sample 1 & 3	244	52.0	296.0	0.23	0.05	0.28	23.00	15.97	672	688	69.4	991
5	Takorase	Sample 2	249	31.0	280.0	0.23	0.03	0.26	17.00	12.48	772	784	73.4	1069
		Sample 1 & 3	259	34.0	293.0	0.24	0.03	0.27	17.00	12.35	779	791	72.7	1089
6	Kade	Sample 2	172	60.0	232.0	0.16	0.06	0.22	8.00	6.28	850	856	78.6	1090
		Sample 1 & 3	184	63.0	247.0	0.17	0.06	0.23	13.00	10.07	849	859	77.5	1109
7	Kade	Sample 2	207	40.0	247.0	0.19	0.04	0.23	6.00	4.47	719	723	74.4	972
		Sample 1 & 3	219	56.0	275.0	0.20	0.05	0.26	8.00	5.98	813	819	74.7	1096
8	Kusi	Sample 2	266.3	34.0	300.3	0.25	0.03	0.28	24.00	16.92	717	734	70.5	1041.3
		Sample 1 & 3	257	63.0	320.0	0.24	0.06	0.30	9.00	6.29	744	750	69.9	1073
		Average				0.21	0.04	0.26					73.9	
		Minimum				0.14	0.03	0.18					60.7	
		Maximum				0.32	0.07	0.39					81.4	

TABLE 6

Mass fraction of kernels and dirt levels in the oversize from small-scale sieving of palm nut cracked mixture

Site No.	Location	Trial	Mass of kernels (g)			Mass fractions of kernels			Mass of whole nuts (g)	Mass of shells on whole nuts (g)	Mass of shells and debris (g)	Total dirt (g)	Dirt level (%)	Total mass of sample
			Whole	Broken	Total	Whole	Broken	Total						
1	Kusi	2	417	76	493	0.37	0.07	0.44	28.00	22.61	594.00	617	55.3	1115
		1 & 3	488	67	555	0.44	0.06	0.50	32.00	25.30	498.00	523	48.2	1085
2	Takorase	2	509	85	594	0.46	0.08	0.53	41.00	28.47	461.00	489	44.7	1096
		1 & 3	518	79	597	0.46	0.07	0.54	40.00	27.81	472.00	500	45.1	1109
3	Takorase	2	309.3	92	401.3	0.28	0.08	0.36	30.00	24.41	662.50	687	62.8	1093.8
		1 & 3	334	94	428	0.30	0.08	0.38	32.00	25.48	635.00	660	60.3	1095
4	Takorase	2	413	116	529	0.37	0.10	0.47	9.00	5.47	449.80	455	46.1	987.8
		1 & 3	374	75	449	0.34	0.07	0.40	32.00	22.21	504.43	527	53.4	985.43
5	Takorase	2	384	48	432	0.34	0.04	0.39	36.00	26.42	625.00	651	59.6	1093
		1 & 3	363	47	410	0.33	0.04	0.37	25.00	18.17	667.00	685	62.2	1102
6	Kade	2	323	43	366	0.29	0.04	0.33	43.00	33.78	638.00	672	63.6	1056
		1 & 3	331	52	383	0.30	0.05	0.34	22.00	17.04	633.00	650	60.8	1070
7	Kade	2	462	67	529	0.41	0.06	0.47	25.00	18.61	540.00	559	51.1	1094
		1 & 3	420	88	508	0.38	0.08	0.46	20.00	14.94	603.00	618	54.6	1131
8	Kusi	2	400	79	479	0.36	0.07	0.43	23.00	16.21	555.00	571	54.0	1057
		1 & 3	395	104	499	0.35	0.09	0.45	29.00	20.28	550.00	570	52.9	1078
	Mean					0.36	0.07	0.43					54.7	
	Min.					0.28	0.04	0.33					44.7	
	Max.					0.46	0.10	0.54					63.6	

TABLE 7

Mass fraction of kernels and dirt levels in undersize from small-scale sieving of palm nut cracked mixture

Site No.	*Location*	*Trial*	*Mass of kernels (g)*			*Mass fractions of kernels*			*Mass of whole nuts (g)*	*Mass of kernels in whole nuts (g)*	*Total mass of kemeb in trash (g)*	*Total mass of sample (g)*	*Kernel in shells and debris (%)*
			Whole	*Broken*	*Total*	*Whole*	*Broken*	*Total*					
1	Kusi	Sample 2	3	33	36	0.003	0.030	0.032	0.000	0.00	36.000	1111	3.2
		Sample 1 & 3	5	14	19	0.005	0.013	0.017	4.000	0.84	19.837	1061	1.9
2	Takorase	Sample 2	4	22	26	0.004	0.020	0.023	0.000	0.00	26.000	1077	2.4
		Sample 1 & 3	2	19	21	0.002	0.017	0.019	0.000	0.00	21.000	1086	1.9
3	Takorase	Sample 2	3.3	24	27.3	0.003	0.022	0.025	0.000	0.00	27.300	1024.3	2.7
		Sample 1 & 3	0	20	20	0.000	0.018	0.018	0.000	0.00	20.000	1021	2.0
4	Takorase	Sample 2	1	11	12	0.001	0.010	0.011	0.000	0.00	12.000	1040	1.2
		Sample 1 & 3	2	13	15	0.002	0.012	0.014	0.000	0.00	15.000	1008	1.5
5	Takorase	Sample 2	0	1	1	0.000	0.001	0.001	0.000	0.00	1.000	1049	0.1
		Sample 1 & 3	11	3	14	0.010	0.003	0.013	2.000	0.55	14.547	1099	1.3
6	Kade	Sample 2	0	6	6	0.000	0.005	0.005	0.000	0.00	6.000	1068	0.6
		Sample 1 & 3	10	13	23	0.009	0.012	0.021	0.000	0.00	23.000	1058	2.2
7	Kade	Sample 2	0	0	0	0.000	0.000	0.000	0.000	0.00	0.000	1095	0.0
		Sample 1 & 3	0	0	0	0.000	0.000	0.000	0.000	0.00	0.000	1074	0.0
8	Kusi	Sample 2	0	12	12	0.000	0.011	0.011	0.000	0.00	12.000	1076	1.1
		Sample 1 & 3	1.2	12.2	13.4	0.001	0.011	0.012	0	0.00	13.400	1011.4	1.3
	Average					0.002	0.011	0.014					1.5
	Minimum					0.000	0.000	0.000					0.0
	Maximum					0.010	0.030	0.032					3.2

* Mass of whole nuts found in the undersize is almost negligible.

TABLE 8

Palm nut cracked mixture cleaning efficiency (reduction in dirt level) in the manual rotating screen

Site No.	*Location*	*Trial*	*Overflow dirt content (%)*	*Reduction in dirt content (%)*	*Kernel in shells and debris (%)*	*Percent of input kernel lost in trash*				*Overflow kernel content (%)*	*Rise in kernel concentration level (%)*		
						Whole	*Broken*	*In shell*	*Total*		*Whole*	*Broken*	*Total*
1	Kusi	Sample 2	55.3	31.5	3.2	0.86	9.48	0.00	10.3	44	153.0	69.5	135.2
		Sample 1 & 3	48.2	39.0	1.9	1.39	3.90	0.23	5.5	50	147.5	94.7	139.7
2	Takorase	Sample 2	44.7	35.7	2.4	0.57	3.13	0.00	3.7	53	67.1	81.1	69.0
		Sample 1 & 3	45.1	35.2	1.9	0.28	2.65	0.00	2.9	54	74.3	72.1	74.0
3	Takorase	Sample 2	62.8	22.8	2.7	0.93	6.76	0.00	7.7	36	95.1	145.0	104.7
		Sample 1 & 3	60.3	24.3	2.0	0.00	4.92	0.00	4.9	38	116.4	76.7	106.2
4	Takorase	Sample 2	46.1	24.1	1.2	0.07	0.75	0.00	0.8	47	14.4	46.3	20.2
		Sample 1 & 3	53.4	23.0	1.5	0.23	1.50	0.00	1.7	40	47.0	38.3	45.4
5	Takorase	Sample 2	59.6	18.8	0.1	0.00	0.12	0.00	0.1	39	47.9	48.5	47.9
		Sample 1 & 3	62.2	14.4	1.3	1.05	0.29	0.05	1.4	37	34.4	32.5	34.2
6	Kade	Sample 2	63.6	19.0	0.6	0.00	1.06	0.00	1.1	33	80.0	-31.3	51.3
		Sample 1 & 3	60.8	21.6	2.2	1.69	2.19	0.00	3.9	34	72.5	-20.9	48.7
7	Kade	Sample 2	51.1	31.4	0.0	0.00	0.00	0.00	0.0	47	114.0	60.6	105.3
		Sample 1 & 3	54.6	26.9	0.0	0.00	0.00	0.00	0.0	46	83.9	50.7	77.1
8	Kusi	Sample 2	54.0	23.3	1.1	0.00	1.39	0.00	1.4	43	44.0	122.8	52.9
		Sample 1 & 3	52.9	24.3	1.3	0.15	1.49	0.00	1.6	45	47.4	58.3	49.5
		Average	54.7	26.0	1.5	0.5	2.5	0.0	2.9	42.9	77.4	59.0	72.6
		Minimum	44.7	14.4	0.0	0.0	0.0	0.0	0.0	32.8	14.4	-31.3	20.2
		Maximum	63.6	39.0	3.2	1.7	9.5	0.2	10.3	53.5	153.0	145.0	139.7

TABLE 9

Correlation between cleaning efficiency and sieve dimensions and sieving rate

	(Pearson's correlation coefficient)		
	Sieving rate (kg/h)	*Sieve length (mm)*	*Sieve diameter (mm)*
Output dirt level (%)	-0.159	-0.161	-0.005
Reduction in dirt level (%)	0.112	0.340	-0.195

Separator, it is also noted that both the small-scale trommel and claybath equipment are relatively cheap and manually operated. Output dirt levels of 10 per cent or lower are satisfactory but 15-17 per cent dirt in kernel with through-put rates more than 2000 kg/h would make the separator very competitive in the small scale palm kernel processing sector.

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