Experimental research on the mechanical properties of *Camellia oleifera* fruit shell breaking by cutting and compression

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Abstract: To mitigate the damage rate of *Camellia oleifera* seeds during the process of *Camellia oleifera* fruit dehulling, a *Camellia oleifera* fruit cutting and compression machine was developed. This machine operates on the principle that the shell-breaking stress of *Camellia oleifera* fruit is reduced following cutting, thereby integrating the steps of grading, cutting, compressing, and separating for the dehulling of *Camellia oleifera* fruit. Utilizing the electronic universal testing machine, a 4-factor single-factor test was conducted, including the number of cutting knives, cutting direction, compressing direction, and *Camellia oleifera* fruit size. The results showed that the average breaking force of *Camellia oleifera* seeds was 196.33 N. Compared with direct separating without cutting, the shell-breaking of *Camellia oleifera* fruit with 1, 2, 3, and 4 cuts decreased 30.14%, 38.62%, 45.05%, and 47.74%, respectively. Compared with cutting along the long axis, the shell-breaking force of *Camellia oleifera* fruit cutting along the minor axis decreased 8.1%; however, the effect of cutting direction on shell-breaking force is not significant. The shell-breaking force of *Camellia oleifera* fruit compressing along the long axis was 24.11% lower than that of *Camellia oleifera* fruit compressed along the minor axis. With the increase of *Camellia oleifera* fruit size, the shell-breaking force of *Camellia oleifera* fruit also increased. The shell-breaking force of 25-30 mm, 30-35 mm, and 35-40 mm was 85.62%, 127.34%, and 178.69% higher than that of 20-25 mm, respectively. In conclusion, using grading measures, making one cut along the long axis and compressing along the long axis is a suitable method for husking of *Camellia oleifera* fruit.

Keywords: *Camellia oleifera* fruit, cutting, compressing, shell-breaking force, seed-breaking force
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1 Introduction

Camellia oleifera is a small evergreen tree of *Camellia* genus in the *Camellia* family, and it is considered one of the four largest woody edible oil plants, along with olive, palm, and coconut[1-3]. The *Camellia oleifera* oil extracted from *Camellia oleifera* fruits can be processed into high-quality edible oil that is nutritious and beneficial to health, and is known as “Oriental olive oil”[4,5]. The Chinese government has made great efforts to develop the *Camellia oleifera* industry. By 2022, the country’s actual *Camellia oleifera* forest area was 4.535 million hm^2, and the *Camellia oleifera* seed output was 2.946 Mt[6]. According to the plan of the National Forestry and Grassland Administration of China, the area of *Camellia oleifera* in China will reach 6 million hm^2 by 2025[7].

Camellia oleifera fruit is composed of seeds and a shell, and the shell does not contain oil. Before oil extraction, the *Camellia oleifera* fruit should be shelled to separate the seeds[8]. Without hulling treatment, the shell will not only affect the quality of oil, but will also cause a certain degree of wear to the oil press machine[9]. The traditional method of artificial hulling is to pile the picked *Camellia oleifera* fruit for 3-5 d, then spread them out on sunny days for 3-5 d, and finally hull them artificially. During the artificial hulling process, respiration caused by stack retting would cause the consumption of organic matter in *Camellia oleifera* fruit, resulting in the decrease of the quality and yield of *Camellia oleifera* oil[10]. Therefore, after picking the *Camellia oleifera* fruit, it should be shelled and sun-dried as soon as possible to reduce the water content of the *Camellia oleifera* fruit and minimize the consumption of organic matter. In summary, it is of great significance to carry out the development and related theoretical research of *Camellia oleifera* fruit husking equipment.

The main shell-breaking methods of *Camellia oleifera* fruit shucking equipment are impact type, grinding type, cutting type, and extrusion type[11–12]. At present, the goal of *Camellia oleifera* fruit breaking equipment research is to increase the breaking rate and reduce the damage rate of *Camellia oleifera* seeds. Lan et al.[13] designed a shelling and sorting machine for *Camellia oleifera* fruit. A shelling rod which had torsion angle, cone angle, and different radius of gyration was constructed into a wedge-shaped shelling chamber to shell the different kinds of *Camellia oleifera* fruit. The results showed that shelling rate was more than 99%, and the seed fragmentation rate was less than 3%. Tang et al.[14] designed a four-channel fully automatic shelling machine. Firstly, the *Camellia oleifera* fruit was graded in four channels, and then the shucking was realized through the impact between *Camellia* fruit and the shucking casing, as well as the impact, extrusion, and rubbing between *Camellia oleifera* fruit. The results showed that the shelling rate of the ripe and fresh *Camellia oleifera* fruit shelling machine was 98.85%, and the seed breakage rate was 3.24%. In addition, Zhu et al.[8] and Meng et al.[15] also carried out the design

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and experiment of *Camellia oleifera* fruit shucking equipment.

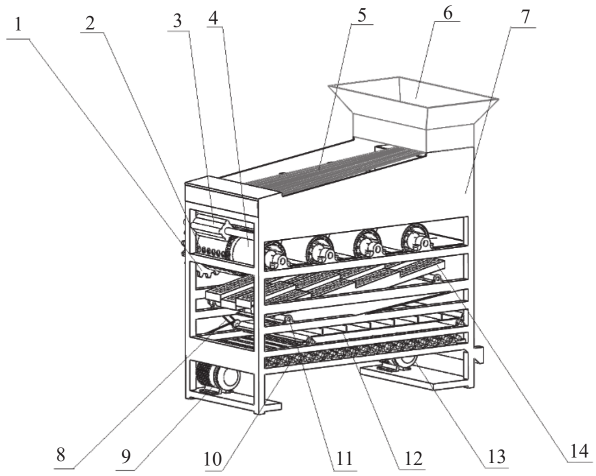
To further improve the breaking rate of *Camellia oleifera* fruit and reduce the damage rate of seeds, it is necessary to carry out theoretical research on the breaking compression characteristics of *Camellia oleifera* fruit. However, there are few studies in this regard, so it is necessary to refer to research on the breaking compression characteristics of other fruits. As described in Huang et al.[16], through the measurement of the physical characteristics of different eastern gamagrass seeds, it was found that the axial shell breaking could effectively reduce the breakage rate of seeds. As described in Rasli et al.[17], mechanical properties were measured using a pendulum impact load test device. The results showed that the values of rupture force and energy for oil palm fruitlets under vertical loading orientation were lower than those under horizontal loading orientation. Meanwhile, the rupture force and energy of oil palm fruitlets decreased as the ripeness stage increased. According to the solid model of chestnut established using ANSYS software, the results show that when the direction of the compressive force is consistent with the direction of the chestnut shell texture, the chestnut is more prone to deformation, as highlighted by Yang and Qi[18]. The research on *Camellia oleifera* fruit is as follows. As described in Wei et al.[19], using reverse engineering technology and finite element simulation analysis methods, it was found that increased loading displacement decreased the stress on the fruit, making it easier to break the shell of *Camellia oleifera* by radial extrusion. As described in Yang et al.[3], by studying the structural changes, moisture transfer, and shrinkage strain of the *Camellia oleifera* shell during the shelling processes, it was found that shelling efficiency of *Camellia oleifera* fruit can be increased by more than 50% under both natural drying and hot air drying, by damaging the exocarp structure. Furthermore, this study proposed that the stress required for shell breaking was reduced by first cutting the shell and then compressing it, which also reduced the stress applied to *Camellia oleifera* seeds.

In this study, a *Camellia oleifera* fruit sheller was proposed, and the compressive mechanical characteristics of *Camellia oleifera* fruit breakage were tested. Four factors including the number of cutting knives, the cutting direction, the compression direction, and the size of *Camellia oleifera* fruit were selected, and the influence of these four factors on the shell-breaking force of *Camellia oleifera* fruit was explored using the control variable method, to provide reference data and a theoretical basis for the design of the *Camellia oleifera* fruit sheller, to increase the breaking rate of the *Camellia oleifera* fruit sheller, and to reduce the *Camellia oleifera* seed damage rate.

2 Materials and methods

2.1 Structural composition and working principle of *Camellia oleifera* fruit cutting-extrusion breaking machine

The *Camellia oleifera* fruit cutting-extrusion breaking machine consists of a classification device, a cutting-extrusion device, and a separation device, as illustrated in Figure 1. The three parts cooperate with each other to complete the process of grading, cutting, extrusion, and separation of *Camellia oleifera* fruit. When *Camellia oleifera* fruit enters the hopper, the motor drives the rubber classification conveyor belt, which is arranged to be narrow at the front and wide at the back. The *Camellia oleifera* fruit on the belt will fall into different collection areas according to their size and then fall into the through-hole of the outer cylinder of the cutting and extrusion device via the bottom opening. Under the drive of the motor, the cutting-extrusion device rotates, and the *Camellia oleifera* fruit inside the through-hole rotates with it. When it moves to a fixed position, the protrusion on the pressure plate of the roller will squeeze the *Camellia oleifera* fruit downward, whereupon it will be cut by the tool and fall into the inner cylinder of the cutting and extrusion device. The inner cylinder is equipped with a spiral stirring blade. The *Camellia oleifera* fruit will be transported axially to the extrusion part with the rotation of the spiral stirring blade. It will be squeezed and rubbed between the roller and the outer cylinder in the extrusion part, and then fall out of the extrusion separation device axially. After being cut and squeezed, the *Camellia oleifera* fruit falls on the key-type separator riddle of the separation device and is separated by further vibration. Under gravity, the material falls into the structure formed by the toothed roller and the smooth roller. Due to their smooth surface and larger size, the seeds are swept into the collection device by the sweeping plate, while the shells, due to their thin shape, are pulled into the gap between the toothed roller and the smooth roller. Finally, the classification, cutting, extrusion, and separation of *Camellia oleifera* fruit was completed.

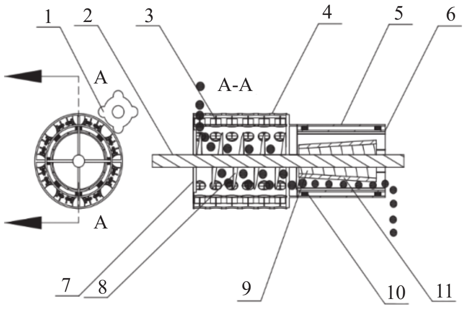


1. Transmission gear 2. Cutting device 3. Extrusion roll 4. Extrusion device 5. Graded rubber tape 6. Enter hopper 7. Machine rack 8. Drive belt 9. Y100L1-4 three-phase asynchronous motor drive 10. Toothed roller and smooth roller device 11. Bearing block 12. Seed sweeping board 13. Y100L2-4 three-phase asynchronous motor 14. Key-type separator riddle

Figure 1 Overall diagram of *Camellia oleifera* fruit shelling machine

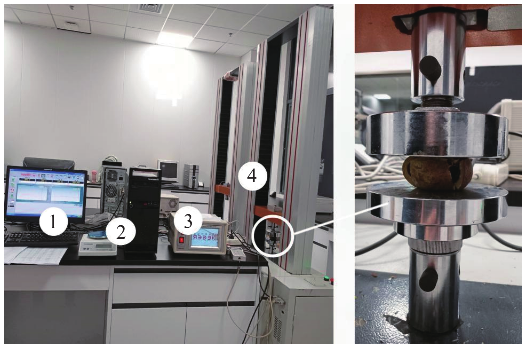
2.2 Design of cutting-extrusion device

The most important part of the *Camellia oleifera* fruit cutting-extrusion breaking machine is the cutting-extrusion device, as illustrated in Figure 2. It is composed of a cutting device and an extrusion device, which mainly includes an extrusion shaft, a shaft, a cutting tool, a cutting outer cylinder, an extrusion outer cylinder, an extrusion inner plate, a cutting inner cylinder, a spiral blade, an extrusion main roller, an extrusion spring, and an extrusion sub-roller. *Camellia oleifera* fruit falls into the through-hole of the outer cylinder of the cutting-extrusion device. During rotation, the bulge on the extrusion shaft will squeeze the *Camellia oleifera* fruit toward the cutting tool, and it will be cut by the tool and fall into the inner cylinder of the shell-breaking device. *Camellia oleifera* fruit is axially transported to the extrusion device by the spiral blade as it rotates inside the inner cylinder. In the extrusion device, it is squeezed and rubbed between the roller and the outer cylinder, and then leaves the extrusion device and enters the separation device for the separation of *Camellia oleifera* seeds and shells.



1. Extrusion shaft 2. Shaft 3. Cutting tool 4. Cutting outer cylinder 5. Extrusion outer barrel 6. Extrusion inner barrel 7. Cutting inner cylinder 8. Spiral blade 9. Extrusion main roller 10. Extrusion spring 11. Extrusion sub-roller

Figure 2 Shell-breaking and extrusion device



1. Display screen 2. Electronic scale 3. Image processing instrument 4. Electronic universal testing machine

Figure 4 Experiment device

2.3 Experimental materials and environment

Fresh *Camellia oleifera* fruit purchased from a local market in Wuhan was selected. The internal structure of *Camellia oleifera* fruits is shown in Figure 3, which consists of three parts: the shell, the column core, and the seed. The number of seeds in each *Camellia oleifera* fruit ranged from 3 to 8. The center of *Camellia oleifera* fruit is the column core, and the seeds are distributed around the core as the axis. Mature *Camellia oleifera* fruit is generally irregular spherical or ellipsoidal, with a particle size ranging from 20 to 50 mm. The shape of seeds is polygonal oval or prismatic, and the thickness of the seeds ranges from 6 to 18 mm. The shell thickness is uneven, generally ranging from 1 to 5 mm. The middle part is thinner than the top, and the multi-petal shell radially converges from all sides to the top.

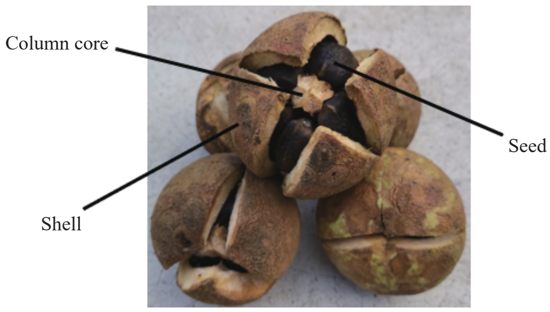


Figure 3 Internal structure and schematic diagram of *Camellia oleifera* fruits

Vernier calipers were used to measure the long axis diameter of *Camellia oleifera* fruit. The diameter of *Camellia oleifera* fruit ranged from 25 mm to 40 mm, and those with a diameter greater than 30 mm accounted for 70%.

The test device is shown in Figure 4. It mainly includes the electronic universal testing machine, Vernier calipers, electronic table scales, cutting tools, and so on. These instruments are located in the laboratory of the Engineering College at Huazhong Agricultural University. The electronic universal testing machine can measure the breaking force and deformation of *Camellia oleifera* fruit. The pressure sensor is installed on the pressure head of the frame, and the distance between the pressure head and the *Camellia oleifera* fruit can be controlled via the operation panel.

2.4 Experimental methods

Firstly, the electronic universal testing machine was used to compress *Camellia oleifera* fruit and *Camellia oleifera* seeds respectively, and the characteristics of the stress-strain curves were analyzed to determine the breaking force of *Camellia oleifera* fruit and *Camellia oleifera* seeds.

Then, the control variable method was used to study the influence of the number of cutting knives, cutting direction, compression direction, and *Camellia oleifera* fruit size (*Camellia oleifera* fruit long axis diameter) on the breaking force of *Camellia oleifera* fruit. In this experiment, other factors were fixed while a single factor was changed to analyze its influence on breaking force and deformation. The factor coding table is listed in Table 1.

Table 1 Test factor level coding table

The number of cutting knives (A)	Cutting direction (B)	Compressing direction (C)	*Camellia oleifera* fruit size (D)
0 (A1)	Cutting along the long axis (B1)	Compressing along the minor axis (C1)	20-25 mm (D1)
1 (A2)	Cutting along the minor axis (B2)	Compressing along the long axis (C2)	25-30 mm (D2)
2 (A3)			30-35 mm (D3)
3 (A4)			35-40 mm (D4)
4 (A5)			

Among them, the number of cutting knives is 0 (no cutting), 1, 2, 3, and 4 knives, respectively. The cutting direction is divided into equal angle cutting along the long axis and equidistant cutting rings along the minor axis. The diagram of cutting is shown in Figure 5. The compressing direction is divided into along the major axis and along the minor axis. The *Camellia oleifera* fruit size is divided into four grades according to the long axis diameter: 20-25 mm, 25-30 mm, 30-35 mm, and 35-40 mm. Based on these four factors, 80 groups of experiments were designed using the control variable method, and each group had three replicates.

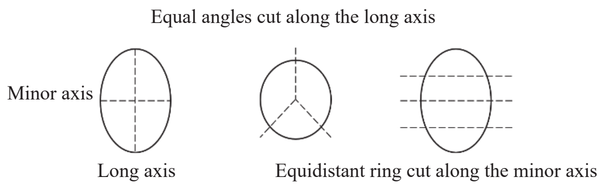


Figure 5 Schematic direction diagram of oil *Camellia oleifera* fruits

In the experiment process, the *Camellia oleifera* fruit size was measured first, and then the *Camellia oleifera* fruit was cut according to the requirements of the experiment. After that, the *Camellia oleifera* fruit was put into the electronic universal testing machine, the distance between the upper pressure head and the *Camellia oleifera* fruit was adjusted, and the machine was started to compress downward at the set speed. When the compression force on the *Camellia oleifera* fruit dropped to 50% of its peak value, the compression was stopped, and the pressure sensor recorded the compression process data for subsequent analysis of displacement and load.

3 Results and discussion

3.1 Analysis of compressive stress-strain curve characteristics of *Camellia oleifera* fruit

As illustrated in Figure 6, a set of load and displacement relationship diagrams was obtained during the experiment. The compression process of *Camellia oleifera* fruit is mainly divided into shell elastic deformation stage, shell yield stage, seed elastic deformation stage, and seed yield stage. The coordinate origin represents the moment when the upper pressure plate of the electronic universal testing machine and the *Camellia oleifera* fruit start to contact and extrude. The segment from the origin to point A is approximately linear, and the relationship between load and displacement is approximately linear. Between origin and point A, the *Camellia oleifera* fruit shell is in the elastic deformation stage. Point A is the breakage point of the fruit shell, and the corresponding load is the breakage force. With the breakage of the fruit shell, the fruit shell enters the compression yield stage (AB segment). As compression displacement increases, the force exerted by the upper pressing plate on the cracked fruit shell compresses the fruit seeds. The BC segment is the elastic deformation stage of fruit seeds compression of the seeds under compression, and the relationship between load and displacement is linear. As the pressure rises, the fruit seeds fracture at point C and enter the yield stage. Theoretically, the difference between point A and point C is the force required to fracture the seeds.

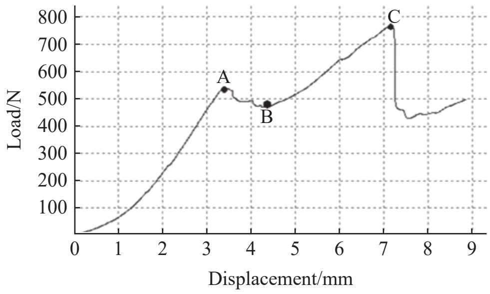


Figure 6 Compression displacement-load curve of *Camellia oleifera* fruits

3.2 Analysis of compressive stress-strain characteristics of *Camellia oleifera* seeds

To verify that the difference between two peak forces in Figure 6 corresponds to seed-breaking forces, the seeds of *Camellia oleifera* fruit of the same size were taken out for compression testing, and the relationship between load and displacement of seeds was obtained as shown in Figure 7. The seed compression is mainly divided into an elastic deformation stage and a yield stage. The coordinate origin represents the moment when the upper pressure plate of the electronic universal testing machine contacts the seeds. The segment from the coordinate origin to point A represents the pressing stage: the seeds have a small displacement, no deformation occurs, and the load is small. The AB segment is the compressive elastic deformation stage, and the relationship between load and displacement is linear. At point B, the seeds are fractured and enter the yield stage (BC segment). The corresponding load at point B is the seed-breaking force. According to the test, the seed-breaking force values corresponding to seeds with 1/2 ball, 1/4 ball, and 1/8 ball shapes were 225 N, 223 N, and 141 N, respectively, and the mean value was 196.33 N. The mean value of seed-breaking force was close to the difference between the two peak forces in Figure 6.

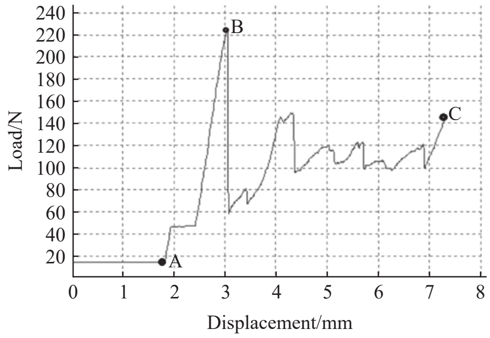


Figure 7 Compression displacement-load curve of *Camellia oleifera* seeds

3.3 Significance analysis of test factors

The test results were analyzed by ANOVA, and the results are listed in Table 2. The cutting direction had no significant effect on the shell-breaking force of *Camellia oleifera* fruit (p>0.05), while the number of cutting knives, the compression direction, and the size of *Camellia oleifera* fruit had significant effects on the shell-breaking force of *Camellia oleifera* fruit (p<0.01). The results show that the cutting direction has little influence on the shell-breaking force, but the number of cutting knives, the compressing direction, and the size of *Camellia oleifera* fruit have great influence on the shell-breaking force of *Camellia oleifera* fruit. The determination of the compression direction and the number of cutting knives is of great significance to the design of *Camellia oleifera* fruit sheller.

Table 2 ANOVA analysis

Source	Sum of squares	Degrees of freedom	Mean square	F values	Significance level
A	8 030 779.66	4	2 007 694.91	69.73	**
B	109 317.57	1	109 317.57	3.80	-
C	2 320 633.23	1	2 320 633.23	80.59	**
D	12 822 340.98	3	4 525 451.35	157.17	**
Error	7 376 613.51	230	28 793.91	-	-
Total	30 659 684.95	239	-	-	-

Note: *represents significant (p<0.05); **represents highly significant (p<0.01).

3.4 Influence of cutter number on compressive mechanical properties

The effect of the number of cutting knives on the shell-breaking force is shown in Figure 8. It can be seen from the figure that the greater the number of cutting knives, the smaller the breaking force. The shell-breaking force without cutting is significantly higher than that of cutting 1-4 knives, and there is little difference between cutting 1-4 knives on the reduction of shell-breaking force. The average value was taken for the analysis. The shell-breaking force of *Camellia oleifera* fruits without cutting ranged from 478.85 to 2117.26 N, and the average shell-breaking force was 1060.05 N. The shell-breaking force of *Camellia oleifera* fruit with 1 cut ranged from 276.94 to 1575.31 N, and the average shell-breaking force was 740.52 N. The shell-breaking force of *Camellia oleifera* fruit with 2 cuts ranged from 264.58 to 1076.28 N, and the average shell-breaking force was 650.64 N. The shell-breaking force of *Camellia oleifera* fruit with 3 cuts ranged from 224.73 to 967.29 N, and the average shell-breaking force was 582.51 N. The shell-breaking force of *Camellia oleifera* fruit with 4 cuts ranged from 207.31 to 982.22 N, and the average shell-breaking force was 553.92 N. Compared to without cutting, those in the cutting ones decreased by 30.14%, 38.62%, 45.07%, and 47.74%, respectively.

Cutting *Camellia oleifera* fruit before compression can effectively reduce the shell-breaking force of *Camellia oleifera* fruit. The greater the number of cutting knives, the smaller the shell-breaking force. However, with the increase of the number of cutting knives, the amplitude of the reduction of shell-breaking force decreases. Compared with the cutting of 1 knife, the reduction degree of the shell-breaking force of the cutting of 2-4 knives is less than 10%. Considering the influence of increasing the number of scratches on the structure and cost of the machine, it is economical and practical to cut with 1 knife.

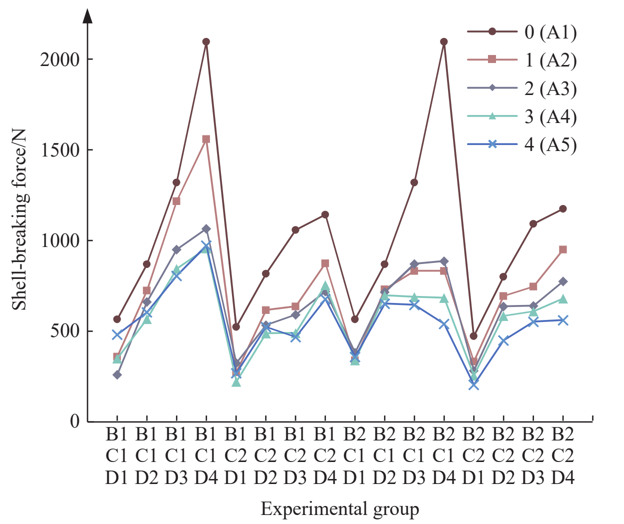


Figure 8 Statistical diagram of the effect of the number of cutting knives on compressive mechanical properties

3.5 Influence of cutting direction on compressive mechanical properties

The effect of the cutting direction on the shell-breaking force is shown in Figure 9. It can be seen from the figure that the two curves are close to coinciding, indicating that there is little difference in the impact of the cutting direction on the shell-breaking force. The shell-breaking force of *Camellia oleifera* fruit cutting along the long axis ranged from 224.73 to 1575.31 N, and the average shell-breaking force was 658.59 N. The shell-breaking force of *Camellia oleifera* fruit cutting along the minor axis ranged from 207.31 to 960.01 N, and the average shell-breaking force was 605.22 N. Compared with the *Camellia oleifera* fruit cut along the long axis direction, the average shell-breaking force of *Camellia oleifera* fruit cut along the minor axis direction decreased by 8.10%, and the reduction degree of force value was not high. The effect of cutting along the long axis and cutting along the minor axis on the shell-breaking force of *Camellia oleifera* fruit was not significant (p>0.05). Because the *Camellia oleifera* fruit is elliptical (like the shape of an egg), it is easily placed vertically along the long axis in the natural state, and it easily achieves equal angle cutting along the long axis. However, equidistant ring cutting along the minor axis requires the tool to rotate radially perpendicular to the long axis, and the long axis of *Camellia oleifera* fruit has different lengths, so it is especially difficult to achieve ring cutting with equal spacing. Based on the fact that the differences in the effect of cutting along the long axis at equal angles and cutting along the minor axis at equal distances on the shell-breaking force of *Camellia oleifera* fruit are not significant, and cutting along the minor axis at equal distances is difficult to achieve, it is possible to cut along the long axis at equal angles instead, thereby reducing the shell-breaking force of the *Camellia oleifera* fruit.

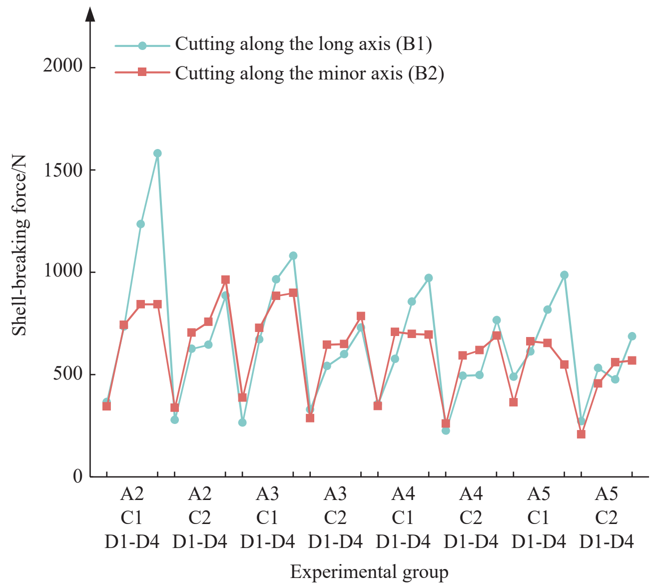


Figure 9 Statistical diagram of the impact of cutting direction on compressive mechanical properties

3.6 Influence of compressing direction on compressive mechanical properties

The effect of the compressing direction on the shell-breaking force is shown in Figure 10. As can be seen from the figure, in 96.25% of the experimental groups, the shell-breaking force of *Camellia oleifera* fruits compressing along the long axis was smaller than that of compressing along the minor axis, and the effects of compressing along the long axis and compressing along the minor axis on shell-breaking force of *Camellia oleifera* fruits were extremely significant (p<0.01). The shell-breaking force of *Camellia oleifera* fruit compressing along the minor axis ranged from 264.58 N to 2117.26 N, and the average shell-breaking force was 815.86 N. The breaking force of *Camellia oleifera* fruit compressing along the long axis ranged from 207.31 to 1186.77 N, and the average shell-breaking force was 619.20 N. Compared with compressing along the minor axis, the average shell-breaking force of *Camellia oleifera* fruit compressing along the long axis decreased by 24.11%. This is because the fibers of the shell tissue are oriented along the long axis. When the shell is broken, the cracks are distributed along the long axis. Therefore, applying external force along the long axis makes the shell prone to rupture.

3.7 Influence of *Camellia oleifera* fruit size on compressive mechanical properties

The effect of *Camellia oleifera* fruit size on shell-breaking force is shown in Figure 11. It can be seen from the figure that the larger the fruit diameter is, the larger the shell-breaking force is. The shell-breaking force of 20-25 mm *Camellia oleifera* fruit ranged from 207.31 to 572.47 N, and the average shell-breaking force was 362.55 N. The shell-breaking force of 25-30 mm *Camellia oleifera* fruit ranged from 454.86 to 878.60 N, and the average shell-breaking force was 669.33 N. The shell-breaking force of 30-35 mm *Camellia oleifera* fruit ranged from 473.66 to 1333.45 N, and the average shell-breaking force was 827.86 N. The shell-breaking force of 35-40 mm *Camellia oleifera* fruit ranged from 547.21 to 2117.26 N, and the average shell-breaking force was 1011.39 N. The effect of different *Camellia oleifera* fruit size on the shell-breaking force of *Camellia* fruit was very significant (p<0.01). Compared with the 20-25 mm *Camellia oleifera* fruit, the average shell-breaking force of 25-30 mm *Camellia oleifera* fruit was increased by 85.62%; the average shell-breaking force of 30-35 mm

Camellia oleifera fruit was increased by 127.34%; and the average shell-breaking force of 35-40 mm *Camellia oleifera* fruit was increased by 178.69%. With the increase of *Camellia oleifera* fruit size, the shell-breaking force of *Camellia oleifera* fruit will increase accordingly.

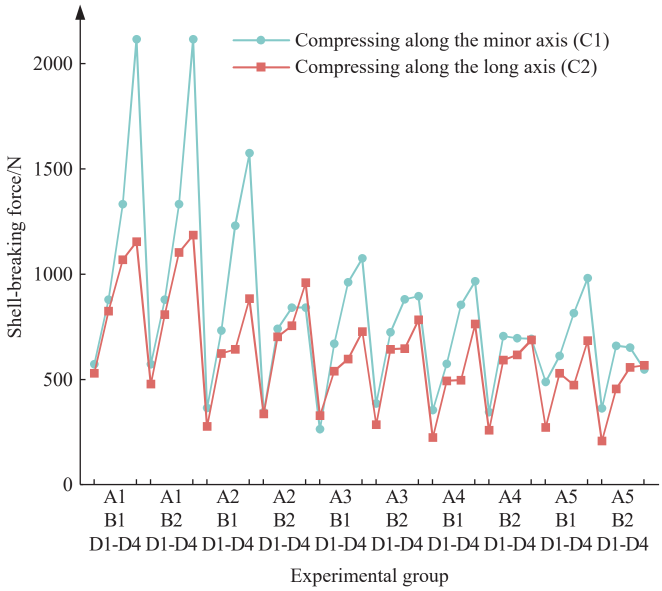


Figure 10 Statistical diagram of the influence of compressing direction on compression mechanical properties

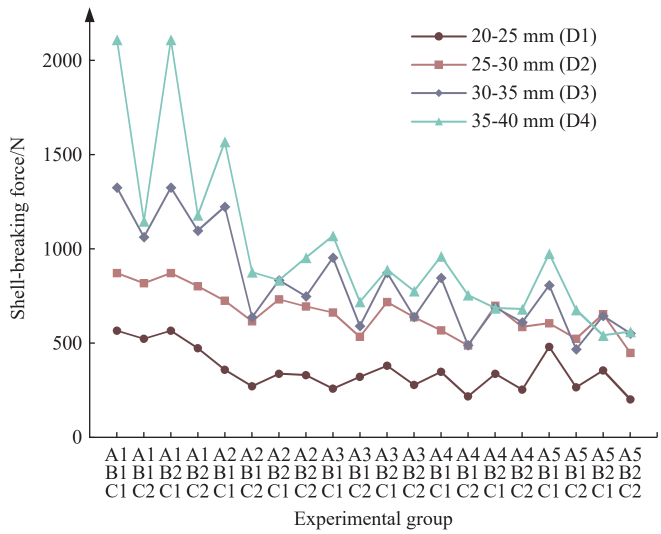


Figure 11 Statistical diagram of the influence of *Camellia oleifera* fruit size on compressive mechanical properties

3.8 Optimal combination for *Camellia oleifera* fruit shell breaking by cutting and compression

Using grading measures, making 1 cut along the long axis and compressing along the long axis is the most effective way to crack the shell of *Camellia oleifera* fruit. Compared with the mechanical property tests of *Camellia oleifera* fruit (no cutting) conducted by Tang et al.[20] and Xue et al.[21], the test results regarding the influence of the compressing direction and the *Camellia oleifera* fruit size on compressive mechanical properties were consistent. The shell-breaking force of *Camellia oleifera* fruit compressing along the long axis was lower than that of *Camellia oleifera* fruit compressing along the minor axis. With the increase of *Camellia oleifera* fruit size, the shell-breaking force of *Camellia oleifera* fruit also increased. However, due to the high moisture content of *Camellia oleifera* fruit used in this experiment, the value of shell-breaking force measured in this experiment is greater than that measured in the two experiments mentioned above.

4 Conclusions

To reduce the rate of seed breaking of *Camellia oleifera* fruit, this paper uses a single-factor test based on the electronic universal testing machine to illustrate the influence law of cutting knife number, cutting direction, compressing direction, and *Camellia oleifera* fruit size on the extrusion shell-breaking force of *Camellia oleifera* fruit, which provides theoretical support for the design of grading-cutting-compressing-separating process and machine. The main conclusions are as follows:

(1) The average breaking force of *Camellia oleifera* seeds was 196.33 N. Cutting could release the stress of *Camellia oleifera* fruit shell, reduce the stress transferred to the seeds, and reduce the damage rate of *Camellia oleifera* seeds.

(2) Compared with direct compression without cutting, the shell-breaking force of *Camellia oleifera* fruit with 1, 2, 3, and 4 cuts decreased by 30.14%, 38.62%, 45.05%, and 47.74%, respectively. However, with the increase of the number of cutting knives, the amplitude of the shell-breaking force reduction of *Camellia oleifera* fruit decreased. Considering the influence of increasing the number of cutting knives on the structure and cost of the machine and tool, it is economical and practical to cut with one knife.

(3) The effect of cutting direction on shell-breaking force is not significant. Although the shell-breaking force of *Camellia oleifera* fruit cut at equal distance along the minor axis direction is 8.10% lower than that of *Camellia oleifera* fruit cut at an equal angle along the long axis direction, the equal angle cutting along the long axis direction can be adopted considering the technical challenges of equidistant cutting along the minor axis direction. The shell-breaking force of *Camellia oleifera* fruit compressing along the long axis was 24.11% lower than that of *Camellia oleifera* fruit compressing along the minor axis, making the long axis the appropriate compression direction.

(4) With the increase of *Camellia oleifera* fruit size, the shell-breaking force of *Camellia oleifera* fruit also increased. The shell-breaking force of 25-30 mm, 30-35 mm, and 35-40 mm increased by 85.62%, 127.34%, and 178.69%, respectively, compared with the shell-breaking force of 20-25 mm. Grading before shell breaking helps to avoid crushing large fruits and causing seed damage to small fruits due to excessive pressure.

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