Test of Mechanical Parameters for Litchi and Analysis for Its Difference

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Abstract. In order to provide the basic mechanical data for the mechanical model and designing of machine for litchi, the compression experiments for the whole litchi fruit and its stone were conducted, while the tensile tests were carried out for the hulls of fresh litchi. The rupture force, stiffness and elastic modulus for the cultivar Feizixiao was obtained, and the elastic modulus for the hulls was also got. The results of tests showed that the rupture force, stiffness and elastic modulus of the whole litchi fruit’s vertical direction were stronger than horizontal direction, while the stone was opposite. Finally, for the elastic modulus of the litchi’s hulls, the horizontal direction was stronger than the vertical direction. The mechanical parameters of the litchi were different in different directions.

Introduction

Litchi is vulnerable mechanically in harvesting process for its thin hull and juicy flesh. And mechanical parameter of litchi is important to establish mechanical model of litchi and conduct the design of implements. In recent years, many scholars had studied the mechanical parameters and properties of fruits such as grape, tomato, longan, oranges, watermelon and red bayberry [1-5]. Also, primary research of mechanical parameters and properties of litchi had conducted, shown that it varies in different cultivars [6].

Mechanical parameters including elastic modulus in different parts, rupture force, rupture energy and the stiffness of the whole litchi, as well as strength of hull, the were obtain in the compression experiment and the tensile test of hull, which could be the basic data for the establishment of mechanical model of litchi and the design and control of implements.

Compression Experiment of the Whole Litchi and Its Stone

Materials, Equipment and Methods

The fresh litchi for the experiment is which was picked in Orchard in Zengcheng, Guangdong Province within 12 h with its stem cut and the diameter of the whole litchi and its stone in $x$, $y$, and $z$ direction are 36.18~42.76 mm, 35.4~42.06 mm and 36.28~42.26 mm. The diameter of the stone of litchi in $x$, $y$, and $z$ direction are 12.46~14 mm, 10.9~12.26 mm and 21.76~23.64 mm respectively. Figure 1 shown that the external pattern and its internal construction of litchi.

![Figure 1. The external pattern and longitudinal section.](image-url)

The instrument for the experiment is WD-2KE precise micro-controlled electrical universal test machine, of which has ±0.05% precision and the ±1/120000 resolution. By means of the...
micro-controller, the data of force and displacement can be collected. Applied the method of compression with rigid flat plate, that is the bottom plate is fixed and the top plate press vertically, the compression experiment of whole litchi and the stone was conducted in a speed of 10 mm/min horizontally and vertically and repeated 20 times respectively.

Results and Analysis

The Force and Deformation of Whole Litchi and the Stone of Litchi. Figure 2 is the curve graphs shows the relationship between the compression force and deformation of the whole litchi horizontal and vertical as well as the stone of litchi. It’s shown in Figure 2a that the compression force and deformation follows a nonlinear relation while being compressed without any evident biological yield point, and the hull torn when the compression force reached the rupture force.

Also, it can be seen in Figure 2b that similar horizontally and vertically, the compression force and deformation of the stone of litchi follows the linear relation without any evident biological yield point. The stone cracked or was crushed when the compression force reached the maximum rupture force.

Table 1 showed the rupture force and rupture energy calculated by the experiment data from Figure 2a. It revealed that the rupture force and rupture energy in vertical direction is stronger in horizontal direction.

![Figure 2. Force deformation curve of litchi compression for the whole fruit and its stone.](image)

Table 1. Rupture force and failure energy for the litchi’s whole fruit

<table>
<thead>
<tr>
<th>Direction of Compression</th>
<th>Rupture Force/ N</th>
<th>Rupture Energy/ N·mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>81.25</td>
<td>304.50</td>
</tr>
<tr>
<td>Vertical</td>
<td>101.69</td>
<td>439.97</td>
</tr>
</tbody>
</table>

The Relation between the Stiffness and Deformation of Whole Litchi. The stiffness of the whole litchi is varied, from Figure 2a. Quadratic equation was concluded with least square method to fit the process of the compression of litchi before its cracking is shown as Eq. 1 below:

\[ F = a_1 D^2 + a_2 D + a_3 \]

So, the stiffness \( K \) is calculated in Eq. 2:

\[ K = \frac{dF}{dD} = 2a_1 D + a_2 \]

The value of the fitting coefficient \( a_1, a_2, a_3 \), were shown on Tabel 2.
Table 2. Stiffness and Fitting coefficient for the litchi’s whole fruit.

<table>
<thead>
<tr>
<th>Direction of Compression</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>Correlation coefficient $R^2$</th>
<th>Stiffness/kN·m$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.6171</td>
<td>0.594</td>
<td>1.5206</td>
<td>0.9996</td>
<td>13.83</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.5456</td>
<td>2.3503</td>
<td>2.2478</td>
<td>0.9994</td>
<td>14.70</td>
</tr>
</tbody>
</table>

The value of the stiffness of the whole litchi, which was the stiffness in limit displacement before its cracking, was calculated and shown on Table 2. It’s also seen in Table 2 that the stiffness in vertical direction is slightly higher than in horizontal direction on the cracking point.

**The Relation between the Elastic Modulus and Deformation of the Whole Litchi and Its Stone.** The elastic modulus could be calculated with Hertz Contact Theory shown in Eq. 3 as follows while compressing the agricultural materials with rigid plate:

$$E = \frac{0.338K^\frac{3}{2}F\left(1 - \mu^2\right)}{D^\frac{3}{2}} \left(1 + \frac{1}{R} + \frac{1}{R'}\right)^\frac{1}{2}$$  \hspace{1cm} (3)

Where $E$ is the elastic modulus of the materials, $F$ is the external force, $\mu$ is the Poisson’s ratio, $D$ is the deformation, $R$ and $R'$ is the minimum and maximum radius of curvature, $K$ is the coefficient [7].

It’s proven that litchi is approximate to sphere for its sphericity is more than 0.96 [6] so that the $R$ is equivalent to $R'$. Besides the Poisson’s ratio could be calculated [7-8]. With the data from the compression experiment, the relation between the elastic modulus and deformation of the whole litchi and its stone both could be found by the Eq. 3 are as follows in Figure 3 and Figure 4.

![Figure 3](image1.png)  \hspace{1cm} ![Figure 4](image2.png)

Figure 4. Elastic modulus - Deformation curve of litchi’s stone.

Figure 3. Elastic modulus - Deformation curve of litchi’s whole fruit.

It can be seen in Figure 3 and Figure 4 that the elastic modulus of the whole litchi and its stone was varied while the deformation is changing. The elastic modulus reached the summit value in the beginning of the compression and declined rapidly to a constant value while the deformation is increasing. That is the elastic modulus of the whole litchi is 0.26~3.09 MPa and the stone of the litchi is 1.28~33.32 MPa. What’s more, the elastic modulus is different in horizontal and vertical direction in the whole litchi and its stone both. With the same displacement elastic modulus of the whole litchi in vertical direction was higher than which in horizontal. On the contrary, the elastic modulus of the stone of the litchi is lower than which in horizontal direction. That has been shown on Table 3.

Table 3. The elastic modulus of litchi’s whole fruit and its stone.

<table>
<thead>
<tr>
<th>Direction of compression</th>
<th>Elastic modulus of the whole litchi/ MPa</th>
<th>Elastic modulus of the stone / MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.33</td>
<td>5.25</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.38</td>
<td>1.28</td>
</tr>
</tbody>
</table>

Notes: The elastic modulus in Table 3 were obtained with the rupture force.
The Tensile Experiment of the Hull of Litchi

Materials, Equipment and Methods

The equipment and materials are the same as that of the compression experiment. Samples of the hulls for the experiment were cut off the litchi in horizontal and vertical directions and it were 20 samples in each group. Samples were cut into rectangles in length of 40 mm and in width between 8~15 mm but they were about 1.24 mm thick primitively. When the sample were complete, each one were put into the fixture and stretched in the speed of 10 mm/min till it was snapped.

Results and Analysis

The Curve of Stress and Strain in the Hull’s Stretching. With the data in the tensile test, the curve of the stress and strain in the hull’s stretching was obtain in Figure 5 with Eq. 4 and Eq. 5:

\[ \sigma = \frac{F}{A} \]  
\[ \varepsilon = \frac{\Delta L}{L} \]  

Where \( \sigma \) is stress, \( \varepsilon \) is strain, \( F \) is the tensile force, \( \Delta L \) is relative extension, \( L \) is the origin length of the sample, \( A \) is the cross-section area which \( A = b \times t \) where \( b \) is the width of the sample and \( t \) is the thickness of the sample.

It was shown in Figure 5 that there were not evident appearances of biological yield point. The first summit point appeared while the hull torn in which the stress in horizontal direction is higher than that in vertical direction. The relation between the strain and stress are nonlinear in general but it was linear before it torn. The stress would volatile before the torn hull was snapped.

![Figure 5. \( \sigma - \varepsilon \) curve of litchi’s hull.](image)

The Relation between the Elastic Modulus and Deformation of the Hull of Litchi. For the elastic modulus \( E \) of the hull of litchi follows \( E = \frac{\sigma}{\varepsilon} \), the relation between the elastic modulus and strain before the hull torn would be obtained with the data from tensile experiment and it was shown on Figure 6. It could be seen in Figure 6 that the relation between the strain and stress of the hull are nonlinear in general but it became a linear relation rapidly while the strain increasing. The elastic modulus of the hull in horizontal and vertical are 5.99 MPa and 3.44 MPa respectively corresponded to the summit tensile, showing that the elastic modulus in horizontal direction is higher than that in vertical direction.
**The Failure Strength of the Hull of Litchi.** The failure strength of the hull, evaluated with \( F/A \) where \( F \) is the tensile force and \( A \) is the cross-section area of the sample, is one of the important indices of the macroscopic failure which is caused by the snapping of its hull usually. Calculated with the data in tensile experiment, the failure strength of the hull of litchi is that 0.37 MPa in horizontal direction and 0.20 MPa in vertical direction. Obviously, the failure strength of hull in horizontal is higher than that in vertical direction.

**Conclusion**

Proven with the compressing experiment of the whole litchi and the stone of the litchi and the tensile experiment of the hull of the litchi, the curve of the relationship between force and deformation of the whole litchi while compressing is approximate to a quadratic polynomial, and its stone is nearly linear. However, the relation between the stain and stress of the tensile of the hull of litchi is generally nonlinear while linear before the hull torn. The elastic modulus, stiffness, rupture force and rupture energy all in vertical direction is higher than that in horizontal direction. It was in vertical direction lower than that in horizontal direction that the elastic modulus of the stone of litchi compressed and the elastic modulus and the failure strength of the hull of litchi stretched.

In summary, there were directional differences of the mechanical parameters of the whole litchi, the stone and the hull of the litchi, for which the mechanical diversity must be taken considered while designing implement for litchi. The interaction among the mechanical parameters of the whole litchi, the stone and the hull of litchi needs a further study.

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**References**


