# Comparative analysis of mechanical properties of two varieties of periwinkle relevant to the design of cracking unit of the shelling machine

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**Abstract:** This study was conducted to investigate and compare the mechanical properties of *Tympanotonus fuscatus* and *Pachymelania aurita* periwinkle varieties. The average force to rupture of *P. aurita* under longitudinal and transverse loading orientations was higher than that of *T. fuscatus*. Also, the average rupture energy of *T. fuscatus* under longitudinal and transverse loading orientations was lower than that of *P. aurita*. The average deformation for *T. fuscatus* under longitudinal and transverse loading orientations was found to be lower than that of *P. aurita* under the same orientations. The average Young's Modulus values of *T. fuscatus* under longitudinal and transverse loading orientations were found to be higher than that of *P. aurita*. Moreso, the average values of angle of repose and coefficient of static friction on glass, galvanized steel and cast-iron surfaces for *P. aurita* variety were higher than that of *T. fuscatus*. These obtained results were applied to develop a sustainable periwinkle processing machine.

**Keywords:** Periwinkle, *Tympanotonus fuscatus*, *Pachymelania aurita*, rupture force, rupture energy, deformation, Young's modulus, frictional and mechanical properties.

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## 1 Introduction

Periwinkle is one the most abundant and cheapest mollusk in the coastal West Africa with two genera: *Tympanotonus fuscatus,* and *Pachymelania aurita*.

Its processing over the years has been through crude traditional manual methods (Ekop et al., 2021). Periwinkle flesh serves as meat while the shell is use for soil amendation, brake pad, sandpaper, erosion control, ornament, aggregates for the construction industry (Solomon et al., 2017; Ekop et al., 2013).

In Nigeria, periwinkles are harvested mainly by traditional methods of hand pickings and by use of rakes during low tides, the harvested periwinkles are washed in water to remove mud and other adhering materials before packaging in jute bags. This method is time consuming, tedious, hazardous, and uneconomical (Ekop, 2020).

The knowledge of mechanical properties of agricultural materials is useful during postharvest handling, processing, storage as well for efficient design, dimensioning and manufacturing different equipment to harness these materials (Fakayode,2020; Mohite and Sharma, 2018).

Although there have some studies carried out on periwinkle but the focus have been on the nutritional

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status of periwinkle (Pessu et al., 2014; Adebay-Tayo and Ogunjobi, 2008), Bacteriological, chemical, functional and proximate compositions of periwinkle (Nwiyi and Okonkwo, 2013; Ogunbenle and Omowole, 2012; Odu et al., 2010; Adebayo-Tayo et al., 2006; Ekanem and Otti, 1997; Ariahu and IIori,1992). Assessment of length-weight relationship and condition factors of periwinkle (Solomon et al., 2017; Moruf and Lawal-Are, 2015; Udo, 2013, Jamabo et al., 2009). Ecology and population estimation of periwinkle (Onwuteaka et al., 2017; Iboh et al., 2015; Bob-Manuel, 2012; Jamabo and Chinda 2010, Egonmwan, 2008; Jamabo, 2007; Carlton and Cohen, 2002; Ajao and Fagade, 1990). Effect of different processing methods on the meat of periwinkle (Pessu et al., 2014). There is dearth of information about some engineering properties of periwinkle shell and meat, no periwinkle meat extraction machine has been known so far, these hinder the efficient mechanization of periwinkle processing. Ituen (2015) studied the mechanical and chemical properties of selected mollusk shells in Nigeria while Eke and Ehiem (2015) looked at the effect of load orientations on some mechanical properties of periwinkle varieties. However, the objectives of this study were to determine some design related mechanical properties of periwinkle shell and meat of two varieties (*Tympanotonus fuscatus* and *Pachymelania aurita*) and then use it as part of input parameters to develop an efficient periwinkle meat processing machine.

## 2 Materials and methods

### 2.1 Sample preparation

Fifteen-kilogram each of *Tympanotonus fuscatus* and *Pachymelania aurita* (Figure 1) varieties of periwinkle were purchased from Itu waterfront market in Akwa Ibom State, Nigeria(Latitude 5°12'4.72" N and Longitude 7°59'1.43" E). The periwinkle samples were washed, cleaned and graded and, then taken to the laboratory for analysis.

(a) *Pachymelania aurita* (b) *Tympanotonus fuscatus*

Figure 1 The two periwinkle varieties studied

### 2.2 Experimental procedure

2.2.1 Determination of mechanical properties of periwinkle samples

The mechanical properties, namely; rupture force; rupture energy and deformation of periwinkle shell and meat were determined following standard procedures. A computerized Cussons Technology, Universal Testing Machine (Figure 2) equipped with a 25kN compression load cell and integrator located at the National Centre for Agricultural Mechanization (NCAM) Ilorin, Kwara State, Nigeria, (Longitude 40° 301' East and Latitude 80° 261' North) was used to determine the various mechanical properties of the periwinkle. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation. Twenty (20) samples of each variety of periwinkles were loaded individually between two parallel plates of the machine (Figure 2) with 10 samples each along longitudinal and 10 samples each along transverse orientations for each variety of periwinkle and compressed at a speed of 20 mm $\mathrm{min}^{-1}$ (Ajav and

Fakayode,2013) until rupture occurred as is denoted by a bio-yield point in the force-deformation curve (figures 3 – 6). Once the bio-yield was detected, the loading was stopped. Rupture force, deformation at rupture point, and hardness were automatically measured and recorded by UTM Computer.

(a) longitudinal loading (b) transverse loading orientations

Figure 2 Universal Testing Machine (UTM) showing samples studied

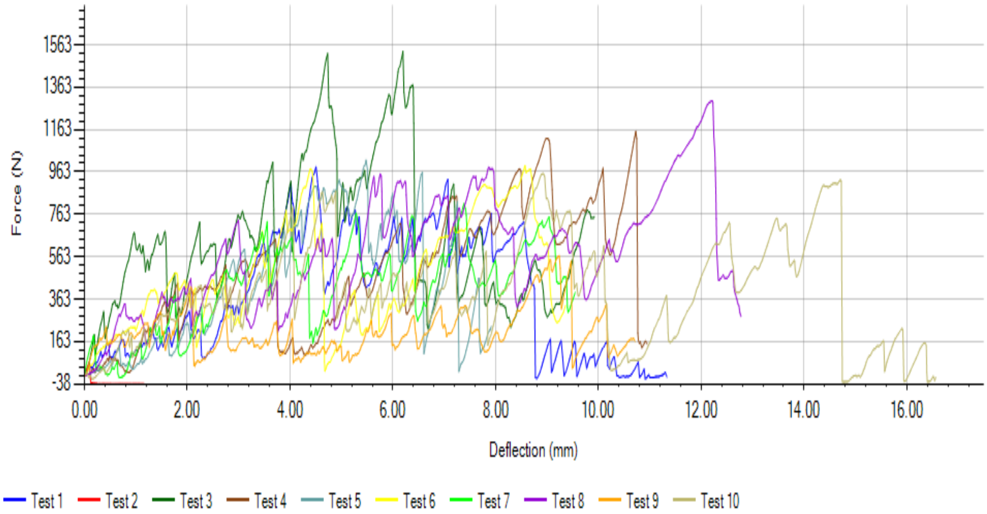


Figure 3 Mechanical properties of *Tympanotonus fuscatus* periwinkle samples under longitudinal compression loading

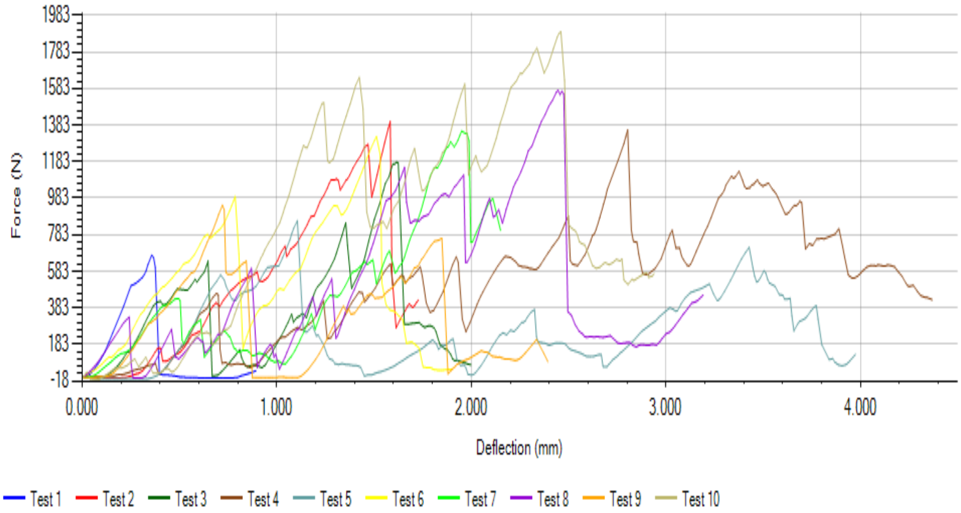


Figure 4 Mechanical properties of *Tympanotonus fuscatus* periwinkle samples under transverse compression loading

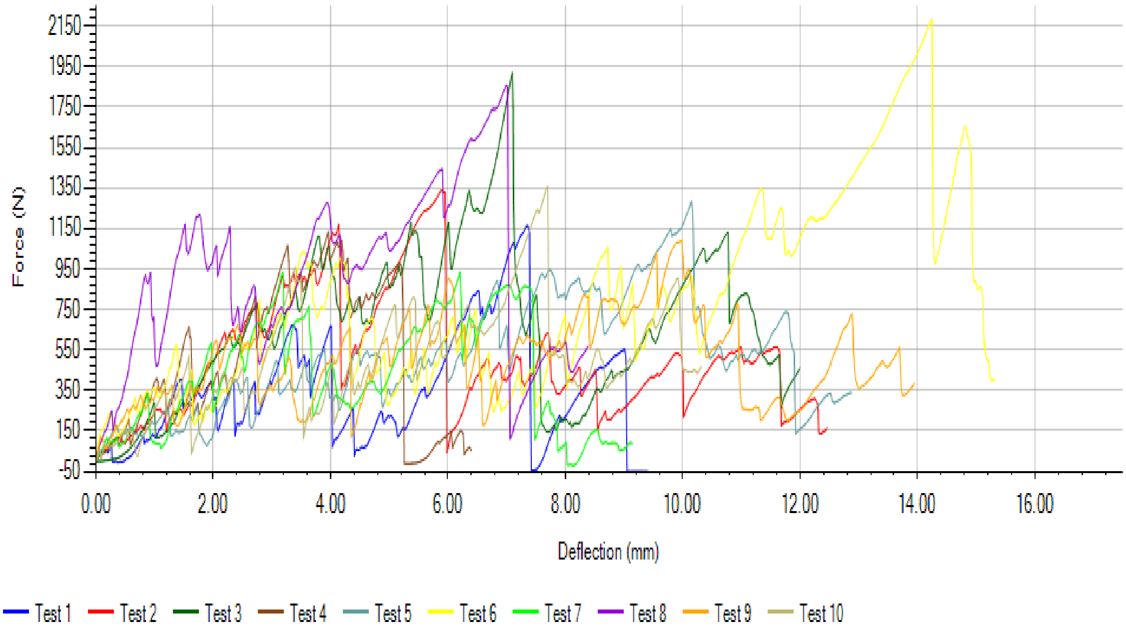


Figure 5 Mechanical properties of *Pachymelania aurita* periwinkle samples under longitudinal compression loading

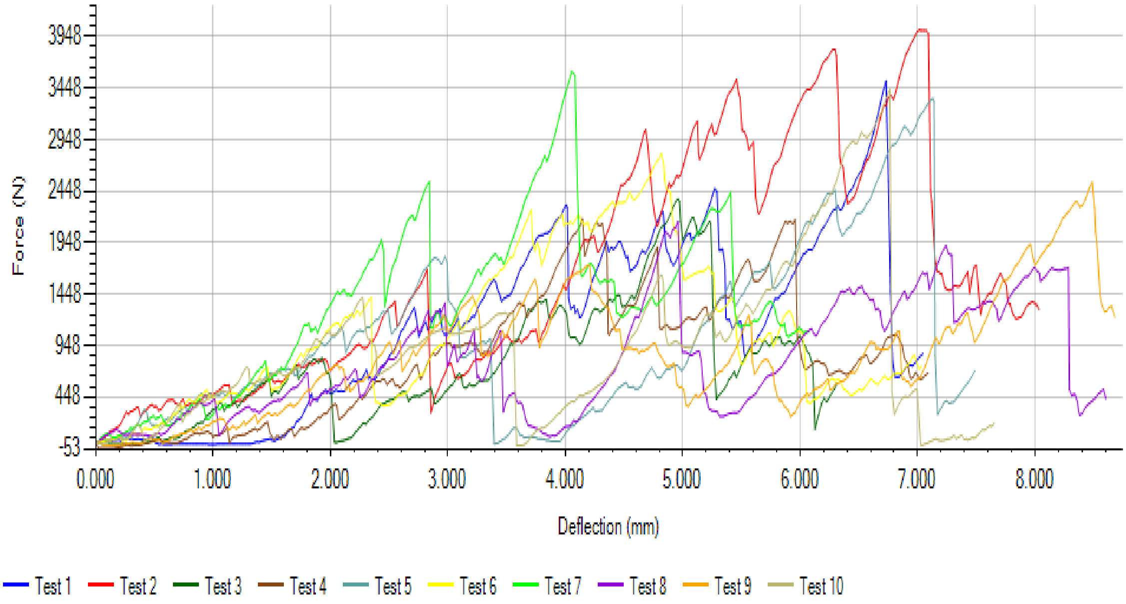


Figure 6 Mechanical properties of *Pachymelania aurita* periwinkle samples under transverse compression loading

## 2.3 Frictional properties of periwinkle samples

### 2.3.1 Angle of repose of periwinkle shell

Angle of repose of periwinkle shell for the two varieties were determined by using a cylinder of 100 mm long and 65 mm in diameter made of cardboard paper, open at both ends. The periwinkles were poured into the cylinder placed on a flat surface to form a pile. The cylinder was then lifted up gradually until, it was completely removed, allowing the samples to spread and form a pile. The experiment was replicated ten times, the radius and the height of piled samples were determined and recorded and the relationship in Equation 1 according to the method described by Ajav and Fakayode (2013) was used to determine the angle of repose, ($\theta$).

$$\theta = tan^{-1}(2h/d) \qquad (1)$$

Where $\theta$ = angle of repose of periwinkle,°; $h$= height of piled sample, $mm$;

$d$ = diameter of spread, $mm$.

### 2.3.2 Determination of static coefficient of friction of periwinkle shell

The static coefficient of friction, $\mu$, of periwinkles for the two varieties was determined on four different surfaces; plywood, glass, cast iron and galvanized steel using an inclined plan apparatus (Figure 7). Sliding motion occurs only when static friction has been overcome by an applied force. The surfaces were gently inclined using a screw device and the angle of inclination at which the sample started sliding was recorded as $\theta$. The procedure was repeated ten times for all the surfaces. The static coefficient of friction was determined using the relation in Equation 2 as:

$$\mu = \tan\theta = \frac{h}{b} \quad (2)$$

Where $\mu$ = static coefficient of friction, dimensionless; $\theta$ = angle of repose of periwinkle,°; $h$ = height raised, $mm$; $b$ = base distance, $mm$.

Figure 7 An inclined plane apparatus for determining coefficient of static friction

### 2.4 Data analysis

Statistical parameters such as standard deviation, coefficient of variance,mean,maximum and minimum values were used to analyze the mechanical properties data of periwinkle samples. Analysis of Variance was carried out to determine the significance and the effect among the two varieties of periwinkle at 5% level of significance. Tukey parwise comparison test was also used to check the difference in means of the responses for the two varieties of periwinkle at 95% confidence level using Minitab 17.0 software.

## 3 Results and discussion

### 3.1 Mechanical properties periwinkle shell and meat

The summary of the values of the mechanical properties of the two varieties of periwinkle samples in longitudinal and transverse loading positions is presented in Tables 1 - 4.

**Table 1 Mechanical properties of *Tympanotonus fuscatus* periwinkle samples under longitudinal compression loading**

| Mechanical Properties | No of Observations | Unit of Measurements | Minimum Value | Maximum Value | Mean Value | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|
| **Force @peak** | 10 | N | 62.090 | 1531.2 | 937.544 | 402.782 | 42.961 |
| **Deformation @peak** | 10 | mm | 0.085 | 12.215 | 7.332 | 3.469 | 47.319 |
| **Stress @peak** | 10 | N mm$^{-2}$ | 1.253 | 14.908 | 4.062 | 3.993 | 15.946 |
| **Energy to peak** | 10 | N m | 0.003 | 7.095 | 3.274 | 2.057 | 62.815 |
| **Force @break** | 10 | N | -37.420 | 752.300 | 255.542 | 237.244 | 105.188 |
| **Deformation@break** | 10 | mm | 1.160 | 16.566 | 10.023 | 3.903 | 38.941 |
| **Stress @break** | 10 | N mm$^{-2}$ | -0.009 | 1.547 | 0.408 | 0.590 | 0.348 |
| **Energy to break** | 10 | N m | 0.035 | 7.391 | 4.394 | 2.207 | 50.230 |
| **Force @yield** | 10 | N | 62.090 | 354.6 | 220.929 | 82.310 | 37.256 |
| **Stress @yield** | 10 | N mm$^{-2}$ | 2.626 | 14.908 | 9.056 | 6.374 | 40.628 |
| **Energy to yield** | 10 | N m | 0.003 | 0.148 | 0.079 | 0.053 | 66.810 |
| **Young's Modulus** | 10 | N mm$^{-2}$ | 80.506 | 8617.110 | 1944.44 | 3034.690 | 9.209 |

**Table 2 Mechanical properties of *Tympanotonus fuscatus* periwinkle samples under transverse compression loading**

| Mechanical Properties | No of Observations | Unit of Measurements | Minimum Value | Maximum Value | Mean Value | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|
| **Force @peak** | 10 | N | 670.20 | 1893.4 | 1255.06 | 358.067 | 28.530 |
| **Deformation @peak** | 10 | mm | 0.356 | 2.8030 | 1.655 | 0.786 | 47.521 |
| **Stress @peak** | 10 | N mm$^{-2}$ | 26.882 | 104.588 | 50.288 | 22.512 | 506.804 |
| **Energy to peak** | 10 | N m | 0.108 | 2.103 | 0.827 | 0.593 | 71.729 |
| **Force @break** | 10 | N | 38.70 | 806.00 | 305.469 | 267.393 | 87.535 |
| **Deformation @break** | 10 | mm | 0.893 | 4.369 | 2.554 | 1.066 | 41.743 |
| **Stress @break** | 10 | N mm$^{-2}$ | 1.405 | 20.827 | 6.820 | 6.523 | 42.555 |
| **Energy to break** | 10 | N m | 0.130 | 2.438 | 1.168 | 0.729 | 62.415 |
| **Force @yield** | 10 | N | 332.34 | 1271.20 | 645.722 | 286.961 | 44.440 |
| **Stress @yield** | 10 | N mm$^{-2}$ | 35.756 | 104.588 | 60.737 | 21.047 | 442.989 |
| **Energy to yield** | 10 | N m | 0.038 | 0.352 | 0.146 | 0.101 | 69.160 |
| **Young's Modulus** | 10 | N mm$^{-2}$ | 57.13 | 5282.22 | 1720.14 | 1442.49 | 2.081 |

**Table 3 Mechanical properties of *Pachymelania aurita* periwinkle samples under longitudinal compression loading**

| Mechanical Properties | No of Observations | Unit of Measurements | Minimum Value | Maximum Value | Mean Value | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|
| **Force @peak** | 10 | N | 935.6 | 2180.3 | 1426.18 | 413.223 | 28.974 |
| **Deformation @peak** | 10 | mm | 3.961 | 14.246 | 7.957 | 2.865 | 36.002 |
| **Stress @peak** | 10 | N mm$^{-2}$ | 2.233 | 6.364 | 4.255 | 1.461 | 2.135 |
| **Energy to peak** | 10 | N m | 2.020 | 10.869 | 4.842 | 2.589 | 53.478 |
| **Force @break** | 10 | N | -49.33 | 569.50 | 289.179 | 209.338 | 72.391 |
| **Deformation @break** | 10 | mm | 6.394 | 15.316 | 11.026 | 2.758 | 25.012 |
| **Stress @break** | 10 | N mm$^{-2}$ | -0.117 | 1.509 | 0.585 | 0.453 | 0.2054 |
| **Energy to break** | 10 | N m | 3.238 | 12.053 | 6.321 | 2.657 | 42.038 |
| **Force @yield** | 10 | N | 241.1 | 921.00 | 471.477 | 215.369 | 45.680 |
| **Stress @yield** | 10 | N mm$^{-2}$ | 3.463 | 24.221 | 8.818 | 5.711 | 32.614 |
| **Energy to yield** | 10 | N m | 0.081 | 0.528 | 0.267 | 0.162 | 60.853 |
| **Young's Modulus** | 10 | N mm$^{-2}$ | 90.70 | 1290.4 | 389.508 | 364.234 | 134667 |

**Table 4 Mechanical properties of *Pachymelania aurita* periwinkle samples under transverse compression loading**

| Mechanical Properties | No of Observations | Unit of Measurements | Minimum Value | Maximum Value | Mean Value | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|
| **Force @peak** | 10 | N | 5123.5 | 4009.0 | 2996.4 | 665.576 | 22.212 |
| **Deformation @peak** | 10 | mm | 4.053 | 8.489 | 5.907 | 1.503 | 25.442 |
| **Stress @peak** | 10 | N mm$^{-2}$ | 14.222 | 42.361 | 25.15 | 7.162 | 51.300 |
| **Energy to peak** | 10 | N m | 2.242 | 11.461 | 5.946 | 2.781 | 46.778 |
| **Force @break** | 10 | N | 196.94 | 1297.5 | 781.867 | 346.962 | 44.376 |
| **Deformation @break** | 10 | mm | 6.076 | 8.681 | 7.402 | 0.873 | 11.794 |
| **Stress @break** | 10 | N mm$^{-2}$ | 1.225 | 8.460 | 5.088 | 2.231 | 4.9770 |
| **Energy to break** | 10 | N m | 4.763 | 13.217 | 7.687 | 2.198 | 28.595 |
| **Force @yield** | 10 | N | 431.620 | 1480.4 | 846.422 | 314.308 | 37.134 |
| **Stress @yield** | 10 | N mm$^{-2}$ | 12.221 | 34.221 | 22.197 | 5.896 | 34.760 |
| **Energy to yield** | 10 | N m | 0.177 | 1.038 | 0.546 | 0.264 | 48.460 |
| **Young's Modulus** | 10 | N mm$^{-2}$ | 105.07 | 450.049 | 264.97 | 133.105 | 17716.80 |

The force-deformation/deflection curves are shown in Figures 3 - 6, for periwinkle samples tested. The average force to rupture of *T. fuscatus* under longitudinal load position was obtained as 255.542 N, while under transverse loading orientation was found to be 305.469 N, whereas the average rupture force of *P. aurita* under longitudinal and transverse loading orientations were obtained as 289.179 N and 781.867 N, respectively. It can be seen that the rupture force is lowest for *T. fuscatus* under longitudinal loading orientation and highest for *P. aurita* under transverse loading orientation (Figure 8). The results were in agreement with those reported by Eke and Ehiem (2015) for *T. fuscatus var radular*.

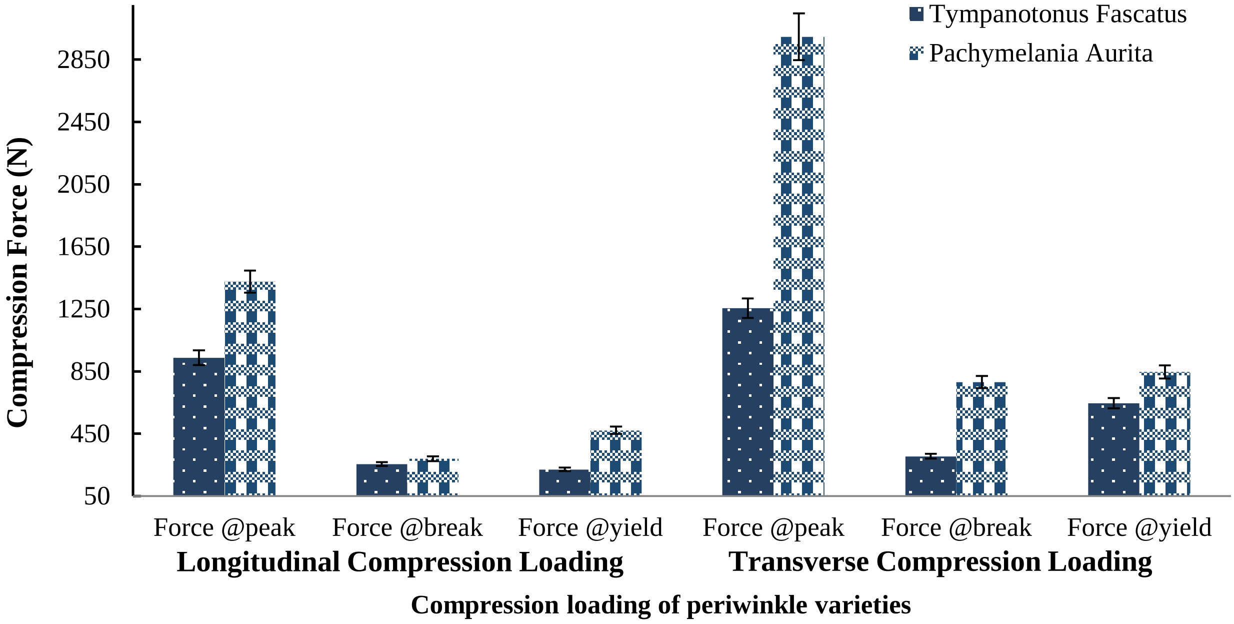


Figure 8 Variation of longitudinal compression loading force and transverse compression loading force of *T. fuscatus* and *P. aurita* varieties of periwinkle samples. *Error bars* represent the standard deviation of the mean (*n=10*)

The average deformations for *T. fuscatus* under longitudinal and transverse loading orientation were 10.023 mm and 2.554 mm, respectively, whereas the average deformations of *P. aurita* under longitudinal and transverse loading orientation were 11.026 mm and 7.402 mm respectively. The deformation under transverse loading orientation was lowest for *T. fuscatus* and highest for *P. aurita* (Figure 9). These depicts the failure mode of the two periwinkle varies. These results are in agreement with those presented by Eke and Ehiem (2015) for *T. fuscatus.*

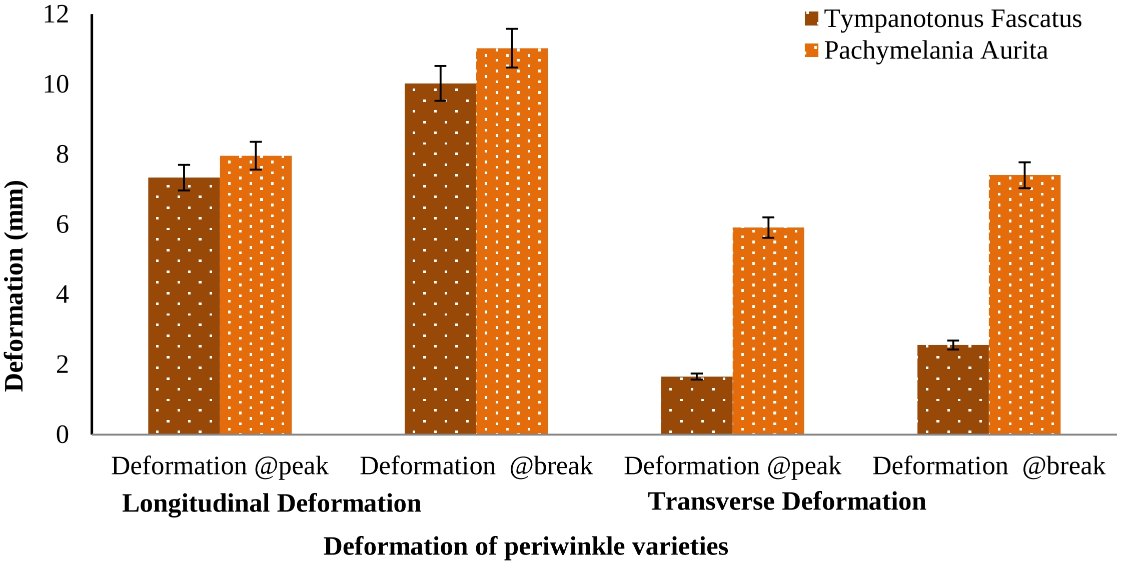


Figure 9 Variation of longitudinal compression loading deformation and transverse compression loading deformation of *T. fuscatus* and *P. aurita* varieties of periwinkle samples. *Error bars* represent the standard deviation of the mean (*n=10*)

Also, the compression stress under longitudinal loading was observed to be equal for the two varieties whereas compression stress under transverse loading was highest for *T. fuscatus* and lowest for *P. aurita* (Figure 10).

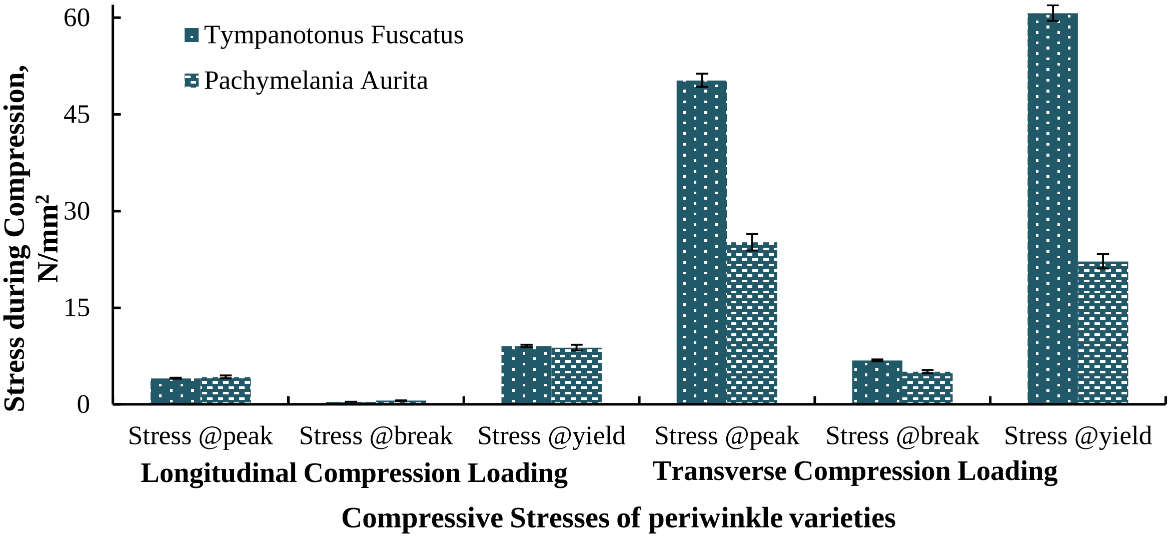


Figure 10 Variation of longitudinal compression loading stress and transverse compression loading stress of *T. fuscatus* and *P. aurita* varieties of periwinkle. *Error bars* represent the standard deviation of the mean (*n=10*)

More so, the average rupture energy of *T. fuscatus* under longitudinal and transverse loading orientations were 4.394 N m and 1.168 N m, respectively, while the average rupture energy of *P. aurita* under longitudinal and transverse loading orientations were 6.321 N m and 7.687 N m respectively. It was found that the rupture energy was lowest for *T. fuscatus* under transverse loading position and highest for *P. aurita* under transverse loading position (Figure 11). The rupture point indicates failure over a significant volume of the material, and beyond it the stress decreases rapidly with increasing deformation (Fakayode and Ajav, 2016). The average Young's Modulus values of *T. fuscatus* under longitudinal and transverse loading orientations were found to be 1944.440 N mm$^{-2}$ and 1720.14 N mm$^{-2}$, respectively, while the average Young's Modulus values of *P. aurita* under longitudinal and transverse loading orientations were found to be 389.508 N mm$^{-2}$ and 264.970 N mm$^{-2}$, respectively. The Young's Modulus values of *T. fuscatus* were found to be highest for both loading orientations.

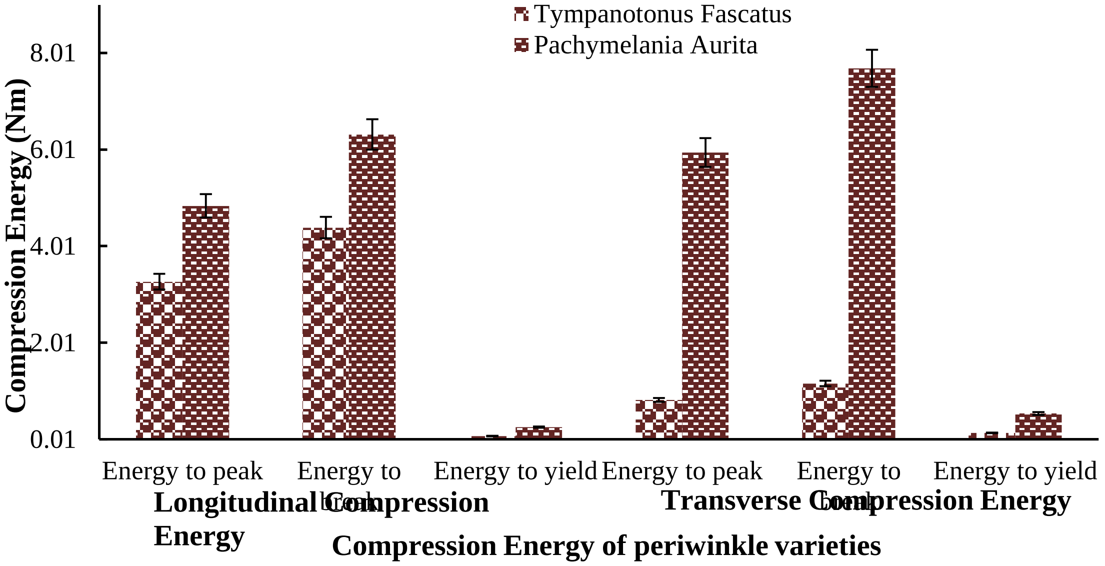


Figure 11 Variation of longitudinal compression loading energy and transverse compression loading deformation energy of *T. fuscatus* and *P. aurita* varieties of periwinkle samples. *Error bars* represent the standard deviation of the mean (*n=10*)

The yield is the point at which the initial straight portion of the force – deformation curves dips (Figures 3 – 6). In comparison with other periwinkle varies, Eke and Ehiem (2015) obtained an average Young' Modulus values of *T. fuscatus var radula* under longitudinal and transverse loading orientations to be 8936±6283 N $mm^{-2}$ and 7689±4734 N $mm^{-2}$ respectively, while that of *T. fuscatus var fuscatus* were 3465±2087 N $mm^{-2}$ and 7740±6010 N $mm^{-2}$, respectively. The variation could be due attributed to periwinkle variety and compression speed of the machine chute. The analysis of variance carried out on the data reported for the all mechanical properties of *T. fuscatus* and *P. aurita* varieties of periwinkle samples under longitudinal and transverse orientations showed that mean values reported were significant ($p < 0.05$) (Supplementary Tables 1 and 2). Similarly, a pairwise comparison analysis carried out on the mean values of all the mechanical properties of *T. fuscatus* and *P. aurita* under both orientations (Supplementary Tables 3 and 4) revealed that there is statistically significant difference at $\alpha< 5\%$ between the mechanical properties of the two varieties of periwinkle samples.

### 3.2 Frictional properties of periwinkle samples

The summary of the coefficient of static friction, $\mu$ and angle of repose, $\theta$ for the two periwinkle shell varieties is presented in Tables 5 and 6. The frictional values for *T. fuscatus* ranged from 0.4452 to 0.4877, 0.4621 to 0.4877,0.5139 to 0.5452 and 0.6249 to 0.7002 on glass, plywood, galvanized steel and cast-iron surfaces respectively and for *P. aurita* it was 0.3959 to 0.5272, 0.4515 to 0.5272, 0.5184 to 0.5774 and 0.6544 to 0.7133 on glass, plywood, galvanized steel and cast iron surfaces respectively. The angle of repose was in the range of 23.90 to 29.34 °for *T. fuscatus* and from 27.68 to 34.51 °for *P. aurita*. This agreed with 0.510 on steel and plywood surfaces for *P. aurita* reported by Ituen (2015). The knowledge of coefficient of static friction is essential in determining frictional force resulting from the cylindrical rollers motion. The angle of repose is used in the determination of the inclination of the hopper to achieve consistent flow of materials to the cracking chamber.

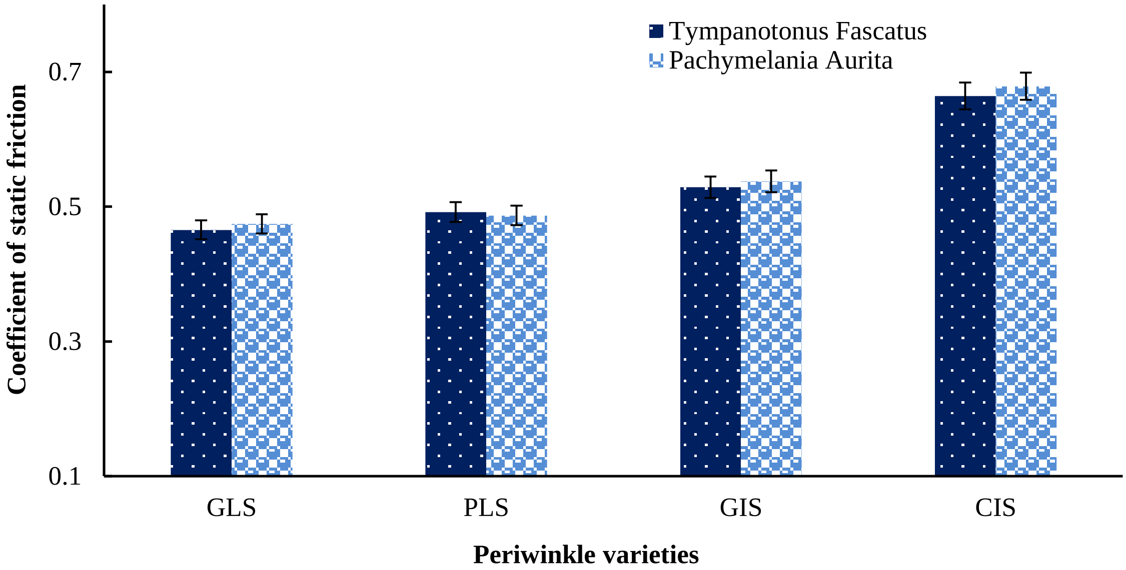
Comparatively, *P. aurita* had higher frictional values on glass, galvanized steel and cast-iron surfaces as well as high angle of repose value than *T. fuscatus* while *T. fuscatus* friction value was higher on plywood surface than *P. aurita*. It is believed that the smoother the structural surface, the lower the static friction of the periwinkle samples on its surface (Figure 12). A pairwise comparison analysis carried out on the mean values for the frictional properties of *T. fuscatus* and *P. aurita* varieties of periwinkle shells revealed a statistically significant at 5% level.

**Table 5 Frictional properties of *Tympanotonus fuscstus* periwinkle**

| Physical Properties | No of Observations | Unit of Measurements | Minimum Value | Maximum Value | Mean Value | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|
| $\mu$ for Glass | 10 | - | 0.4452 | 0.4877 | 0.4656 | 0.2075 | 0.0043 |
| $\mu$ for Plywood | 10 | - | 0.4621 | 0.4877 | 0.4920 | 0.3408 | 0.0012 |
| $\mu$ for Galvanized steel | 10 | - | 0.5139 | 0.5452 | 0.5290 | 0.0112 | 0.0001 |
| $\mu$ for Cast iron | 10 | - | 0.6249 | 0.7002 | 0.6642 | 0.0268 | 0.0007 |
| $\theta$ | 10 | ° | 23.9000 | 29.3400 | 26.1800 | 2.7100 | 7.3400 |

**Table 6 Frictional properties of *Pachymelania aurita* periwinkle**

| Physical Properties | No of Observations | Unit of Measurements | Minimum Value | Maximum Value | Mean Value | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|---|---|
| $\mu$ for Glass | 10 | - | 0.3959 | 0.5272 | 0.4743 | 0.0492 | 0.0024 |
| $\mu$ for Plywood | 10 | - | 0.4515 | 0.5272 | 0.4871 | 0.0274 | 0.0008 |
| $\mu$ for Galvanized steel | 10 | - | 0.5184 | 0.5774 | 0.5378 | 0.0237 | 0.0006 |
| $\mu$ for Cast iron | 10 | - | 0.6544 | 0.7133 | 0.6788 | 0.0252 | 0.0006 |
| $\theta$ | 10 | ° | 27.6800 | 34.5100 | 30.5700 | 3.4700 | 12.0200 |



GLS = Glass surface PLS = Plywood surface GIS = Galvanized iron surface
CIS = Cast iron surface

Figure 12 Variation of coefficient of static friction of *T. fuscatus* and *P. aurita* varieties of periwinkle shells. *Error bars* represent the standard deviation of the mean (*n=10*)

## 4 Conclusion

The following conclusions were reached from the results of the study:

The rupture force was lowest for *T. fuscatus* under longitudinal loading orientation and highest for *P. aurita* under transverse loading orientation.

Also the rupture energy was lowest for *T. fuscatus* under transverse loading position and highest for *P. aurita* under transverse loading position.

The deformation under transverse loading orientation was lowest for *T. fuscatus* and highest for *P. aurita.*

The Young's Modulus values of *T. fuscatus* were found to be highest for both loading orientations.

*P. aurita* had higher static friction values on glass, galvanized steel and cast-iron surfaces alongside angle of repose value than *T. fuscatus* while *T. fuscatus* static friction value was higher on plywood surface than *P. aurita*.

The mechanical and frictional properties of the two periwinkle varieties were significant on all the parameters investigated at $p < 0.05$.

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# Supplementary data

Comparative Analysis of Mechanical Properties of Two Varieties of Periwinkle Relevant to Its Processing Equipment Design

**Table 1 Summary of One-way Analysis of Variance (ANOVA) for the Mechanical Properties of the two varieties of Periwinkle under Longitudinal Orientation.**

| Source | Factor/ Type | Variety levels | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Force @peak, (N) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 238767 | 238767 | 3.22658E+09 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 238767 | | | |
| Force @break, (N) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 1131.65 | 1131.65 | 22632992.00 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 1131.65 | | | |
| Force @yield, (N) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 62774.8 | 62774.8 | 1.93153E+09 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 2.40260 | | | |
| Deformation @peak, (mm) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 0.393756 | 0.393756 | 8160.75 | 0.0005 |
| Error | | | 2 | 0.000096 | 0.000048 | | |
| Total | | | 3 | 0.393853 | | | |
| Deformation @break, (mm) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 1.01304 | 1.01304 | 19766.68 | 0.0005 |
| Error | | | 2 | 0.00010 | 0.00005 | | |
| Total | | | 3 | 1.01314 | | | |
| Stress @peak, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 0.036672 | 0.036672 | 397.53 | 0.003 |
| Error | | | 2 | 0.000185 | 0.000092 | | |
| Total | | | 3 | 0.036857 | | | |
| Stress @break, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 0.031329 | 0.031329 | 62658.00 | 0.0005 |
| Error | | | 2 | 0.000001 | 0.000001 | | |
| Total | | | 3 | 0.031330 | | | |
| Stress @yield, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 0.057121 | 0.057121 | 2284.84 | 0.0005 |
| Error | | | 2 | 0.000050 | 0.000025 | | |
| Total | | | 3 | 0.057171 | | | |
| Energy to peak, (N m) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 2.46176 | 2.46176 | 28961.89 | 0.0005 |
| Error | | | 2 | 0.00017 | 0.00008 | | |
| Total | | | 3 | 2.46193 | | | |
| Energy to break, (N m) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 3.71911 | 3.71911 | 46928.86 | 0.0005 |
| Error | | | 2 | 0.00016 | 0.00008 | | |
| Total | | | 3 | 3.71927 | | | |
| Energy to yield, (N m) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 0.035344 | 0.035344 | 70688.00 | 0.0005 |
| Error | | | 2 | 0.000001 | 0.000001 | | |
| Total | | | 3 | 0.035345 | | | |
| Young Modulus, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 2417810 | 2417810 | 5.89710E+10 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 2417810 | | | |

**Table 2 Summary of One-way Analysis of Variance (ANOVA) for the Mechanical Properties of the two varieties of Periwinkle under Transverse Orientation.**

| Source | Factor/ Type | Variety levels | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Force @peak, (N) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 3032265 | 3032265 | 6.06453E+10 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 3032265 | | | |
| Force @break, (N) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 226956 | 226956 | 6.98326E+09 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 226956 | | | |
| Force @yield, (N) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 40280.5 | 40280.5 | 5.59451E+08 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 40280.5 | | | |
| Deformation @peak, (mm) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 18.0710 | 18.0710 | 976810.86 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 18.0710 | | | |
| Deformation @break, (mm) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 23.5128 | 23.5128 | 276621.19 | 0.0005 |
| Error | | | 2 | 0.0002 | 0.0001 | | |
| Total | | | 3 | 23.5130 | | | |
| Stress @peak, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 631.969 | 631.969 | 15413885.88 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 631.969 | | | |
| Stress @break, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 2.99636 | 2.99636 | 73081.98 | 0.0005 |
| Error | | | 2 | 0.00008 | 0.00004 | | |
| Total | | | 3 | 2.99644 | | | |
| Stress @yield, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 1485.33 | 1485.33 | 60625779.59 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 1485.33 | | | |
| Energy to peak, (N m) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 26.2093 | 26.2093 | 1233377.89 | 0.0005 |
| Error | | | 2 | 0.00017 | 0.00008 | | |
| Total | | | 3 | 26.2093 | | | |
| Energy to break, (N m) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 42.5039 | 42.5039 | 1504562.13 | 0.0005 |
| Error | | | 2 | 0.0001 | 0 | | |
| Total | | | 3 | 42.5039 | | | |
| Energy to yield, (N m) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 0.160000 | 0.160000 | 320000.00 | 0.0005 |
| Error | | | 2 | 0.000001 | 0.000001 | | |
| Total | | | 3 | 0.160000 | | | |
| Young Modulus, (N mm$^{-2}$) | | | | | | | |
| Periwinkle Variety | (Fixed) | 2 | 1 | 2117520 | 2117520 | 4.23504E+10 | 0.0005 |
| Error | | | 2 | 0 | 0 | | |
| Total | | | 3 | 2117520 | | | |

**Table 3 Summary of Tukey Pairwise Comparisons for Mechanical Properties of the two varieties of Periwinkle under Longitudinal Orientation.**

| Periwinkle Variety Levels | Difference of Means | SE of Difference | Simultaneous 95% CI | T-Value | P-Value |
|---|---|---|---|---|---|
| Force @peak, (N) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -488.638 | 0.009 | (-488.675,-488.601) | -56803 | 0.0005 |
| Force @break, (N) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -33.6400 | 0.0071 | (-33.6704,-33.6096) | -4757. | 0.0005 |
| Force @yield, (N) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -250.549 | 0.006 | (-250.574,-250.524) | -43949 | 0.0005 |
| Deformation @peak, (mm) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -0.62750 | 0.00695 | (-0.65739,-0.59761) | -90.34 | 0.0005 |
| Deformation @break, (mm) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -1.00650 | 0.00716 | (-1.03730,-0.97570) | -140.6 | 0.0005 |
| Stress @peak, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -0.19150 | 0.00960 | (-0.23283,-0.15017) | -19.94 | 0.003 |
| Stress @break, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -0.177000 | 0.000707 | (-0.180042,-0.173958) | -250.3 | 0.0005 |
| Stress @yield, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus* – *P.Aurita* | 0.23900 | 0.00500 | (0.21749,0.26051) | 47.80 | 0.0005 |
| Energy to peak, (N m) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -1.56900 | 0.00922 | (-1.60867,-1.52933) | -170.2 | 0.0005 |
| Energy to break, (N m) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -1.92850 | 0.00890 | (-1.96680,-1.89020) | -216.6 | 0.0005 |
| Energy to yield, (N m) | | | | | |
| *T.Fuscatus* – *P.Aurita* | -0.18800 | 0.000707 | (-0.191042,-0.184958) | -265.9 | 0.0005 |
| Young Modulus, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus* – *P.Aurita* | 1554.93 | 0.01 | (1554.90,1554.96) | 242839.42 | 0.0005 |

**Table 4 Summary of Tukey Pairwise Comparisons for Mechanical Properties of the two varieties of Periwinkle under Transverse Orientation.**

| Periwinkle Variety Levels | Difference of Means | SE of Difference | Simultaneous 95% CI | T-Value | P-Value |
|---|---|---|---|---|---|
| Force @peak, (N) | | | | | |
| *T.Fuscatus – P.Aurita* | -1741.34 | 0.01 | (-1741.37,-1741.31) | -246262.7 | 0.0005 |
| Force @break, (N) | | | | | |
| *T.Fuscatus – P.Aurita* | -476.399 | 0.006 | (-476.424,-476.374) | -83565.91 | 0.0005 |
| Force @yield, (N) | | | | | |
| *T.Fuscatus – P.Aurita* | -200.700 | 0.008 | (-200.737,-200.663) | -23652.72 | 0.0005 |
| Deformation @peak, (mm) | | | | | |
| *T.Fuscatus – P.Aurita* | -4.25100 | 0.00430 | (-4.26951,-4.23249) | -988.34 | 0.0005 |
| Deformation @break, (mm) | | | | | |
| *T.Fuscatus – P.Aurita* | -4.84900 | 0.00922 | (-4.88867,-4.80933) | -525.95 | 0.0005 |
| Stress @peak, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus – P.Aurita* | 25.1390 | 0.0064 | (25.1114,25.1666) | 3926.05 | 0.003 |
| Stress @break, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus – P.Aurita* | 1.73100 | 0.00640 | (1.70345,1.75855) | 270.34 | 0.0005 |
| Stress @yield, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus – P.Aurita* | 38.5400 | 0.0049 | (38.5187, 38.5613) | 7786.26 | 0.0005 |
| Energy to peak, (N m) | | | | | |
| *T.Fuscatus – P.Aurita* | -5.11950 | 0.00461 | (-5.13933,-5.09967) | -1110.58 | 0.0005 |
| Energy to break, (N m) | | | | | |
| *T.Fuscatus – P.Aurita* | -6.51950 | 0.00532 | (-6.54237,-6.49663) | -1226.61 | 0.0005 |
| Energy to yield, (N m) | | | | | |
| *T.Fuscatus – P.Aurita* | -0.400000 | 0.000707 | (-0.403042,-0.396958) | -565.69 | 0.0005 |
| Young Modulus, (N $mm^{-2}$) | | | | | |
| *T.Fuscatus – P.Aurita* | 1455.17 | 0.01 | (1455.14,1455.20) | 205792.11 | 0.0005 |