applied sciences

MDPI

Review

Applications of Water Jet Cutting Technology in Agricultural Engineering: A Review

Dandan Cui [1,2], Hongwen Li [1,2,*], Jin He [1], Qingjie Wang [1], Caiyun Lu [1], Hongnan Hu [3], Xiupei Cheng [4] and Chunlei Wang [1]

1 College of Engineering, China Agricultural University, Beijing 100083, China
2 Scientific Observing and Experiment Station of Arable Land Conservation (North Hebei), Ministry of Agricultural and Rural Affairs, Beijing 100083, China
3 College of Mechanical and Electrical Engineering, Zhongkai University of Agriculture and Engineering, Guangzhou 510225, China
4 College of Agricultural Engineering and Food Science, Shandong University of Technology, Zibo 255000, China
* Correspondence: lhwen@cau.edu.cn; Tel.: +86-10-62737300

Abstract: Cutting is a significant part of agricultural material processing, and the cutting technology determines the quality of agricultural products. Water jet cutting technology is a non-contact and cold cutting technology suitable for cutting agricultural materials. It can realize an environmentally friendly cutting process avoiding such problems as heat generation, sharpening and cleaning blades, and microbial cross-contamination. This paper reviews the current status of water jet cutting of six kinds of agricultural materials, including vegetables, fruits, meats, woods, stems, and soils. By analyzing how to complete different cutting operations, improve cutting ability, or control post-cutting influences, the problems and solutions of water jet cutting of each material are summarized. Then, combined with the application requirements, some suggestions are put forward for developing water jet cutting technology. The results would help researchers determine key information required by cutting agricultural materials and provide a reference for further research on water jet cutting technology in agricultural engineering.

Keywords: water jet cutting technology; agricultural materials; agricultural machinery; non-contact

check for updates

Citation: Cui, D.; Li, H.; He, J.; Wang, Q.; Lu, C.; Hu, H.; Cheng, X.; Wang, C. Applications of Water Jet Cutting Technology in Agricultural Engineering: A Review. *Appl. Sci.* **2022**, *12*, 8988. https://doi.org/10.3390/app12188988

Academic Editor: Roberto Romaniello

Received: 10 August 2022
Accepted: 5 September 2022
Published: 7 September 2022

1. Introduction

As an indispensable processing technology in agricultural engineering, cutting is widely used to peel, slice, trim, dice, and harvest agricultural materials [1,2]. Agricultural products include edible and flammable materials, so clean and pollution-free operation is required. Existing cutting methods can be divided into traditional cutting technologies represented by blade cutting and non-traditional cutting technologies involving multiple energy sources and processes (i.e., wire electrical discharge machining, plasma arc cutting, laser cutting, flame cutting, water jet cutting, etc.) [3,4]. Among them, water jet cutting technology, as a cold cutting method, is suitable for cutting agricultural materials because of its no-heat and spark-free processing characteristic and non-contact cutting way [5].

At present, water jet cutting technology has been widely applied in industry, medicine, and other fields, involving ores, metals, plastics, and other materials, accompanied by a variety of technical and theoretical supports [6–15]. There are many specific advantages that have been found. For example, the water jet cutting process will not cause problems such as a heat-affected zone and thermal deformation, which can avoid fire hazards [16]. Unlike traditional cutting tools contacting objects directly, which need to sharpen, clean, and change blades in time, water jet cutting has a non-contact way and can save time and labor by less often replacing worn nozzles [17–19]. Water is the primary medium for water jet cutting, which is green and recyclable [20]. These advantages are conducive to cut agricultural materials by water jet cutting technology. However, the research depth of water jet cutting technology in agriculture engineering is low due to the variety of agricultural materials [21,22]. Most processed products become foods, which require high quality and safety [23,24]. Some cutting operations are carried out in complex field environments rather than factories, such as cutting stems and soils, whose applications are more challenging [22,25]. Moreover, there are many outcomes of water jet cutting (i.e., cutting depth, kerf width, surface roughness, etc.) and post-cutting influences on agricultural materials (i.e., microbial counts, brownish cut edges, the loss of raw materials, etc.), which are the major indices to judge the cutting quality [26].

Therefore, this paper reviews the application status of water jet cutting technology in agricultural engineering, including six kinds of agricultural materials (i.e., vegetables, fruits, meats, woods, stems, and soils). How to cut each material to complete different cutting operations, improve the cutting ability, or control post-cutting influences is analyzed. Then, suggestions for future directions of water jet cutting technology are put forward, including deepening mechanism research, optimizing agricultural machinery, and adopting intelligent control.

2. Description and Components of Water Jet Cutting Technology

The water jet cutting system consists of a water supply device, a filter device, a pressurizing device, a jet nozzle, and a working object (Figure 1). When working, pure water in the water supply device is filtered, compressed, and mixed with the jet medium in disparate methods (pre-mixing or post-mixing) to form the working fluid. Then, the working fluid is ejected from the jet nozzle and acts on the surface of the working object. Finally, the object cracks or breaks under the continuous impact of the working fluid until the cutting operation is completed [27–31]. Therefore, water jet cutting is a dynamic destruction process. Agricultural materials refer to the objects involved in breeding, planting, growing, and processing [32]. Cutting operations (i.e., peeling, slicing, trimming, etc.) may be done in the factory. When working in the field, mobile machines with jet cutting systems need to carry enough water with them for harvesting, fertilizing, or other purposes [25,33].

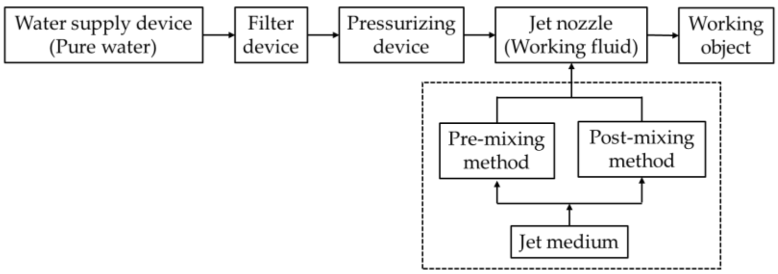


Figure 1. Operation flow chart of water jet cutting system.

Water jet cutting parameters of jet pressure, nozzle diameter, traverse speed, and target distance control the cutting outcome. The jet pressure is adjusted at the pressurizing device and may increase with the quality requirements and costs of the pressurizing device [21,25]. There are two common pumps, involving the triplex pump and the piston-type pump, which can generate pressures greater than 100 MPa [34]. The triplex pump directly pressurizes the water jet, while the piston-type pump indirectly pressurizes the water jet through pressurizing hydraulic oil or air [34]. The nozzle diameter, traverse speed, and target distance are adjusted as required at the jet nozzle. The nozzle is generally made of wear-resistant materials such as artificial gemstones, which can withstand high-speed and high-pressure jets [35].

There are three water jet cutting technologies with different working fluids, including pure water jet cutting technology, abrasive water jet (AWJ) cutting technology, and liquid jet cutting technology [6,9,36]. First, the working fluid of pure water jet cutting technology is pure water, which does not need to be mixed with other media, while the other two technologies require a mixture of water and jet media. Second, the abrasive water jet cutting technology has a stronger cutting ability than the pure water jet cutting technology due to the addition of solid abrasives in the working fluid, involving typical hard abrasives such as garnet and fine river sand, as well as salt particles, sugar particles, and ice particles for processing food [37]. Third, liquid jet cutting technology refers to cutting materials with a working fluid that mixes a liquid medium with water, which is often used to cut vegetables for disinfection, cut soils for jet fertilization, or improve cutting ability [25,38,39]. There are two mixing methods, which have different mixing states of water and jet media before and after entering the nozzle. Water and jet media are mixed in a mixing device before entering the nozzle named the pre-mixing method, and they are mixed in the nozzle named the post-mixing method [25,40]. For the post-mixing method, jet media are inhaled by the negative pressure generated by high-speed water jets entering the mixing chamber of the nozzle and then are ejected after mixing with water jets [41]. As a result, the post-mixing jet nozzle has one more mixing medium inlet (Figure 2) [25,41].

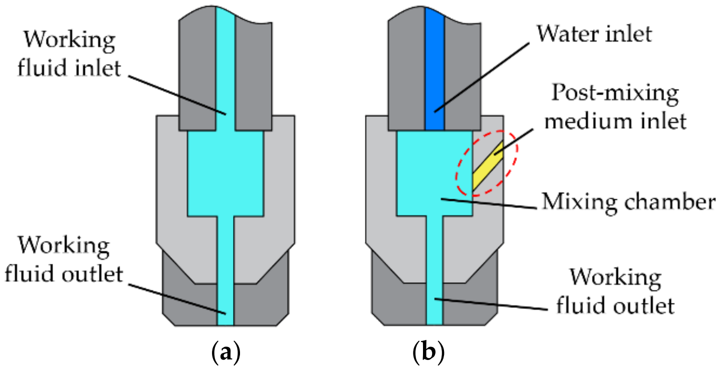


Figure 2. Different jet nozzle structures of two mixing methods: (**a**) Pre-mixing jet nozzle; (**b**) Post-mixing jet nozzle.

3. Applications of Water Jet Cutting Technology on Different Agricultural Materials

3.1. Vegetables

Vegetables can be cut and harvested using water jet cutting technology. Appearance, flavor, texture, and nutritional properties are the four criteria to measure the quality and safety of food [24]. Hence, it is important to control the influences after cutting while completing cutting operations.

3.1.1. Harvesting and Fresh Cutting

As early as 1972, Schield [33] designed a horizontal jet cutting machine for harvesting lettuce crops and found that the complex field environment and cleanliness of lettuce after cutting would limit its application. Moreover, the mobile harvester must carry enough water, which requires more space and increases its weight. Juenemann et al. [42] added a catcher device near the horizontal jet nozzle of the sugar beet harvester to recycle cutting water to reduce the water carried. They advised that the catcher on a mobile machine should be designed as a compact device to collect cutting water. Furthermore, they proposed dissipating the water jet energy into kinetic energy of many small obstacles to minimize the abrasion caused by water jet splash.

Comparably, the trimming and cutting of vegetables in the factory can be achieved more easily than harvesting in the field with fewer limitations of equipment and environment. Soft leafy vegetables and rhizomes with stable structures have achieved fresh cutting operations using water jets, including lettuces, carrots, potatoes, etc. Irwansyah et al. [43] conducted water jet cutting experiments using polycarbonate, polystyrene, and polyethylene materials with a thickness of 2 mm as samples to replace agricultural goods with similar characteristics. The results indicated that water jet cutting technology could process post-harvest products. Posselius et al. [44] successfully cut carrots with diameters of 90 mm using a water jet to trim carrot crowns.

3.1.2. Controlling Post-Cutting Influences

Due to convenience and health, the fresh vegetable processing market is expanding steadily. However, cutting vegetables will inevitably cause mechanical damage to plant tissues, trigger various reactions, and accelerate aging, affecting fresh vegetables' safety and shelf life [18]. Therefore, it is necessary to control post-cutting influences such as cut browning, bacterial infection, and so on [28,38].

When cutting carrots, loose layers of cells appeared on the cut surface, which quickly dehydrated and formed white tissue, affecting the appearance and texture of carrot products [45]. Tatsumi et al. [46] found as much white tissue formed by water jet cutting as by a culinary knife on the cutting surface of carrots during storage with scanning electron microscopy. They advised exploring further the possibility of using a smaller water jet nozzle or adjusting the traverse speed to avoid the creation of loose cell layers. Lu et al. [28] found that using water jets to cut lettuce had an inhibitory effect on the browning of cut surfaces, whether working at 2 °C or 20 °C. Wulfkuehler et al. [18,23], respectively, evaluated the effects of using pure water jets (0.1 mm nozzle diameter, 250 MPa pressure) and conventional blades to cut fresh radicchio and red oak leaf lettuce. They discovered that both methods had a low degree of microbial counts, which were calculated with weighed arithmetic means. Therefore, they proposed that water jet cutting might be an effective alternative to blade cutting and could effectively avoid sharpening blades and cross-contamination during operation interruption. Water jets were used by Hägele et al. [19] to cut salad with fresh iceberg lettuce and endive as raw materials, which obtained the same product quality as conventional blades. Meanwhile, after professional evaluations by the sensory panel, they concluded that water pressures and nozzle parameters slightly affected the sensory quality and the appearance of cut edges. Becker et al. [47] used water jets (0.152 mm nozzle diameter, 207 MPa pressure) to slice potato tubers and observed the results with scanning electron microscopy. They found that because the nonuniformity of the water jet column and surrounding droplets might form a furrow from top to bottom, French fries cut with the water jet resulted in more color irregularities than blade cutting. However, there was no difference in taste or texture. When seed potatoes are cut and prepared in an automated blades process, the microbial cross-contamination of cut surfaces among seed potatoes may occur, reducing production [38]. Yang et al. [38] designed an assembly line for cutting seed potatoes with the liquid jet cutting technology. They adopted the liquid jets containing chemicals for disinfecting potatoes to avoid microbial cross-contamination.

Therefore, when harvesting vegetables by water jet cutting technology in the field, the design and function realization of the mobile harvester are vital, including cleanliness, water capacity, and machine size. Recycling water from a horizontal jet harvester is a great way to reduce water consumption. When cutting fresh vegetables, attention should be paid to the post-cutting influences. For example, optimizing jet cutting parameters controls cut browning and extra tissue generation. Water jets and traditional blades have similar cutting effects when cutting some vegetables. However, the non-contact cutting way makes water jet cutting avoid microbial cross-contamination compared to blade cutting. In addition, liquid jet cutting technology can use working fluids containing disinfection, but further studies should be explored to improve the method.

3.2. Fruits

Fruits are generally removed, peeled, and cut into blocks or segments by water jets with the main purpose of post-harvest processing and a small part for field harvesting (i.e., sugarcanes) [48,49]. The details are as follows:

3.2.1. Post-Harvest Processing

Post-harvest processing is an important part of fruit processing. Due to the simple structure, some fruits can be easily identified in shape and position, which is conducive to matching the water jet cutting technology with intelligent technologies (i.e., machine vision, image recognition, robot technology, etc.) to improve work efficiency.

Lin et al. [50] designed a machine for removing strawberry calyx automatically. It was equipped with a color-based machine vision section (Figure 3) and a water jet cutting system with 206.8 MPa jet pressure and a 0.127 mm diameter diamond orifice nozzle. Results indicated that when medium sized (25–38 mm diameter) strawberries were processed by water jets at the traverse speed of 0.3 m/s, calyx-free strawberries could be produced at the highest rate of 2270 kg/h. Meanwhile, the calyx-free fruit, calyx and white shoulder, residual, and return fruit weight percentages were 49.6%, 18.2%, 8.1%, and 24.1%, respectively. The return fruit meant that it would be fed back into the machine for a second processing opportunity. For further advancements, they advised that building a multi-axis calyx removal system accommodates a wider range of shapes and sizes. To minimize the direct contact between product and personnel, Olejua et al. [21,24] combined robotics, water jets, and image processing techniques to complete an integrated process of peeling or cutting fruits such as mangos, melons, pineapples, and apples. Under such parameters as the maximum water flow rate of 0.6 L/min, the nozzle diameter of 0.15 mm, and the average pressure of 292–308 MPa, the post-harvest processing of these fruits could be realized.

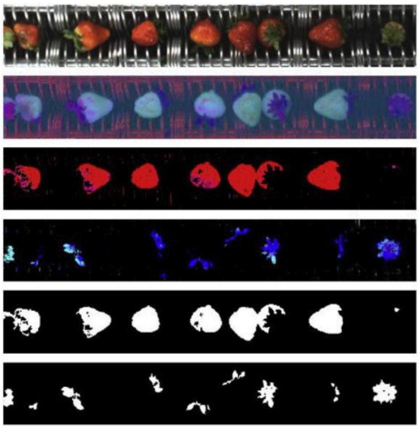


Figure 3. Image recognition assisted water jet in removing strawberry calyx ([50], adapted from “Design and testing of an automated high-throughput computer vision guided waterjet knife strawberry calyx removal machine” with permission from Elsevier, 2022).

3.2.2. Field Harvesting

It is a developing direction to use water jet cutting technology to harvest fruits in the field. There are some studies on sugarcane harvesting at present. The chopper used for sugarcane harvesting is easily blocked around the rotating blades, resulting in rapid blade wear, and repeated cutting with dull blades harvesting will damage the stalk [51,52]. Thus, water jet cutting as a non-contact cutting option is proposed to replace the rotating tool.

Valco et al. [51] used pure water jets with the pressure of 400 MPa and a nozzle diameter of 0.36 mm to cut sugarcane stalks under laboratory conditions. However, specifications for mobile water jet cutting sugarcane were not achieved. To explore the possibility of cutting sugarcane in the field environment, Thanomputra et al. [49] proposed a post-mixing AWJ harvesting method using fine river sand as an abrasive to improve the cutting ability. The jet with a water inlet and a nozzle diameter combination of 0.25 and 0.76 mm at 360 MPa water pressure produced a water flow rate of 1.6 L/min and a power input of 15 kW by the Hoogstrate model [53] and a MATLAB program. The study showed that cutting sugarcane with diameters of 30 and 120 mm required a traverse speed of 1.22 m/s and 0.31 m/s, respectively. It also was found that sugarcane stalks could be completely cut off at a farther target distance by reducing the traverse speed. However, to ensure the thickness of cutting sugarcane and the optimum traverse speed, the target distance should be set to no more than 210 mm when the minimum transverse speed is 0.17 m/s.

Consequently, water jet cutting technology has realized the post-harvest processing and field harvesting of some fruits. To increase the efficiency and utilization of processing machines, intelligent control systems and multi-fruit machines should be designed and manufactured. Cutting sugarcane with water jet under laboratory conditions has been achieved. However, field harvesting is more challenging with complex environments compared with post-harvest processing, so the possibility and applicability of water jet harvesting fruits should be further studied.

3.3. Meats

As microbial cross-contamination cannot be avoided entirely by blade cutting and the cost of disposable knives is high, water jet cutting technology is gradually applied in meat cutting and trimming. Moreover, it is essential to improve the cutting ability for cutting off meat with bone and control meat loss to guarantee economic benefits.

3.3.1. Cutting and Trimming

Choosing the right operation parameters is important to cut and trim various meats, including the jet pressure, the nozzle diameter, and the transverse speed.

Heiland et al. [54] investigated the method of removing undesirable substances from beef clip bone slices by high-pressure water jet. The results showed that the best cutting effect could be obtained when the diameter of the water jet nozzle was 0.15 mm, the water pressure was 380 MPa, the slice thickness was 19 mm, and the traverse speed was 0.18 m/s. Bansal et al. [55] conducted a replicated experiment to determine the optimum settings for cutting boneless chicken breast meat with high-pressure water jets. They found that the best results of sharp and clean cuts could be gotten with a 0.127 mm nozzle, a water pressure in the range of 179 to 224 MPa, and a 0.1 m/s or slower speed. Meanwhile, good cutting effects were obtained for chicken fillets to approximately 0 °C. That was because firm frozen meat was difficult to cut, and meat that was soft at room temperature had not enough firmness for even wide slices. Kasperowicz et al. [56] conducted jet cutting experiments with fresh trout, and the results showed that water jet cutting had the characteristic of selective cutting fish tissues. When appropriate nozzles and specific pressure values are used, soft tissue (i.e., muscles, fat, and peritoneal membranes) can be cut without affecting harder tissues such as the intermuscular fibers or bones, providing a new idea for fish processing.

Comparing the efficiency of trimming lamb fat by manual, machine, and water jet methods, Purnell et al. [57] found the productivity of water jets was approximately ten times more than both manual and machine trimming. However, the cost of water jet cutting equipment was at least ten times greater than blade trimming equipment. As a result, they proposed that water jet cutting equipment suitable for processing varieties of meats needed to be developed, which would increase its potential market size. Beef cattle are even-toed ungulates, which means that regular trimming must be carried out to avoid disease with hooves' continuing growth and unbalanced wear [58]. As the blade cutting method would produce heat, Čačko et al. [58] proposed using the AWJ cutting method to trim cattle hooves, increasing livestock welfare. They found the temperature at the cut was lower than the body temperature, and when the jet pressure was 150 MPa and the traverse speed was 70 mm/min, the cutting effect was the best.

3.3.2. Improving Cutting Ability

To improve the jet cutting ability and complete cutting operation of bone or larger sections of meat, adding jet media (i.e., abrasives and liquids) to the working fluid is studied.

Typical hard abrasives such as garnet are not suitable for meat processing, so salt, sugar, bone meal, and ice particles are used as abrasives [37]. Alitavoli et al. [59] concluded that AWJ using sugar and salt as abrasives could be successfully applied to beef and pork cutting. Wang et al. [60] studied the cutting effect of salt abrasive water jets on beef, pork, and lamb meat. It was shown that AWJ cutting could deepen the depth of boneless meat compared with pure water jet cutting, and with more salt particles hitting the meat, the depth of the cut was deeper. Meanwhile, the freezing or chilling costs could be eliminated because AWJ cutting was completed at room temperature. Shakouri et al. [61] compared the qualities of bovine femur bones obtained by pure water jet cutting, bone meal abrasive water jet machining, and sugar abrasive water jet machining (350 MPa pressure, 50 mm/min transverse speed). The results showed that bone meal and sugar biocompatible abrasive particles improved the surface roughness and cut quality compared to pure water jets. In addition, sugar particles had better properties than bone meal because of a lower density and a more uniform aggregation. However, salt and sugar as abrasives can have a certain impact on the taste of the final products, so ice particles are proposed as a substitute. McGeough [37] found that ice particle water jets were 40% deeper into bones than pure water jets, which meant that ice particles might be applicable in the primary cutting of meats and bones in abattoirs. Ice particles were also suitable for cutting frozen and soft foods. When ice particles were used as abrasives with 0.15–0.3 mm diameters, properties such as the hardness, flowability, and elastic modulus have temperature dependence. Therefore, ice particles should be generated below −20 °C, and injecting ice abrasives with cooling water was recommended [62,63].

Polyethylene oxide (PEO) is a safe polymer commonly used in the food industry as a thickener or flocculant [64]. Pogrebnyak et al. [39] used PEO solution mixed with water as the working fluid to perform liquid jet cutting tests on varying meats (i.e., chicken fillet, hake fish, beef, and pork). The experiments were carried out at temperatures of −7 and −25 °C, with pressures changing from 50 to 150 MPa and cutting speeds ranging from 0.015 to 0.1 m/s. They showed that with the increasing PEO molecular mass and concentration, the cutting depth of frozen food increased rapidly and then decreased, which could reach a maximum at some optimal concentrations. When the cutting depth was the same, the required PEO solution jet pressure was only 45–65% of the pure water jet.

3.3.3. Reducing Meat Loss

Meat loss (or kerf width) is the central problem encountered in water jet cutting, closely related to economic benefits [60]. Bansel et al. [55] found that large nozzles caused excessive meat loss, especially at higher water pressures and slower traverse speeds. Franklínsdóttir [65] conducted pure water jet cutting experiments on cod and salmon fillets. The results showed that super-chilling applied before cutting had a better cutting effect. Due to the kerf width increasing with transverse speed and nozzle diameter, the transverse speed range should be set for disparate parts of the fish fillet (i.e., tail, waist, and abdomen), and a smaller nozzle aperture could obtain a better cutting performance. Wang [60] et al. found that a salt abrasive water jet could make the surface of meats with bone smooth and the kerf width measured by a variable thickness feeler gauge was less than 1 mm, making less meat loss (Figure 4, 400 MPa jet pressure, 5 mm/s traverse speed, 16.2 kg/h salt mass flow rate for salt water jet). Moreover, as the cutting depth deepens, the kerf width gradually decreases.

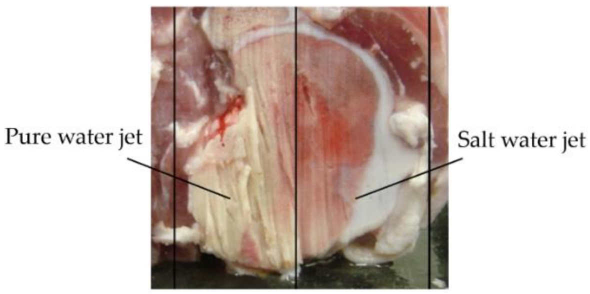


Figure 4. Contrast tests of cutting pork included bone with pure water jet and saltwater jet ([60], adapted from "Cutting meat with bone using an ultrahigh pressure abrasive waterjet" with permission from Elsevier, 2022).

Hence, meat cutting operations can be completed by water jet cutting under the optimal cutting parameters and suitable jet media. Pre-cooling meat is convenient for pure water jet cutting. Adding abrasives or liquids can improve the cutting ability and cut larger sections of meat, bone, or meat with bone. Furthermore, meat can be cut at room temperature using AWJ, which will reduce the cost of pre-cooling but increase the cost of abrasives. As for reducing meat loss, it is necessary to add abrasives or pre-cooling based on optimizing the cutting parameters (i.e., a low transverse speed and a small nozzle diameter). Moreover, water jet cutting devices with a wide applicability and strong functionality need to be designed to reduce the overall costs.

3.4. Woods

With the increasing demand of wood and wood-based products, it is necessary to improve the utilization rate of raw materials during processing [66]. Compared with planing and sawing, water jet cutting makes smaller kerf widths, fewer dusts, and acceptable noise outputs [66]. Generally, the surface roughness and kerf width are crucial factors determining the quality of wood products [67–69].

Lee [69] conducted AWJ cutting on sixteen Korean domestic wood species and found that with the increase in the cutting depth, the surface roughness increased, and the cut width decreased. Gerencsér et al. [66] took nine important Hungarian tree species with a thickness of 25 mm as samples to study the influence of AWJ cutting technology on the moisture uptake, surface roughness, and kerf width of solid wood. The results showed that residual moisture caused by abrasive water jets mainly concentrated in the surface layer, and there were no significant changes after one day compared to the original state, so residual moisture could not affect practical applications. The mean roughness depth parameter (Rz) values varied between 15 and 85 μm depending on the species and cutting direction, and they were always lower than those of planing and sawing. The entry kerf width values of various species ranged from 0.8 to 1.6 mm, and the egress width values ranged from 0.4 to 0.8 mm, which meant that the edge was not perpendicular to the material surface. This problem could be solved by properly adjusting the jet angle [67]. Xie et al. [70] used garnet sand as the abrasive to cut red oak and bamboo samples. The study found that the factors affecting the surface roughness were ranked as follows: cutting pressure > traverse speed > abrasive flow rate > target distance > air-dry density. The processing quality of both woods was best when the cutting pressure was 310 MPa, the traverse speed was 0.25 m/s, the abrasive flow rate was 35 kg/h, the target distance was 3 mm, and the air-dry density was 620 kg/m^3. Pelit et al. [71] cut pine, beech, and oak samples in an abrasive water jet system (Figure 5) and determined surface roughness values by a surface test device. The tests found that surface roughness values of pine and oak samples were higher during tangential cutting and a lower cutting pressure, while beech was the opposite. The textural structure of beech specimens might have an influence on the results. The surface roughness of all samples increased with the increasing traverse speed (50–200 mm/min) and the thickness (18–54 mm) of the wood sample and decreased with the increase in the abrasive flow rate (12–27 kg/h).

Thus, water jet cutting technology has an environmentally friendly characteristic and can be used to cut many wood species. Due to the hard material of woods, abrasives are usually used for improving cutting ability. The surface roughness of cuts is positively correlated with the cutting depth and traverse speed, and negatively correlated with the abrasive flow. Furthermore, the jet pressure, wood species, and cutting direction affect the roughness values to varying degrees. The residual moisture has a weak effect on the practical application of woods. To keep the edge of the cut perpendicular to the material surface, the jet angle should be properly adjusted.

Figure 5. Cutting wood in an abrasive water jet (AWJ) system ([71], reproduced from "Influence of processing parameters on the surface roughness of solid wood cut by abrasive water jet" with permission from NC State University, 2022).

3.5. Stems

Stems are cut by water jets for anti-blocking and jet weeding in the field.

3.5.1. Anti-Blocking

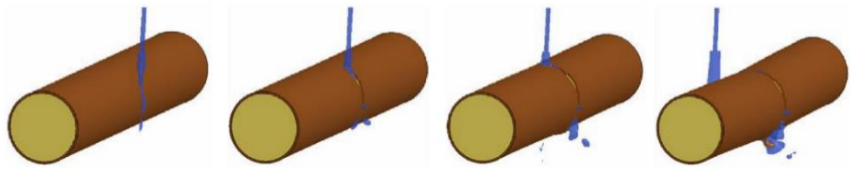
No-tillage sowing in stalk mulching fields can effectively prevent soil erosion and improve soil [72]. However, the sowing operation cannot proceed smoothly because crop stems are on the soil surface, so the stems should be reduced in length or cut off to prevent the openers from blocking. When chopping the stem with a rotary blade or cutting the stem with a disc knife, tool wear occurs due to the direct contact between the tool and the stem, while water jet cutting technology has a non-contact way, which can avoid this problem [72].

To deal with stems blockage, Desbiolles et al. [73] evaluated the cutting capacity of a pure water jet cutting device for a wheat straw internode stem under laboratory conditions (Figure 6). The results showed that the device delivered a cutting capacity of 10–35 Mg/ha of wheat straw stems across the range of nozzle diameters (0.15–0.3 mm) and traverse speeds (1.67–3.33 m/s) under a 380 MPa pressure. Moreover, when the wheat stem was wet and compressed, the water jet work efficiency was the highest. A full factorial design with 200 tests was implemented by Hu et al. [74] to study the effect of different jet parameters on the cutting depth of one single corn stem. The experimental results showed that the cutting depth could increase with a high water jet pressure, a low traverse speed, and a short target distance. When the target distance was less than 10 mm and the water jet pressure was 280 MPa, all single corn stem samples could be completely cut off. Besides, they advised a 10–15 mm standoff distance to avoid the impact of soil and stubble on the nozzle when working in the field. Furthermore, Hu et al. [22] found that the double-disc opener had a better performance than the hoe opener through field experiments assisted by pure ultrahigh water jet cutting (Figure 7). When the water jet pressure was 267–280 MPa, the jet angle was 80.2–90.0°, and the traverse speed was 1.11–1.23 m/s, the overall performance of the double-disc opener reached the maximum. To study the damage process of water jet cutting a single corn stem, Hu et al. [75] adopted an ALE-FEM (arbitrary Lagrangian Eulerian-finite element method) fluid-structure coupling numerical model (Figure 8). Compared with results captured by the high-speed camera, it was confirmed that the simulation model could predict the cutting depth of corn stalk under jet action. Besides, computational fluid dynamics (CFD) models could be used to simulate water jet diffusion inside or around the jet nozzle, and the discrete element method (EDM) could establish the corn stem model [76,77].

Figure 6. Bench tests of cutting wheat straw internode stem by water jet ([73], reproduced from "A laboratory evaluation of waterjet cutting of crop residue using the Aqua-Till® liquid coulter" with permission from Elsevier, 2022).

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

Figure 7. Field experiments for disparate types of furrow openers coordinate with a water jet: (**a**) Double-disc opener; (**b**) Hoe opener ([22], adopted from "Anti-blocking performance of ultrahigh-pressure waterjet assisted furrow opener for no-till seeder" with permission from IJABE Editing and Publishing Office, 2022).



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

Figure 8. Simulation of jet cutting process: (**a**) breaking; (**b**) deepening; (**c**) crossing; (**d**) cutting off ([75], reproduced from the Ph.D. thesis "Study on anti-blocking device for no-till seeder with non-connect stalk cutting by ultra-high-pressure waterjet" with permission from the Author, 2022).

Compared with pure water jet cutting, Perotti et al. [78] found that a number of garnet abrasives (3 kg/h) could improve the jet-cutting ability of wheat stems and reduce the maximum hydraulic power required by laboratory experiments. The cutting operation was estimated to require 5000–7500 W hydraulic power at 6–10 Mg/ha surface density. An average jet hydraulic power of 6400 W could guarantee a 90% cutting efficiency in the presence of heavy residue distribution. In addition, they advised that further research was needed to investigate the residual effects on soil physical properties after cutting.

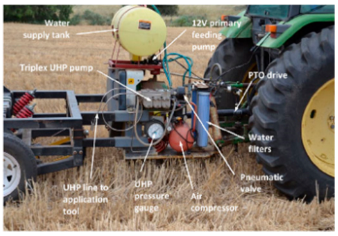
3.5.2. Jet Weeding

Long-term use of chemical weeding will increase herbicide-resistant weeds, and herbicides may cause water pollution and affect the farmland environment. Therefore, thermal or mechanical methods are put forward, and water jet weeding is one of the mechanical weeding methods [79,80].

Fogelberg et al. [81] found that small oilseed rape could be cut off by water jet at 100–300 MPa of pressure and a 1–5 m/s traverse speed, which indicated that as a new physical weeding method, water jet weeding could be used along roadsides or railway embankments. Ishida et al. [82] conducted water jet cutting single seedlings experiments using rice seedlings instead of weeds. The results showed that seedlings could be completely cut off at 30 MPa of pressure (the highest pressure tested), a 100 mm target distance, and a 0.4 mm nozzle parameter, and the cutting ability was stronger near the beginning of water jet diffusion. Meanwhile, the appropriate angle between the water jet and the seedling was approximately 45°. Through experiments on water jet cutting weeds, Zhang [83] concluded that the nozzle diameter less than 1.5 mm was suitable for weeding. That was because a larger nozzle diameter would lead to a jet impact force exceeding the bending capacity of weeds, making weeds bend rather than be cut off. Nevertheless, water jet weeding has some limitations. The growing points of some grass species are protected at or below the soil, making them more difficult to control with water jets [84].

In general, there has been some success with water jet cutting stems, including anti-blocking and jet weeding, but there are still some problems in the design of mobile machines. Due to the limitation of pressurization equipment and water tanks, mobile water jet cutting devices are heavy with large sizes (taking anti-blocking devices as an example, as shown in Table 1) that may cause soil compaction. Hence, soil compaction needs to be dealt with in different ways. For example, adjusting the cutting parameters in real-time according to the amounts of stems on the soil surface is of great significance to reduce water consumption. In addition, equipping the jet nozzle in front of the furrow opener can complete operations of anti-blocking and opening furrow at one time, reducing the number of machines entering the field.

Table 1. Water jet cutting stem devices for anti-blocking.

Stem	Picture	Linkage	Booster Pump
Wheat		Three-point linkage	An ultra-high pressure triplex pump is driven by PTO with a small volume and expensive cost ([73], reproduced from "A laboratory evaluation of waterjet cutting of crop residue using the Aqua-Till® liquid coulter" with the permission from Elsevier, 2022).
Corn		Traction	A piston-type pump uses additional matching diesel engine units to get power with a large volume and slightly expensive cost ([75], reproduced from the Ph.D. thesis "Study on anti-blocking device for no-till seeder with non-connect stalk cutting by ultra-high-pressure waterjet" with permission from the Author, 2022).

3.6. Soils

The purpose of cutting soil is to change soil structure and composition for jet fertilization. With the growth of fertilizer prices, the existing fertilizer application techniques have shown a trend away from the conventional spreading technique towards injection, which means that fertilizers are directly injected into the soil and deposited near the plant roots [85,86]. Compared with injection methods such as spokes, furrow openers, jet fertilization as an application of liquid jet technology can effectively avoid crop damage, fertilization holes blockage, and soil contact parts wear and tear [87]. A water depot forms inside the soil after jet injection, which may store some liquids [88]. Additionally, the higher the soil moisture content, the deeper the water jet injection depth [88].

Jet fertilization should ensure that fertilizers are successfully injected into the soil and reduce the volatilization of ammonia and nitrogen after fertilization. Nyord et al. [36] compared three application techniques: a disc coulter injector, a spoke wheel injector, and a high-pressure injector using a trailing shoe technique (Figure 9). They found that in the yield test of winter wheat, spoke wheel, and high-pressure injection yields were higher than surface application yields. Both high-pressure injection and disc coulter could reach a 50–70 mm depth measured by pressing a ruler to the bottom of the soil in a laboratory environment. These results showed that the type of injection technique was not important as long as the fertilizer was injected to at least a 50 mm depth. A working pressure of more than 2.0 MPa was needed to apply water jet cutting technology in the field. Zheng et al. [25] designed a jet fertilization device to reduce the nitrogen loss in liquid fertilizer for rice, which belonged to the post-mixing liquid jet technology. Under the parameters of a 12 MPa constant jet pressure, a 10–30 mm target distance, and a 0.6–0.8 m/s traverse speed, liquid jets could cut paddy soil to depths of 19 to 52 mm. They also carried out computational fluid dynamics (CFD) simulations (Figure 10). Simulation results showed that the nitrogen fixation was the highest when the fertilizer inlet diameter and the nozzle diameter were 1 mm. When their diameters were 0.6 and 0.8 mm, respectively, the soil cutting capacity was the strongest.

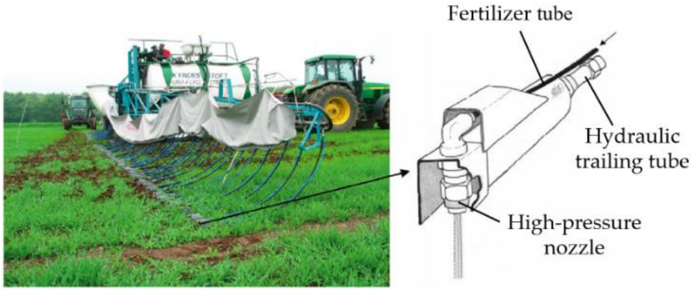


Figure 9. The commercial sprayer mounted with a high-pressure injection system ([36], adopted from "Injection methods to reduce ammonia emission from volatile liquid fertilisers applied to growing crops" with permission from Elsevier, 2022).

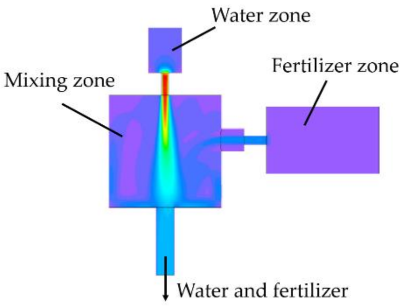


Figure 10. Simulated velocity contours in the model domain ([25], adopted from "Development of a liquid-jet nozzle for fertilizer injection in paddy fields using CFD" with permission from Elsevier, 2022).

Therefore, as an emerging production technology, cutting soil for jet fertilization has a broad application prospect, focusing on cutting depth and fertilizer volatilization. The jet pressure required for a 19–70 mm injection depth is generally lower than 20 MPa. In contrast, other materials require jet pressures greater than 100 MPa. Optimizing cutting parameters through experiments is necessary to reduce fertilizer volatilization. However, there are still some problems when cutting soil, including a slow transverse speed or a shallow injection depth, which requires further research on agricultural machinery for good operation performance and stability.

3.7. Comparison of the Capability of Water Jet Cutting the above Agricultural Materials

By exploring applications of water jet cutting technology in agricultural engineering, it can be confirmed that jet media and cutting parameters have a significant influence on the cutting capability of various agricultural materials, as shown in Table 2.

Table 2. Cutting six kinds of agricultural materials under different jet media and typical parameters.

Authors	Agricultural Materials	Jet Media	Jet Pressure (MPa)	Nozzle Diameter (mm)	Target Distance (mm)	Traverse Speed (m/s)	Cutting Capability
[18,19,38,42,47]	Vegetables	Pure water jet and liquid jet	250–330	0.1–0.6	35–150	0.017–0.6	Harvesting and fresh cutting vegetables; controlling microbial cross-contamination and brownish cuts.
[24,49,50]	Fruits	Pure water jet and abrasive water jet (AWJ)	200–400	0.08–0.76	3–180	0.005–0.3	Peeling and cutting fruits; 20–210 mm cutting depth of sugarcane stalks; minimizing the direct contact.
[39,59,60,65]	Meats	Pure water jet, AWJ, and liquid jet	50–400	0.1–1	2–90	0.025–0.067	Cutting and trimming meats; less than 1 mm kerf width; 12–150 mm cutting depth; reducing meat loss (kerf width).
[66,70,71]	Woods	AWJ	250–380	0.76–1	3–8	0.00083–0.35	15–85 µm the mean roughness depth parameter (*Rz*); 2–14 µm the arithmetic mean deviation of the profile (*Ra*); 0.4–1.6 mm kerf width; 18–54 mm wood thickness; improving surface quality.
[22,73,74,78,82,83]	Stems	Pure water jet and AWJ	30–380	0.15–1	5–100	0.83–3.33	Anti-blocking and weeding; 6–35 Mg/ha wheat straw stems; above 95% cut off ratio of corn stalks; cutting off single weeds.
[25,36]	Soils	Liquid jet	2–12	0.4–1.2	10–30	0.6–1.83	Fertilization; 19–70 mm soil cutting depth; reducing fertilizer volatilization.

Different jet media, including pure water, abrasive particles, and special liquids, are needed to complete various cutting purposes. Specifically, pure water jets can cut many agricultural materials, such as vegetables, fruits, meats, and stems. Abrasive water jets improve the cutting ability to cut woods, sugarcanes, and meat with bone by adding traditional abrasives such as garnet or abrasives for cutting food such as ice particles, salt particles, and sugar particles [37]. When cutting vegetables and soils, different liquid jets can be used for disinfection and fertilization, respectively [36,38]. Besides, using PEO solutions as liquid jets can improve the meat cutting ability [39].

There are four typical cutting parameters (i.e., jet pressure, nozzle diameter, target distance, and traverse speed) affecting the cutting effects in different ways. First, compared with other materials, cutting soil can complete fertilization operations for the required cutting depth with jet pressures lower than 20 MPa. Adding abrasives or liquids to the working fluid increases the cutting ability, so cutting some meats needs lower pressures [39,60]. Second, nozzle diameters of pure water jets and liquid jets are smaller than abrasive jets mixed with solid abrasives. When the nozzle diameter is larger, the kerf width and water consumption will increase, resulting in more raw material loss and water carried, which affects economic benefits and the weight of agricultural machinery, respectively [42,60]. Third, many vegetables, fruits, and boneless meats can be cut at high target distances because of soft materials. It is necessary to increase the distance between the nozzle and the stem to avoid soil and stubble impacting the nozzle while working in the field [74]. Decreasing the target distance can reduce the volatilization of fertilizers [25]. Fourth, a low traverse speed can be combined with intelligent technology to cut fruits automatically, and it also can reduce the surface roughness of some wood products to improve their surface quality [50,71]. When cutting stems and soils outdoors, a high traverse speed is needed to improve the operating efficiency [22,36].

In addition to the parameters in Table 2, additional attention should be paid to the jet angle, cutting direction, abrasive flow rate, post-mixing media inlet diameter, and other parameters. For example, adjusting the jet angle can ensure that the edge is perpendicular to the wood surface or achieve the best effect of jet weeding [67,82]. Research shows that some woods have different radial and tangential cutting results [71]. The abrasive flow rate and post-mixing media inlet diameter will change the quantity or concentration of the jet media, thereby affecting the jet impact force [25,70,71].

4. Conclusions and Recommendations

As a non-contact and cold processing method, water jet cutting technology can cut various agricultural materials without heat generation, sharpening and cleaning blades, and cross-contamination. Nowadays, relevant reviews have been carried out on six agricultural materials (i.e., vegetables, fruits, meats, woods, stems, and soils) for completing different cutting operations, improving cutting ability, or controlling post-cutting influences. To achieve specific purposes and products, water jet cutting technology is used for harvesting, slicing, peeling, trimming, and injecting. Adjusting the water jet cutting parameters and jet media properly can deepen the cutting depth, decrease the kerf width, or reduce the surface roughness, so as to obtain a better cutting ability. Similarly, some phenomena and questions after cutting, including brownish cut edges of vegetables, microbial counts, and the loss of raw materials, are controlled by adjusting relevant parameters.

Moreover, the research focus of water jet cutting of each material in agricultural engineering is different. Specifically, cutting parameters are optimized by cutting experiments to control the browning of vegetable cuts for good quality. Meanwhile, harmless disinfectants can be mixed into the working fluid of liquid jet cutting to prevent the bacterial infection of vegetables. When harvesting vegetables or fruits in the field, it is necessary to keep them clean. To improve work efficiency, the post-harvest processing of fruits adopts water jet technology equipped with intelligent control methods. Adding abrasives or liquids to working fluids can cut bone and larger sections of meat and reducing meat loss (or kerf width) needs AWJ cutting or pre-cooling. As for wood cutting, abrasives are required for better surface qualities of a smaller surface roughness value and kerf width. Cutting stems and soils needs mobile machines working in the field. Besides, anti-blocking and jet weeding require that stems are cut off, and the cutting depth of soil is vital to jet fertilization.

Therefore, water jet cutting technology has become an important approach to cutting agricultural materials. However, the research on water jet technology is still in its infancy with high costs and needs further development of deepening mechanism research, optimizing agricultural machinery, and adopting intelligent control. First, simulate jet generation processes, cutting processes, and microscopic damages under different parameters to deepen the research on the cutting mechanism of agricultural materials. Meanwhile, the optimal cutting parameters of simulation experiments can provide a reference for practical operations and reduce research and development costs. Second, optimize agricultural machinery to reduce water consumption and jet pressure. Recycling water from horizontal jet harvesting machines allows for smaller volume tanks. Adding abrasives achieves the same cutting effect under low pressure, but further research is needed for additional effects on the field environments. Third, adopt intelligent control methods to improve work efficiency and reduce labor costs. Some technologies (i.e., machine vision, image processing, robotics, sensors, etc.) should combine with water jet cutting technology to realize real-time monitoring of cutting effects and automatic adjustment of cutting parameters.

Author Contributions: Conceptualization, D.C. and H.L.; writing—original draft preparation, D.C.; writing—review and editing, J.H., Q.W., C.L., H.H., X.C. and C.W.; funding acquisition, H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by China Agriculture Research System of MOF and MARA (Grant No. CARS-03); Chinese Universities Scientific Fund (Grant No. 2021TC011).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This research was supported by the 2115 Talent Development Program of China Agricultural University.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xu, W.; Wang, J.; Deng, Y.; Li, J.; Yan, T.; Zhao, S.; Yang, X.; Xu, W.; Wang, W.; Liu, D. Advanced cutting techniques for solid food: Mechanisms, applications, modeling approaches, and future perspectives. *Compr. Rev. Food Sci. Food Saf.* **2022**, *21*, 1568–1597. [CrossRef] [PubMed]
2. Park, J.G.; Jung, H.M.; Kang, B.S.; Mun, S.K.; Lee, S.H.; Lee, S.H. Analysis of mechanical properties of agricultural products for development of a multipurpose vegetable cutting machine. *Korean J. Agric. Sci.* **2016**, *43*, 432–440. [CrossRef]
3. Ho, K.H.; Newman, S.T.; Rahimifard, S.; Allen, R.D. State of the art in wire electrical discharge machining (WEDM). *Int. J. Mach. Tools Manuf.* **2004**, *44*, 1247–1259. [CrossRef]
4. Jiang, X. Development and trend of cutting technology. *Non-Ferr. Min. Metall.* **2016**, *32*, 42–44.
5. Chen, G. Application of high pressure water jet cutting technology in food processing. *Mach. Tool Hydraul.* **2008**, *36*, 220–223.
6. Natarajan, Y.; Murugesan, P.K.; Mohan, M.; Khan, S.A.L.A. Abrasive water jet machining process: A state of art of review. *J. Manuf. Process.* **2020**, *49*, 271–322. [CrossRef]
7. Elamin, W.M.; Endan, J.B.; Yosuf, Y.A.; Shamsudin, R.; Ahmedov, A. High pressure processing technology and equipment evolution: A review. *J. Eng. Sci. Technol. Rev.* **2015**, *8*, 75–83. [CrossRef]
8. Luo, S.D.; Xu, Y.J. The research and development of water jet technology. *Appl. Mech. Mater.* **2013**, *273*, 45–48. [CrossRef]
9. Liu, X.; Liang, Z.; Wen, G.; Yuan, X. Waterjet machining and research developments: A review. *Int. J. Adv. Manuf. Technol.* **2019**, *102*, 1257–1335. [CrossRef]
10. Hreha, P.; Radvanská, A.; Hloch, S.; Peržel, V.; Królczyk, G.; Monková, K. Determination of vibration frequency depending on abrasive mass flow rate during abrasive water jet cutting. *Int. J. Adv. Manuf. Technol.* **2014**, *77*, 763–774. [CrossRef]
11. Perec, A. Environmental aspects of abrasive water jet cutting. *Rocz. Ochr. Sr.* **2018**, *20*, 258–274.
12. Anand, U.; Katz, J. Prevention of nozzle wear in abrasive water suspension jets (AWSJ) using porous lubricated nozzles. *J. Tribol.* **2003**, *125*, 168–180. [CrossRef]
13. Ranjan, P.; Chaubey, P.; Suresh, P.; Vidya, S. Current Research Aspects and Trends in Abrasive Water Jet Machining: A Review. In *Advances in Mechanical Engineering and Technology*; Springer: Singapore, 2022; pp. 193–198.
14. Kartal, F. A review of the current state of abrasive water-jet turning machining method. *Int. J. Adv. Manuf. Technol.* **2017**, *88*, 495–505. [CrossRef]
15. Dahiya, A.K.; Bhuyan, B.K.; Kumar, S. Perspective study of abrasive water jet machining of composites-a review. *J. Mech. Sci. Technol.* **2022**, *36*, 213–224. [CrossRef]
16. Wang, X.R. The Key Technology and Climbing Wall Experiments Study of the Ship Rust Removal Based on Ultrahigh Pressure Pure Water Jet. Ph.D. Thesis, Dalian Maritime University, Dalian, China, 2010.
17. Galindo, F.G.; Sjöholm, I.; Rasmusson, A.G.; Widell, S.; Kaack, K. Plant stress physiology: Opportunities and challenges for the food industry. *Crit. Rev. Food Sci.* **2008**, *47*, 49–763. [CrossRef] [PubMed]
18. Wulfkuehler, S.; Stark, S.; Dietz, J.; Schmidt, H.; Weiss, A.; Carle, R. Effect of water jet cutting and moderate heat treatment on quality of fresh-cut red oak leaf lettuce (Lactuca sativa L. var. crispa). *J. Food Process Eng.* **2014**, *7*, 3478–3492. [CrossRef]
19. Hägele, F.; Nübling, S.; Schweiggert, R.M.; Nolte, L.; Weiss, A.; Schmidt, H.; Carle, R. Comparison of ultra-high-pressure water jet and conventional rotating blade cutting for the production of fresh-cut iceberg (*Lactuca sativa* L.) and endive (*Cichorium endivia* L.). *Eur. Food Res. Technol.* **2016**, *242*, 2071–2081. [CrossRef]
20. Henning, A. Cutting with high-pressure jet in the food industry. *Fleischwirtschaft* **1998**, *78*, 43–45.
21. Olejua, R.C.; Hofacker, W.C.; Hensel, O. Use of image analysis in process control of high pressure water-jet peeling and cutting of fruits. In Proceedings of the ASABE Annual International Meeting, Reno, Nevada, 21–24 June 2009.
22. Hu, H.; Li, H.; Wang, Q.; He, J.; Lu, C.; Wang, Y.; Liu, P. Anti-blocking performance of ultrahigh-pressure waterjet assisted furrow opener for no-till seeder. *Int. J. Agric. Biol. Eng.* **2020**, *13*, 64–70. [CrossRef]

23. Wulfkuehler, S.; Dietz, J.; Schmidt, H.; Weiss, A.; Carle, R. Quality of fresh-cut radicchio cv. Rosso di Chioggia (*Cichorium intybus* L. var. foliosum Hegi) as affected by water jet cutting and different washing procedures. *Eur. Food Res. Technol.* **2015**, *240*, 159–172. [CrossRef]
24. Olejua, R.C.; Hofacker, W.C.; Hensel, O. High-pressure water-jet technology as a method of improving the quality of post-harvest processing. *Food Bioprocess Technol.* **2010**, *3*, 853–860. [CrossRef]
25. Zheng, W.; Jiang, Y.; Ma, X.; Qi, L. Development of a liquid-jet nozzle for fertilizer injection in paddy fields using CFD. *Comput. Electron. Agric.* **2019**, *167*, 105061. [CrossRef]
26. Cantwell, M.I.; Melo, A.A.M.; Hong, G.; Klose, S. Quality of waterjet and blade-cut romaine salad. *Acta. Hortic.* **2016**, *1141*, 153–158. [CrossRef]
27. Liu, H.; Wang, Z.; Cheng, M.; Xu, W.; Liu, H.; Yu, X.; Zhi, S. Development and application status of high pressure water jet cutting technology. *Mach. Tool Hydraul.* **2018**, *46*, 173–179.
28. Lu, S.; Yu, T.; Yu, T.; Liu, S. Experiment and mechanism analysis of inhibiting browning of semi-processed lettuce cutting with water jet. *Trans. CSAM* **2007**, *38*, 202–204.
29. Klocke, F.; Schreiner, T.; Schüler, M. Material removal simulation for abrasive water jet milling. *Procedia CIRP* **2018**, *68*, 541–546. [CrossRef]
30. Hashish, M. Cutting with high-pressure abrasive suspension jets. In Proceedings of the 6th American Water Jet Conference, Houston, TX, USA, 24–27 August 1991.
31. Kowsari, K.; Nouraei, H.; James, D.F.; Spelt, J.K.; Papini, M. Abrasive slurry jet micro-machining of holes in brittle and ductile materials. *J. Mater. Process. Technol.* **2014**, *214*, 1909–1920. [CrossRef]
32. Ma, Y.H. *Physical Properties of Agricultural Materials*; Chemical Industry Press: Beijing, China, 2015.
33. Schield, M. Harvesting Lettuce by Severing with a Water Jet. Master's Thesis, University of Arizona, Tucson, AZ, USA, 1972.
34. Xue, S. *High Pressure Waterjet Technology and Engineering*; Hefei University of Technology Press: Hefei, China, 2006.
35. Liu, L.; Wang, Z. High pressure water jet cutting technique and its application. *Trans. CSAM* **2000**, *31*, 117–119.
36. Nyord, T.; Søgaard, H.T.; Hansen, M.N.; Jensen, L.S. Injection methods to reduce ammonia emission from volatile liquid fertilisers applied to growing crops. *Biosyst. Eng.* **2008**, *100*, 235–244. [CrossRef]
37. McGeough, J.A. Cutting of food products by ice-particles in a water-jet. *Procedia CIRP* **2016**, *42*, 863–865. [CrossRef]
38. Yang, Z.; Liu, F.; Zhang, Q.; Li, Y.; Yang, Y. Optimization design of potato seed tiling and sequencing device. *Agric. Eq. Technol.* **2020**, *46*, 32–34.
39. Pogrebnyak, A.; Pogrebnyak, V.; Perkun, I.; Vasyliv, N. Influence of geometric and dynamic parameters of a water-polymer jet on characteristics of food products hydro-cutting process. *Ukr. Food J.* **2020**, *9*, 197–208. [CrossRef]
40. Song, L. Analysis of Influencing Factors on Water Jet Performance and WJ System Design. Master's Thesis, Shenyang University of Technology, Shenyang, China, 2009.
41. Sun, X. Research on Key Technologies of a High Pressure Waterjet Cutting System. Master's Thesis, Huazhong University of Science and Technology, Wuhan, China, 2013.
42. Juenemann, D.; Harms, H.H. Development of a water catcher for high pressure water jet cutting of agricultural goods. In Proceedings of the CIGR XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering, Québec City, QC, Canada, 13–17 June 2010.
43. Irwansyah, I.; Ibrahim, M.; Ferdiansyah, H. Influence of water-jet nozzle geometry on cutting ability of soft material. *J. Rekayasa Kim. Lingkung.* **2012**, *9*, 6–11.
44. Posselius, J.H.J.; Conklin, G.T. Crowning carrots with a high pressure water jet. *Am. Soc. Agric. Eng.* **1988**, *4*, 340–343. [CrossRef]
45. Tatsumi, Y.; Watada, A.E.; Ling, P.P. Water jet technology and salt treatment used for carrot sticks. *HortScience* **1992**, *27*, 651f-651. [CrossRef]
46. Tatsumi, Y.; Watada, A.E.; Ling, P.P. Sodium chloride treatment or waterjet slicing effects on white tissue development of carrot sticks. *J. Food Sci.* **1993**, *58*, 1390–1392. [CrossRef]
47. Becker, R.; Gray, G.M. Evaluation of a water jet cutting system for slicing potatoes. *J. Food Sci.* **1992**, *57*, 132–137. [CrossRef]
48. McGlynn, W.G.; Bellmer, D.D.; Reilly, S.S. Effect of precut sanitizing dip and water jet cutting on quality and shelf-life of fresh-cut watermelon. *J. Food Qual.* **2003**, *26*, 489–498. [CrossRef]
49. Thanomputra, S.; Kiatiwat, T. Simulation study of cutting sugarcane using fine sand abrasive waterjet. *Agric. Nat. Resour.* **2016**, *50*, 146–153. [CrossRef]
50. Lin, J.; Holmes, M.; Vinson, R.; Ge, C.; Pogoda, F.C.; Mahon, L.; Gentry, R.; Seibel, G.E.; Chen, X.; Tao, Y. Design and testing of an automated high-throughput computer vision guided waterjet knife strawberry calyx removal machine. *J. Food Eng.* **2017**, *211*, 30–38. [CrossRef]
51. Valco, T.D.; Coble, C.G.; Ruff, J.H. Water jet cutting of sugarcane. *Trans. ASAE* **1989**, *32*, 373–378. [CrossRef]
52. Hu, X.; Zheng, L.; Yuan, Y.; Lian, M. Simulation study on bad cutting state criterion of sugar cane. *Adv. Mater. Res.* **2011**, *219–220*, 235–238. [CrossRef]
53. Hoogstrate, A.M. Towards High-Definition Abrasive Waterjet Cutting. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2000.
54. Heiland, W.K.; Konstance, R.P.; Craig, J.C. Robotic high pressure water jet cutting of chuck slices. *J. Food Process Eng.* **1990**, *12*, 131–136. [CrossRef]

55. Bansal, R.K.; Walker, J.T. A study of high pressure water jets for cutting chicken breast meat. *J. Food Process Eng.* **1999**, *22*, 307–318. [CrossRef]
56. Kasperowicz, M.B.; Chomka, G.P.; Bil, T. Determination of supply pressure during cutting fish using high-pressure water stream taking into account the cutting place and diameter of the water nozzle. *Int. J. Food Eng.* **2019**, *16*, 814–825. [CrossRef]
57. Purnell, G.; Brown, T. Equipment for controlled fat trimming of lamb chops. *Comput. Electron. Agric.* **2004**, *45*, 109–124. [CrossRef]
58. Čačko, V.; Ondruška, J.; Onderová, I.; Šooš, L.; Krajný, Z. Research into a new method for trimming hooves by liquid jet. *Appl. Mech. Mater.* **2016**, *832*, 177–183. [CrossRef]
59. Alitavoli, M.; McGeough, J.A. An expert process planning system for meat cutting by high pressure water-jet. *J. Mater. Process. Technol.* **1998**, *84*, 130–135. [CrossRef]
60. Wang, J.; Shanmugam, D.K. Cutting meat with bone using an ultrahigh pressure abrasive waterjet. *Meat Sci.* **2009**, *81*, 671–677. [CrossRef]
61. Shakouri, E.; Abbasi, M. Investigation of cutting quality and surface roughness in abrasive waterjet machining of bone. *Arch. Proc. Inst. Mech. Eng. H J. Eng. Med.* **2018**, *232*, 850–861. [CrossRef]
62. Jerman, M.; Orbanić, H.; Junkar, M.; Lebar, A. Thermal aspects of ice abrasive water jet technology. *Adv. Mech. Eng.* **2015**, *7*, 1–9. [CrossRef]
63. Kovacevic, R.; Hashish, M.; Mohan, R.; Ramulu, M.; Kim, T.J.; Geskin, E.S. State of the art of research and development in abrasive waterjet machining. *J. Manuf. Sci. Eng.* **1997**, *119*, 776–785. [CrossRef]
64. Stone, F.W.; Stratta, J.J. Ethylene oxide polymers. *Encycl. Pol. Sci. Technol.* **1967**, *6*, 103–145.
65. Franklínsdóttir, H. Application of Water Jet Cutting in Processing of Cod and Salmon Fillets. Master's Thesis, University of Iceland, Reykjavik, Iceland, 2014.
66. Gerencsér, K.; Bejó, L. Investigations into the water jet cutting of solid wood. *Wood Res.* **2007**, *52*, 57–64.
67. Pinkowski, G.; Szymański, W.; Krauss, A.; Stefanowski, S. Effect of sharpness angle and feeding speed on the surface roughness during milling of various wood species. *BioResources* **2018**, *13*, 6952–6962.
68. Kılıç, M. Effects of machining methods on the surface roughness values of Pinus Nigra Arnold wood. *BioResources* **2015**, *10*, 5554–5562. [CrossRef]
69. Lee, H. Abrasive-assisted high energy water-jet machining characteristics of solid wood. *J. Korean Wood Sci. Technol.* **2004**, *32*, 1–7.
70. Xie, W.; Fang, J.; Wang, Z.; Huang, L. Optimization of technological parameters of water jet cutting of red oak and bamboo based on three-dimensional surface topography measurement. *BioResources* **2020**, *15*, 3270. [CrossRef]
71. Pelit, H.; Yaman, Ö. Influence of processing parameters on the surface roughness of solid wood cut by abrasive water jet. *BioResources* **2020**, *15*, 6135–6148. [CrossRef]
72. He, J.; Li, H.; Chen, H.; Lu, C.; Wang, Q. Research progress of conservation tillage technology and machine. *Trans. CSAM* **2018**, *49*, 1–19.
73. Desbiolles, J.; Taki, O.; Butler, G. A laboratory evaluation of waterjet cutting of crop residue using the Aqua-Till®liquid coulter. *Soil Tillage Res.* **2020**, *198*, 104537. [CrossRef]
74. Hu, H.; Li, H.; Wang, Q.; He, J.; Lu, C.; Wang, Y.; Wang, C. Performance of waterjet on cutting maize stalks: A preliminary investigation. *Int. J. Agric. Biol. Eng.* **2019**, *12*, 64–70. [CrossRef]
75. Hu, H.N. Study on Anti-Blocking Device for No-Till Seeder with Non-Connect Stalk Cutting by Ultra-High-Pressure Waterjet. Ph.D. Thesis, China Agricultural University, Beijing, China, 2020.
76. Hu, H.; Chen, W.; Li, H.; Wang, Q.; He, J.; Lu, C.; Zhang, Z.; Niu, Q. Design and simulation research of ultra high pressure water-jets pre-opener for no-till planter. In Proceedings of the ASABE Annual International Meeting, Spokane, WA, USA, 16–19 July 2017.
77. Hu, H.; Li, H.; Niu, Q.; Wei, Z.; Zhao, H. Numerical model of maize straw under ultra-high pressure waterjet. In Proceedings of the ASABE Annual International Meeting, Detroit, MI, USA, 29 July–1 August 2018.
78. Perotti, F.; Annoni, M.; Calcante, A.; Monno, M.; Mussi, V.; Oberti, R. Experimental study of abrasive waterjet cutting for managing residues in no-tillage techniques. *Agriculture* **2021**, *11*, 392. [CrossRef]
79. Coleman, G.R.Y.; Stead, A.; Rigter, M.P.; Xu, Z.; Johnson, D.; Brooker, G.M.; Sukkarieh, S.; Walsh, M.J. Using energy requirements to compare the suitability of alternative methods for broadcast and site-specific weed control. *Weed Technol.* **2019**, *33*, 633–650. [CrossRef]
80. Butler, G. Exploring the potential of UHP jet-stream technology. In *SANTFA: Cutting Edge South Aust. No-till Farmers Assoc*; SANTFA: Clare, SA, Australian, 2013; pp. 410–413.
81. Fogelberg, F.; Blom, A. Water-jet cutting for weed control. In Proceedings of the 5th EWRS Workshop on Physical and Cultural Weed Control, Pisa, Italy, 11–13 March 2002.
82. Ishida, Y.; Okamoto, T.; Imou, K.; Kaizu, Y. A study on physical weeding using a water jet. *J. Jpn. Soc. Agric. Machin.* **2005**, *67*, 93–99.
83. Zhang, L. Studies on Water Jet Used to Cut Weeds. Master's Thesis, Hunan Agricultural University, Changsha, China, 2012.
84. Wöltjen, C.; Haferkamp, H.; Rath, T.; Herzog, D. Plant growth depression by selective irradiation of the meristem with CO_2 and diode lasers. *Biosyst. Eng.* **2008**, *101*, 316–324. [CrossRef]
85. da Silva, M.J.; Magalhães, P.S.G. A liquid injection dosing system for site-specific fertiliser management. *Biosyst. Eng.* **2017**, *163*, 150–158. [CrossRef]

86. Matoka, C.M. Bacterial Community Responses to Soil-Injected Liquid Ammonium Nutrition and Effect of Temperature on Barley (*Hordeum vulgare* L.) grain Yield Formation. Ph.D. Thesis, Justus-Liebig University, Giessen, Germany, 2007.
87. Lu, Y.L. Design and Experiment of Jet Fertilization Structure for the Rice. Master's Thesis, South China Agricultural University, Guangzhou, China, 2016.
88. Niemoeller, B.; Harms, H.H.; Lang, T. Injection of liquids into the soil with a high-pressure jet. *Agric. Eng. Int. CIGR J.* **2011**, *13*, 1–15.