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Selected Physical, Mechanical and Chemical Properties of Fresh Fruit Bunches for Processing of Palm Oil

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***Abstract*:** *Data on engineering properties of palm fruits enable the design of machinery for optimal production of palm oil. Specific physical, chemical, and mechanical characteristics of fresh fruit bunches are examined in this study. Fresh palm fruit's selected mechanical, chemical, and physical characteristics were determined using standard formulas and equations. One hundred fresh fruit bunch samples were used to ascertain the physical characteristics of the fruit bunches. While the chemical properties were ascertained using suggested standard equations and formulae, the fresh fruit bunches were tested for their strength properties under compression when loaded under an INSTRON Universal Testing Machine. Using the Microsoft Excel program, statistical analysis was performed on the collected data. The average length, breadth, thickness, geometric mean, sphericity, surface area, true mass, true volume and true density mean for palm fruits were 3.35±0.48 cm, 1.92±0.32 cm, 2.24±0.33 cm, 2.42±0.25 cm, 0.73±0.08 cm, 18.61±3.62 cm^2, 7.99±1.81 g, 7.01±1.72 cm^3, 1.17±0.24 g/cm^3 respectively. The average static coefficient of frictions for palm fruits were 0.46±0.13, 0.64±0.18, 0.57±0.21 and 0.59±0.22 while the average angle of reposes was 24.48±6.08, 31.62±9.14, 29.26±6.80, and 29.91±9.11 on wood, mild steel, glass and stainless-steel surface respectively. The energy at break, force at break, deformation at break, strain at break, and stress at break for the palm fruits were 6.87±0.95 J, 2.22±0.80 kN, 14.58±3.02 mm, 0.36±0.08 mm/mm and 123.46±44.31 MPa respectively. The moisture, ash, fat, crude fibre, crude protein, and carbohydrate contents (proximate composition) of the palm fruits were 22.80±0.02%, 0.52±0.01%, 46.47±0.06%, 18.66±0.01%, 2.4±0.21%, and 9.14±0.30% respectively. The sodium, potassium, calcium, magnesium, iron, phosphorus and zinc contents of the palm fruits were 58.75±0.07 ppm, 94.20±0.14 ppm, 68.45±0.64 ppm, 5.21±0.00 ppm, 1.22±0.00 ppm, 1.60±0.00 ppm and 55.70±0.28 ppm respectively. This study has provided relevant information which will help engineers to develop a more efficient palm fruit extraction machines that will in turn increase the productivity and profitability of the farmers and food processors. These measured engineering properties of palm fruits help in development of palm fruit processing machines.*

***Keywords*:** Physical, coefficient of friction, angle of repose, mechanical, proximate, mineral.

1. INTRODUCTION

The primary purpose of the tropical tree crop known as palm fruit (*Elaeis guineensis*) is to produce vegetative oil for industrial use. It is grown on a small scale in other tropical regions as well as commercially in Southeast Asia, Africa, South America, and the South Pacific [1-2] reported that palm oil is highly sought after by all living things, because of its high nutritional value in addition to the oil palm tree's other uses, the high demand for oil palm has led to special attention being paid to the growth of the fruit bearing seeds. Palm oil is a significant source of vitamin A, which has been suggested as a good agent for good eye sight, weight development, and disease resistance. The oil's main unsaturated acids are linoleic and oleic, while its saturated constituents are palmitic, stearic, lauric, and myristic acids.

Numerous scholars have examined the physical characteristics of a range of agricultural products, including locust bean seed [3], wheat [4], nutmeg [5], pistachio nut and kernel [6], Bambara groundnut [7], caper fruit (Capparis spp), arigo seed [8], cowpea [9], soybean [10], cocoa bean [12], pigeon pea [13], locust bean seed [3], wheat [4], and locust bean [7]. There is therefore a need to study the engineering properties of palm fruits related to the development of processing machines that will enable engineers to design more efficient machines that will improve and increase the oil extraction efficiency, oil extraction ratio (oil yield), material discharge efficiency, and minimize oil loss during processing of waste products.

There have been numerous attempts over the years to mechanize the different processes involved in processing palm oil. The most attention has been paid to mechanizing extraction (pressing). The bulk of processors are small and medium-sized businesses, and they cannot easily afford the extremely expensive imported screw press machines currently in use for oil palm. Due to a lack of spare parts, poor maintenance, and the inability to meet certain local requirements, industries founded using imported

technology do not last for very long [14]. The development of indigenous technology is imperative in tackling the problem of food processing. The necessity of developing domestic technology in the various facets of agricultural and food processing operations has been covered by numerous authors. To efficiently extract crude oil from oil palms, it is essential to produce domestic machinery to process the anticipated boom in palm fruits for palm oil [15]. In order to produce a high-quality product, engineering properties are crucial. Developing and improving technology for crop processing requires a basic understanding of the crop [16]. When designing processing equipment for major agricultural crops, physical attributes like sphericity, size, shape, aspect ratio, true density, bulk density, and porosity—as well as mechanical ones like fracture resistance, angle of repose, and coefficient of friction—are crucial. Therefore, in order to create more effective locally palm fruit processing machinery, research into the effect of moisture content of fresh palm fruit on engineering properties of fresh palm fruit is necessary. Thus, this study looks into these crucial characteristics for the two types of palm fruit.

2. MATERIALS AND METHODS

For this investigation, fresh palm fruits at 52% wet base were procured from the Federal College of Agriculture (FECA) located in Akure, Ondo State, Nigeria. Fruits were visually sorted based on factors such as size, maturity, and physical damage.

2.1 Determination of Physical and Mechanical Properties

Table 1 presents the standard formulas and equations that were used to determine the physical properties of the palm fruits [17]. Four surfaces were considered in the determination of the static coefficient of friction: mild steel, glass, stainless steel, and wood. [18] used the inclined-plane method to achieve this. The Instron Universal Testing Machine (UTM) (Testometric Machine, Model M500 – 25KN) was used to test the palm fruits for strength properties under compression. These characteristics include stress at break MPa, strain at break in mm/mm, deformation at break in mm, energy at break in J, force at break in kN, and so on. Based on the force-deformation properties of the palm fruits, a test was conducted. The machine consists of three main parts: a driving unit, a data acquisition system, and a stable-up and motion-bottom platform. The palm fruit sample was put on the stable-up platform for the compressive test, and it was compressed using a motion probe at a steady speed until the specimen broke. The machine was programmed to determine the necessary mechanical properties of the palm fruits, so it automatically generated the mechanical parameters of the test. The dynamometer and data acquisition system measured the rupture force of the sample.

2.2 Determination of Chemical Properties: Proximate Composition

The samples undergo analysis using the official method of analysis as described by [19-21], and the following measurements: moisture content in %, protein content in %, fat content in %, ash content in %, crude fibre content in %, and carbohydrate content in %.

2.2.1 Determination of moisture content

The oven drying method yielded the moisture content. Equation (1), as given by the Association of Official and Analytical Chemists [21], was used to compute the percentage moisture. Using an analytical balance, each 5 g sample was weighed and placed into Petri dishes that had already been weighed. After the sample was weighed and placed in a petri dish, it was dried in an oven set to 100–105 °C for 30 minutes, or until each sample reached a consistent weight. The weight variations between every petri dish and the dried residue were noted along with the percentage of the original sample.

$$mc = \frac{w_1 - w_2}{w_s} x\ 100\% \quad (1)$$

where mc is the moisture content in %, w_1 is the final weight of the crucible + sample in g, w_2 is the initial weight of crucible + sample in g and w_s is the weight of sample in g.

2.2.2 Determination of protein content

Equations (2) and (3) were used to calculate the crude protein content in accordance with the [21]. Ten millilitres of concentrated solution and a Kjeldahl catalyst tablet were added to a 0.5 g finely ground sample that had been weighed into a digestion flask. After adding H_2SO_4, the mixture was digested for four hours, producing a clear solution with a blue-green hue. After cooling, the digest was poured into a 100 ml volumetric flask and diluted with distilled water. A conical flask was filled with 20 ml of boric acid, 5 drops of indicator, and 75 ml of distilled water. After dispensing 10 ml of the digest into the Kjedahl distillation flask and fixing the conical and distillation flask in place, 20 ml of 2% NaOH was added to the digest via the glass funnel. When the boric acid and indicator solution turned green, the steam exit was closed and the timing began. After 15 minutes of distillation, the distillate was titrated with a 0.05 N HCl solution until it took on a pink hue. Every stage as described above was also done with a blank. Thus, the percentage of nitrogen was multiplied by a constant factor of 6.25 to get the crude protein content.

$$pc = n\ x\ 6.25 \quad (2)$$

where, pc is the crude protein content in %, n is the percentage total nitrogen

$$n = tv\ x\ amn\ x\ nHcl\ x\ 4 \quad (3)$$

where, n is the total nitrogen in %, amn is the atomic mass of nitrogen in g, $n\,HCl$ is the normality of hydrochloric acid used in moles.

2.2.3 Determination of fat content

The Soxhlet apparatus was used to determine fat using the ether extract method, as per the [21] description in Equation (4). Using the Soxhlet apparatus and the ether extraction method, fat was measured. After weighing and wrapping 1 g of the dried sample in filter paper, it was put in a fat-free thimble that was loosely plugged with cotton wool. It was then extracted using petroleum ether (N-Hexane) in a Soxhlet apparatus that was set up for 5 hours. To begin extraction, the water and heater were turned on. Ether was allowed to evaporate following the fourth through sixth siphoning, and the beaker was disconnected prior to the final siphoning. After ether washing and ether evaporation in a water bath, the extract was poured into a clean glass dish. After cooling in a desiccator for two hours at 105 °C, the residue extract in the dish was weighed.

$$fc = \frac{(w_{fp}+w_s)-w_r}{s_w} x\ 100\% \quad (4)$$

where, fc is the of fat content in %, w_{fp} is the weight of filter paper in g, w_s is the weight of sample in g and s_w is the sample weight in g.

2.2.4 Determination of ash content

Equation 5 shows the percentage of ash that was determined using [21]. For 12 to 24 hours, a crucible that had been cleaned and emptied was kept at 600 °C in a muffle furnace. The sample's organic matter had completely oxidized, as evidenced by the appearance of gray-white ash. After cooling, the sample-filled crucible was weighed.

$$ac = \frac{w_3-w_1}{w_2}\ x\ 100\ \% \quad (5)$$

where ac is the ash content in %, $w_3$is the weight of the sample with crucible before ashing in g, w_1 is the weight of the sample in g and w_2 is the weight of the sample with crucible after ashing in g.

2.2.5 Determination of crude fibre content

As recommended by [21-22], Equation 6 was utilized to calculate the crude fibre content. After precisely weighing the 5 g sample, 200 ml of running water and 1.25 ml of H_2SO_4 were added to the flask. For thirty minutes, the mixture was heated under reflux. The heated blend was passed through a fibre-muslin cloth filter. After discarding the obtained filtrate, the residue was put back into the fibre flask and heated for an additional half-hour with 200 ml of running water and 1.25 g of NaOH. N-hexane and ethanol were used to remove the residue, which was then moved into the crucible that had already been weighed. For four hours, the crucible and the residue were oven dried at 105 °C.

$$cfc = \frac{w_1-w_2}{w_s}\ x\ 100\% \quad (6)$$

where cfc is the crude fibre content in %, $w_1$is the oven dried crucible containing the residue in g, w_2 is the crucible containing white or grey ash (Free of carbonaceous materials) in g and w_s is the weight of sample in g.

2.2.6 Determination of carbohydrate content

Equation 7 [21] was used to determine the total carbohydrate by the difference method. The total percentage of moisture, ash, crude lipid, crude protein, and crude fiber was deducted from 100%.

$$Cbh = 100 - (mc + pc + fc + ac + cfc) \quad (7)$$

where Cbh is the total carbohydrate in %, mc is the moisture content in %, pc is the protein content in %, fc is the fat content in %, ac is the ash content in %, and cfc is the crude fibre content in %.

2.3 Mineral composition

As per the guidelines provided by [23], the mineral contents of the test samples were ascertained by using the dry ash extraction method, which involved burning 2 g of the samples to ash on a muffle. The ash that was left behind was then dissolved in 20 ml of diluted hydrochloric acid (1 M HCl) and 20 ml of nitric acid. The resulting solution was then diluted to 400 ml volumetric flask using distilled water.

2.3.1 Determination of sodium content

The photometric method was used to determine the samples' sodium content. The manufacturer's instructions were followed when configuring the instrument. After turning on, the apparatus was left for roughly ten minutes. The start knob was turned on, opening the gas and air inlets. Given that the apparatus was self-igniting, the flame was gradually increased to a non-luminous level until a blue hue was achieved. In the meantime, 2, 4, 6, 8, and 10 ppm of a standard sodium solution were prepared and diluted. All of the standard solutions were pumped into the device and made to spray over the non-luminous flame, starting at the lowest concentration of 2 ppm. The sodium content of the sample was estimated by recording the readings, plotting them onto a standard curve, and using the results. Following the standard, the sample solutions were successively sipped into the device, and the readings were noted. Equation 8 was used to calculate and obtain the test mineral's concentration in the sample using the curve as a guide.

$$Na_{100g}^{mg} = 100\ \mathrm{Vt}\ x\ D * W \quad (8)$$

where Na is the sodium content, Vt is the total extract volume, X is the concentration of Sodium from the graph, D is the dilution factor, and W is the weight of sample used.

2.3.2 Determination of Potassium, Calcium, Magnesium, Iron, Phosphorus and Zinc content

A flame atomic absorption spectrophotometer was used to measure the amounts of magnesium, iron, and calcium, as stated by [21]. Each sample was digested in about 0.5 ml of HNO_3 and H_2SO_4 acid solutions (20 ml total). Heat was applied to the matching solution until white fumes emerged. Filtered through Whatman filter paper no. 1, the clear solution was diluted with distilled water to a volume of 50 millilitres. To create the standard calibration curve, the standard working solutions for the elements of interest were prepared. The concentration of a specific element in a

sample solution can be ascertained by absorption using the calibration curves. Radiation sources in use are cathode lamps. All of the experiments used air-acetylene gas. Since other components in the sample typically do not absorb the selected wavelength and will not impede the measurement, this method offers both sensitivity and selectivity. For every sample, three separate experiments were carried out.

Table 1: Determination of physical properties of cassava tubers [20]

Property	Method or equation for determining of physical properties	Reference
L (cm)	Measuring tape	[24]
W (cm)	Digital vernier caliper	[24]
T (cm)	Measuring three different segments of the cassava tubers using digital vernier caliper	[24]
D_g (cm)	$D_g = (LWT)^{1/3}$	[25-26]
S_a (cm^2)	$S_a = \pi D_g^{\,2}$	[24, 27]
S_p (cm)	$S_p = \frac{(LWT)^{1/3}}{L}$ 100%	[24, 27]
ε (%)	$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100$	[26]
Mt (g)	A digital weighing balance 10 kg was used in weighing each of the cassava tubers	[24, 27]
Vt (cm^3)	By putting a known mass of a (unit) sample into a cylindrical container of water, change in level of the liquid in the cylinder gives the unit volume	[25]
ρ_t (g/cm^3)	$\rho_t = \frac{W_t}{V_t}$	[26-27]
α (°)	The apparatus consisting of plywood box with a fixed stand attached with a protractor and an adjustable plate at the surface	[4]
μ	μ = tan α	[24, 27]

where L denotes length in cm, W denotes width in cm, T denotes thickness in cm, D_g stands for size in cm, R_a stands for aspect ratio in %, S_a stands for surface area in cm^2, S_p stands for sphericity in cm, ε is denotes porosity in %, Mt denotes true mass in g, Vt denotes true volume in m^3, ρ_t denotes true density in g/cm^3, α denotes angle of repose in ° and μ denotes coefficient of static friction.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Palm Fruits

The physical properties of palm fruit are shown in Table 2. The average length, breadth, thickness, geometric mean, sphericity, surface area, true mass, true volume and true density mean for palm fruits were 3.35±0.48 cm, 1.92±0.32 cm, 2.24±0.33 cm, 2.42±0.25 cm, 0.73±0.08 cm, 18.61±3.62 cm^2, 7.99±1.81 g, 7.01±1.72 cm^3, 1.17±0.24 g/cm^3 respectively. Therefore, the geometric mean diameter is a useful parameter to have when designing systems to separate seeds from other materials [28]. More recently,[29] stressed the significance of these and other characteristic axial dimensions in determining aperture sizes and other parameters in machine design. When developing seed sizing, grading, and equipment for separating it from undesired materials [3]. Any grain or fruit's ability to roll or slide is determined by its aspect ratio and sphericity; sphericity values show that the seed is nearly spherical in shape and rolls easily on surfaces, especially in hoppers and dehulling machinery; elevated sphericity and aspect ratio suggest that the seeds are moving toward a spherical form; these characteristics are useful when designing equipment for dehulling; true density is useful in determining how to separate food products from unwanted ingredients because, as [30] notes, leaning is an essential step in the food processing process. The ratio of true mass to true volume was used to determine each kernel's true density, which is an important factor in material selection, machine component design, and groundnut processing machine design. When developing agricultural machinery, such as palm fruit processing machines, density is a crucial factor to take into account when choosing materials, designing machine frames, and designing hopper capacities [16]. In order to assess the projected area of a particle traveling through a turbulent or nearly turbulent region of an air stream.

Tables 3 and 4 show the coefficient of friction and angle of repose of palm fruit. The average static coefficient of frictions for palm fruits were 0.46±0.13, 0.64±0.18, 0.57±0.21 and 0.59±0.22 while the average angle of reposes was 24.48±6.08, 31.62±9.14, 29.26±6.80, and 29.91±9.11 on wood, mild steel, glass and stainless-steel surface respectively. [31] reported for apple on glass and wood surfaces were 26.3 and 26.8 degrees respectively and 21.44

degrees for moringa seeds [32]. The coefficient of friction is helpful in designing machine components like the shaft and hopper, as well as in determining machine performance evaluation parameters like efficiency, throughput capacity, percentage broken seed, etc. [16]. When designing machinery for the handling and processing of palm fruits, the angle of repose is a very helpful consideration. Stainless steel is an essential tool in the food processing industry. Stainless steel is a non-rusting material that is also highly machinable and does not contaminate food items. Because they are more costly, they are therefore being utilized more and more for processing equipment.

Table 2: Physical properties of palm fruit

Properties	Mean	SD	Min	Max
Length (cm)	3.35	0.48	2.04	4.24
Breadth (cm)	1.92	0.32	1.00	3.08
Thickness (cm)	2.24	0.33	1.25	3.42
Geometric mean (cm)	2.42	0.25	1.37	2.95
Sphericity (cm)	0.73	0.08	0.60	1.06
Surface area (cm^2)	18.61	3.62	5.86	27.29
True Mass (g)	7.99	1.81	2.50	14.25
True Volume (cm^3)	7.01	1.72	2.00	11.00
True Density (g/cm^3)	1.17	0.24	0.58	2.33

Table 3: Coefficient of friction of palm fruit

Coefficient of Friction	Mean	Min	Max	SD
Wood	0.46	0.12	0.78	0.13
Mild Steel	0.64	0.18	1.19	0.22
Glass	0.57	0.21	0.97	0.16
Stainless Steel	0.59	0.18	1.19	0.22

Table 4: Angle of repose of palm fruit

Angle of Repose (°)	Mean	Min	Max	SD
Wood	24.48	7.00	38.00	6.08
Mild Steel	31.62	10.00	50.00	9.14
Glass	29.26	12.00	44.00	6.80
Stainless Steel	29.91	10.00	50.00	9.11

3.2 The Mechanical Properties of Palm Fruit

The values of the result obtained in the determination of the mechanical properties of palm fruit are shown in the Table 5. The energy at break, force at break, deformation at break, strain at break, and stress at break for the palm fruits were 6.87±0.95 J, 2.22±0.80 kN, 14.58±3.02 mm, 0.36±0.08 mm/mm and 123.46±44.31 MPa respectively. The compressive force is needed to cause the crop to rupture. The force required to rupture the palm fruit was about 2220±0.80 N which is higher when compared with the results obtained in onion as reported by [33]. Development of machinery and equipment for processing and handling, as well as understanding the material's reaction to applied force, depend heavily on an understanding of the properties of agricultural materials in terms of stress, strain, and deformation [16]. Toughness or strain energy is defined as the energy absorbed by the palm fruit prior to the palm fruit rupture per unit volume [5]. Results showed toughness of the palm fruit as 6.87±0.95 Joules. This is the measure of the stiffness and rigidity of the specimen. In other words, it shows how easily the palm fruit surface can be deformed.

Table 5: Mechanical properties of palm fruit

Sample Number	Energy at break (J)	Force at break (kN)	Deformation at break (mm)	Strain at break (mm/mm)	Stress at break (MPa)
Mean	6.87	2.22	14.58	0.36	123.46
Min	5.82	1.30	12.40	0.31	72.31
Max	7.66	2.71	18.03	0.45	150.28
SD	0.95	0.80	3.024	0.08	44.31

3.3 The Proximate and Mineral Composition of Palm Fruit

Table 6 and 7 show the proximate and mineral compositions of palm fruit. The moisture, ash, fat, crude fibre, crude protein, and carbohydrate contents (proximate composition) of the palm fruits were 22.80±0.02 %, 0.52±0.01 %, 46.47±0.06 %, 18.66±0.01 %, 2.4±0.21 %, and 9.14±0.30 % respectively. The prepared products' nutritional value and textural quality are crucial factors in determining their general acceptability [35].

The sodium, potassium, calcium, magnesium, iron, phosphorus and zinc contents of the palm fruits were 58.75±0.07 ppm, 94.20±0.14 ppm, 68.45±0.64 ppm, 5.21±0.00 ppm, 1.22±0.00 ppm, 1.60±0.00 ppm and 55.70±0.28 ppm respectively. The result showed potassium to be the highest, followed by calcium which was also reported by [34]. The magnesium, phosphorus and iron concentrations were much lower and ranged from 0.06 – 0.08 ppm which was also reported to be 0.05 – 0.08 mg/100 ml by [34].

Table 6: Proximate composition of palm fruit

Proximate Composition	Mean	Min	Max	SD
Moisture content (%)	22.80	22.78	22.81	0.02
Ash content (%)	0.52	0.52	0.53	0.01
Fat content (%)	46.47	46.42	46.51	0.06
Crude fibre (%)	18.66	18.65	18.67	0.01
Crude protein (%)	2.40	2.25	2.55	0.21
Carbohydrate content (%)	9.14	8.93	9.35	0.30

Table 7: Mineral composition of palm fruit

Mineral composition	Mean	Min	Max	SD
Na (ppm)	58.75	58.70	58.80	0.07
K (ppm)	94.20	94.10	94.30	0.14
Ca (ppm)	68.45	68.00	68.90	0.64
Mg (ppm)	5.21	5.21	5.21	0.00
Fe (ppm)	1.22	1.22	1.22	0.00
P (ppm)	1.60	1.60	1.61	0.00
Zn (ppm)	55.70	55.50	55.90	0.28

4. CONCLUSION

The selected physical, mechanical, and chemical properties of fresh fruit bunches for the processing of palm oil have been determined. The data provide baseline information for engineers to develop more efficient machines for processing palm fruits that will improve and increase the oil extraction efficiency, oil extraction ratio (oil yield), material discharge efficiency, and minimize oil loss during the processing of waste products. Selected physical, mechanical, and chemical properties of palm fruits between two and twelve days should be investigated since local food processors using semi-automated processing machines for processing palm fruits usually use up to twelve days when processing palm fruits.

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