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Research Paper

EXPERIMENTAL STUDIES ON INFLUENCES OF
PARAMETERS OF ADAPTIVE CASHEW SHELLING
CUTTER ON SHELLING PERFORMANCEYun-Fei Fu¹, Jie Gong¹, Hui Huang¹, Yi-Jun Liu¹, Fan Zhang¹ and Mao-Fang Huang^{1*}*Corresponding Author: Mao-Fang Huang ✉ huangmaofang666@163.com

The study involves the performance evaluation of the adaptive cashew shelling cutter, which is used to produce kernels of cashew nuts by removing shells (pericarp), under different design parameters (i.e., the distance between upper and lower cutters, the pre-pressure caused by the spring, and the velocity of the scraper). In particular, the adaptive cashew shelling cutter has a pair of the cutters connected with springs so as to fit various sizes of cashew nuts. Before the shelling test, the pre-shelling treatments of cashew nuts are carried out under the combination of the steaming time of 20 minutes, steaming temperature of 115 °C, and the drying time of 36 hours. During the shelling test, each group of the shelling test consumes 150 cashew nuts, and each group of the shelling test is repeated five times. The overall results show that to get the maximum number of whole kernels, the distance between upper and lower cutters should be 8.5 mm, the velocity of the scraper should be 0.36 m/s, and the pre-pressure caused by spring should be 170 N. With the rise in the pre-pressure caused by the spring, the number of the whole kernels obtained by hand declines, while the number of the whole kernels obtained by hand witnesses an opposite tendency with the rise in the distance between upper and lower cutters. Particularly, when the velocity of the scraper is 0.48 m/s, the number of the whole kernels obtained by hand achieves the highest point.

Keywords: Adaptive cashew shelling cutter, Whole kernel rate, Pre-shelling treatment, Shelling performance, Shelling test platform

INTRODUCTION

Cashew (*Anacardium occidentale L.*) nut originated from South American countries (e.g., Bolivia, Brazil, Ecuador, and Peru) (Aliyu and Awopetu, 2007). Nowadays, cashew nuts have already become an extremely important tropical

fruit crop worldwide, basically because cashew nuts are of considerable economic importance. In 2002, India was the largest producer and processor of cashew nuts all over the world - 0.46 million tons of raw cashew nuts per year. However, in the year of 2013, Vietnam constituted

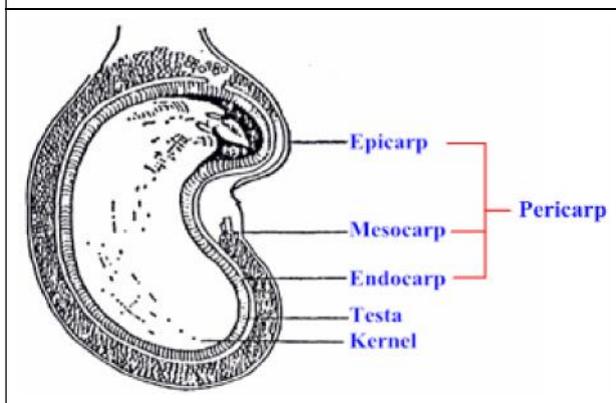
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the largest amount in terms of exporting cashew nuts with 25 million tons, valuing at roughly 1.8 billion dollars (Uchiyama *et al.*, 2014). Undoubtedly, cashew processing industries indeed contribute to improve the employment rates, especially in Third World countries such as India, Tanzania, Mozambique, Nigeria, Guinea-Bissau, and Kenya. Practically, the cashew nut chiefly consists of a nutshell (pericarp) and a kernel, and the pericarp is composed of the epicarp, mesocarp, and endocarp, as shown in Figure 1 (Thivavarnvongs *et al.*, 1995). In addition to that, there is a testa between the endocarp and kernel, in an attempt to protect the kernel again. Importantly, the kernels of cashew nuts are of high food value with approximately 40-57% oil and 21% protein contents. As the matter of fact, kernels are chiefly utilized in confectioneries or are made into dried fruits. Additionally, kernels are being considered as an additional source of protein concentrates and isolates used in human food products (Ogunwolu *et al.*, 2009; and Fu *et al.*, 2015).

There is no doubt that the shelling technologies of cashew nuts are extremely essential for the sustainable development of cashew nut industries. Although there are a great number of shelling tools, like the cutter with two blades,

hammer-like tool, wedge-like tools, and so forth, these tools have a couple of drawbacks (Fu *et al.*, 2015; and Gong *et al.*, 2016). Firstly, cashew nuts must be previously classified by size. Secondly, the shelling efficiency is relatively low. On top of this, the whole kernel rate relies on employers' shelling skills greatly. Finally, it is extremely tough to connect these tools with an automatic feeding device. Therefore, in recent years, the scholars from different countries devote to inventing new machines and novel techniques so as to achieve the kernels of cashew nuts efficiently. Ojolo *et al.* (2010) presented a category of cashew nut shelling machine, which was affordable to workers and was convenient for workers to operate and maintain this cashew nut shelling machine. During the shelling process, cashew nuts were cracked by the impact generated by an impeller, which was driven by the electric motor (Ojolo *et al.*, 2010). Swain *et al.* (2011) developed a semi-automatic cashew nut shelling machine on the basis of the principle of impulse and tension, which was suitable for drum roasted cashew nuts. In terms of this semi-automatic cashew nut shelling machine, the sizes of cashew nuts had significant effects on the whole kernel recovery, shelling percentage, and shelling efficiency, but it had no significant influences on splitted half percentage and broken percentage (Swain *et al.*, 2010). Balsubramanian (2011) reported a radial arm type cashew nut shelling machine, in order to ease shelling operation in the processing industries of cashew nuts. In his research, the basic principle of cutting and shearing was used to extract edible kernels from steam boiled cashew nuts in a single operation. Uchiyama *et al.* (2014) illustrated a sort of cashew-shelling machine, which consisted of the vibrating cashew feeder, conveyor belts, rollers, cashew milling cutter, and cashew shell

Figure 1: Sectional View of Cashew Nut



splitter. The shelling process of this cashew-shelling machine can be divided into three main steps. To begin with, the vibrating cashew feeder placed cashew nuts between a pair of conveyor belts. Next, the conveyor belt transported cashew nuts into the gap between a pair of disk cutters. Eventually, cashew nuts were conveyed into a splitter, removing shells from kernels (Uchiyama *et al.*, 2014). Through learning and soaking up the shelling techniques above, Fu *et al.* (2015) designed a novel adaptive cashew shelling cutter, which could automatically adapt to the changes in the sizes of cashew nuts and could be utilized with various sorts of feeding facilities (Gong *et al.*, 2016). This means that this adaptive cashew shelling cutter is capable of shelling cashew nuts in a highly-efficient way.

Although the studies on the parameters optimization and the prediction of the whole-kernel rate of the adaptive cashew shelling cutter are carried out via using BP neural network and genetic algorithm and grey neural network, the investigations regarding the effects of the single parameter on the shelling performance, which is really essential for forming the basis for studying the second generation product, are not by far executed. Therefore, the experimental studies on the impacts of the parameters of the adaptive cashew shelling cutter on the shelling performance are discussed in details, aiming at providing valuably experimental data for the future research on the adaptive cashew shelling cutter.

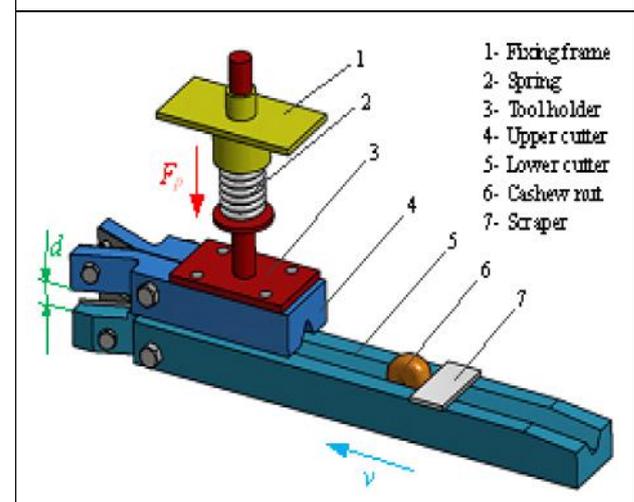
ADAPTIVE CASHEW SHELLING CUTTER AND SHELLING TEST PLATFORM

Adaptive Cashew Shelling Cutter

The schematic of the adaptive cashew shelling cutter is indicated in Figure 2. Evidently, this

adaptive cashew shelling cutter is mainly made of the fixing frame, spring, tool holder, upper cutter, lower cutter, and scraper. In fact, the fixing frame and lower cutter are fixed on the cashew shelling machine. Particularly, both upper and lower cutters have V-shaped grooves, whose role is to ensure cashew nuts to keep standing posture, improving the shelling performance of cashew nuts. With the help of the spring and tool holder, cutters have the ability to adapt the changes in the sizes of cashew nuts. During the shelling process, the scraper conveys cashew nuts into the gap between upper and lower cutters. In most cases, the scraper is driven by the chain transmission system. Furthermore, upper and lower cutters have been proved that they are of high reliability by means of the finite element analysis method, showing that the working performance of cutters would not be affected adversely during a span of 495 days when the working time of the adaptive cashew shelling cutter is 18 hours per day (Fu *et al.*, 2015). Consequently, the performance degeneration of the adaptive cashew shelling cutter could be ignored during the shelling test.

Figure 2: Mechanisms of Adaptive Cashew Shelling Cutter



In Figure 2, d denotes the distance between upper and lower cutters in millimeters; F_p denotes the pre-pressure caused by the spring in Newtons; v denotes the velocity of the scraper in meters per second. Apparently, the distance between upper and lower cutters, pre-pressure, and the velocity of the scraper are the three crucial parameters affecting the shelling performance.

Shelling Principle of Adaptive Cashew Shelling Cutter

Both upper and lower cutters have V-shaped blades, whose role is to break cashew nuts and remove shells from kernels. The force analysis of cashew nuts during the shelling process is shown in Figure 3, aiming at illustrating the shelling theory of the adaptive cashew shelling cutter in a relatively scientific way. According to Figure 3, it is obvious that the V-shaped blade is made of a front blade and two side blades. When cashew nuts are conveyed into the gap between the upper cutter and lower cutter, cashew nuts are subjected to two pressures (F_l and F_u) generated by upper and lower cutters. With the

help of F_l and F_u , the front blade has the ability to produce the main shelling force F_f on cashew nuts, which can let the shells of cashew nuts generate the initial crack. Then, side blades apply two outward forces (F_{s1} and F_{s2}) on cashew nut shells, accelerating the crack growth of cashew nut shells.

Virtually, the shelling process of cashew nuts is an impact process. That is, the main shelling force F_f is an impact force. According to the kinetic energy theorem, the main shelling force F_f can be expressed by Liu (2011).

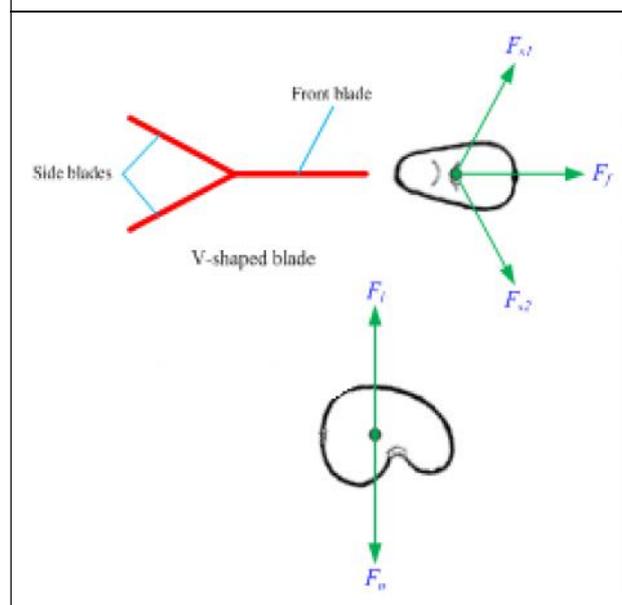
$$F_f = \frac{mv^2}{2\Delta S} \quad \dots(1)$$

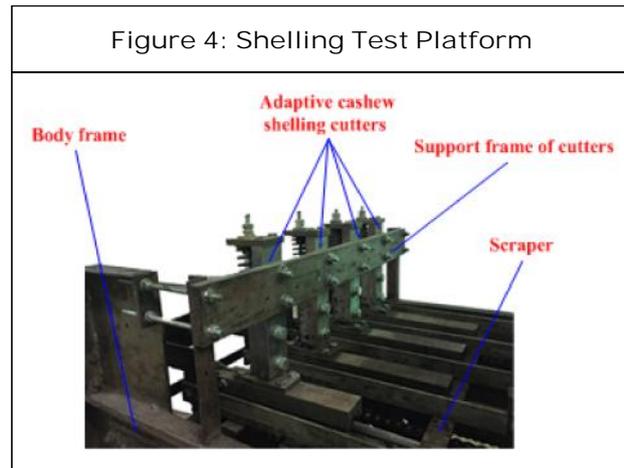
where m is the average mass of each cashew nut in kilograms, v is the velocity of the scraper in meters per second, and ΔS is the relative displacement during the impact process in meters.

Shelling Test Platform

The shelling test platform is demonstrated in Figure 4. From Figure 4, it is notable that the shelling test platform chiefly consists of the body frame, scraper, support frame of cutters, and adaptive cashew shelling cutters. In this shelling test platform, there are four adaptive cashew shelling cutters, which is convenient for researchers to acquire different groups of experimental results under distinct parameters of adaptive cashew shelling cutters at the same time. As a consequence, this shelling test platform could save researchers a great variety of time and energy. More importantly, as the cashew nut shell liquid is a kind of corrosive liquid, to ensure the service life of the shelling test platform, the whole shelling test platform is made of stainless steel.

Figure 3: Force Analysis of Cashew Nut





SHELLING TEST OF CASHEW NUTS

Selection of Experimental Samples

Through investigating the cashew nut market, it is found that middle-sized cashew nuts dominate the largest proportion, so middle-sized cashew nuts are representative. To obtain more reliable results, this study chooses middle-sized cashew nuts as experimental samples. In particular, these samples are reserved for a period not longer than one year. Additionally, to avoid the influences of abnormal and defective cashew nuts on test results, these types of cashew nuts are removed from cashew nut samples.

Pre-Shelling Treatment of Cashew Nuts

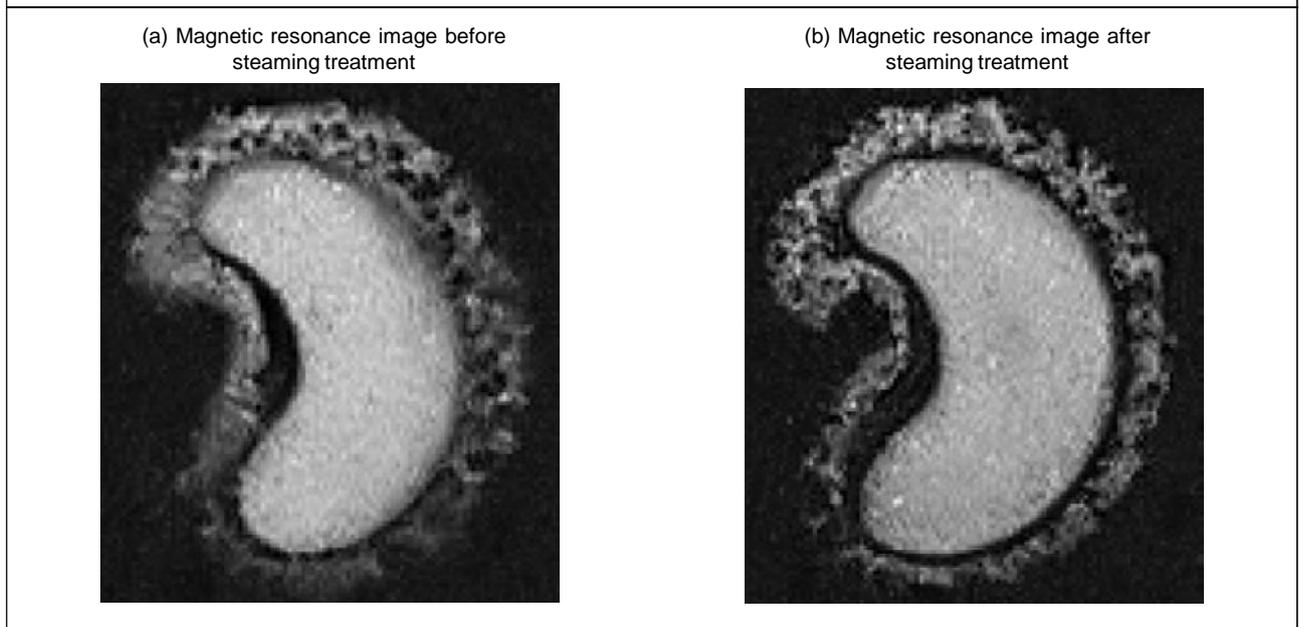
Researches have shown that the shelling performance is not only related to the machinery equipment but the pre-processing method of cashew nuts (Balasubramanian, 2006; Ogunsina and Bamgboye, 2014; and Gong *et al.*, 2015). Understandably, for different types of cashew nut shelling cutters, the optimal pre-shelling treatments of cashew nuts are distinctly different. Through observing the sheer volume of experimental data obtained by our research team, it is found that the optimum pre-processing method for the adaptive cashew shelling cutter

is the combination of the steaming time of 20 minutes, steaming temperature of 115 °C, and the drying time of 36 hours (Liu *et al.*, 2014; Gong *et al.*, 2015; and Liu *et al.*, 2016). To meet the demand of the pre-shelling treatment, the vertical pressure steam sterilizer is used to steam cashew nuts, as shown in Figure 5. On top of this, the low-field magnetic resonance measurement is employed to investigate the effects of the steaming treatment on cashew nuts in a scientific way. The magnetic resonance images of the cashew nut are shown in Figure 6. Comparing Figure 6a with Figure 6b, the gap between the shell and kernel of the cashew nut after the steaming treatment is considerably larger than that before the steaming treatment, showing that the adhesion between the shell and kernel is broken by the pre-shelling treatment, which is beneficial to remove shells from kernels.

Figure 5: Vertical Pressure Steam Sterilizer



Figure 6: Magnetic Resonance Images of Cashew Nut



Data Collection of Cashew Shelling Test

To ensure the reliability of experimental results and reduce the cost of shelling tests, each group of the shelling test consumes 150 cashew nuts rather than 200 cashew nuts reported in Fu *et al.* (2015). More importantly, because of the size variance of cashew nuts, each group of the shelling test has certain randomness, so each group of the shelling test is repeated five times to obtain more reliable data in this study. Presently, the whole kernel rate of cashew nuts is still a key factor to evaluate the performance of cashew shelling tools. Therefore, during the shelling tests of cashew nuts, the data related to the whole kernel rate are collected.

The whole kernel rate of cashew nuts can be expressed by Ojolo *et al.* (2010) Swain *et al.* (2010) Balsubramanian (2011) and Fu *et al.* (2015).

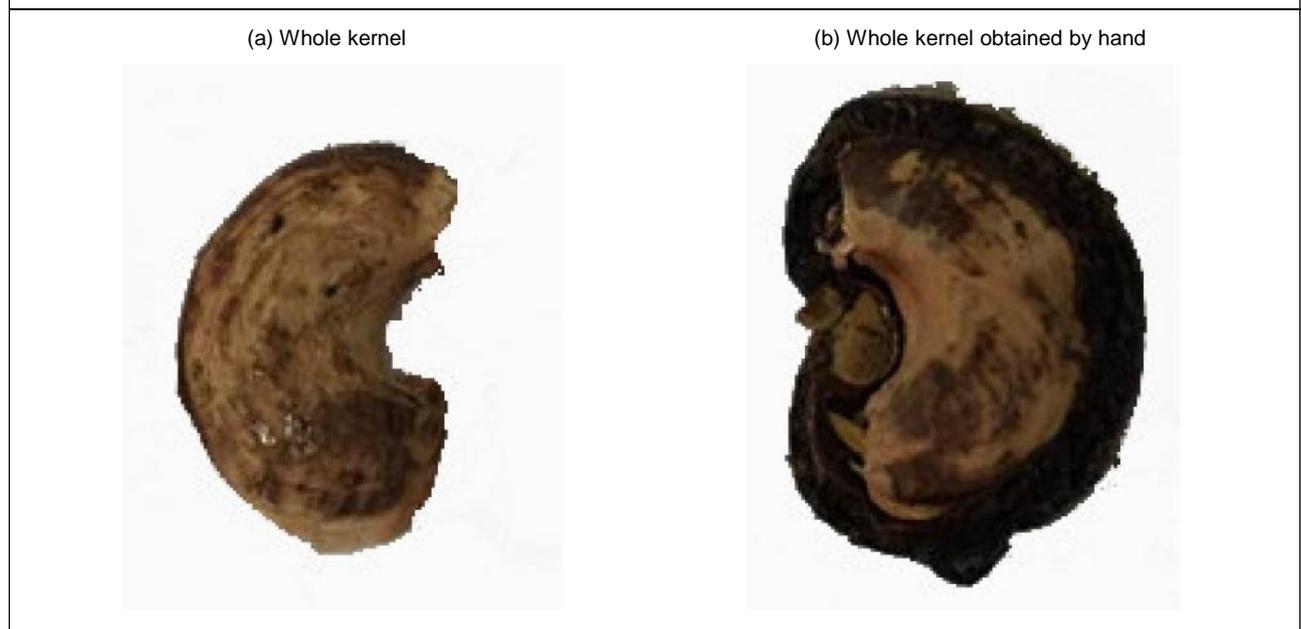
$$R_k = \frac{W_k}{W_t} \dots(2)$$

where W_k is the number of whole kernels or the weight of whole kernels in kilograms, and W_t is the total number of cashew nuts or the total weight of cashew nuts in kilograms.

Generally, for processing enterprises, the ratio of the weight of whole kernels to the total weight of cashew nuts is used to calculate the whole kernel rate of cashew nuts. However, in terms of the scientific research, the ratio of the number of whole kernels to the total number of cashew nuts is utilized to calculate the whole kernel rate of cashew nuts. Therefore, this study takes advantage of the numbers of whole kernels and cashew nuts to obtain the whole kernel rate.

By analyzing test results, it is found that there are two types of data related to the whole kernel rate. These two groups of data are the number of whole kernels and the number of the whole kernels obtained by hand, and these two categories of cashew nuts are shown in Figure 7. There is no doubt that the number of whole kernels, which is shown in Figure 7a, is directly

Figure 7: Cashew Nuts Counted in Shelling Test



relevant to the whole kernel rate. Additionally, although a number of cashew nuts are broken by the adaptive cashew shelling cutter, and kernels are not damaged, kernels and shells are not entirely separated, as shown in Figure 7b. In consequence, whole kernels can be obtained by hand from this category of cashew nuts. As the matter of the fact, the cashew nuts shown in Figure 7b will not spend workers too much energy and time in removing shells from whole kernels. To put it differently, it is a low labor intensity work for employers. Consequently, the number of the whole kernels obtained by hand has effects on the whole kernel rate.

Virtually, the main parameters determining the shelling performance of the adaptive cashew shelling cutter are the distance between upper and lower cutters, the pre-pressure caused by the spring, and the velocity of the scraper. In this case, the most suitable experimental design is based on the RCBD approach (Randomized Complete Block Design), employing 4 levels of the distance between upper and lower cutters of

8, 8.5, 9 and 9.5 mm, 4 levels of the pre-pressure caused by the spring of 160, 170, 180, and 190 N, and 4 levels of the velocity of the scraper of 0.24, 0.36, 0.48, and 0.6 m/s (Thivavarnvongs *et al.*, 1995).

TEST RESULT ANALYSIS

Influences of Distance Between Upper and Lower Cutters on Shelling Performance

The change laws of the numbers of whole kernels and the whole kernels obtained by hand varying with the distance between the upper and lower cutters are shown in Figure 8. Figure 8a shows the change laws under the velocity of the scraper of 0.36 m/s and the pre-pressure caused by the spring of 160 N. As shown in Figure 8a, the number of whole kernels soars to 106 at 8.5 mm, and then the corresponding figure plummets, ranging from 106 at 8.5 mm to 72 at 9.5 mm. In addition, the number of the whole kernels obtained by hand indicates a growth from 22 at 8 mm to 32 at 9.5 mm.

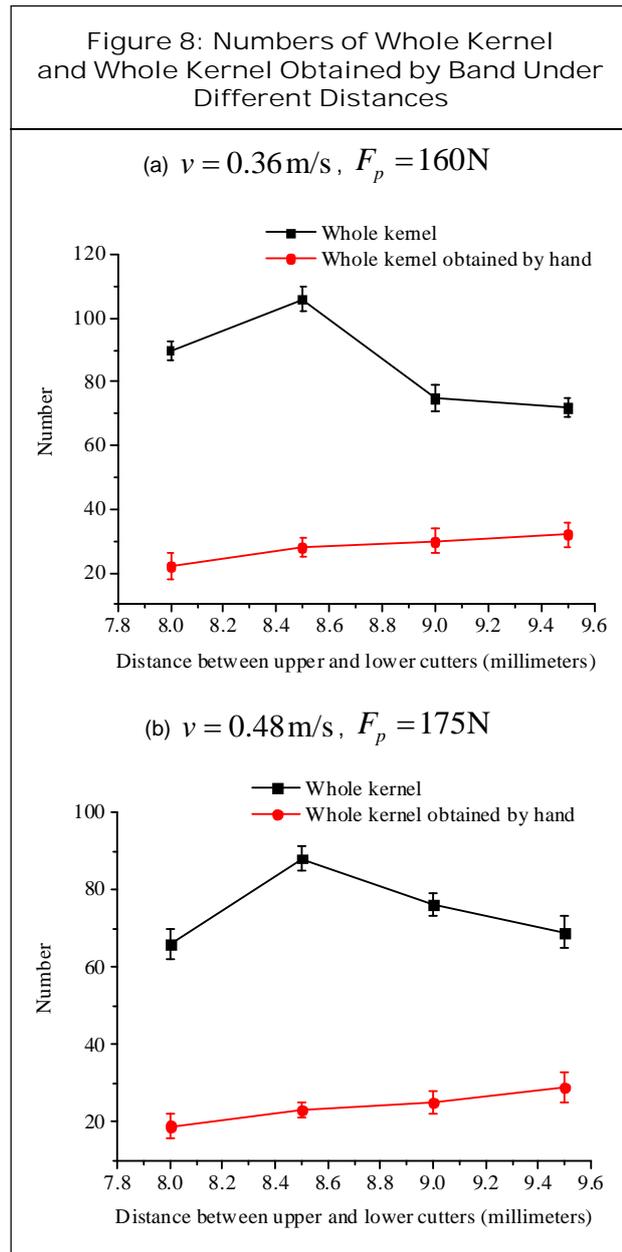


Figure 8b shows the change laws under the velocity of the scraper of 0.48 m/s and the pre-pressure caused by the spring of 175 N. According to Figure 8b, there is an increase from 66 to 88 between 8 and 8.5 mm in the number of whole kernels, and then the corresponding figure continuously falls to 69 at 9.5 mm. On top of this, the number of the whole kernels obtained by hand consistently grows, ranging from 19 to 29 between 8 and 9.5 mm.

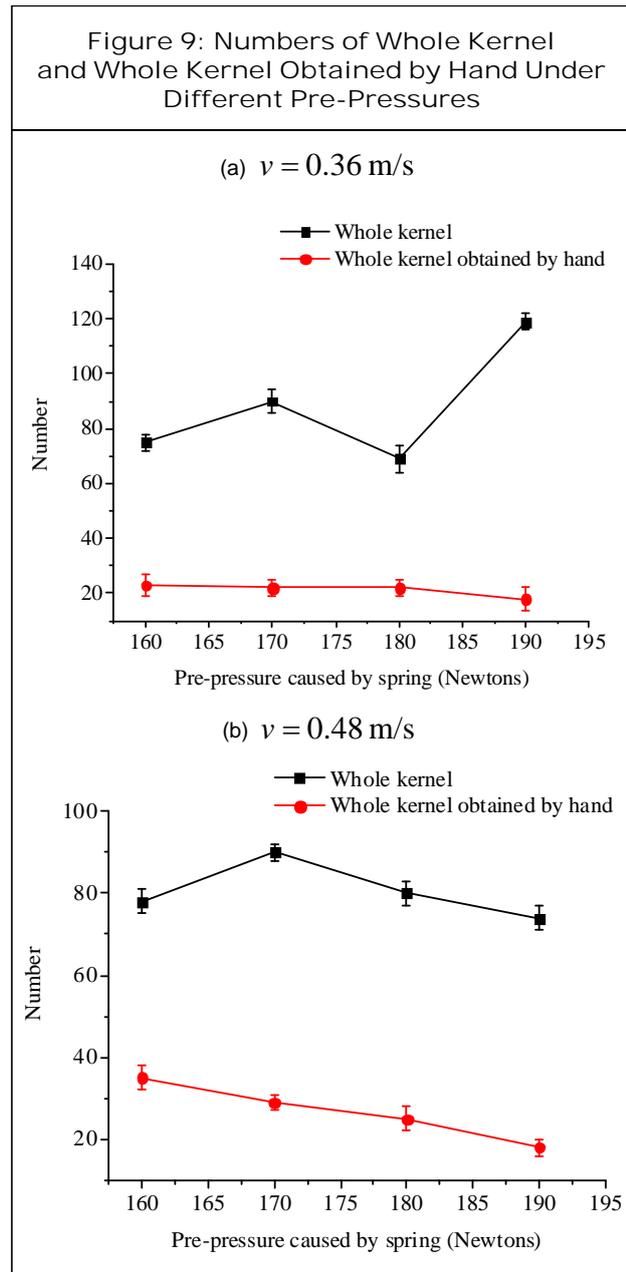
Depending on the analysis above, the number of whole kernels is the largest when the distance between upper and lower cutters is 8.5 mm. Furthermore, with the increase of the distance between upper and lower cutters, the number of the whole kernels obtained by hand shows an upward trend.

Influences of Pre-Pressure Caused by Spring on Shelling Performance

The change laws of the numbers of whole kernels and the whole kernels obtained by hand varying with the pre-pressure caused by the spring are shown in Figure 9. Figure 9a shows the change laws under the velocity of the scraper of 0.36 m/s and the distance between the upper and lower cutters of 10 mm. From Figure 9a, the number of whole kernels climbs to 90 at 170 N, and then the corresponding figure returns to 69 at 180 N. Afterwards, this figure rockets to 119 at 190 N. Additionally, the number of the whole kernels obtained by hand shows a downward tendency, ranging from 23 at 160 N to 18 at 190 N.

Figure 9b shows the change laws under the velocity of the scraper of 0.48 m/s and the distance between the upper and lower cutters of 9.5 mm. It can be seen from Figure 9b that the number of whole kernels witnesses an upward trend from 78 to 90 between 160 and 170 N, and then the corresponding figure decreases to 74 at 190 N. In addition to that, the number of the whole kernels obtained by hand consistently drops to 18 at 190 N.

Evidently, the number of whole kernels is not closely linked to the pre-pressure caused by the spring. By contrast, the influences of the pre-pressure caused by the spring on the number of whole kernels somewhat rely on the combinations of the velocity of the scraper and

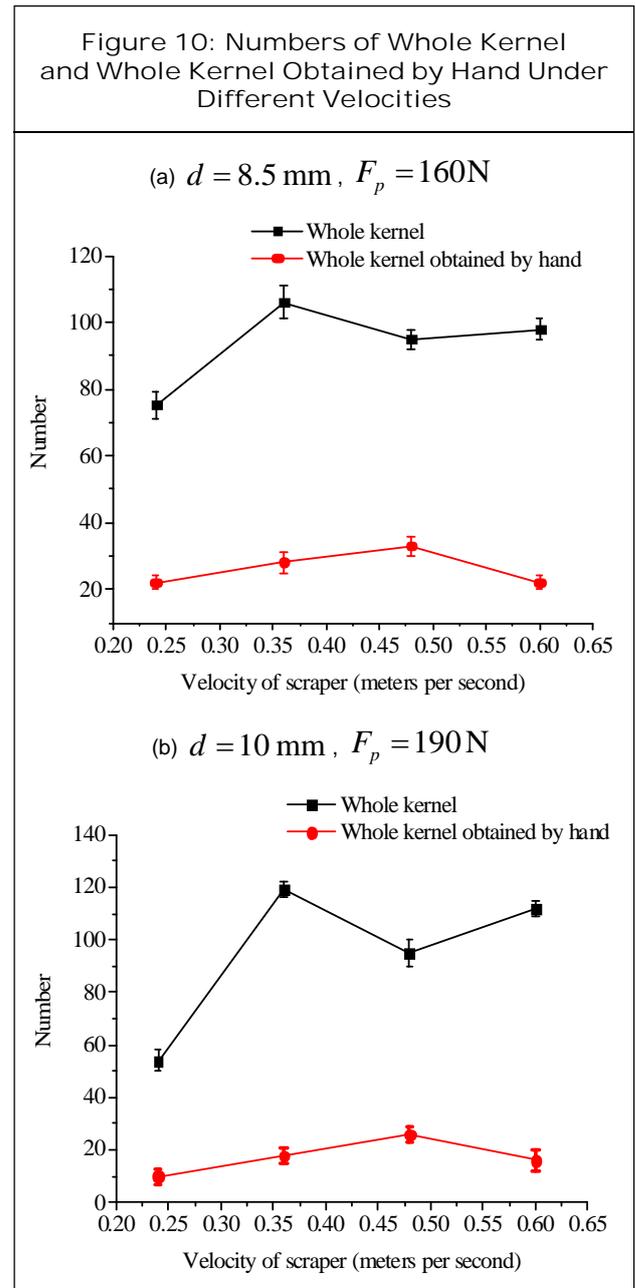


the distance between upper and lower cutters. Furthermore, with the increase of the pre-pressure caused by the spring, the number of the whole kernels obtained by hand shows a downward trend.

Influences of Velocity of Scraper on Shelling Performance

The change laws of the numbers of whole kernels and the whole kernels obtained by hand varying

with the velocity of the scraper are shown in Figure 10. Figure 10a shows the change laws under the distance between the upper and lower cutters of 8.5 mm and the pre-pressure caused by the spring of 160 N. As indicated in Figure 10a, the number of whole kernels increases between 0.24 m/s and 0.36 m/s, peaking at 106, and then there is a minor fluctuation from 106 at 0.36 m/s to 98 at 0.6 m/s. On top of this, the number of the whole



kernels obtained by hand smoothly grows to 33 at 0.48 m/s, and then this figure returns to 22 at 0.6 m/s.

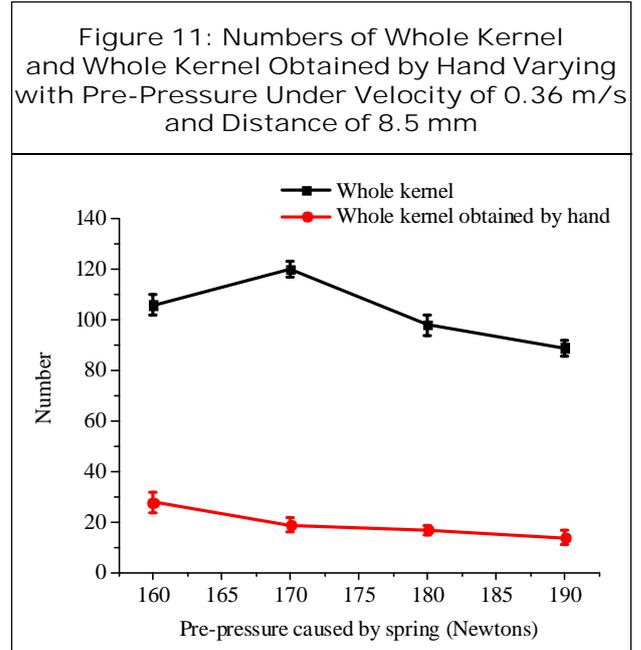
Figure 10b shows the change laws under the distance between the upper and lower cutters of 10 mm and the pre-pressure caused by the spring of 190 N. It can be seen from Figure 10b that the number of whole kernels dramatically increases to the highest point, 119 at 0.36 m/s, and then the corresponding figure fluctuates significantly, ranging from 119 at 0.36 m/s to 112 at 0.6 m/s. Moreover, the number of the whole kernels obtained by hand slightly goes up to 26 at 0.48 m/s, and then this figure drops to 16 at 0.6 m/s.

Through analyzing the data above, when the velocity of the scraper is 0.36 m/s, the number of whole kernels is the highest. When the velocity of the scraper is 0.48 m/s, the number of the whole kernels obtained by hand is the maximum.

Selection of Optimal Pre-Pressure Caused by Spring

According to the analysis above, it is known that the velocity of the scraper of 0.36 m/s and the distance between upper and lower cutters of 8.5 mm are the optimum parameters in terms of achieving the largest number of whole kernels. Actually, the optimal pre-pressure caused by the spring can be determined based on these two optimum parameters. The change laws of the numbers of whole kernels and the whole kernels obtained by hand varying with the pre-pressure caused by the spring under the velocity of the scraper of 0.36 m/s and the distance between upper and lower cutters of 8.5 mm are shown in Figure 11.

From Figure 11, it is evident that when the pre-pressure caused by spring is 170 N, the highest number of whole kernels can be obtained. Under



the combination of the velocity of the scraper of 0.36 m/s, the distance between upper and lower cutters of 8.5 mm, and the pre-pressure caused by spring of 170 N, the number of whole kernels is approximately 120, and the number of the whole kernels obtained by hand is roughly 20. If the number of the whole kernels obtained by hand is counted, the whole kernel rate of cashew nuts is about 93.33%. If not, the whole kernel rate of cashew nuts is around 80%.

However, it must be admitted that the whole kernel rate reported in this study cannot be achieved by processing enterprises of cashew nuts, basically because the experimental condition is extremely strict. Firstly, experimental samples are selected by hand in order to remove abnormal and defective cashew nuts from experimental samples, which will consume a huge amount of time and energy, so it is not suitable for processing enterprises. Secondly, researchers place cashew nuts into the V-shaped grooves of cutters so as to ensure the standing posture of cashew nuts rather than using automatic feeding device. For most of

the processing enterprises, they will definitely employ the feeding device to improve the production efficiency. Next, to ensure the quality of the pre-shelling treatment of cashew nuts, a limited number of cashew nuts are put into the vertical pressure steam sterilizer. On the other hand, processing enterprises will use large-scale steaming equipment to execute the pre-shelling treatment of cashew nuts to improve the working efficiency. Undoubtedly, this sort of method will cause the phenomenon that the steaming quality of cashew nuts would be distinctly different. Finally, after each shelling test, adaptive cashew shelling cutters will be cleaned carefully. Yet processing enterprises will not clean adaptive cashew shelling cutters so frequently, mainly because cleaning adaptive cashew shelling cutters is really a time-consuming process.

CONCLUSION

Depending on experimental studies, the conclusions can be drawn as follows:

- 1) In terms of obtaining the largest number of whole kernels, the optimum parameter combination is the combination of the velocity of the scraper of 0.36 m/s, the distance between upper and lower cutters of 8.5 mm, and the pre-pressure caused by spring of 170 N.
- 2) The number of the whole kernels obtained by hand is directly proportional to the distance between the upper and lower cutters, whereas the number of the whole kernels obtained by hand is inversely proportional to the pre-pressure caused by the spring. In addition, when the velocity of the scraper is 0.48 m/s, the number of the whole kernels obtained by hand is the maximum.
- 3) Through observing experimental results, the number of whole kernels is far more than that of the whole kernels obtained by hand, showing the excellent shelling performance of the adaptive cashew shelling cutter.
- 4) The optimization design of the angle between the two side blades in the V-shaped blade will be discussed in the future, and a new generation of the adaptive cashew shelling cutter will be designed based on the data obtained in this study.

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