Effect of heat treatment during mechanical cracking using varieties of palm nut

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Abstract: Palm nut is characterized with unique physical and mechanical properties which determine performance of machine during cracking.   In this research work, commercially acceptable varieties of palm nut were selected, examined and periodically dried to temperature 120 ℃/h, 135 ℃/h, 150 ℃/h, 165 ℃/h and 180 ℃/h before cracking.   At 120 ℃/h, *local, dura* and *tenera* nuts moisture content were found to be: 12.5%, 12.0% and 12.0% respectively; at 135 ℃/h, 11.6%, 11.1% and 11.0% respectively; at 150 ℃/h, 10.7%, 10.2% and 10.0% respectively; at 165 ℃/h, 10.3%, 9.6% and 9.1% respectively; and at 180 ℃/h, 9.8%, 9.0% and 8.2% respectively.   An improved automated palm nut cracker of 2004 model was used for the experiment and results shown that the highest throughput, functional efficiency and quality performance efficiency were 1,260 kg/h, 99.07% and 98.80% respectively while mechanical damage reduced to 0.20%.   Simple multiple linear regression model was used to establish the relation between machine and crop parameters.

Keywords: drying, efficiency, cracker, effect, varieties, palm nut

1   Introduction

The palm kernel production potentials of several countries are far from been fully exploited.   In Nigeria National Milling capacity, palm kernel stands at about 23% potential from fresh fruit production in 1991 (FAO, 2002).   At present, the country is operating below expected capacity and efforts have been developed towards an improved processing technique to increase production of palm kernel and enhance export earnings. There are three varieties of oil palm as reported by Jimoh (2004), namely *dura, tenera* and *pisifera. Dura* is characterized by thin mesocarp, thick endocarp (shell) with generally large kernel.   The *dura* type is genetically homozygous and dominant for shell. It is denoted by DD. *Tenera* possesses thin mesocarp, thin endocarp with large

kernel.   This is a dual-purpose palm for the production of mesocarp oil and kernel. It is genetically heterozygous and is denoted by Dd. *Pisifera* possesses thick mesocarp with very little oil content, no endocarp (shell less) with small kernel, the female flowers are often sterile, this results in bunch failure and it is genetically homozygous, recessive for shell and it is denoted by dd.

Badmus (1990) stated that typical African *dura* is about 8-20 mm in length and has a fairly uniform shell thickness of about 2 mm.   The *tenera* is about 7-15 mm in length with shell thickness of 1.2 mm. Since *pisifera* was not readily available in the country for commercial purpose, this was replaced with *local* palm nut that is common in Africa and is about 15-40 mm in length with shell thickness of 2.2 mm.   It is characterized with too hard brittle shell with small and heavy kernel.   Kernel is an edible endosperm, which is covered by reddish brown to black testa.   The kernel fits tightly into the shell and varied in shape and size depending on the shape and size of the nuts.   The role played by palm kernel in our daily

activities cannot be over emphasized. Some of its uses include the production of palm kernel oil, soap, black oil (Adin dudu), palm kernel cake etc. The dry kernel yields about 46%-57% kernel oil, this is similar to that of coconut oil which is about 35%-65% (Olukunle et al. 2008).

Babatunde and Okoli (1988) designed, fabricated and tested a prototype centrifugal palm nut cracker using horizontal shaft and vertical rotor type in National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. The design was based on centrifugal principle in which the nuts to be cracked were directed to rotor which hurls the nut and strikes it against a hard breaker plate. The cracker was tested on local palm nuts at 9%-11% moisture context (wet basis). Results of machine evaluation revealed that nut-cracking efficiencies of 94.50% and 87.50% at 14.70% and 6.0% mechanical damage (kernel breakage) respectively. The maximum quality performance efficiency was 77.85% at a throughput of 155.30 kg/h. Manuwa (1997) designed, fabricated and tested a palm nut cracker. Locally available materials were used in some parts of the machine to reduce cost and weight of the machine. Maintainability was considered an important factor in the design and fabrication of the machine. The machine was tested using local variety of nuts from "wild" palm fruits. The nuts were cracked at moisture context 8%, 10% and 12% (wet basis). The prime mover used was an electric motor at the power rating of 2.25 kW. The maximum throughput capacity was 1.2 ton/h with a performance efficiency of about 89% and mechanical damage of 10% at a rotor speed of 5,500 r/min. These machines were characterized with relative low machine efficiency and high mechanical damage. These deficiencies bring about poor commercial value of both the machines and the product.

Ilechie (1985) designed a single-stage nut cracker as an integral component of the Small-Scale processing equipment in Nigerian Institute for Oil Palm Research, Benin City, Nigeria (NIFOR). The nut cracker was driven with the same prime mover as the horizontal digester and this was to reduce the cost of power. Ilechie (1985) further reported that rotational speed of centrifugal impact contributed greatly to the poor state of product after processing. Olukunle et al. (2008) found that cracking of wet palm nuts from depericarper drum eliminate the requirement of nut silo, heater and fan, thus results in savings on capital investment, electrical power, steam consumption and maintenance cost. High cracking efficiency (average 98%) was achieved which led to: lesser loss of whole nuts and half cracked nut in hydro cyclone separator, higher kernel extraction rate, higher cracking capacity and no grading of nuts by size is required. It was specifically designed for *tenera* type. The merits of this machine over the previous one are its appreciable improvement in machine efficiency and reduced mechanical damage while the major constraint was inability of the machine to crack nut with thick shell (*local* and *dura*) successively.

Akpobi and Oniah (2009) reported that efficient processing of palm fruit is a pre-condition for high efficiency in palm nut cracking. The smoothness of the shell, freedom of nut from fiber and degree of shrinkage of the kernel affect the efficiency of palm nut cracker. Thickness of the shell and regular feeding of nuts into the hopper and cracking chamber also have significant effect on the cracking. Ituen and Modo (2000) also reported that fermentation of palm fruit gives clean nut and influence quality cracking product.

Palm nut as one of the most important crops in the world has been investigated by several researchers and due to the difficulty in extracting a whole kernel from the shell, damaging of the kernels during the cracking process greatly reduces the market value of palm kernel. Therefore, in this study, varieties of palm nut were treated at various temperature level and the effects of this on performance of the machine were closely evaluated and analyzed. This condition is necessary so as to enable the kernel to shrink away from shell prior to cracking and therefore boost economic value of the products.

2 Materials and methods

2.1 Machine description

The isometric drawing of the machine (Figure 1) was developed in the Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria. The

machine consists of cracking chamber, hopper, metering device, a pair of hammer, driving shaft, pulley and main frame. The hopper is made from flat plate of 1mm thickness in trapezoidal shape with height 400 mm, upper dimension 400 mm^2 and lower dimension 200 mm^2. It forms the feeding chute through which nuts were metered into the cracking chamber of the machine. The cracking chamber consists of a pair of hammer with dimension (130 mm×80 mm×12 mm) made from mild steel and arranged at 180° to each other. The drive mechanism consist of a V-belt, pulley and a single phase electric motor with power rating 5 kW and speed 1,840 r/min while the designed power requirement was 4.8 kW and speed 1,718 r/min. The machine has ability to crack palm nut with minimum damage to the kernels. Labour requirement and drudgery were reduced to the minimum and the machine cracked with higher efficiency compared to other existing machines. The cost of the machine is within the buying capacity of local farmers and is simple to operate and maintain.
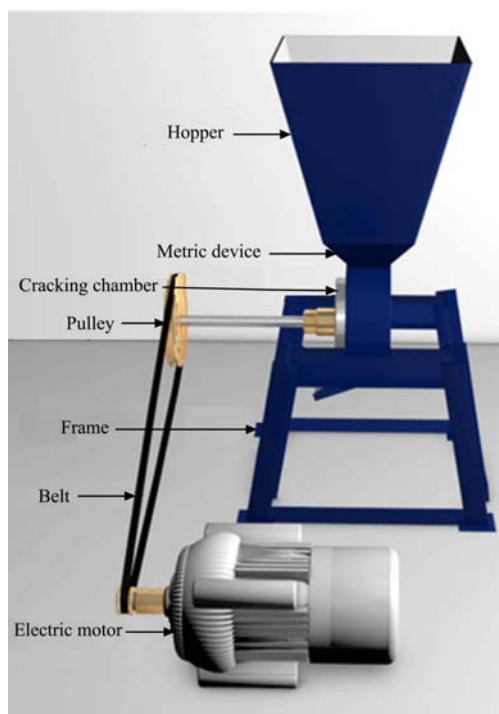

Figure 1   Isometric drawing of an indigenous automated palm nut cracker

2.2   Material selection

Tenera palm nuts were collected from NIFOR and Okitipupa Oil Palm PLC, Okitipupa Nigeria. *Dura* nuts were collected from Araromi Ayesan Oil Palm plc,

Araromi-Obu Nigeria. *Local* nuts were collected from local mill at Aiyetumora Camp, Igbotako, Ondo State, Nigeria. These nuts were selected as fresh materials and with very high moisture content with 18%-20%.
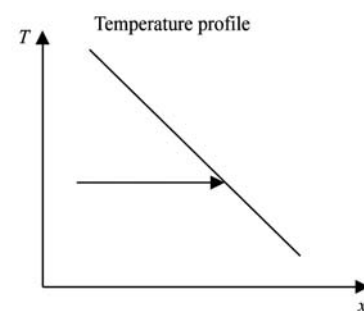
2.3   Effect of heat transfer

2.3.1   Heat concept

Since temperature changes with time during heat treatment (transient state), for the shell thickness *dx* (Figure 2), the following energy balance can be made for one dimensional conduction analysis as reported by Holman (1999):
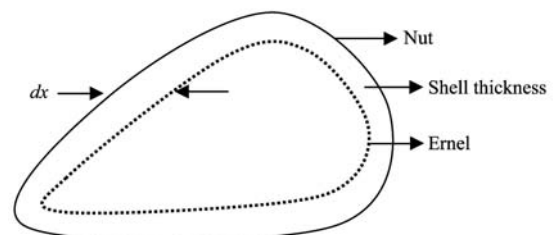
a. Physical structure of palm nut

b. Direction of heat flow

Figure 2   Temperature profile during heat treatment

Heat conducted into shell + energy generated within shell = change in internal energy + energy conducted out of shell

$$\text{Energy conducted into shell: } q_x = -kA\frac{\partial T}{\partial x} \qquad (1)$$

where, k = thermal conductivity of the shell and minus sign indicated shows that it obey second law of thermodynamics; A = cross sectional area through flow, $\frac{\partial T}{\partial x}$ = temperature gradient in the direction of heat flow.

$$\text{Energy generated within shell} = qAdx \qquad (2)$$

where, q = energy generated per unit volume, W/m^3.

$$\text{Change in internal energy} = \rho cA\frac{\partial T}{\partial t}dx \qquad (3)$$

where, ρ = density of shell, kg/m^3; c = specific heat of

shell, J/kg ℃ and $\frac{\partial T}{\partial t}$ = change in temperature with respect to time.

Energy conducted out of shell: $qx + dx = -KA\left[\frac{\partial T}{\partial x}\right]_{dx}$

(4)

Therefore energy conducted into shell is proportional to the temperature from heat source while energy conducted out of shell is inversely proportional to the thickness of the shell.   In other word, part of energy conducted is converted to internal energy.

2.3.2   Determination of moisture content

In general, palm nuts have relatively high moisture content when freshly picked up from trees and the kernel is in contact with the shell (Jimoh and Olukunle, 2011). To reduce the possibility of crushing kernel when cracking the nut, the nuts were subjected to heat treatment whereby its temperature is periodically increased and as the temperature increases, the moisture content of the nuts reduces favorably prior to cracking.   As temperature increases, the palm nut shell expand while the kernel contract creating sufficient clearance between kernel and shell.   As a result of this, kernel is becoming loose from the shell, and as kernel shrinks, cracks are initiated in the shell due to thermal stress.   It was noted from this experiment that 80% of the nuts were initiated with crack when dried.   The drying was by oven method and the results are shown in Table 1.   Each variety was weighed in weighing balance and put inside moisture content cans; the cans were put inside oven at 120℃, 135℃, 150℃, 165℃ and 180℃ temperature respectively for one hour.   The cans were removed and the nuts were reweighed.   Percentage moisture content is determined as follow:

$$\%(db) = (M_1 - M_2)\, M_2^{-1} \times 100 \qquad (5)$$

where, M_1 = initial weight of palm nut, kg; M_2 = final weight of palm nut.

Table 1   Determination of moisture content (M.C.) at different temperature

	120 ℃/h	135 ℃/h	150 ℃/h	165 ℃/h	180 ℃/h
Local nut M.C. / %	12.5	11.6	10.7	10.3	9.8
Dura nut M.C. /%	12.0	11.1	10.2	9.6	9.0
Tenera nut M.C. /%	12.0	11.0	10.0	9.1	8.2

2.3.3   Determination of shearing force

Shearing force f_h is obtained from expression given by Jimoh (2011):

$$f_h = \frac{\Pi}{8L} l^3 \delta_s f_s \qquad (6)$$

where, l = thickness of shell, m; L = thickness of hammer, m; δ_s = allowable stress, Nm^{-2} and f_s = compressive force, N.

Six different size ranges with longitudinal diameter d_1/cm: $0 < d_1 \leq 0.50$, $0.50 < d_1 \leq 1.00$, $1.00 < d_1 \leq 1.50$, $1.50 < d_1 \leq 2.00$, $2.00 < d_1 \leq 2.50$ and $2.50 < d_1 \leq 3.00$ were considered for the experiment as shown in Table 2.

Table 2   Determination of shearing force of palm nut varieties

No of observation		Shearing force /N		
		Local	Dura	Tenera
$0 < d_1 \leq 0.50$	100	-	-	11.40
$0.50 < d_1 \leq 1.00$	100	32.80	29.00	11.90
$1.00 < d_1 \leq 1.50$	100	32.90	29.70	12.40
$1.50 < d_1 \leq 2.00$	100	33.40	30.80	13.20
$2.00 < d_1 \leq 2.50$	100	35.60	32.20	14.40
$2.50 < d_1 \leq 3.00$	100	36.30	33.80	-
Mean value	100	34.20	31.10	12.66

2.4   Machine testing and performance evaluation

The machine was tested on varieties of palm nut under changing temperature condition and at low machine speed.   The effects of this heat treatment on machine functional efficiency, quality performance efficiency and mechanical damage were determined. During cracking, weight of completely cracked nut, weight of unbroken kernel, weight of broken kernel, weight of partially and un-cracked nut were taken for all temperature variation.   In other word, five tests were carried out for each variety. Machine parameters such as functional efficiency, quality performance efficiency and mechanical damage were determined as follows:

Functional efficiency $(E_f) = W_{cc} W_{LO}^{-1} \times 100$ (7)

Quality performance efficiency $(E_p) = W_u W_{LO}^{-1} \times 100$

(8)

Mechanical damage $(M_d) = (W_{cc} - W_u)\, W_{LO}^{-1} \times 100$ (9)

where, W_{cc} = Weight of completely cracked kernel, kg; W_{LO} = weight of kernel for each loading, kg; W_u = weight of unbroken kernel, kg.

3   Results and discussion

3.1   Effect of heat treatment on machine performance

The results of the experiment revealed that while temperature increases, nut moisture content reduces and drying is accomplished (Table 1). Cracking of dried nuts improved the performance of the machine as compared with previous machines. Functional efficiency and quality performance efficiency increases progressively while mechanical damage reduces to almost 0%. The machine can produce an average kernel to the tons of 6.3 of *local* variety per 8 working hours, 5.8 of *dura* variety per 8 working hours and 7.5 of *tenera* variety per 8 working hours.

Figure 3 shows that mechanical damage reduces from 2.37% at 120 ℃/h to 1.25% at 180 ℃/h for *local* nut; it also reduces from 2.47% at 120 ℃/h to 1.40% at 180 ℃/h for *dura* nut and reduces from 1.16% at 120 ℃/h to 0.20% at 180 ℃/h for *tenera* nut. Figure 4 shows that functional efficiency increases from 93.00% at 120 ℃/h to 97.20% at 180 ℃/h for *local* nut; it also increases from 92.30% at 120 ℃/h to 96.40% at 180 ℃/h for *dura* nut and increases from 95.50% at 120 ℃/h to 99.07% at 180 ℃/h for *tenera* nut. Figure 5 shows that quality performance efficiency increases from 92.50% at 120 ℃/h to 96.60% at 180 ℃/h for *local* nut; it also increases from 91.00% at 120 ℃/h to 95.30% at 180 ℃/h for *dura* nut and increases from 95.50% at 120 ℃/h to 98.80% at 180 ℃/h for *tenera* nut. The reason while there is serious improvement in the performance of *tenera* over other varieties is because *tenera* is characterized with light shell and terminal velocity of its shell is less than that of its kernel in confirmation to Fellow (2003). Generally, cracks are initiated on the shell during drying to enhance complete splitting of the shell from whole kernel with low speed and little impact during cracking. At 180 ℃/h, there is tendency for palm kernel oil extraction and this will reduce its market value if further dried. Shearing force increases as nut size increases (Table 2): the mean shearing force for *local, dura* and *tenera* varieties are 34.20 N, 31.10 N and 12.66 N respectively. This confirms that shell thickness in *local* and *dura* are closely related and stronger than that of

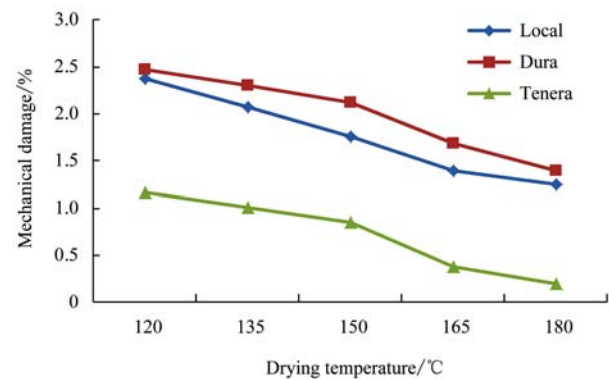t*enera* in accordance to Badmus, (1990).

Figure 3   Effect of heat treatment on mechanical damage
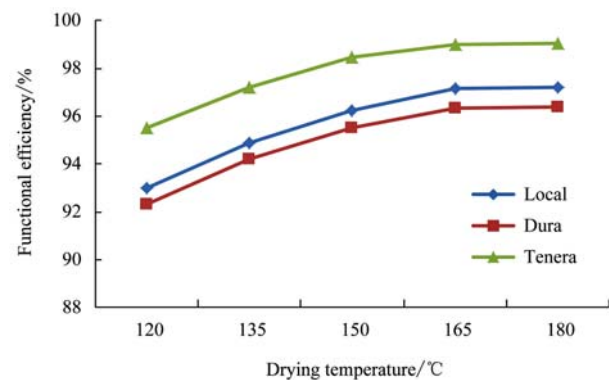

Figure 4   Effect of heat treatment on functional efficiency
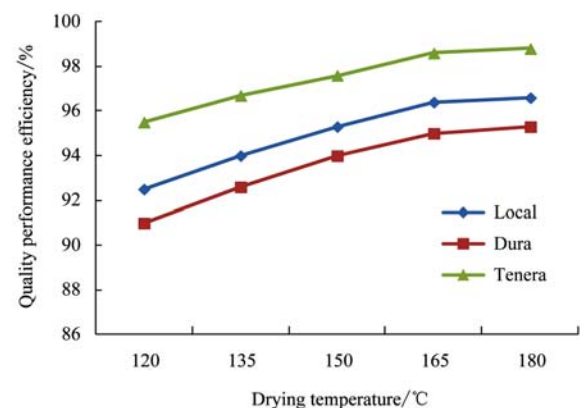

Figure 5   Effect of heat treatment on quality performance efficiency

The result of the regression analysis (Table 3) is of the form:

$$\gamma = \beta_0 + \beta_1\theta - \beta_2 V + \beta_3\theta_v \qquad (10)$$

where, γ explain variables and represents any of the evaluation variables; θ = moisture content, %; V = speed, m/s; θ_v = interaction term and β_0 to β_3 are model coefficient; T_L = throughput capacity in *local* variety; T_D = throughput capacity in *dura* variety; T_T = throughput capacity in *tenera* variety; M_L = mechanical damage in

local variety; M_D = mechanical damage in *dura* variety; M_T = mechanical damage in *tenera* variety; F_L = functional efficiency in *local* variety; F_D = functional efficiency in *dura* variety; F_T = functional efficiency in *tenera* variety; Q_L = quality performance efficiency in *local* variety; Q_D = quality performance efficiency in *dura* variety; Q_T = quality performance efficiency in *tenera* variety.

The simple multiple linear regression models used to explore relations between machine speed, evaluation parameters (throughput capacity, mechanical damage, functional efficiency and quality performance efficiency) and crop parameters (moisture content). These interactions demonstrated that evaluation parameters

were estimated with a high degree of accuracy based on machine speed, moisture content and interaction term with minimum $R^2 = 0.861$, standard error = 0.35, $P < 0.0001$. About 97% of the variations in the machine performance were accounted for by these three parameters. The response of *tenera* to mechanical system further confirms its suitability for mechanization. It is also the highest oil yielding variety for both mesocarp and palm kernel oils as reported by Opeke (1997). Table 2 further shows that mechanical damage is not influenced by moisture content in the local variety because of its shell thickness and small size of its kernel. In other word, local variety could permit higher moisture content for cracking with minimum damage.

Table 3   Regression analysis for various models explaining variations in evaluation parameters of Palm nut cracker

Model	Variables			Model coefficients				Overall Statistics		
	1	2	3	β_0	β_1	β_2	β_3	R^2	SE	*p*- value
T_L	θ	V	-	1277.55	-99.68	0.47	0	0.974	42.50	0.001
T_D	-	V	$θ_V$	269.16	0	0.68	-0.032	0.965	29.92	0.001
T_T	θ	V	$θ_V$	480.07	-0.024	0.69	-0.038	0.931	42.77	0.009
M_L	-	V	$θ_V$	-0.44	0	0.0043	-0.00023	0.963	0.19	0.001
M_D	θ	V	-	4.81	-0.14	0.00085	0	0.914	0.13	0.001
M_T	θ	V	$θ_V$	3.32	-0.089	0.0017	0.00007	0.953	0.12	0.001
F_L	θ	V	-	95.82	-0.25	0.0026	0	0.958	0.23	0.001
F_D	θ	V	$θ_V$	104.27	-1.30	-0.00082	0.00044	0.959	0.42	0.003
F_T	θ	V	$θ_V$	106.28	-0.90	-0.0029	0.0004	0.861	0.35	0.001
Q_L	θ	-	$θ_V$	104.81	-1.42	0	0.00038	0.944	0.56	0.001
Q_D	θ	V	-	90.23	1.19	0.008	0	0.954	0.83	0.001
Q_T	θ	V	$θ_V$	104.60	-1.04	-0.0013	0. 00041	0.936	0.39	0.003

4   Conclusions and recommendation

The following conclusions are drawn from this work:

1) The effect of heat treatment on mechanical damage, functional efficiency and quality performance efficiency shows rapid change from 120 ℃/h to 165 ℃/h and the change reduces from 165 ℃/h to 180 ℃/h. That is, the effect was less felt at rate 180 ℃/h and this is likely to be as a result of oil flow.

2) *Tenera, dura and local nuts* at 8.2%, 9.0% and 9.8% moisture content respectively are recommended for effective cracking and production of high quality kernel.

3) *Tenera,* as an improved variety genetically developed from *dura* and *pisifera,* has the best machine performance with 99.07% functional efficiency, 98.80%

quality performance efficiency and 0.20% mechanical damage. However, for economic reason and food security, and in accordance to Opeke (1997), *tenera* variety is recommended for farmers.

4) The multiple linear regression model obtained in this study can be used to predict the best relation between machine parameters and crop parameters for effective and optimal performance.

5) The mean shearing force in *tenera* is 12.66 N which is low compared with that of *local* and *dura* varieties and fall within sustainable human potential power 70 – 500 W (Jimoh, 2011). This makes it possible for *tenera* variety to be cracked with human teeth.

Nomenclature

k = thermal conductivity of the shell, W/m ℃

A = cross sectional area through flow, m^2

$\partial T/\partial x$ = temperature gradient in the direction of heat flow, ℃/m

q = energy generated per unit volume, W/m^3

ρ = density of shell, kg/m^3

c = specific heat of shell, J/kg ℃

$\partial T/\partial t$ = change in temperature with respect to time, ℃/s

M_1 = initial weight of palm nut, kg

M_2 = final weight of palm nut, kg

l = thickness of shell, m

L = thickness of hammer, m

δ_s = allowable stress, Nm^{-2}

v = machine speed, ms^{-1}

d_1 = longitudinal diameter of palm nut, cm

T_L = throughput capacity = kg/h

E_f = functional efficiency, %

E_p = quality performance efficiency, %

M_d = mechanical damage, %

W_{cc} = weight of completely cracked kernel, kg

W_{LU} = weight of kernel for each loading, kg

W_U = weight of unbroken kernel, kg

θ = moisture content, %(db)

θ_v = interaction term

β_0 to β_3 = model coefficient

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