EFFECTS OF MOISTURE CONTENT ON SOME ENGINEERING PROPERTIES OF ARECANUT (*ARECA CATECHU* L.) FRUIT WHICH ARE RELEVANT TO THE DESIGN OF PROCESSING EQUIPMENT
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PENGARUH KADAR AIR TERHADAP BEBERAPA SIFAT KETEKNIKAN BUAH PINANG (ARECA CATECHU L.) YANG RELEVAN UNTUK PERANCANGAN PERALATAN PENGOLAHANNYA

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ABSTRACT
The physical and mechanical properties of fresh arecanut fruit have not been comprehensively and thoroughly investigated scientifically yet. This made the researchers and engineers not to be precise in designing the fresh arecanut handling machine. Thus, the present study was aimed to investigate some engineering properties of arecanut fruit in three moisture viz. 67.66%, w.b. (underripe stages), 64.86%, w.b. (ripe stages), and 33.90%, w.b. (overripe stages). In general, the results of the study show that the geometric and arithmetic mean diameter, surface area, bulk and true density, porosity, angle of repose, compression force and static coefficient of friction at different surfaces (stainless steel, plywood, and glass) of arecanut fruit were found to increase 2.16%, 2.70%, 4.26%, 0.02%, 42.16%, 42.41%, 9.97%, 17.04%, 20.30%, and 22.04% respectively at decrease of moisture content from 67.66%, w.b. to 33.90%, w.b. However, sphericity, aspect ratio, thousand fruit mass, and bulk density of the arecanut fruit were found to decrease 2.31%, 3.31%, 34.54%, and, 50.24%, respectively at a decrease of moisture content from 67.66% (w.b.) to 33.90% (w.b.). Some engineering properties of arecanut fruit indicate something slightly different from the arecanut kernels so that this data can help the researcher or engineer to design the fresh arecanut fruit handling machine more precisely.

ABSTRAK
Sifat fisik dan mekanik buah pinang belum komprehensif dan mendalam diselidiki secara ilmiah. Hal ini menyebabkan banyak para peneliti dan perekayasa kurang presisi dalam merancang mesin penanganan buah pinang. Oleh karena itu, penelitian ini bertujuan untuk menyelidiki beberapa sifat keteknikan dari buah pinang dalam tiga kandungan kadar air yaitu 67,66%, b.b. (tahap kurang matang), 64,86%, b.b. (tahap matang), dan 33,90%, b.b. (tahap lewat matang). Secara umum, hasil penelitian menunjukkan bahwa diameter rata-rata geometris dan aritmatika, luas permukaan, massa dan kepadatan sebenarnya, porositas, angle of reposes, gaya kompresi dan koefisien gesekan statis pada permukaan yang berbeda (stainless steel, kayu lapis, dan kaca) buah pinang ditemukan masing-masing meningkat 2,16%, 2,70%, 4,26%, 0,02%, 42,16%, 42,41%, 9,97%, 17,04%, 20,30%, dan 22,04% seiring dengan penurunan kadar airnya dari 67,66%, b.b. hingga 33,90%, b.b. Namun, spericity, aspect ratio, massa seribu buah pinang, dan kepadatan massa buah pinang ditemukan menurun masing-masing adalah 2,31%, 3,31%, 34,54%, dan, 50,24%, seiring dengan penurunan kadar airnya dari 67,66% (b.b.) menjadi 33,90% (b.b.). Beberapa sifat rekayasa dari buah pinang menunjukkan hal berbeda dari biji pinang itu sendiri sehingga data ini dapat membantu peneliti atau perekayasa untuk merancang mesin penanganan buah pinang segar lebih presisi.

INTRODUCTION

Arecanut (*Areca catechu* L.) is a large-scale plantation plant in Aceh Province, Indonesia. The availability of post-harvest handling of arecanut is still not widely investigated scientifically, which results in the inefficiency of the arecanut fruit processing chain from harvest in the field to the product that can be used. Meanwhile, the level of need for the use of betel nuts as a mixture of medicines and cosmetics from areca products continues to increase.

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Therefore, some engineering properties are importantly related to the design of machines and the analysis of the behaviour of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting, drying, and packaging [*Moradi et al., 2019*].

According to several studies (*Moradi et al., 2019; Pandiselvam et al., 2019; Singh and Meghwal, 2019; Bajpai et al., 2019*) the design of machines handling agricultural products is determined by the physical and mechanical properties of the product itself. Therefore, many researchers and engineers made the determination of physical properties of agriculture products such as us *Kaleemullah and Gunasekar (2002)*, *Sarajeh et al. (2014), Ahmed et al. (2019)*, determined physical properties of arecanut kernels, grass peas, smany and zaghloul date fruit, respectively.

The lack of published articles on moisture dependent physical properties of arecanut is only about the measurement of physical properties from kernels (*Kaleemullah and Gunasekar, 2002)*. Therefore, the present study is envisaged to investigate some engineering properties of arecanut fruit such as mean diameters (geometric and arithmetic), sphericity, aspect ratio, surface area, thousand fruit mass, true density and bulk density, porosity, angle of repose, compression force, and static coefficient of friction at different surfaces (stainless steel, plywood, and glass) over moisture content range from 67.66%, (w.b.) to 33.90%, (w.b.).

Three stages of arecanut fruit that were commonly harvested in arecanut farmers in Aceh Province were investigated, namely underripe phase (67.66%, w.b.), ripe phase (64.86%, w.b.), and overripe phase (33.90%, w.b.) (Figure 1). The effects of arecanut fruit (*Areca catechu* L.) age on some engineering properties relevant to the design of processing equipment was investigated and modelled too. We hope, measurement of some engineering properties of arecanut fruit will be helpful for researchers and engineers in machine designing for industrial processing and fabrication of preharvest and postharvest handling equipment like planting, harvesting, sorting, grading, collecting, drying, pulper, grinding, packaging machines, and storage structures more precisely.

MATERIALS AND METHODS

Three stages of arecanut fruit maturation are used as samples to be measured in this study. These three samples are based on the habits of arecanut farmers in Aceh Province in harvesting arecanut. The three samples are included in the category underripe phase, ripe phase, overripe phase whose moisture content is 67.66% (w.b.), 64.86% (w.b.), and 33.90% (w.b.), respectively (Figure 1). The moisture content of each sample was determined using the AOAC (1995) method and calculated using Equation 1.

$$M_C = \left(\frac{W_i - W_d}{W_i} \right) \times 100\%$$
(1)

Fig. 1 - Three stages of arecanut fruit which are commonly harvested by farmers in Aceh Province

The arecanut fruit size was determined by picking one hundred arecanut fruit (underripe stages (67.66%, w.b.), ripe stages (64.86%, w.b.), and overripe stages (33.90%, w.b.)) randomly and measuring their three main dimensions (major, medium and minor diameters). After that, the geometric mean diameter is determined using Equations 2 and arithmetic mean diameter using Equation 3.

$$D_G = \sqrt[3]{LWT}$$
(2)

$$D_a = \frac{LWT}{3}$$
(3)

After that, sphericity, aspect ratio, and surface area of arecanut fruit were determined by the following relationship Equation 4 to Equation 6 (*Mohsenin, 1986*).

$$s = \frac{(LWT)^{1/3}}{L}$$
(4)

$$A_R = \frac{L}{W} \tag{5}$$

$$A_S = \pi \times D_G{}^2 \tag{6}$$

The bulk density was calculated by filling a one-litre glass measuring cup with arecanut fruit and then weighing the fruits. The fruit density was researched by the water displacement method as recommended by *Kaleemullah and Gunasekar (2002), Yahya et al. (2013)* and *Sacilik et al. (2003).* After that, porosity could be determined using Equation 1.

$$\varepsilon = \left(1 - \frac{\rho_{BD}}{\rho_{TD}}\right) \times 100\% \tag{7}$$

To measure the angle of repose, a container with a diameter of 30 cm was chosen with a ceramic base. This is following the method used by *Amin et al. (2004)*. The height, minor and major width in the surface after shedding was measured, and the angle of repose was calculated using the tangent rule according to Equation 8.

$$\theta = \tan^{-1}\left(\frac{2H}{D_1 + D_2}\right) \tag{8}$$

To determine the compression force of arecanut fruit, a Universal Testing Machine (UTM) unit was used (Force maximum 500 N, the accuracy of 0.5N). The fruits were placed between two iron plates and pressed at the 0.01 mm/s speed until they arrive at to rupture point. Simultaneity force vs. deformation curves were recorded by a personal computer (Figure 2).
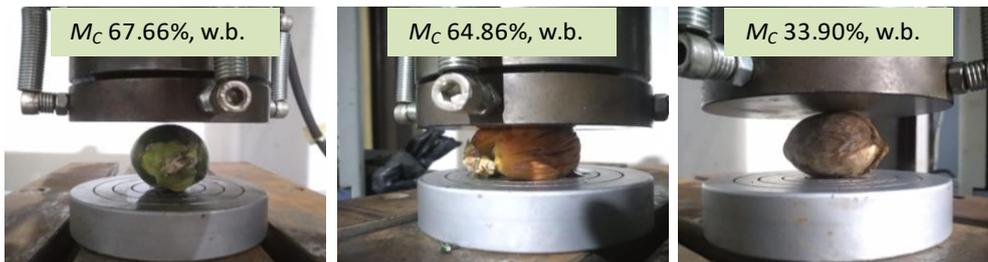

M_C 67.66%, w.b. M_C 64.86%, w.b. M_C 33.90%, w.b.

Fig. 2 -Compression force testing from arecanut fruit using UTM

To calculate the static coefficient of friction that occurs in arecanut fruit, it is computed using Equation 9. Three types of surfaces that are potentially used in the design of the arecanut models are used in this study, namely stainless steel, plywood, and glass (*Mollazade et al., 2009*).

$$\mu = \tan(\alpha) \tag{9}$$

RESULTS AND DISCUSSION
Arecanut fruit size

The dimensions of arecanut fruit were determined in three basic sizes. The geometric mean diameter of arecanut increased from 37.05 mm to 39.81 mm as the moisture content decreased from the underripe arecanut stages (67.66%, w.b.) to ripe arecanut stages (64.86%, w.b.). In the next steps, the geometric mean diameter of the overripe arecanut stages (33.90%, w.b.) decreased to 37.86 mm. The arithmetic mean diameter of arecanut increased from 38.04 mm to 40.05 mm as the moisture content decreased from the underripe arecanut stages (67.66%, w.b.) to arecanut ripe stages (64.86%, w.b.). Furthermore, the arithmetic mean diameter of the arecanut decreases again from 40.05 mm to 39.10 mm as the moisture content falls from the ripe arecanut stages (64.86%, w.b.) to overripe arecanut stages (33.90%, w.b.) (Figure 3). This phenomenon is thought to be caused by the biological factors of the arecanut fruit, which keep growing until the arecanut is in the ripe phase and decreases when the betel nut is in the overripe stages. The variations of bulk and true densities were found to be polynomial equations for both with the moisture content and can be represented by the following regression Equation 10 and Equation 11.

$$D_A = -0.022 M_C{}^2 + 2.22 M_C - 10.66 \tag{10}$$

$$D_G = -0.031 M_C{}^2 + 3.14 M_C - 32.70 \tag{11}$$

both with a value for the coefficient of determination R^2 of 1.0.
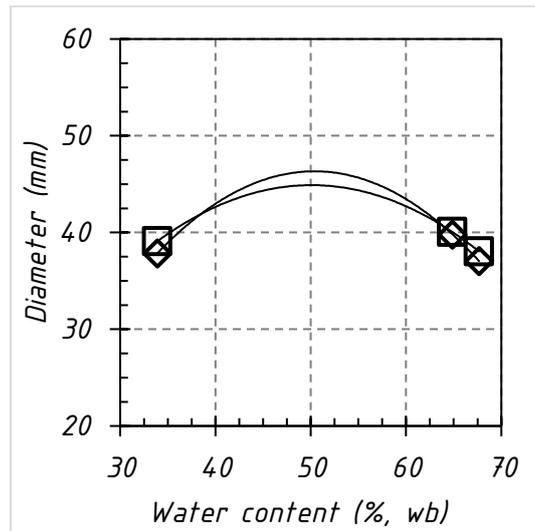
Fig. 3 - Arecanut fruit geometric (◇) and arithmetic (⊟) mean diameter at different moisture content

The geometric equation model for mean diameter and arithmetic one for mean diameter are different from Opeaburoo and Abontem maize as reported by *Hayford et al. (2019)*. However, the results of *Singh et al. (2010)* for barnyard millet grain and kernel found a relationship model that is in line with arecanut fruit that is following the polynomial equation. This indicates that arecanut fruit tend to have dimensions (geometric and arithmetic) more similar to millet grain millets and kernels than Opeaburoo and Abontem maize.

Sphericity and aspect ratio

The sphericity of arecanut fruit was found to increase from 0.73 to 0.86 with a decrease in moisture content from 67.66% (w.b.) to 64.86% (w.b.) and subsequently decreased to 0.71 in the moisture content of 33.90% (w.b.) (Figure 4). The relationship model increase and decrease between sphericity and moisture content was polynomial, too. This increase and decrease can be described by the following Equation 12 and Equation 13. This behaviour has been in line with those reported by *Hayford et al. (2019)* for Opeaburoo and Abontem maize, *Zewdu and Solomon (2008)* for grass pea seeds.

$$s = -0.002M_C^2 + 0.16M_C - 2.87 \qquad (12)$$

$$A_R = -0.002M_C^2 + 0.21M_C - 4.18 \qquad (13)$$
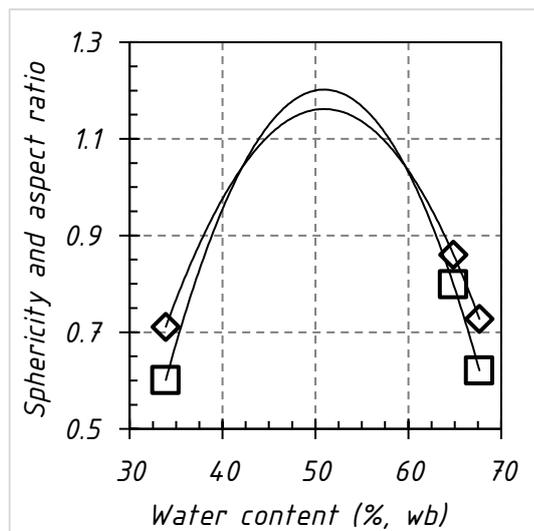
with a value for R^2 of 1.

Fig. 4 - Effect of moisture content on sphericity (◇) and aspect ratio (⊟)

Surface area

The surface area of arecanut fruit was found to increase from 4334.78 mm² to 5004.53 mm² with a decrease in moisture content from 67.66% (w.b.) to 64.86% (w.b.) (Figure 5). Furthermore, the reduction in

moisture content from 64.86% (w.b.) to 33.90% (w.b.) was found to decrease the surface area of arecanut fruit from 5004.53 mm^2 to 4527.53 mm^2. The relationship existing between surface area and moisture content is non-linear and can be expressed by the regression Equation 14. The connection of model surface area with a moisture content of arecanut fruit has been in line with research results reported by *Ganjloo et al. (2018)* for green peas, *Singh et al. (2010)* for barnyard millet grain and kernel and *Mollazade et al. (2009)* for cumin seed.

$$A_S = -7.55M_C^2 + 760.99M_C - 12594 \tag{14}$$
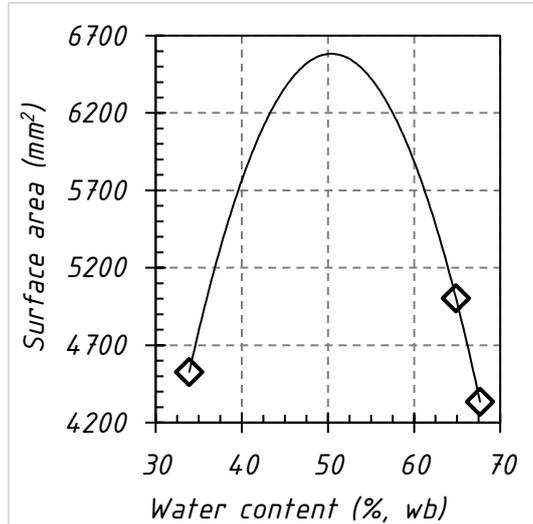
With a value for R^2 of 1.0.

Fig. 5 - Effect of moisture content on surface area

Thousand fruit mass

Thousand fruit mass for arecanut fruit with an increase in moisture content from 33.90% (w.b.) to 67.66% (w.b.), was found to tend to increase from 2620.50 g to 3525.70 g (Figure 6). The linear equation for the description of this behaviour was found in the following relation to Equation 15. The linear increase of thousand arecanut fruit mass is in line with the results of the research of *Ganjloo et al. (2018)* for green peas, *Aviara et al. (2013)* for Moringa oleifera seed, *Hayford et al. (2019)* for Opeaburoo and Abontem maize and *Iyilade et al. (2019)* for bush mango nut.

$$M_{1000} = 0.29M_C + 16.40 \tag{15}$$
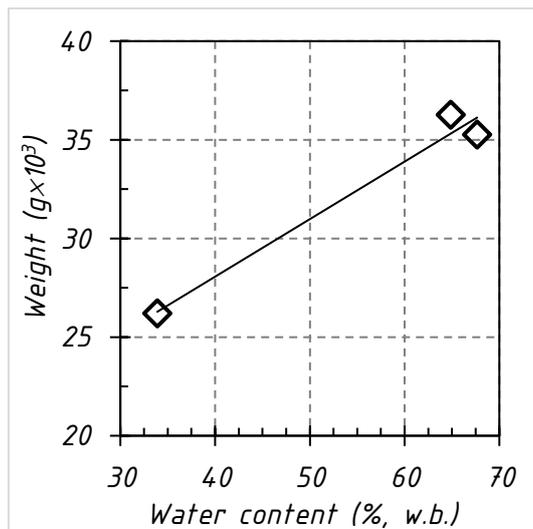
with a value for R^2 of 0.973.

Fig. 6 - Effect of moisture content on thousand fruits weight

Bulk and true densities

As arecanut fruit moisture content increases, the bulk density and true density were found to increase. This increase was linear. The range of change with increase in moisture content from 33.90% (w.b.) to 67.66% (w.b.) for the bulk density and true density was, 395.90 kg/m^3 to 594.80 kg/m^3, and 866.50 kg/m^3 to 866.31

kg/m³, respectively (Figure 7). The relationship existing between bulk and true densities and moisture content is linear and can be expressed by the regression Equation 16 and Equation 17. The linear increase of bulk and true densities of arecanut fruit is in line with the results of the research of *Ganjloo et al. (2018)* for green peas, *Aviara et al. (2013)* for Moringa oleifera seed, *Hayford et al. (2019)* for Opeaburoo and Abontem maize, *Iyilade et al. (2019)* for bush mango nut and *Pradhan et al. (2008)* for Karanja kernel.

$$\rho_{BD} = 5.35M_C + 212.83 \tag{16}$$

$$\rho_{TD} = 0.0053M_C + 866.69 \tag{17}$$
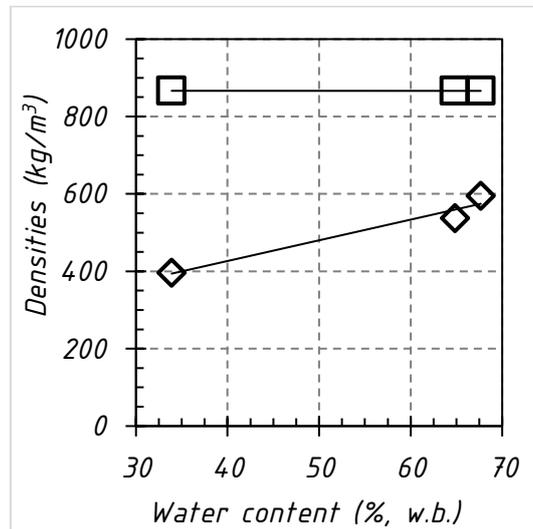
with a value for R² of 0.957.

Fig. 7 - Effect of moisture content on bulk density (⊟) and true density (◇)

Porosity

Porosity of arecanut fruit decreases with increasing moisture content (Figure 8). Its decrease was linear. The range of change with an increase in moisture content from 33.90% (w.b.) to 67.66% (w.b.) for porosity was, 54.35% to 31.43%. The relationship existing between porosity and moisture content is linear and can be expressed by regression Equation 18. The linear decrease of arecanut fruit porosity is in line with the results of *Mollazade et al. (2009)* for cumin seed, *Tavakoli et al. (2009)* for soybean grains, *Sessiz et al. (2007)* for caper fruit and *Garnayak et al. (2008)* for jatropha seed.

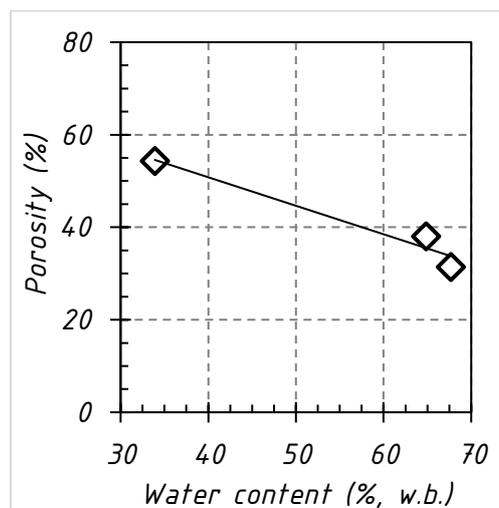$$\varepsilon = -0.62M_C + 75.45 \tag{18}$$

with a value for R² of 0.957.

Fig. 8 - Effect of moisture content on porosity

Angle of repose

Experimentally determined values of angle of repose are plotted against moisture content, as shown in Figure 9. From this, it can be observed that the angle of repose decreased from 22.60° to 13.01° as the fruit

moisture content decreased from 67.66% (w.b.) to 33.90% (w.b.). *Hayford et al. (2019)* and *Iyilade et al. (2019)* reported a similar type of result in the case of Opeaburoo and Abontem maize, bush mango nut, respectively.

The relationship existing between the angle of repose and moisture content is linear and can be expressed as Equation 19.

$$\theta = -0.26M_C + 31.52 \tag{19}$$
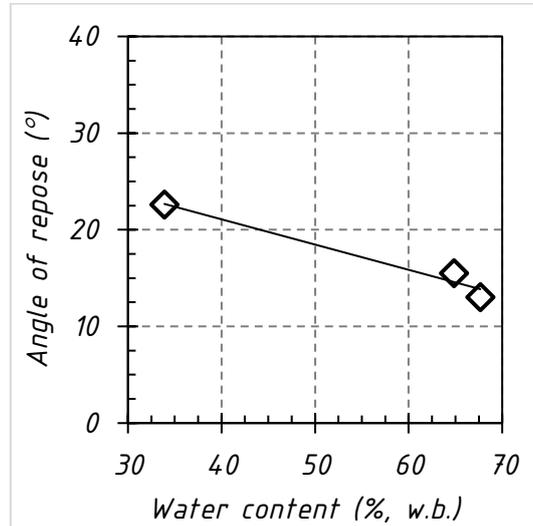
With a value for R² of 0.968.

Fig. 9 - Effect of moisture content on angle of repose

Compression force

The compression force of arecanut fruit in moisture content from 33.90% (w.b.) to 67.66% (w.b.) was deeply scrutinized. Compression force of arecanut fruit in moisture content from 33.90% (w.b.) to 64.86% (w.b.) tends to increase from 79.50 kgf to 104.74 kgf and in moisture content from 64.86% (w.b.) to 67.66% (w.b.) tends to decrease from 104.74 kgf to 71.57 kgf (Figure 10). It is thought to be caused by the biological factors of the arecanut, which tends to harden in the ripe stages and tends to soften again in the overripe stages. The relationship existing between compression force and moisture content is represented by polynomial equations and can be expressed by the regression Equation 20. This model is in line with the results of *Singh et al. (2010)*, who discovered that the compression force on a millet grain and kernel barnyet follows the polynomial equation.

$$C_F = -0.376M_C{}^2 + 37.90M_C - 773.73 \tag{20}$$

with a value for R² of 1.0.

Static coefficients of friction

The coefficient of static friction between the arecanut fruit and three surfaces, namely stainless steel, plywood and glass, was determined. On all these surfaces a polynomial increase of the static coefficient of friction has been found.

With an increase in moisture content from 33.90% (w.b.) to 67.66 (w.b.), this decrease for stainless steel, plywood and glass was found from 0.25 to 0.21, 0.18 to 0.19 and 0.18 to 0.14, respectively (Figure 11). *Kudos and Solanki (2018)* and *Hayford et al. (2019)* quoted similar types of results in the case of amaranth grain, Opeaburoo and Abontem maize, respectively. The polynomial equation for the description of this behaviour for stainless steel, plywood, and glass was found in the relations (Equation 21 to 23), respectively.

$$\mu_{SS} = -0.0004M_C{}^2 + 0.0358M_C - 0.54 \tag{21}$$

$$\mu_W = -0.0004M_C{}^2 + 0.0379M_C - 0.63 \tag{22}$$

$$\mu_G = -0.0004M_C{}^2 + 0.0358M_C - 0.54 \tag{23}$$
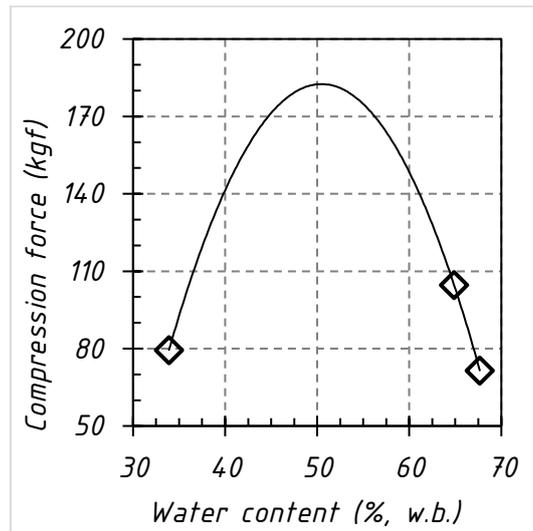
with a value for R² of 1.0.

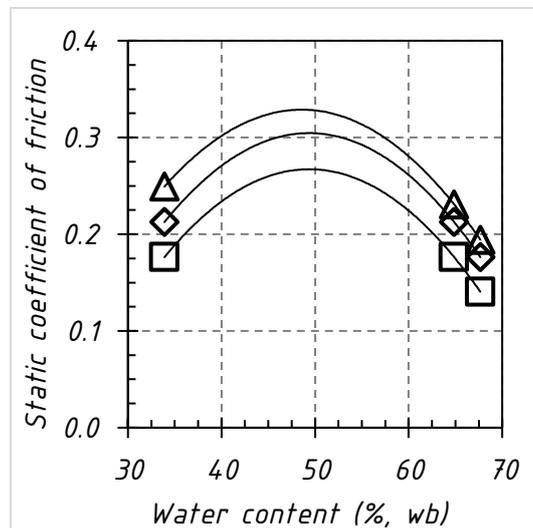**Fig. 10 - Effect of moisture content on compression force**

Fig. 11 - Effect of moisture content on static coefficients of friction at some material
(△stainless steel, ◇ plywood, ⊟ glass)

CONCLUSIONS

Three phases of common types of arecanut fruit that farmers harvested were identified, namely underripe, ripe and overripe, with their moisture content of 67.66% (w.b.), 64.86% (w.b.), 33.90% (w.b.), respectively. The relationship between water content in the three phases of betel nut with seven characteristic physical parameters and two mechanical properties was modelled in a linear and non-linear equations.

Engineering properties geometric mean diameter, arithmetic mean diameter, sphericity, aspect ratio, surface area compression force, and static coefficient of friction follow the polynomial equation model.

Engineering properties such as porosity and angle of repose follow the decreasing linear equation model, and a thousand mass of fruits bulk density and true density follow the increasing linear equation model. The next work of this research is to investigate the model of the relationship of rupture force to the physical properties of arecanut fruits in various stages.

It is crucial for researchers and engineers of pre-harvest and post-harvest agricultural machinery to estimate the force limits that can be applied in handling arecanut fruit without damaging the product itself.

ACKNOWLEDGEMENT

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