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Experimental Study on the Effect of Water Jet Cutting Parameters on Maize Stalks

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Abstract: Cutting maize stalks using water jet cutting technology is a new method of stalk management before no-tillage sowing. Aiming to cut off the maize stalks (stems and stem nodes), we conducted an all-factor cutting experiment on stems and single-factor cutting experiments on stem nodes under different cutting parameters. The results showed that the cutoff ratio of the stems and stem nodes increased with water jet pressure and decreased with target distance and traverse speed. For cutting off the stems with a maximum traverse speed, the parameters were 120 MPa water jet pressure, 10 mm target distance, and 1371 mm/min traverse speed. When the target distance was 30 mm, the traverse speed was 4000 mm/min, and the water jet pressure was greater than or equal to 160 MPa, the cutoff ratio of stem nodes was 100%. Therefore, the water jet pressure $\geq$ 160 MPa, the target distance $\leq$ 10 mm, and the traverse speed $\leq$ 1371 mm/min were needed to cut off both. Moreover, bottom burrs, surface stripes, and cutting residue might appear due to the divergent and lagging characteristics of water jets. The results could provide basic data and technical support for cutting maize stalks with water jets.

Keywords: water jet cutting technology; maize stalks; no-tillage sowing; experiments

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1. Introduction

No-tillage sowing can reduce the amount of soil movement and the number of machine penetrations, so it effectively controls soil erosion, soil compaction, and other problems [1]. However, it is easy to block or wind the furrow opener when crop stalks cover farmlands, affecting the operational efficiency of the seeder [2]. Currently, common stalk management methods are divided into three types: utilize the gravity of the machine to cut stalks, use the power provided by the tractor to chop stalks, or accelerate the flow of the stalks [3]. These methods require disc openers, chopping blades, and specific mechanical structures, respectively, which directly act on the stalks or the soils, making them vulnerable to wear and tear due to contact. In recent years, water jet cutting technology, as a non-contact method, has been applied in cutting off crop stalks before no-tillage sowing [4].

Water jet cutting technology uses the water as the energy carrier and processes various materials with high-kinetic-energy water jets [5]. There is no direct contact with the objects, and no spark is generated during the cutting process, so it has been widely used to cut metals, ceramics, wood, and other materials [6]. In the farmland environment, water jet cutting technology is being studied for weeding, fertilizing, harvesting, and cutting crop stalks [7]. Ishida et al. [8] and Fogelberg et al. [9] used water jets to cut weeds, proving that water jet cutting technology was an effective physical weeding method. Zheng et al. [10] designed a jet fertilization device for applying liquid fertilizers. The results showed that the soil cutting ability was the strongest when the jet pressure was 12 MPa, the forward speed was 0.6 m/s, the fertilizer inlet diameter was 0.6 mm, and the nozzle diameter was 0.8 mm. Valco et al. [11] and Thanomputra et al. [12] proposed cutting sugarcane stalks with pure water jets or abrasive water jets, respectively, and studied the possibility of harvesting sugarcanes in the field by using water jet cutting technology.

As for water jets cutting crop stalks, Hu et al. [13] found that when the target distance was less than 10 mm, the traverse speed was less than 5000 mm/min, and the jet pressure was 280 MPa, all the single maize stalk samples were cut off by pure water jets. Desbiolles et al. [14] studied cutting wheat stems with water jets to deal with stalk blockage. The results showed that when the pressure was 380 MPa, the nozzle diameter was 0.15–0.3 mm, and the forward speed was 1.67–3.33 m/s, the wheat stem cutting ability was 10–35 Mg/ha. Compared with pure water jet cutting, Perotti et al. [15] added a small amount of garnet abrasive (50 g/min) to the water jets to improve the cutting ability of the wheat stem. However, abrasives are additional materials in the farmland environment with uncertain effects, and there are more studies using pure water jets. These show that the cutting parameters affect the cutting results and appropriate parameters should be used for different materials and purposes. In addition to the water jet cutting parameters, the phenomena after cutting may also affect the cutting results, but there is a lack of research.

Therefore, to ensure that water jets can cut off maize stalks, we conducted pure water jet cutting experiments on newly harvested maize stalks (including stems and stem nodes). Firstly, the influence of water jet cutting parameters on the cutoff ratio of stems and stem nodes was studied, and the parameter range of cutting off the stems and stem nodes at the same time was obtained. Then, we analyzed the causes and effects of the phenomena after cutting. This study is expected to guide the application of water jet cutting technology to manage maize stalks.

2. Water Jet Cutting Principle

The water jet cutting system comprises a water supply device, a filter device, a pressurizing device, and a water jet nozzle, as shown in Figure 1 [16]. When cutting maize stalks, the water supply device provides water. After the filter device removes the impurities, the water is pressurized by the pressurizing device and finally ejected from the water jet nozzle. The water jet nozzle converts the potential energy of pressurized water into the kinetic energy of a small concentrated area, forming a high-speed and high-pressure water jet acting on the maize stalk [17,18]. At this time, the water jet has a strong impact force. Under the continuous impact, the maize stalk is gradually penetrated, and as the nozzle advances, the maize stalk is cut off, thus completing the cutting operation.

After the water jet is ejected from the nozzle, it gradually diverges without the constraint of the pipe (Figure 1) [19,20]. In the outer layer of the continuous flow zone, the water jet is atomized by contact with the air [19]. Moreover, the farther away from the nozzle, the larger the droplet layer, which eventually transitions to the atomization zone [20]. The solid jet layer is in the middle of the continuous flow zone. The water jet flowing out of the nozzle has the same velocity in the conical area around the axis, equal to the velocity in the nozzle outlet [16]. This area is the core region of the solid jet layer. Then, the water jet velocity gradually decreases along the axis direction, while the velocity in the radial direction decreases to zero from the middle to the edge (Figure 1). Therefore, the closer the distance to the nozzle is, the more concentrated the water jet is, and the cutting impact force is stronger.

According to the cutting process and the structure characteristics of the water jet, it can be seen that the cutting effect of maize stalks is mainly affected by the continuous impact force. This is related to the water jet velocity, the pressure, the target distance (the distance between the water jet nozzle and the maize stalk), and other parameters. In addition, the traverse speed (the forward speed of the nozzle) determines the impact time and cutting efficiency of water jets on maize stalks. Considering the importance and adjustability of each parameter, the water jet pressure, the target distance, and the traverse speed are finally determined as the parameter variables in water jet cutting experiments.

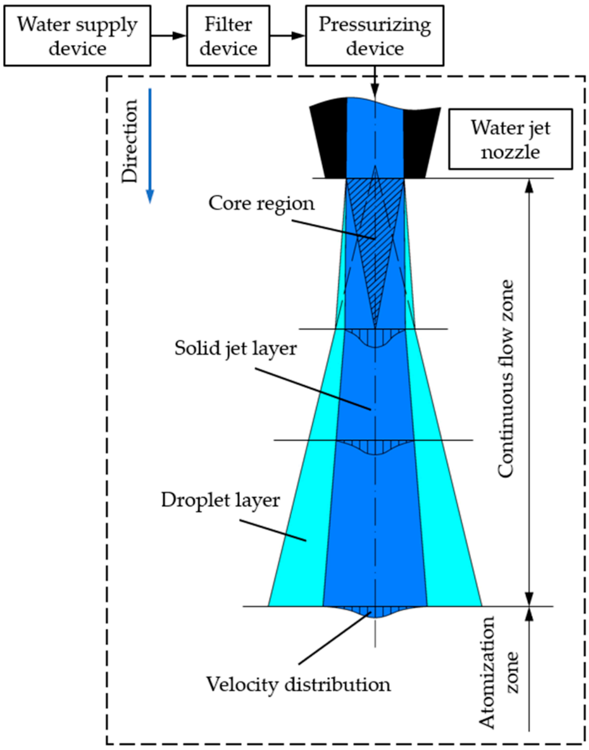


Figure 1. Schematic diagram of water jet cutting system and jet structure.

3. Materials and Methods

3.1. Sample Preparation

Maize stalk samples were obtained in Wangzhuang village of Zhandian Town of Wuzhi County, Jiaozuo City, Henan Province, China. The experimental variety of maize was Denghai 605. The average plant height was 221.39 cm. The row spacing was 60 cm, and the plant spacing was 25 cm. Fresh maize stalks after picking spikes were taken. The leaves were manually removed. Then, the stalks were stored in a naturally ventilated environment for experimental study.

Maize stalks are elliptical cylinders with multiple stems connected by stem nodes (Figure 2). The maize stalk has different characteristics from the root to the top [21]. Different parts of the maize stalks were cut by adjusting the range of the water jet pressure, the target distance, and the traverse speed. It was found that the stalk closer to the root was more difficult to cut off. Therefore, the first stem and stem node near the root were selected for water jet cutting experiments. Forty maize stalks were measured with a vernier calliper and a drying oven. The average short-axis diameter of the first stem was 20.30 mm, the average long-axis diameter was 24.10 mm, and the average water content was 80.05%. The average long-axis diameter of the stem node was 29.84 mm, the average short-axis diameter was 25.53 mm, and the average water content was 80.75%.

Figure 2. The first stem and stem node of the maize stalk.

3.2. Experimental Equipment

The experiments were conducted on a cutting test bench, as shown in Figure 3. The test bench mainly included a universal plane water jet machine (model J-136-2020 of Shanghai Jinjian Waterjet Equipment Manufacturing Co., Ltd., Shanghai, China), EF-200 sunlamp (Shanghai Jinbei Photographic Equipment Industrial Co., Ltd., Shanghai, China), 5F01C-16G high-speed camera (Hefei Junda High-tech Information Technology Co., Ltd., Hefei, China), and a stalk holder. The water jet machine was operated by professional personnel. The diameter of the pure water gem in the nozzle was 0.3 mm. We placed the long axis of the maize stalk horizontally on the stalk holder, and the middle distance of the stalk holder on both sides was 50 mm. A high-speed camera was used to capture the cutting process. The high frame rate was 3000 fps, and the exposure time was 900 µs. Before the experiment, we manually adjusted the pressure valve knob to adjust the water jet pressure and changed the numerical control parameters of the water jet machine to adjust the target distance and the traverse speed. Then, we started the water jet machine and completed the cutting experiments of a single maize stalk with the advance of the nozzle.

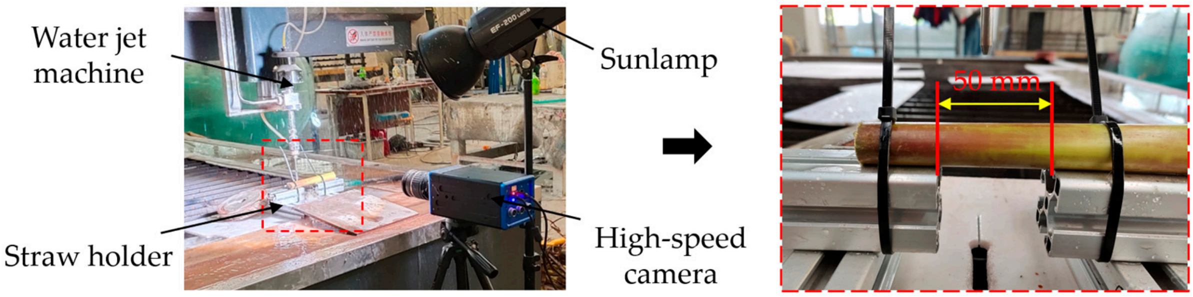


Figure 3. The bench for water jet cutting experiments.

3.3. Experiments

3.3.1. Cutting Stems

The experimental factors selected were the water jet pressure, the target distance, and the traverse speed. The water jet pressure was set as 40, 80, and 120 MPa. To prevent the nozzle from being damaged by soils or stalks, that is, to ensure a safe distance between the nozzle and the ground, the minimum target distance was set as 10 mm, and the target distance levels were determined as 10, 20, and 30 mm. The traverse speed levels were determined to be 1000, 4000, and 7000 mm/min. Then, 27 groups of all-factor tests with 3 factors and 3 levels were carried out. The levels of each factor are shown in Table 1. One of the stems was cut thrice, each time changing the traverse speed. The experiment was repeated three times for each group.

Table 1. The levels of factors in all-factor stem cutting tests.

Levels	Water Jet Pressure (MPa)	Target Distance (mm)	Traverse Speed (mm/min)
1	40	10	1000
2	80	20	4000
3	120	30	7000

3.3.2. Cutting Stem Nodes

For the single-factor cutting test carried out on the first stem node, the specific parameters are shown in Table 2. Each group was repeated three times.

Table 2. The levels of factors in single-factor stem node cutting tests.

Groups	Water Jet Pressure (MPa)	Target Distance (mm)	Traverse Speed (mm/min)
1	40, 80, 120, 160, 200	30	4000
2	120	10, 20, 30, 40, 50	4000
3	120	30	1000, 2500, 4000, 5500, 7000

3.4. Cutoff Ratio

To analyze the water jet cutting ability, the cutoff ratio was defined as the index, which meant the ratio of the cutting depth to the diameter of the short axis. Maize stalks with similar short-axis diameters were selected in the experiment. The diameter of stems was 20.5 ± 0.5 mm, and the diameter of stem nodes was 25.5 ± 0.5 mm. The position of the high-speed camera was fixed, and the pictures were taken after cutting. The computer software of the high-speed camera was used to measure the short diameter D_1 of the cutting position and the cutting depth D_2 (taking the stem as an example, as shown in Figure 4). The cutoff ratio Y was obtained according to the ratio of the two.

$$Y = D_2/D_1 \tag{1}$$

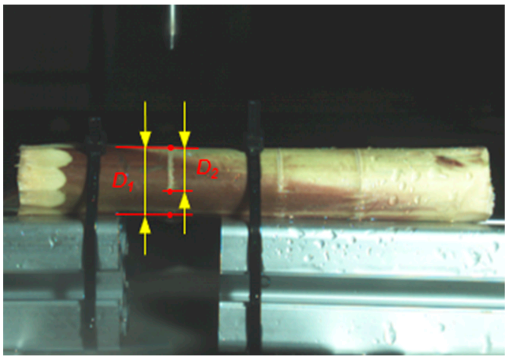


Figure 4. Cutting effects of water jets captured by the high-speed camera.

4. Results and Discussion

4.1. Influence of Cutting Parameters on the Cutoff Ratio of Stems

4.1.1. Results of Different Cutting Parameters

Under three levels of water jet pressure, the cutoff ratios of the stems at different target distances and traverse speeds were analyzed, as shown in Figure 5. The different letters a−c of the same pressure and target distance in the figures indicate a significant difference in the cutoff ratio at different traverse speeds.

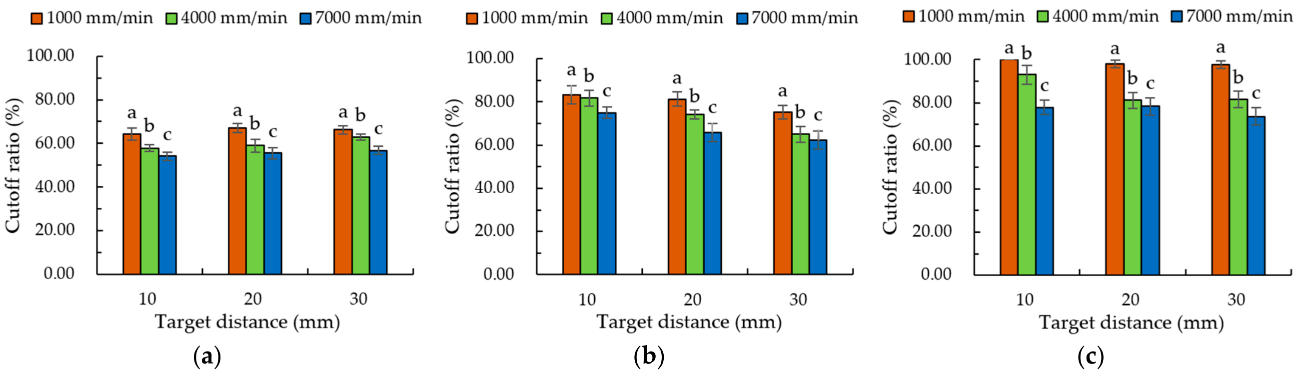


Figure 5. Experimental results of different cutting parameters. (**a**) 40 MPa; (**b**) 80 MPa; (**c**) 120 MPa.

When the water jet pressure is 40 MPa, the cutoff ratio is about 60%, as shown in Figure 5a. Under this pressure, when the target distance is 10 mm, and the traverse speed is 7000 mm/min, the cutoff ratio reaches a minimum of 54.11%. Moreover, when the target distance is 20 mm, and the traverse speed is 1000 mm/min, the cutoff ratio is the highest, which is 66.92%. When the target distance is fixed, the cutoff ratio decreases with the increase in the traverse speed in the range of 1000–7000 mm/min. However, the cutoff ratio does not change regularly with the target distance. Therefore, when the water jet pressure is 40 MPa, the cutoff ratio decreases with the increase in the traverse speed, and no effect of the target distance on the cutoff ratio was found in this single group.

When the water jet pressure is 80 MPa, the cutoff ratio is more than 60%, and the target distance and traverse speed have an influence on the cutoff ratio, as shown in Figure 5b. When the traverse speed is the same, the cutoff ratio decreases with the increase in target distance. When the target distance is the same, the cutoff ratio decreases with the increase in the traverse speed. Therefore, when the water jet pressure is 80 MPa, the target distance is 10 mm, and the traverse speed is 1000 mm/min, the cutoff ratio is the highest, which is 83.18%.

When the water jet pressure is 120 MPa, the cutoff ratio is more than 70%, and the cutoff ratio tends to decrease with the increase in the traverse speed, as shown in Figure 5c. When the traverse speed is 1000 mm/min, the cutoff ratio decreases with the increase in the target distance. When the traverse speed is 4000 mm/min and 7000 mm/min, the target distance has no influence on the cutoff ratio. The cutoff ratio reaches 100% when the water jet pressure is 120 MPa, the target distance is 10 mm, and the traverse speed is 1000 mm/min. At this point, the stems are cut off.

Therefore, the cutoff ratio is positively correlated with the water jet pressure and negatively correlated with the traverse speed. With the pressure increasing, the impact velocity and kinetic energy of the jet acting on the stems increases, and the stems are more easily destroyed [16]. However, with the increase in the traverse speed, the time of the water jet impacting on the stems decreases, and the stems are not sufficiently impacted. Generally, increasing the target distance will increase the distance between the water jet nozzle and the work object. Due to the higher atomization over a long distance, the cutting ability is reduced, resulting in a decrease in the total impact force [20]. In these figures, the effect of the target distance on the stems' cutoff ratio is not obvious, so it is necessary to further explore this through significance analysis and regression analysis. In addition, Hu et al. [13,22] found that when the water jet pressure was 280 MPa, all samples of the stems could be cut off. This water jet pressure is larger than the 120 MPa water jet pressure in this paper. The moisture content of the stems used by Hu et al. [13] was 54.7%, which is different from the 80.05% in this paper. Moreover, Desbiolles et al. [14] found that the cutting efficiency was highest when the wheat stem was wet and compressed. Therefore, the water content might have an effect on the cutoff ratio, and relevant experimental studies could be carried out in the future.

4.1.2. Multilinear Stepwise Regression Analysis

In Table 3, the p values of the water jet pressure A, the target distance B, and the traverse speed C are all less than or equal to 0.01. Therefore, these three factors all have highly significant effects on the cutoff ratio Y. Meanwhile, the p value of $A \times B$ is 0.010, which means that there is a highly significant interaction between the water jet pressure and the target distance. The p value of $A \times C$ is $0.032 < 0.05$, so the interaction between the water jet pressure and the traverse speed is significant. Moreover, the p value of $B \times C$ is $0.419 > 0.10$, so there is no interaction between the target distance and the traverse speed.

Table 3. Results of the analysis of significance.

Source	*F* Values	*p* Values
Model	38.340	0.000
A (Water jet pressure)	235.927	0.000
B (Target distance)	8.709	0.010
C (Traverse speed)	74.771	0.000
$A \times B$ (Water jet pressure × Target distance)	7.120	0.010
$A \times C$ (Water jet pressure × Traverse speed)	4.607	0.032
$B \times C$ (Target distance × Traverse speed)	1.100	0.419

Note: $p > 0.05$ means not significant; $0.01 < p \leq 0.05$ means significant; $p \leq 0.01$ means highly significant.

Based on the results of the analysis of significance in Table 3, multiple linear regression analysis was carried out, and the regression equation was obtained by the stepwise method:

$$Y = 47.209 + 0.521A - 0.004A \times B - 2.997 \times 10^{-5} A \times C, \quad (2)$$

All the parameters in Formula (2) are actual values. $R^2 = 0.945$, $F = 132.240$, and $p < 0.01$ of the regression equation indicate that the equation has a significant statistical significance. The results show that A, $A \times B$, and $A \times C$ significantly influence the cutoff ratio ($p < 0.05$). To ensure that stems are cut off with a high cutting efficiency, the parameter combination was obtained according to the regression equation: when the water jet pressure A is 120 MPa, and the target distance B is 10 mm, the traverse speed C reaches the maximum value, which is 1371 mm/min.

4.2. Influence of Single Factors on the Cutoff Ratio of Stem Nodes

4.2.1. Influence of the Water Jet Pressure

The water jet cutting experiments on the stem nodes were conducted within a water jet pressure range of 40–200 MPa, and the results are shown in Figure 6. According to the variation trend in the data, the cutoff ratio increases with the increase in the water jet pressure until it reaches 100% when the pressure is 160 MPa. Therefore, only the first 4 data are fitted during the linear regression analysis, and the value of R^2 of the fitting equation is 0.9305, which is statistically significant. A significance test was conducted on the test results, and the p value was 0.035 < 0.05, indicating that the water jet pressure had a significant influence on the cutoff ratio of the stem nodes. When the water jet pressure was greater than or equal to 160 MPa, the stem node was cut off.

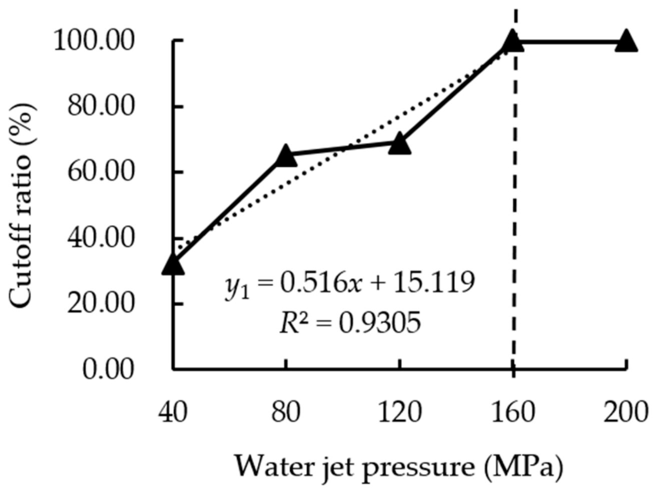


Figure 6. Influence of the water jet pressure on the cutoff ratio.

4.2.2. Influence of the Target Distance

The influence of a target distance within 10–50 mm on the cutoff ratio of the stem nodes is shown in Figure 7. With the increase in the target distance, the cutoff ratio decreases slightly. According to the linear regression equation, the target distance is negatively correlated with the cutoff ratio. The value of R^2 of the linear regression equation is 0.7917, indicating that the equation fits the results less effectively. The significance test was conducted, and the p value was 0.043 < 0.05, which proved that the influence of the target distance on the cutoff ratio was statistically significant. In this experiment, none of the stem nodes was cut off, and the highest cutoff ratio is 68.45% when the target distance is 10 mm, the water jet pressure is 120 MPa, and the traverse speed is 4000 mm/min.

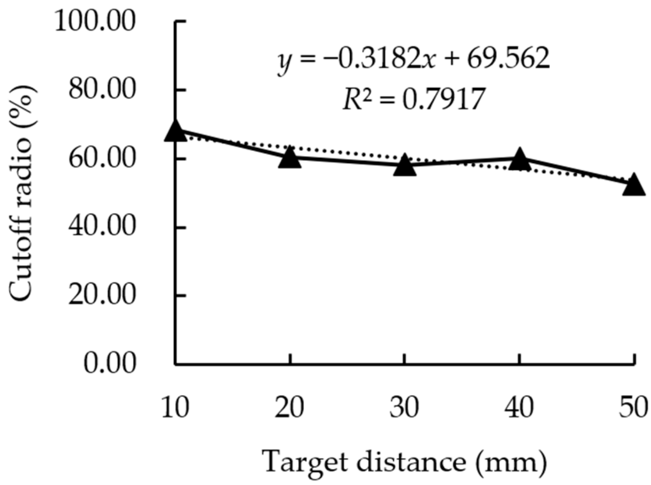


Figure 7. Influence of the target distance on the cutoff ratio.

4.2.3. Influence of the Traverse Speed

The influence of the traverse speed on the cutoff ratio of the stem nodes was studied by fixing the water jet pressure and target distance, as shown in Figure 8. The cutoff ratio decreases with the increase in the traverse speed. In the figure, the value of R^2 of the linear regression equation is 0.9672, indicating that the equation has a good linear fit. The cutoff ratio of the stem nodes decreases linearly with the increase in the traverse speed in the range of 1000–7000 mm/min. The maximum cutoff ratio is 86.08% when the traverse speed is 1000 mm/min. The minimum value is 42.86% when the traverse speed is 1000 mm/min. The significance analysis of the test results shows that the p value is 0.003 < 0.01, indicating that the traverse speed significantly influences the cutoff ratio.

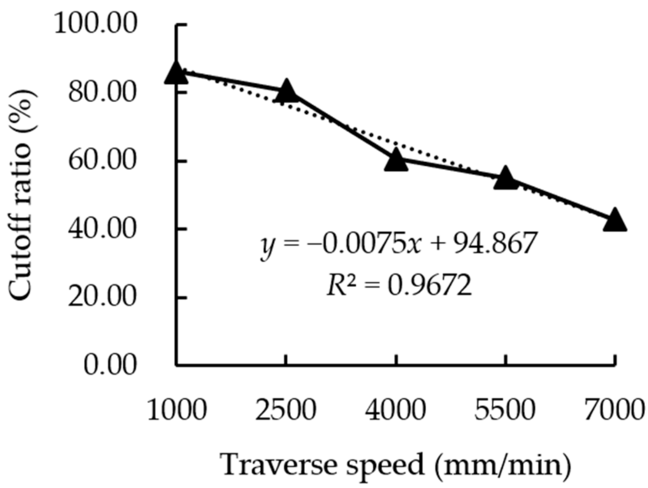


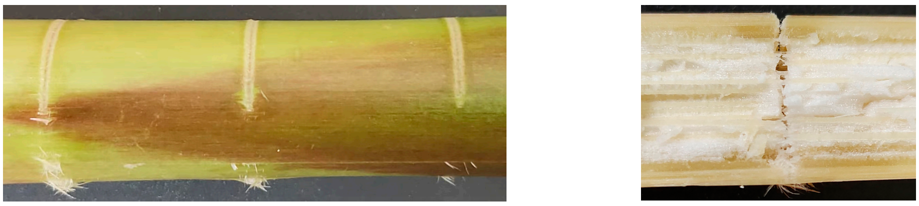
Figure 8. Influence of the traverse speed on the cutoff ratio.

Consequently, the water jet pressure, the target distance, and the traverse speed all influence the cutoff ratio of stem nodes. The higher the pressure is, the higher the cutoff ratio is. When the pressure is greater than or equal to 160 MPa, the cutoff ratio reaches 100%. The cutoff ratio decreases with the increase in the target distance and the traverse speed. In addition, the influence of the water jet pressure and the traverse speed on the cutoff ratio of the stem nodes is more significant. Comparing with the results from stem cutting experiments, it is found that when the water jet pressure is 120 MPa, the target distance is 10 mm, and the traverse speed is 4000 mm/min, the cutoff ratio of the stems or stem nodes is 93.03% or 68.45%. Thus, cutting off stem nodes requires a greater impact force (higher water jet pressure and lower target distance and traverse speed) than cutting off stems, and the cutting parameters should be set to a water jet pressure $\geq$ 160 MPa, target distance $\leq$ 10 mm, and traverse speed $\leq$ 1371 mm/min to ensure that both stems and stem nodes are cut off.

4.3. Analysis of the Phenomena after Cutting

4.3.1. Bottom Burrs

After water jet cutting, the unbroken maize stalk has a kerf at the top and may have burrs at the bottom. When the impact force of the jet is insufficient to penetrate the maize stalk, there will be no burr at the bottom. A group of stem cutting experiments is taken as an example when the water jet pressure is 40 MPa, the target distance is 10 mm, and the traverse speed from left to right is 1000, 4000, and 7000 mm/min, as shown in Figure 9a. Figure 9b shows the cutting effect inside the stem.



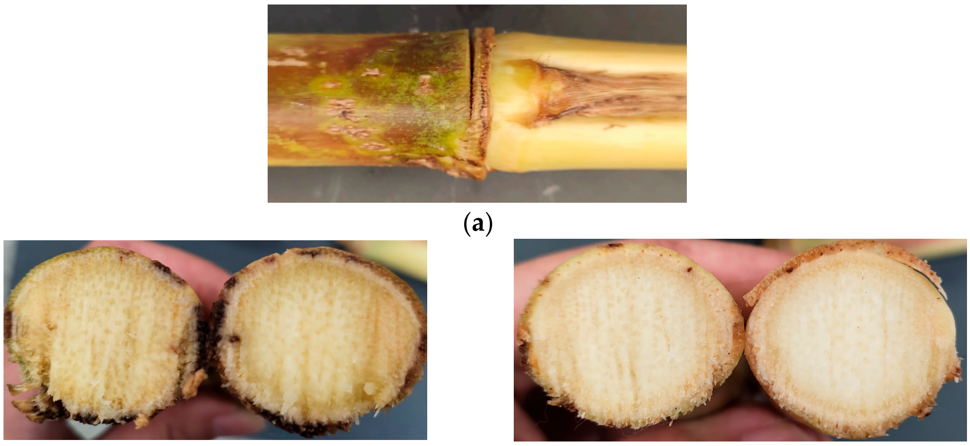
(**a**) (**b**)

Figure 9. Effects of water jet cutting on the stem. (**a**) Outside the stem. (**b**) Inside the stem.

The generation of bottom burrs is mainly related to the water jet's structure and the maize stem's composition. Firstly, after the water jet is ejected from the nozzle, divergence will occur with the increasing distance. Atomization will occur at the edge, and the long distance and the kinetic energy of the jet in the atomization zone will decrease, the impact force of the water jet will be insufficient, and the cutting ability is finally reduced [19]. Secondly, the maize stem mainly comprises the outer rind and inner pulp. The inner pulp is soft and more easily damaged by the water jet than the outer rind [21]. Therefore, during the cutting operation, the water jet first breaks through the upper rind of the stem and then forms a kerf on the inner pulp. After that, with the loss of energy and the divergent jet, the impact force on the bottom rind is insufficient, resulting in some of the fibers breaking and forming burrs. In contrast, the unbroken fibers are still connected, as shown in Figure 9b. In addition, when the impact force of the water jet is insufficient, the faster the traverse speed, the shorter the time of the water jet acting on the stem, and only a few bottom fibers are broken through.

4.3.2. Surface Stripes

Surface stripes appear at the cross section of severed maize stalks. Figure 10 compares the cutting effects of stem nodes under 3 pressures (120, 160, and 200 MPa). In Figure 10a, when the water jet pressure is 120 MPa, the stem node is not cut off, and there is a kerf on the top. Figure 10b,c show that the stem nodes are cut off when the water jet pressure is 160 and 200 MPa. However, the cut surface is rough and has stripes. The lower the water jet pressure is, the more obvious the stripes on the surface are.



(**a**) (**b**) (**c**)

Figure 10. Effects of water jet cutting on the stem nodes under different pressures. (**a**) 120 MPa; (**b**) 160 MPa; (**c**) 200 MPa.

In Figure 10b, the surface stripes at the bottom are significantly deeper than those at the top. That is because the divergent characteristic of the water jet makes the farther distance from the jet nozzle and the greater atomization of the water jet result in a smoother upper surface than lower surface. In Figure 10c, no difference between the stripes of the upper and lower parts is apparent. The reason is that the higher the pressure is, the more concentrated the water jet is, and the stronger the impact force on the maize stalk is, which can improve the smoothness of the cut surface. This is consistent with the results of wood cutting using water jet cutting technology [23]. However, higher pressures are accompanied by increasing costs of booster devices and pipelines [24], and surface stripes have no effect on cutting off maize stalks. Therefore, the pressure should be set to meet the minimum required for cutting off maize stalks in the field operation.

4.3.3. Cutting Residue

The cutting experiments found that although the top and bottom of the maize stalks had been removed, the end might still be connected. As shown in Figure 11, there is a phenomenon called cutting residue. Wu [25] found that removal of the upper and lower materials at the cutting edge was inconsistent when cutting regular metal materials with water jets. In this paper, since maize stalks are elliptical cylinders, the uneven material removal is reflected in the cutting residue at the cutting edge of the maize stalk.

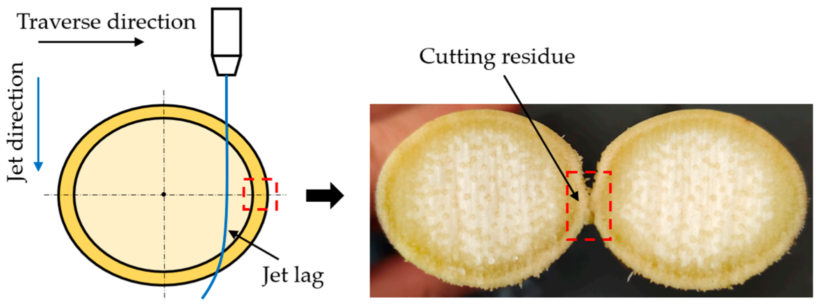


Figure 11. The phenomenon of cutting residue.

The generation of cutting residue is caused by jet lag [20,26]. Since the water jet cannot instantly penetrate a certain thickness of the material, there will be a removal process from top to bottom. As the jet moves forward, the upper material is removed first, and then the jet can act on the lower material. Therefore, the jet will gradually deflect along the cutting depth direction, and jet lag occurs. When the water jet acts on the maize stalk, the elliptic surface makes the nozzle become farther and farther away from the upper surface of the stalk and closer and closer to the lower surface. Finally, the cutting residue is lower in the middle of the maize stalk. However, cutting residue only appeared in some of the cutting experiments, which were related to different cutting parameters and the individual differences in the maize stalks. Generally, the greater the impact force of the water jets is, the lower the possibility of cutting residue is. Moreover, a kerf will be left on the surface of the maize stalk after the water jet cutting. It is possible to try to use the disc opener to cut again along the kerf to ensure that the residue at the cutting edge is completely cut off.

Therefore, due to the divergent and lagging characteristics of the water jet, bottom burrs, surface stripes, and cutting residue may appear after cutting. Firstly, when the impact force of the water jet is not enough to cut off the maize stalks, some bottom fibers are broken and others are still connected, creating the burrs on the bottom. When the impact force is too small to break the bottom rind, the bottom of the maize stalks is smooth. Secondly, stripes on the cut surface have no effect on the results of cutting off the stalks, only on the surface quality. A higher water jet pressure will have a better cut surface quality. Thirdly, cutting residue may appear, with a remaining connection at the end of the maize stalk that is not completely cut off. This phenomenon might be solved by improving the impact force (higher water jet pressure and lower target distance and traverse speed) or cutting the stalks again with a disc opener.

5. Conclusions

Based on the cutting principle of water jet cutting technology, we conducted water jet cutting experiments on maize stalks (including stems and stem nodes) and studied the effects of different cutting parameters on the cutoff ratio of the maize stalks and the phenomena after cutting. The main conclusions are as follows:

(1) The cutoff ratio of stems and stem nodes cut by water jets increases with the increase in the water jet pressure and the decrease in the target distance and the traverse speed. Compared with the target distance, the water jet pressure and the traverse speed have more significant effects on the cutoff ratio of maize stalks.

(2) We carried out 27 groups of all-factor cutting tests on the stems, and a significance analysis of the results and the establishment of a regression equation were completed. Under the optimal condition that the traverse speed is the maximum and the stem is cut off, the corresponding parameter combination is: a water jet pressure of 120 MPa, target distance of 10 mm, and traverse speed of 1371 mm/min. Next, single-factor cutting tests were carried out on the stem nodes. When the target distance is 30 mm, the traverse speed is 4000 mm/min, and the water jet pressure is greater than or equal to 160 MPa, the cutoff ratio of the stem nodes is 100%. To cut off stems and stem nodes simultaneously, a parameter range of a water jet pressure $\geq$ 160 MPa, target distance $\leq$ 10 mm, and traverse speed $\leq$ 1371 mm/min should be ensured.

(3) Bottom burrs, surface stripes, and cutting residue may appear after cutting because of the divergent and lagging characteristics of the water jet. The bottom burrs are caused by the insufficient impact force of the water jet, which cannot completely break the bottom of the maize stalk. The surface stripes only affect the surface quality but not the cutting results. However, even though the upper and lower parts of the maize stalks are cut off, cutting residue may appear at the end of the maize stalks. Improving the impact force or cutting again with a disc opener is essential to deal with this phenomenon.

This study shows that the cutting parameters and the phenomena after cutting affect the cutting effect of maize stalks. To ensure that the maize stalks are completely cut off by water jets, it is necessary to obtain an optimal range of cutting parameters and deal with the phenomenon of cutting residue that may appear after cutting. Among the cutting parameters, the traverse speed determines working efficiency. High water jet pressure is associated with high operating costs and requires paying more attention to operating safety. Therefore, future experimental studies are needed to explore the possibility of increasing the traverse speed and reducing the water jet pressure. For example, studying the water jet cutting effect of maize stalks under different water contents and whether to cut them off requires different parameters, or using image recognition and intelligent control technology to save water, that is, controlling the opening and closing of the water jet based on whether there are stalks on the soil surface.

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