

## Review

# Research and Overview of Crop Straw Chopping and Returning Technology and Machine

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## Abstract

Crop straw chopping and returning technology has gained global implementation to enhance soil structure and fertility, facilitating increased crop yield. Nevertheless, technological adoption faces challenges from inherent limitations in machinery performance, including poor chopping and returning quality and high energy consumption. Consequently, this review first presented a theoretical framework that described the mechanical properties of straw, its fracture dynamics, interactions with airflow, and motion characteristics during the chopping process. Then, based on the straw returning process, the chopping devices were classified into five types: the chopped blade, the chopping machine, the chopping device combined with a no-tillage or reduced-tillage seeder, the chopping and ditch-burying machine, the chopping and mixing machine, and the harvester-powered chopping device. Advancements in spreading devices were also summarized. Finally, six key directions for future research were proposed: developing an intelligent field straw distribution mapping system, engineering adaptive self-regulating mechanisms for chopping and returning equipment, elucidating the mechanics and kinematics of straw in the chopping and returning process, implementing real-time quality assessment systems for straw returning operations, pioneering high forward-speed (>8 km/h) straw returning machines, and establishing context-specific straw residue management frameworks. This review provided a reference and offered support for the global application of straw returning technology.

**Keywords:** crop straw; straw management; straw chopping and returning machine; chopping quality; spreading uniformity



Academic Editor: Ciro Santus

Received: 26 May 2025

Revised: 22 June 2025

Accepted: 23 June 2025

Published: 28 June 2025

**Citation:** Liu, P.; Song, C.; He, J.; Li, R.; Cheng, M.; Zhang, C.; Li, Q.; Zhang, H.; Wang, M. Research and Overview of Crop Straw Chopping and Returning Technology and Machine. *Machines* **2025**, *13*, 564. <https://doi.org/10.3390/machines13070564>

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## 1. Introduction

Crop straw, a by-product of agricultural production, is extensively generated worldwide, with an annual yield exceeding 3000 million tons (Mt) [1–3]. Notably, in China, the straw yields from maize, rice, and wheat in 2024 surpassed 600, 240, and 150 Mt, respectively [4]. Although crop straw is traditionally considered a biomass resource [5,6], it is often disposed of through open burning, particularly in Asia, to prevent obstruction of planting and tillage activities. However, this practice results in significant environmental pollution and resource wastage, thereby hindering the sustainable development of agriculture [7–9].

Crop straw is rich in nitrogen, phosphorus, potassium, fiber, and organic carbon. When chopped and returned to the field, it increases soil organic carbon content, enhances

water use efficiency, promotes microbial activity, and reduces soil bulk density [10–13]. This process creates a favorable environment for increased crop yields while also reducing production costs, such as irrigation and fertility expenses.

The crop straw chopping and returning machine, a key piece of equipment for mechanical straw return to the field, primarily relies on high-speed rotating blades to cut the straw into filamentous or lumpy fragments, which are then distributed across the field by airflow. The quality of chopping and spreading, critical performance indicators of the returning machine, directly impacts the efficiency of subsequent no-till or reduced-till seeding, straw decomposition, soil nutrient distribution, seed germination and growth, and, ultimately, crop yield [14]. Therefore, research on straw chopping and returning technology and equipment is essential for enhancing straw resource utilization and promoting the reduction in chemical fertilizer use, which is vital for advancing sustainable agricultural practices and minimizing environmental pollution from agricultural inputs.

Studies on crop straw chopping and returning equipment have primarily focused on how structural parameters (e.g., blade design and arrangement and chopping method), operational parameters (e.g., forward speed, rotational speed, installation angle, and ground clearance), and airflow characteristics (e.g., velocity and pressure distribution) affect the mechanical behavior and trajectory of straw, as well as the operational performance (e.g., chopping quality and spreading uniformity) and energy consumption during the chopping and spreading process, providing a basis for the design and optimization of such equipment. This study, therefore, presented a comprehensive review of crop straw chopping and returning machines worldwide based on published literature. It covered the development of theoretical analyses of chopping and spreading processes, as well as advancements in chopping and spreading devices. Finally, recommendations for the future development of crop straw chopping and returning machines were provided, serving as a reference for further advancements in crop straw chopping and returning technology.

## 2. Theoretical Analysis for Chopping and Spreading of Crop Straw

To clarify the principles of the changes in broken force, energy consumption, motion velocity, and acceleration of crop straw during the chopping and spreading process, several studies have been conducted to analyze the physical and mechanical properties of crop straw, the development of simulation analysis models for crop straw, analysis of broken force and kinematic characteristics of crop straw during chopping process, and the examination of the interaction between chopped straw and airflow within the chopped chamber.

### 2.1. Research on Mechanical Properties of Crop Straw

During the chopping and spreading process, the kinematic behaviors and force-loading conditions of the straw exhibits are highly complex. Solely relying on physical experiments often makes it difficult to obtain comprehensive data (e.g., force, velocity, and acceleration) during the chopping process. Therefore, constructing an accurate straw simulation model is essential for crop straw (a typical anisotropic material). This model enables the collection of detailed data on the forces exerted on the straw and its kinematic parameters, providing valuable guidance for the design and optimization of straw chopping and spreading machines [15–21]. To achieve this, researchers focused on two primary areas: determining the biomechanical parameters of straw and developing the straw simulation model. These efforts have led to a series of results with significant theoretical and practical value.

In determining the biomechanical parameters of crop straw, key factors, such as moisture content, inner and outer diameters, density, and mass, were predominantly measured [22]. Regarding the mechanical characteristics of straw, properties such as elastic modulus, shear strength, compressive strength, and yield strength were obtained from

mechanical tests, including shear, tension, and bending experiments (Figure 1) [15,21–25]. By elucidating the stress–strain relationship, fundamental constitutive data were provided for the precise construction of straw discrete or finite element simulation models [26,27].

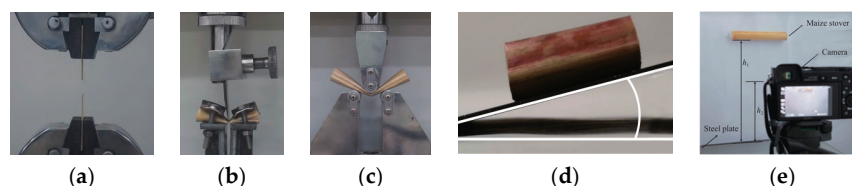


**Figure 1.** Mechanical properties test of crop straw [15], (a) Tensile test (b) Shear test (c) Three-point bending test (d) Measurement of static friction coefficient (e) Measurement of restitution collision coefficient.

## 2.2. Research on Simulation Analysis Model of Crop Straw

Research on the straw simulation models primarily focused on the development of the finite or discrete element model (DEM) of straw. In the case of discrete-element particle models for straw, they were categorized into the rigid-particle model and the flexible, deformable straw particle models. The rigid-straw particle model predominantly utilized the assembly of multiple spherical particles (Figure 2a) [28]. This method effectively represented complex shape characteristics while offering high computational efficiency. Therefore, rigid-particle straw models were widely used in the analysis of the force-bearing process during collisions between mechanical devices or airflow and straw [28–30]. However, this model was limited in simulating deformation behaviors, such as bending and torsion, that occur when the straw experiences force-induced collisions [31,32].



**Figure 2.** Simulation models of crop straw. (a) Multi-sphere rigid particles (b) Bonded contact model (c) Model of multi-segment rigid sphere-cylinder elements (d) Straw finite-element model. The color in (b) represented the bonding contacting positions; (d) The color represented the distribution of stress.

The flexible, deformable straw particle model primarily involved adding bonding bonds or connection points between particles (Figure 2b,c) [24,33]. This enabled a more accurate simulation of the straw's deformation behaviors under compression, tension, and bending [33–35]. At that time, the development trend in straw discrete-element models was a gradual transition from the rigid straw particle model to the flexible, deformable straw particle model.

In addition, some straw finite-element models were also established to analyze the variation in the force exerted and energy consumption during the cutting process, providing fundamental data to support the optimization of the chopped blade and the implementation of energy consumption reduction (Figure 2d) [36–40]. For example, Liu et al. (2021) developed a finite element model for maize stalks (Figure 2d) and analyzed the interaction between the chopped blade and maize stalks, focusing on their effects on cutting force and energy consumption [16]. Han et al. (2024) built a smooth particle hydrodynamic-finite element method simulation model for cutting rapeseed stem to research the cutting quality of abrasive gas jet cutting [39]. Wang et al. (2023) built a finite-element model to obtain the stress, force, and velocity of cotton stalk during the chopping process [40].

## 2.3. Fracture Dynamics and Kinematic Characteristics of Crop Straw During Chopping

During the straw chopping process, the high-speed rotating blades repeatedly cut the straw within microseconds [16,38]. This dynamic process involved continuous energy

transfer from the blades to the straw, inducing cellular tissue fracture through mechanical stress while facilitating energy-force conversion between the plant material and cutting components [38–41]. These mechanical interactions critically influenced both operational efficiency (through energy consumption) and chopping quality, necessitating optimization of blade geometry, kinematic parameters, and cutting mechanics to minimize power requirements while maintaining processing effectiveness [42–44].

Fixed-angle cutting and sliding cutting methods are the two main cutting types. The fixed-angle method maintained a constant angle between the blade's absolute motion vector and the straw's longitudinal axis, with orthogonal cutting configurations being most prevalent [45,46]. Conversely, sliding cutting dynamically altered this angular relationship during operation. Experimental observations revealed that conventional straight-edged blades exhibited significant static sliding angle variations during engagement, resulting in abrupt torque fluctuations and consequently elevated energy expenditure [44,47–49]. Optimal sliding angle selection must satisfy two critical thresholds: exceeding the material's friction angle to initiate effective sliding while remaining below thresholds causing processing complications or straw entanglement. Parametric optimization through combined computational modeling and empirical validation has proven essential for determining ideal sliding angles that balance energy efficiency with operational reliability [48,50].

The chopped blade is the primary component directly acting on the straw; the structure and operational parameters of the blade affect the cutting force and energy consumption. Therefore, research in these field has focused on aspects, such as incorporating serrations [51] or the slide-cutting function in the cutting-edge curves of the rotational chopped blade and fixed blade [38,52–57], altering the structural configuration of the crushing knife [58], converting the crushing mode from non-supported or single-supported to dynamic double-supported [44,50], optimization of the cutting-edge of a chopped blade based on bionic technology to mimic the contour-curve features of the sharp anatomical parts of animals, such as claw toes [59,60], teeth [51,61], mantis forelimb [62], and upper jaws [63–65]. These measures aim to decrease the linear velocity and the cutting force and energy consumption requisite for straw chopping, thereby efficiently reducing the energy consumption in the process of straw comminution.

In terms of the dynamic changes in the mechanical behavior of straw during the chopping process, an integrated approach, which combines theoretical analysis and numerical simulation, is employed to develop dynamic and kinematic equations. These equations explored the influence of structural parameters of the chopping knife on the missed-detection area of straw and the force-bearing process during the chopping phase. This work provided the basis for determining the optimal structural and operational parameters for the chopping blade [66–70].

Furthermore, while previous studies focused primarily on the force and energy consumption of the chopping process, providing a reference for the reduction in energy consumption. However, the crop straw chopping and returning process is a comprehensive process, not just involving straw chopping. To further reduce the energy consumption, these studies of the total energy consumption of the chopping and returning process were executed to establish regression equations between operational parameters and the overall machine energy consumption through methodologies such as orthogonal rotation experiments and orthogonal experiments. Operational parameters, such as spindle speed [71], the structural parameters of the chopped blade (edge inclination angle, sliding cutting angle, number of serrations on the blade edge, etc.) [48,72–74], the height of stationary knives [75], the thickness of chopped blade [76], straw moisture content [77], and operational speed of the machinery [67] were all considered. Through solving these equations, optimal structural configurations and operational parameter combinations were identified to enhance operational efficiency and reduce overall operational power consumption. Furthermore, by integrating with adjacent machinery to

form compound operation machines, such as seeders [78], rotary tillers [79], and moldboard plows [80], multiple procedures can be performed in a single operation, thereby enhancing operational efficiency and reducing crushing energy consumption. Additionally, effectively increasing the duration of stable machine operation while minimizing non-operational time, such as turning and stopping [81], significantly reduced the energy consumption associated with starting the moving parts, thus effectively lowering the overall operational energy consumption of the machinery.

#### *2.4. Effects on Airflow Distribution in Chamber*

Rotational chopping blades not only cut the straw but also generate a rotating airflow field within the chopping chamber during the straw returning process. Under the combined action of the airflow field and the rotational chopped blades, the motion of straw with varying shapes becomes highly complex. Therefore, the key factors affecting the spreading uniformity of chopped straw are the distribution characteristics of the airflow field and the interaction between the chopped straw and the airflow. Among them, the airflow serves as the carrier for transporting the chopped straw outside the chopping chamber, and the spreading device affects the distribution of the airflow field and the force acting on the transportation of the chopped straw. By altering the structure of the spreading device and adjusting operational parameters, the distribution of the airflow field and the force acting on the transportation process of the chopped straw can be altered, thereby influencing the spreading uniformity of the chopped straw.

The research on the airflow regulation during the spreading process and the interaction between the chopped straw and the airflow has become a prominent area of study in the agricultural production process [82–85]. It primarily combined theoretical analysis, simulation, and experimental verification, which is of great significance for improving the spreading uniformity of the chopped straw and optimizing the structural design of the spreading device. Currently, numerous studies have been conducted focusing on the airflow regulation during the spreading process and the interaction between the chopped straw and the airflow [86–89].

For research on the regulation law of airflow distribution, a series of studies have been conducted from two aspects: improving the distribution characteristics of the flow field in the chopped chamber and increasing the airflow migration velocity [90,91]. To improve the distribution characteristics of the airflow field in the chopped chamber, computational fluid dynamics (CFDs) technology was employed to systematically investigate the effects of key structural and operational parameters on the distribution of the airflow field in the chopped chamber. These included the shape of the chopped chamber and blades [46], the blade configuration (the arrangement and rotational and operational speed) [55,89,92], and the inclination angle of the airflow guiding plate [93]. Based on these findings, the structure of the spreading device was optimized to improve the airflow distribution within the chopped chamber.

Regarding the increase in airflow migration velocity, methods, such as installing fans blades on the chopped blades or the blade shaft [46,94], increasing the rotational speed of the chopped blades [95], or installing an air blower [96], are commonly employed to increase the airflow velocity in the chopped chamber and the initial spreading velocity of the chopped straw, thereby expanding the spreading range of the chopped straw and improving the spreading uniformity of the chopped straw.

#### *2.5. Interaction Between Chopped Straw and Airflow in the Chopped Chamber*

To clarify the influence of the distribution characteristics of the airflow field on the transportation of chopped straw, multiphase flow coupling simulations and high-speed photography were used to study the change processes of the movement trajectory, velocity,

acceleration, and forces (drag force, airflow shear lift force, contact force between chopped straws, collision force between chopped straws and the device, etc.) of chopped straw during the spreading process [96,97]. They analyzed the influence of parameters, such as the shape of the chopped straw, the diameter of the pipeline, the flow guiding structure, and the airflow velocity, on the spreading uniformity of the chopped straw [98–100]. Through optimization tests, the optimal operation parameters of the spreading device were obtained to improve the spreading uniformity of the chopped straw [87,101]. During the spreading process, according to the motion posture of the chopped straw, based on aerodynamics, mathematical models of the velocity, acceleration, and forces of the chopped straw during the processes of upward oblique throw, horizontal throw, and downward oblique throw were constructed. The influence of parameters such as the initial velocity, mass, and motion time of the chopped straw on the motion and spreading range of the chopped straw was analyzed, thus providing a theoretical basis for improving the spreading uniformity of the chopped straw [102,103].

Totally, most of the studies mentioned above assumed the uniform distribution of chopped straw in the chopping chamber as a premise to carry out the design optimization and performance tests of the spreading device. However, during actual operation, the distribution of the amount of chopped straw in the chopped chamber is uneven, and the transportation mechanisms of chopped straw inside and outside the chopped chamber are not clear. This led to an uneven distribution of chopped straw, which hindered the promotion and resource utilization of the straw returning technology. Therefore, it is necessary to further explore the distribution of the amount of chopped straw in the chopped chamber and study new methods for regulating the transportation of chopped straw inside and outside the chopped chamber to achieve uniform spreading of chopped straw.

### 3. Development of Crop Straw Chopped Device

During the operational process of the crop straw chopping device, crop straw is cut, chopped, and segmented into fibrous pieces by the high rotational velocity of the blade. Consequently, the key component of the crop straw chopping device is the chopping blade [104]. The structure, type, and arrangement of the chopped blade directly influence the chopping and spreading quality, energy consumption, and lifespan of the chopping device. Depending on the power source, the chopping device can be powered by a tractor or a combined harvester. In terms of functionality, the tractor-powered chopping device can be further classified into crop straw chopping machine, crop straw chopping device combined with no/reduced tillage seeders, and straw chopping and burying or mixing machine.

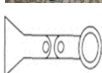
#### 3.1. Crop Straw Chopped Blade

According to the structure, the crop straw chopped blade can be categorized based on structure and type, such as the hammer type, straight blade type, bent blade type, and combined bent blade. The structural features of the chopped blade are shown in Table 1.

**Table 1.** Structural features of crop straw chopped blade.

| Type                 | Structural Features                                                                                                                                          | Figure                                                                                |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Hammer [105]         | High impact force, better collecting ability, high energy consumption, suitable for hard straw, such as cotton.                                              |  |
| Straight blade [106] | Lower energy consumption, high working efficiency, existing sawtooth at cutting edge, poor collecting ability, suitable for soft straw, such as wheat, rice. |  |

Table 1. Cont.

| Type                               | Structural Features                                                                                                                                          | Figure                                                                                |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Bent blade [107]                   | Batter chopping and collecting ability, suitable for hard straw, such as maize.                                                                              |    |
| Combined bent blade [108]          | Both collecting and chopping ability, combined utilization of two bent blades and one straight blade, suitable for hard straw, such as maize.                |    |
| Smoothing chopped blade [109]      | High working efficiency and life, suitable for soft straw, such as weed.                                                                                     |    |
| Double-edged blade [110]           | Batter symmetry, cutting edge on both sides of blade, manufacturing difficulty, suitable for hard straw, such as maize.                                      |    |
| L type [111]                       | With tangent edge and side cutting edge, easy to warp and deform failure, suitable for banana straw.                                                         |    |
| E type [112]                       | High working area, complex structure, high strength of blade, suitable for banana straw.                                                                     |    |
| Fan-type combined blade [113]      | High collecting ability and high velocity of airflow in chopped chamber, high energy consumption, and rotational inertia, suitable for rice and maize straw. |    |
| T type [88]                        | Both horizontal and vertical cuts, complex structure, suitable for soft straw, such as rice.                                                                 |   |
| V-L type [114]                     | High chopping ability, high structural strength, complex structure, suitable for maize straw.                                                                |  |
| Three linked sections [115]        | High cutting velocity, complex parts, aggravate machine vibration, suitable for maize and wheat straw.                                                       |  |
| Logarithmic spiral disc blade [50] | Providing support for Y-type chopped blade, providing higher breaking force on maize straw, suitable for maize straw.                                        |  |
| Bionic sawtooth chopped blade [61] | Tooth profile of the saw blade imitating blue shark teeth, reducing energy consumption, suitable for banana straw.                                           |  |

The arrangement of the chopped blade directly affected the collecting, chopping, and spreading ability of the straw returning machine [116]. During the design process, due to the high rotational velocity of the chopped blade, a reasonable arrangement can effectively reduce the energy consumption and variation of the straw-returning machine. Common arrangement methods included symmetrical arrangement, spiral arrangement, and symmetrical staggered arrangement [117].

In terms of optimization of chopped blade parameters, based on static tests, simulation methods, and validation tests, the optimal parameters of the chopping blade (e.g., rational speed [50,118], structure of the chopping blade such as curvature radius of blade edges [119], installation inclination [120], thickness [48], cutting frequency [121], operating forward speed [67], gap and angle of chopping and fixed blade [122,123], cutting angle between blade and straw [124,125], amount of feedstock [126], cutting depth [127,128], mass of cut crop per unit time [35], and vibration frequency of the machine [129]) were used to investigate the impact of these parameters on the fragmentation force, cutting stress, and energy consumption of the straw, thereby providing guidance for optimizing the

structural parameters of the chopping blades. In addition, some chopping blades have also been designed based on bionic technology to improve the ability of chopping [43,51,130].

In general, the structure and operational parameters of the crop straw chopped blade are designed and optimized through bench or field experiments. It is important to note that while bench experiments provide clear mechanical changes during the straw chopping process, the cutting speed in these experiments is much lower than that in actual field experiments. On the other hand, field experiments directly assess the impact of the chopped blade on chopped quality, but it is difficult to establish the relationship between the structure and operational parameters of the crop straw chopped blade and the force and motion of the crop straw in the chopped chamber. This limitation hinders the widespread improvement of the chopped quality of crop straw.

### 3.2. Crop Straw Chopped Machine

The crop straw chopping machine is the most widely used straw returning machine at present and is suitable for crop straw, such as maize, cotton, rice, wheat, banana, and cane [14,111,120,131,132]. According to the method of operation, the chopped machine can be divided into two types: the rotational collecting and chopping type and the vertical cutting type. The working principle of the rotational collecting and chopping machine is that, under the support of fixed blades, straw is chopped into filamentous or striped pieces by high-speed rotating blades, and then the chopped straw is spread on the field surface. According to the transmission type, the chopped machine can also be divided into three types: the single shaft with single side transmission type (SS), the single shaft with double side transmission type (SD), and the double shaft with double side transmission type (DD). Based on the rotational direction of the chopped shaft, the chopped machine can also be divided into horizontal type and vertical type, and the horizontal-type crop straw chopped machine is the most widely used. In addition, the working principle of vertical cutting type chopped machine is that the vertically standing maize straw is overwhelmed and placed vertically along the working direction by an overwhelm carding device, and then, under the support of the field surface, the maize stalks are cut into segments by a cutting blade with vertical motion. Some typical crop straw chopping machines are shown in Table 2.

**Table 2.** Typical crop straw chopping machine.

| Name                              | Chopped Type | Transmission | Structure                                                                            | Features                                                                                                                                                      |
|-----------------------------------|--------------|--------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1JH220-type chopped machine [133] | Horizontal   | SS           |  | Removable encryption fixed knife, high inertia moment of chopped blade, rotational velocity (RV) 2100 r/min, working efficiency (WE) 0.80 hm <sup>2</sup> /h. |
| 1JH220-type chopped machine [134] | Horizontal   | SS           |  | Left and right lateral movement by hydraulic, RV 2400 r/min, WE 0.99–1.12 hm <sup>2</sup> /h.                                                                 |
| 1JH455-type chopped machine [135] | Horizontal   | SD           |  | Suitable for maize, rice, wheat straw, RV 2100–2422 r/min, working width (WW) 4550 mm.                                                                        |
| TR46-type chopped machine [136]   | Horizontal   | SD           |  | Spreading amount of chopped stalk is adjustable, WW 3100 mm, matching power (MP) > 41.04 kW.                                                                  |
| Flail mower [137]                 | Horizontal   | SD           |  | Offset suspension, WW 2300 mm, RV 1850 r/min, MP 30–56 kW.                                                                                                    |

Table 2. Cont.

| Name                             | Chopped Type | Transmission | Structure                                                                            | Features                                                                                                                                                                                 |
|----------------------------------|--------------|--------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1JH type-chopped machine [138]   | Horizontal   | DD           |    | Hammer installed in front shaft, Y-type blade installed in back shaft; velocity of front shaft is small than that of back shaft; suitable for straw from tall and densely planted crops. |
| 1JHS-type chopped machine [139]  | Horizontal   | DD           |    | Suitable for ridge tillage region, flail blade installed in front shaft, cutting blade installed in back shaft, MP 147–161.7 kW, WE 1.33–1.53 hm <sup>2</sup> /h.                        |
| SC600-type chopped machine [140] | Horizontal   | DD           |    | Collapsible, WW 6000 mm, WE 6 hm <sup>2</sup> /h.                                                                                                                                        |
| Albatros plus [141]              | Horizontal   | DD           |    | Collapsible, adjustable working height, velocity of blade 52 m/s, suitable for weed, crop straw, shrub, MP 90–120 kW, WW 8300 mm.                                                        |
| Maschio Jolly 210 [142]          | Vertical     | SS           |    | Chopped shaft is vertical with field surface, MP 26–36 kW.                                                                                                                               |
| John Deere FM3012 [143]          | Vertical     | SS           |   | Adjustable working height, velocity of blade 82.30 m/s, MP 19–45 kW.                                                                                                                     |
| 60A-type chopped machine [144]   | Vertical     | SS           |  | Adjustable embedded depth, vertical motion of cutting blade, MP 8.82–13.23 kW.                                                                                                           |

To enhance the quality of straw chopping, diverse designs and optimizations have been proposed based on the physical and mechanical properties of different crops' straw. For the chopping of soft straw, such as wheat and rice straw, sugarcane leaf, Li et al. (2008) designed a sugarcane leaf fragmentation and returning machine. Compared to conventional chopping equipment, this machine reduced energy consumption by 7% while improving straw collection efficiency and qualified chopped length rate by 4% and 11%, respectively [145]. Qiu et al. (2015) developed a coaxial rice straw chopping and returning machine integrating rotary and stationary blades. At a rotary blade speed of 977.23 rpm, the qualified rate for chopped straw length reached 96.98% [146]. Sun et al. (2019) proposed a differential sawing-based straw chopper for rice straw (Figure 3), employing counter-rotating saw discs and crushing knives operating at differential speeds to achieve synergistic cutting. When the blade rotational velocity was 1800 rpm, the qualification rate for chopped straw length attained 93.23% [88]. Li et al. (2024) employed an integrated CFD-DEM multi-physics simulation approach combined with field validation experiments to systematically investigate and optimize the operational and geometric parameters of a rice straw chopping device [91].

For the hard-straw types, such as cotton, banana, and maize straw, a series of chopping devices were designed. For instance, Li et al. (2021) designed an anti-clogging banana straw crushing and returning machine supported by a flailing blade and found that working velocity, rotational speed of the blade, and bending angle were the main factors affecting the chopping quality of straw [147]. Zhang et al. (2024) proposed a dual fixed-blade, slip-cutting, and anti-tangling banana straw chopping machine, reporting a chopping qualification rate of 93.8% at a blade roller speed of 1800 rpm [148] (Figure 4). Liu et al. (2020 and 2021) provided a dynamically supported maize straw chopping device (Figure 5), where side-cutting blades and collecting blades rotated synchronously, achieving a stalk

chopping pass rate exceeding 90% [44,50]. For cotton straw, a vertical stalk chopping machine demonstrated a chopped length qualification rate of 92.24% when the rotational velocities of the large and small discs reached 1200 rpm and 1380 rpm, respectively [93]. Wang et al. (2023) enhanced performance by increasing circumferential chopping blades from 2 to 4, achieving a qualified chopping rate of 84.6% at 1800 rpm blade speed [40].

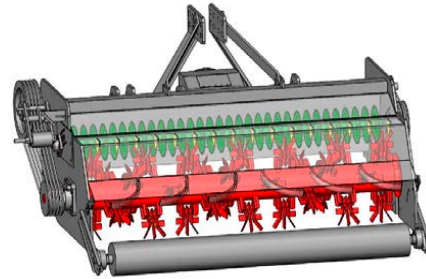


**Figure 3.** Straw chopper based on the principle of differential sawing.

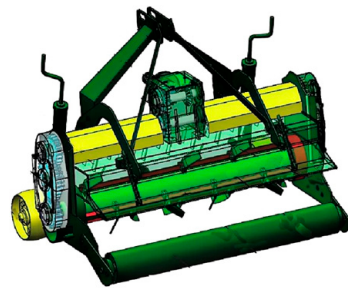


**Figure 4.** Vertical cotton stalk chopping and returning machine.

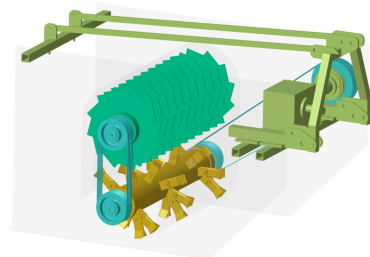


**Figure 5.** Dynamic supporting-type maize straw chopping retention device.

Current straw returning machines predominantly utilize high-speed rotary chopping blades for chopping straw. However, the inherent imbalance forces generated during blade–soil/stone interactions or multi-blade operations exacerbate shaft manufacturing complexity and reduce machinery lifespan. To address these limitations, researchers have explored reciprocating cutting mechanisms leveraging ground surface support for improved straw incorporation. For instance, Wang et al. (2018) designed a vertical maize straw cutter based on a four-bar linkage mechanism, achieving a chopped length qualification rate exceeding 95% in field trials [149]. Lin et al. (2024) developed a low-speed, high-frequency straw chopper (Figure 6) employing a constant-breadth cam mechanism to enable reciprocating cutting against the ground surface [150,151]. Furthermore, to accelerate the decomposition of chopped straw, integrated machines have been developed to spray decomposing agents post-chopping [152,153].

In summary, supported chopping systems integrating fixed and rotary blades are widely adopted due to lower blade tip speeds and reduced vibration compared to unsupported configurations. However, enhancing blade rotational speed remains the primary method for improving chopping quality, albeit at the cost of elevated vibration and energy

consumption. Therefore, developing an innovative chopping method characterized by low energy consumption, cost-effectiveness, and high forward speed should constitute a primary research focus in the future.

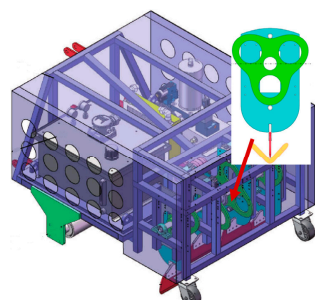


**Figure 6.** Low-speed and high-frequency straw chopping device.

### 3.3. Crop Straw Chopped Device Combined with No/Reduced Tillage Seeder

A crop straw chopping device combined with no/reduced tillage seeder is primarily installed in front of the furrow opener to collect, chop, transport, and spread the crop straw within the seeding row. These devices ensure clearance of the seeding path and prevent blockages caused by straw accumulation at the opener. Based on straw transport mechanisms, two configurations dominate: lateral-type chopping and spreading devices and rear-spreading-type chopping and spreading devices.

A lateral-type chopping and spreading device was mainly installed in front of the opener of seeder and combined with fixed blade or opener using the rotational chopped blade to cut the straw in front of opener, and then the chopped straw was conveyed to side of opener to improve the flow of straw to prevent seeding clogging. For instance, Luo et al. (2019) developed a rotary tillage-integrated wheat seeder employing counter-rotating chopping blades to fragment straw, followed by a diversion mechanism to distribute residue between seeding rows [154]. Shi et al. (2019) engineered a minimum-tillage planter equipped with straw chopping and strip-laying functionalities to maintain full-field straw coverage while clearing stubble from seed zones [155]. Zhao et al. (2020) introduced an inter-row side-throwing straw cleaning device (Figure 7), featuring angled side-rake blades to deflect chopped straw laterally from the opener's path [156]. Hou et al. (2021) devised a multi-stage lateral migration system for maize straw, achieving simultaneous chopping and lateral displacement within the seeding row [157]. Zhu et al. (2022) addressed challenges in high-clay, high-stubble rice fields by designing a dual-axis stubble disruptor (Figure 8), which achieved >95% cutting efficiency for both rice straw and root stubble [158]. Liu et al. (2023) analyzed the interaction dynamics between T-shaped furrow openers and maize straw and indicated the positive relationship between the displacement of straw and the forward speed of the blade [159]. Guo et al. (2024) proposed an active spiral-driven straw sorting device for no-tillage planter that directs surface residue to non-seeding areas via high-speed spiral-notched blades [160].

The rear-spreading-type chopping and spreading device is also positioned in front of the opener. This system employs the chopping device to collect, cut, and chop crop straw, propelling the processed residue rearward behind the seeder to create a debris-free soil surface for the furrow opener, thereby ensuring unimpeded operation. The chopping quality of the rear-spreading configuration surpasses that of lateral-type systems. To facilitate rearward dispersal, the device incorporates a deflector mechanism to modulate airflow and residue trajectories, enabling controlled backward distribution. For example, Chen et al. (2014) developed a peanut no-tillage seeder equipped with a straw-cleaning device that simultaneously chopped straw ahead of the opener and discharged it behind the seeder [161]. Wu et al. (2017) integrated a straw-chopping and back-throwing mechanism with a no-tillage planter, demonstrating enhanced operational efficiency [78].

Zhao et al. (2021) engineered a cotton planter combining seed-row rotary tillage with straw chopping, achieving an average chopped straw length of 140 mm and a qualification rate of 91.34% [162]. Shi et al. (2022) introduced a precision-chopping device to optimize straw-chopping stability and inter-row mulching uniformity [163]. Gu et al. (2022, 2023) proposed a no-till planter with integrated chopping, conveying, and backward-spreading capabilities (Figure 8), validating optimal operational parameters through field experiments and CFD-DEM coupled simulations [96,164]. Zheng et al. (2024) designed a rear-spreading guide chamber (Figure 9) that harnesses blade-generated airflow and chamber geometry to direct chopped straw behind the furrow opener [165].

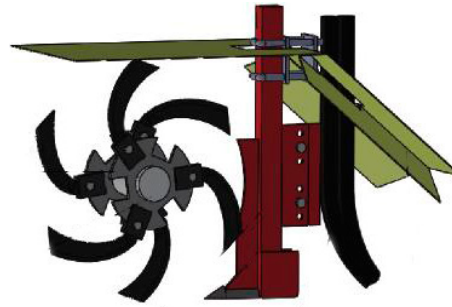


**Figure 7.** Strip-type inter-row side-throwing device.

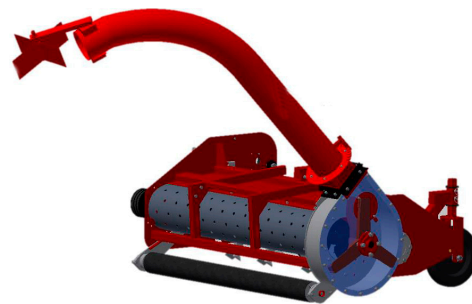


**Figure 8.** Chopping, conveying, and backward spreading device.

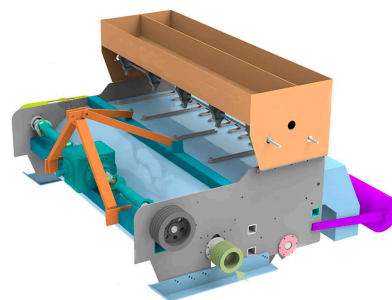


**Figure 9.** Rear-spreading guide chamber.

In total, for both lateral-type and rear-spreading-type straw chopped devices integrated with no/reduced tillage seeder, the primary objective involves transporting chopped straw behind the seeder or distributing it between seeding rows. These systems prioritize reducing straw length to mitigate clogging risks at furrow openers and prevent entanglement around rotary blade shafts. While straw chopping quality remains a secondary consideration, excessive accumulation of inter-row mulch can impede straw decomposition and interfere with subsequent cultivation. Similarly, rearward straw dispersal without dedicated diversion mechanisms often results in undesirable strip-wise accumulation or row coverage, compromising crop emergence and growth.

Notably, industry-driven innovations by agricultural machinery manufacturers have led to front-mounted chopping devices that simultaneously chop and spread straw while preventing opener blockages. Representative configurations of no-till seeder-integrated straw chopping systems are summarized in Table 3.

**Table 3.** Crop straw chopped device combined with no/reduced tillage seeder.

| Version                                                       | Type                                       | Structure                                                                            | Characters                                                                                                                                                 |
|---------------------------------------------------------------|--------------------------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2BMQF no-tillage planter [166]                                | Strip-type crop straw and stubble chopped  |    | Sawtooth roll blades were installed in front of opener and could chop and side spread the crop straw, WE 0.40–0.67 hm <sup>2</sup> /h.                     |
| 4FMJB crop straw chopping no-tillage precision seeder [167]   | Full chopped straw returning to the field  |    | Crop straw chopping device was combined with no-tillage seeder.                                                                                            |
| 2BYSF no-tillage planter with chopped straw back spread [168] | Straw chopped combined with back spreading |    | Full chopped of crop straw and spread to the back of the seeder; quickly combined with a variety of planters; MP 88.2 kW, WE 0.39–0.75 hm <sup>2</sup> /h. |
| Dasmesh Combo no-tillage planter [169]                        | Back spread of chopped straw               |    | Full chopped of straw and spread to the back of seeder by diversion chamber; WE 0.30 hm <sup>2</sup> /h.                                                   |
| LandForce HSS no-tillage planter [170]                        | Back spread of chopped straw               |   | Straw in front of seeder opener was chopped by chopped blade with high rotational speed in situ, WW 2286 mm, MP < 44.78 kW.                                |
| Dasmesh 610 no-tillage planter [171]                          | Strip-type back spread of chopped straw    |  | Chopped straw was transferred by drainage plate to back of opener, MP 37.31–44.78 kW.                                                                      |

### 3.4. Crop Straw Chopping and Ditch-Burying Machine

In regions with substantial straw residues, particularly maize–rice/wheat rotation systems, excessive surface mulching of chopped straw impedes sowing, fertilization, and seedling emergence in subsequent crops while retarding straw decomposition. To address these challenges, ditch-burying techniques for chopped straw have been developed to optimize plough layer management [45,172–174]. Conventional methods involve sequential operations: initial straw chopping followed by burial using moldboard plows. This two-stage process necessitates multiple field passes with distinct machinery, resulting in elevated energy consumption, exacerbated plow pan formation, and soil structure disruption. Consequently, innovative ditch-burying systems have emerged, where pre-chopped straw is deposited into pre-excavated trenches, compacted, and overlaid with soil to minimize surface residue interference. To accelerate decomposition, microbial inoculants or decomposition accelerants are often applied to the buried straw [172].

Integrated chopping and ditch-burying machinery represents the primary mechanized solution for efficient straw incorporation. To advance operational efficiency and energy sustainability, extensive research has focused on optimizing straw-feeding mechanisms into trenches. Based on straw transport methodologies, these machines are categorized into two types: pneumatic conveying systems and mechanical guidance systems.

Pneumatic conveying systems utilize mechanical fans or high-speed rotary blades to generate positive-pressure airflow for straw transport into trenches. For instance, Tian et al. (2018) developed a pneumatic straw deep-burying system, comprising integrated collection, chopping, and pneumatic conveyance modules [175]. Similarly, Wang et al. (2018) engineered a straw pulverizing device, where chopped maize straw was horizontally distributed into furrows

via transverse spreaders before final burial by plowing [176]. To address challenges posed by high stubble residues and substantial straw volumes following rice harvesting—factors contributing to shallow tillage layers and inadequate burial rates—Wei et al. (2020) designed a plowing-rotary tillage hybrid device for rapeseed direct seeding. Field trials demonstrated 137 mm deeper plowing and 33% higher stubble burial rates compared to conventional rotary tillers [177]. Chen et al. (2021) innovated a pickup-chopped and deep-buried device, where sieved straw was pneumatically injected into furrows [178]. To overcome limitations of pneumatic systems, including frequent blockages from high maize straw volumes and inconsistent burial depths, Yuan et al. (2023) engineered a centralized full-depth straw returning machine. This device employed optimized airflow dynamics to achieve >90% burial depth stability in pre-excavated ditches [179]. Further advancements by Tong et al. (2024) introduced a direct-injection pricking mechanism, which enhanced straw fragmentation and burial precision through synergistic mechanical-aerodynamic action [180,181].

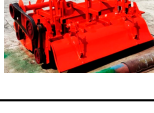
The mechanical guidance-type straw chopping and burying machine mainly employs mechanical devices, such as screw augers, toothed conveyors, or spiral trenchers, to transport the chopped straw into furrows. Lin et al. (2017) pioneered a spiral trencher-based machine integrating chopping, trenching, soil covering, and transport modules, achieving simultaneous straw burial and soil mulching [182]. Gao et al. (2018) enhanced this design by integrating soil-cutting blades into the spiral trencher, reducing energy consumption while maintaining 92.03% deep burial efficiency [183]. Zheng et al. (2017) combined spring-tooth collectors and chopping blades in an integrated machine that partially buried straw in furrows via airflow while retaining surface mulch [45]. Qin et al. (2017) developed a dual-purpose seeding and stalk-disposal system where guided rice straw entered collection ditches, with excavated soil automatically backfilled over residues [184]. Song et al. (2018) advanced rotary spade technology for soil trenching and backward soil-straw layering, improving burial uniformity [185]. Wang et al. (2023) optimized depth-adjustable ditching mechanisms, demonstrating through MBD-DEM simulations and field trials that trench stability correlated positively with operational speed and sprocket velocity but negatively with horizontal inclination angles [186]. Zhang et al. (2024) validated >90% chopping quality and burial rates in orchards using a green manure-specific burying machine [187].

Despite their efficacy, the straw chopping and ditch-burying systems and machines face inherent challenges: trench depths exceeding 20 cm necessitate complex machinery with high energy demands, while prolonged straw decomposition risks interfering with subsequent sowing. Future research should prioritize the development of energy-efficient furrow-opening mechanisms adaptable to variable soil conditions, simplified machine architectures, and accelerated straw decomposition protocols. Additionally, integrating geo-referencing technologies, such as satellite navigation for mapping burial trenches, could enable precise avoidance of residual straw zones during subsequent planting cycles, thereby reducing interference from undecomposed biomass.

### 3.5. Crop Straw Chopping and Mixing Machine

To enhance the contact area between chopped straw and soil and accelerate decomposition, a method integrating straw chopping with soil mixing was developed. The mixing mechanism, functionally analogous to a rotary tillage system, achieves soil-straw homogenization through soil pulverization and turbulent mixing. Representative configurations of straw chopping and mixing machines are summarized in Table 4.

**Table 4.** Straw chopping and mixing machine.

| Type                                                                         | Structure                                                                           | Technical Characters                                                                                                                                                   |
|------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1GZMH-type straw chopping and mixing machine [188]                           |    | Straw and stubble were chopped and evenly mixed with soil at one time, the exposure rate of straw and root stubble $\leq 5\%$ .                                        |
| Straw returning and stubble cleaning combined soil preparation machine [189] |    | Straw chopping and returning, stubble cutting, and mixed with soil operations can be completed at one time, MP 59.6–163.9 kW, WE 15–30 hm <sup>2</sup> /h.             |
| Double shaft-type straw returning machine combined with rotary tillage [190] |    | For vertical or laid corn, cotton, and other straws, straw and stubble chopping and rotary mixing and burying operations were completed at one time; MP 37.3–96.98 kW. |
| 1JHM-165 straw and stubble chopping and returning machine [191]              |    | Functions: straw chopping, stubble cleaning, mixed and buried with soil, RV of chopped blade 2100 r/min, RV of stubble cleaning blade 500 r/min, MP 60–70 kW.          |
| 1GKF-200 straw returning machine combined with rotary tillage [192]          |    | Suitable for straw of rice, maize, cotton, and sorghum, qualified rate of crop straw chopping length $\geq 93\%$ .                                                     |
| Combined machine for land preparation and full straw returning [193]         |   | The operations of crop straw chopping, stubble cleaning, and layered straw and stubble buried, MP 52.15–223.5 kW.                                                      |
| SGTN-350 combined machine for stubble cleaning and land preparation [194]    |  | Stubble chopping and rotary tillage and burying operations were completed at one time, WW 3500 mm, MP 134.1–171.35 kW.                                                 |
| Straw chopping machine for mixed-burying or covering [195]                   |  | Part chopped straw mixed with soil and another part straw mulched on field surface, WW 1836 mm, MP 80–120 kW.                                                          |
| Rice straw chopping and mixing combined operation machine [196]              |  | At the same time, the chopping and mixing with soil of rice straw was completed, distance between chopping device and mixing device was adjusted.                      |

To optimize mixing performance, extensive research has been conducted. For instance, to address challenges in cohesive and compact soils prevalent in the middle and lower Yangtze River Basin, innovative designs, such as helical-blade integrated cutter rollers and six-head spiral knife rollers, were engineered to enhance mixing efficiency while minimizing energy consumption [197,198]. Xu et al. (2022) investigated straw–soil–tool dynamics, quantifying straw transport and stratification patterns across tillage regimes. Their results demonstrated that at a straw length of 5 cm, tillage depth of 13 cm, and rotary speed of 320 rpm, straw burial rates reached 95.5% with lateral displacement of 27.6 cm [199]. Lin et al. (2024) developed a DEM-validated simulation model to analyze interactions between a shovel-type seedbed preparator, straw, and soil. The study revealed stratified straw distribution: 76.02% within 0–80 mm, 17.91% at 80–160 mm, and 6.07% at 160–240 mm depths [200]. Yang et al. (2020) designed a telescopic finger stalk of a maize straw mixing machine, achieving an 83.25% burial rate in the 0–50 mm layer—10 percentage points higher than conventional rotary tillers [201]. Wang et al. (2020) designed a counter-rotating rice straw mixer using kinematic soil–blade position modeling, which prevented soil backflow and achieved 85% straw incorporation, >95% soil fragmentation, and surface leveling [202]. To indicate the spatial distribution effects of straw in the soil after incorporation and mixing,

Zhou et al. (2020) found that straw chopping and mixing machines enhanced subsurface straw allocation by 154.9% relative to traditional tillage [203]. Wang et al. (2023) addressed rotary tiller entanglement issues in rapeseed cultivation through a hybrid stubble-mixing and anti-blocking device [204]. Liang et al. (2023) refined a dual-auger burial system for rape straw, significantly improving in-soil straw distribution uniformity [205]. Patel et al. (2024) demonstrated a vertical-axis straw mixer-burier for rice stubble, achieving 98% mixing-burial efficiency with 7 mm mean straw length under optimal settings [206]. Du et al. (2024) developed a rapeseed direct-seeding system incorporating anti-blocking and stubble-mixing components, which increased straw incorporation rates by 27% compared to standard tillage [207].

Compared to ditch-burying systems, straw chopping and mixing machines exhibit simpler structural configurations. However, inherent limitations in combined-operation devices, particularly uneven chopping consistency and dispersal heterogeneity, compromise soil–straw homogenization, adversely affecting seedbed preparation and crop establishment.

### 3.6. Crop Straw Chopped Device Powered by Combined Harvester

Integrated crop straw chopping devices mounted on combined harvesters are widely employed during wheat, maize, and rice harvesting to simultaneously collect and chop field residues. This integrated approach minimizes the need for additional machinery, thereby reducing operational costs and field traffic. For maize harvesters, the chopping mechanism is typically installed in the mid-lower section of the equipment [208], utilizing high-speed rotary blades analogous to horizontal-axis residue collectors to fragment surface straw. Conversely, rice and wheat harvesters commonly position the chopping unit behind the main body [209], employing axially symmetric arrays of smooth or serrated straight blades to process threshed stalks along the cutter shaft.

To improve the chopped quality of rice straw, Wang et al. (2018) optimized a straw chopping device for a rice–wheat combined harvester (Figure 10), and the field experiment showed that the rotational speed of the chopped blade at 2500–3000 r/min, and a bend angle of the blade at 65–70° led to a 94.57% qualification rate of crop straw chopping length and 88.88% uniformity of the spread chopped straw [73]. Bur'yanov et al. (2018) implemented a post-header chopping system that distributed residues either uniformly or in controlled strips via adjustable guide ducts [210]. Zhang et al. (2018) developed a cross-sectional sawtooth blade configuration mounted behind the harvester header, reporting a 92.14% length qualification rate at 2 m/s forward speed and 850 rpm blade rotation [211]. Wang et al. (2019) analyzed the interplay between maize cultivars, harvester operating speeds, and stalk moisture content, identifying maximum stalk fragmentation (61%) in the mid-lower sections of straw [212]. Wang et al. (2021) developed a rice straw chopping device for agitation sliding cutting and tearing (Figure 11), and when working velocity, the rotational speed of the chopped blade, and the fixed blade clearance were 0.95 m/s, 2600 r/min, and 150 mm, the qualified rate of the crop straw chopping length was 95.49% [213]. Jia et al. (2022) used a fixed blade and a high-speed moving blade to slice the maize straw in horizontal and longitudinal sections, and the qualified rate of straw crushing was 94.40% [214]. Xin et al. (2023) enhanced vertical roller header systems through a grip-optimized clamping conveyor, improving straw retention during high-speed chopping [215]. Chen et al. (2023) optimized a feeding and chopping device of silage maize harvester, and the standard grass length rate and energy consumption were 95.35% and 37.63 kJ/kg, respectively, under a feeding speed of 3.39 m/s, and a rotating speed of 1016.17 r/min [216]. Zhou et al. (2024) investigated the chopping and damage mechanisms of sugarcane to optimize the operational parameters of the chopping device [217].

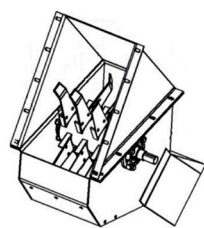


**Figure 10.** Straw chopping device for rice-wheat combined harvester.

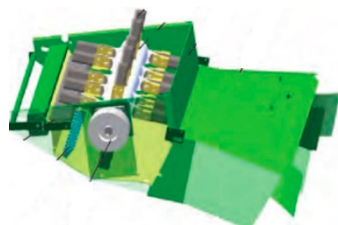


**Figure 11.** Rice straw chopping device for combined harvester.

In summary, harvester-integrated choppers primarily rely on high-speed linear blades for residue processing. However, limitations persist, including inadequate mechanical stabilization of straw during cutting, leading to dragging-induced incomplete fragmentation and substantial incremental energy demands.

### 3.7. Summary of Different Crop Straw Chopped Devices

Based on the above review, the current state of development of straw chopping devices has been summarized and analyzed. To better support both researchers and farmers, it is necessary to further describe the advantages and limitations of different straw chopping equipment (Table 5).

**Table 5.** Advantages and limitations of different crop straw chopped devices.

| Crop Straw Chopped Devices                             | Advantages                                                                                                                                    | Limitations                                                                            |
|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Chopped machines                                       | Simple structure and easy to maintain; widely used; high chopping quality                                                                     | Low operational speed                                                                  |
| Chopped device combined with no/reduced tillage seeder | Enhance the seeder's ability to operate in fields with residue and prevent crop residues from clogging the seeder; multifunctional operation  | Enhancement of straw chopping quality is required.                                     |
| Chopping and ditch-burying machine                     | Accelerate the decomposition rate of straw; create a favorable seeding environment                                                            | High energy consumption; exacerbated plow pan formation; and soil structure disruption |
| Chopping and mixing machine                            | Accelerate the decomposition rate of straw; high chopping quality                                                                             | Exacerbated plow pan formation and soil structure disruption                           |
| Chopped device powered by combined harvester           | Multifunctional operation; lower the frequency of machine passes and reduce operational costs; suitable for chopping straw from various crops | Complex structure and high individual machine cost                                     |

## 4. Development of Chopped Straw Spreading Device

The straw spreading process constitutes an integral extension of the chopping sequence within residue management systems. The kinematic behavior of fragmented straw during dispersal exhibits significant complexity, necessitating engineered airflow modulation through spreading apparatus to govern particle trajectories and orientations, thereby optimizing dispersion homogeneity.

Core components of spreading systems include a chopping chamber and guidance mechanisms. Predominant chamber configurations employ polygonal geometries, offering structural simplicity and manufacturing feasibility, albeit compromising directional control over straw fragments and limited adjustability of ejection trajectories. To address these limitations, directional regulators, such as the guiding devices, like the guide vanes, spreading discs, or wind-powered conveying pipes, are integrated downstream of the chamber outlet to manipulate fragment velocity vectors and spatial distribution patterns.

Guidance systems are categorized as passive or active based on energy input requirements. Passive guidance mechanisms utilize static or angle-adjustable vanes to redirect airflow–straw interactions, achieving basic dispersion control with minimal mechanical complexity. While cost-effective and widely adopted in horizontal chopping systems, these systems lack real-time adaptability to dynamic field conditions.

A passive-type guiding device mainly uses the guiding vanes, and by adjusting the installed angle of guiding vanes, the motion velocity of airflow and chopped straw is changed to further adjust the spreading uniformity. The guiding vanes are simple to install, convenient to operate, and are widely used in horizontal-type chopping and returning machines, but they cannot be adjusted in real time according to the field operation.

In contrast, active-type guiding devices employ the driven spreading disc or fan-generated wind-powered conveying pipe. The spreading disc, typically mounted on combine harvesters, enables stepless regulation of rotational velocity and angular orientation via hydraulic or electronic controls, permitting variable swath widths and enhanced uniformity. However, the transmission structure of the spreading disc-type flow guiding and spreading device is complex, and within the working width, there is a tendency that the amount of chopped straw is more in the middle and less on both sides [218]. The fan-generated wind-powered conveying pipe, integrating axial fans and auger transporters, accelerates straw fragments through ducted pathways, achieving elevated ejection velocities and extended throw distances [78,219]. Nevertheless, additional devices for collecting, conveying, and accelerating the chopped straw need to be installed. Some typical spreading devices for chopped straw are shown in Table 6.

**Table 6.** Spreading devices for chopped straw.

| Version                                             | Type                                      | Structure                                                                            | Characters                                                                                                                          |
|-----------------------------------------------------|-------------------------------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| 4JH-168 straw chopping and returning machine [220]  | Guiding vane                              |  | Six guiding vanes installed symmetrically, deflection angle of guiding vane (DAGV) < 25°, rotated up and down around the pin shaft. |
| 4JQ straw chopping and spreading machine [221]      | Guiding vane                              |  | Six guiding vanes installed symmetrically, high spreading area, DAGV < 35°.                                                         |
| 4JQM-300 straw chopping and returning machine [222] | Fan-generated wind-powered conveying pipe |  | Installed on the side of the machine, high initial spreading velocity of chopped straw, WW 3000 mm.                                 |
| 4SJ-180 straw chopping machine [223]                | Fan-generated wind-powered conveying pipe |  | Installed in the middle of the machine, rear overhead fan conveying, rotational speed of convey auger 800 r/min.                    |
| 1JH straw chopping and spreading machine [224]      | Spreading disc                            |  | Special-shaped fans installed on the disc, high initial speed, and spreading area of chopped straw.                                 |

Table 6. Cont.

| Version                             | Type           | Structure                                                                          | Characters                                                                                                   |
|-------------------------------------|----------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| S780 combined harvester [225]       | Spreading disc |  | Spreading width 9.14~13.72 m, double-layer spreading disc, adjustable rotational speed.                      |
| CX7 combined harvester [226]        | Spreading disc |  | Evenly thrown by the positive pressure airflow generated by the high-speed rotational chopped blade.         |
| Axial-Flow combined harvester [227] | Spreading disc |  | Double spreading discs, adjust the opening and closing distance of the throwing mouth by electronic control. |
| Avero 240 combined harvester [228]  | Guiding vane   |  | Adjustable spreading velocity of chopped straw and adjustable position of guiding vane.                      |

Uniformity quantification serves as the paramount metric for evaluating spreading performance. To improve the spreading uniformity, the spreading device was optimized and developed. In terms of the passive-type guiding device, Zhang et al. (2017) designed a logarithmic spiral chopped chamber (Figure 12), which effectively improved the distribution uniformity of the airflow field in the chopped chamber, and adjusted the throwing width and uniformity of the chopped maize straw through a synchronous adjustment device [46]. A spreading angle adjustment device for a wheat/rice combined harvester was developed by Wang et al. (2019) and mainly included an installed plate, spreading plate, and electric push rod, and the device effectively improved spreading uniformity of chopped straw by 15% [229]. Qin et al. (2020) parameterized vane inclination effects through computational modeling, identifying 22° vane angles as optimal for achieving 90.2% swath compliance and 11.9% dispersion variability [230]. Xu et al. (2021) engineered a cam-actuated guidance assembly with telescoping linkages, attaining >79.8% uniformity in horizontal chopping systems [231]. Zhang et al. (2024) indicated that increasing the clearance between the tip of the chopped blade and the chopping chamber has an adverse effect on straw spreading performance [43]. Zhang et al. (2024) found that the increase in height and rotational speed of the anti-winding plate boosted the airflow velocity within the chopping chamber, causing banana straw blocks to be thrown more dispersedly and reducing spreading unevenness [148]. Zheng et al. (2024) further advanced directional strip-spreading technology (Figure 13) through DEM-coupled field validation, achieving 4.6% improvement in seedbed clearance metrics [165].



Figure 12. Logarithmic spiral chopped chamber.

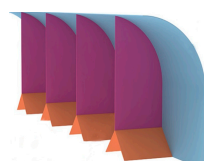


Figure 13. Directional strip spreading device.

Active system innovations include helical auger throwers enabling operator-selectable dispersion modes (uniform broadcast vs. strip mulching) and bidirectional auger transporters for inter-row straw redistribution [232,233]. To improve the spreading uniformity of a wind-powered conveying pipe, Shi et al. (2022) designed a throwing impeller (Figure 14) for wind-powered conveying pipe. The throwing impeller was driven by the airflow, and then the agglomerated straws were disrupted by the throwing impeller to further improve spreading uniformity [163,219]. According to the structure and operation of rape live broadcast machine, Jia et al. (2022) designed a straw breaking and diversion device for maize harvesters to guide the chopped straw into the ridge furrow (Figure 15) [214]. Liu et al. (2024) demonstrated 16.98% lateral uniformity variation using centrifugal spreaders at 255 rpm disc speeds (Figure 16) [234]. Yan et al. (2025) developed a side-throwing device (Figure 17), which chopped cotton stalks were spread by a rotational throwing disc to one side of the returning machine, and the spreading uniformity of chopped straw was larger than 85% [235].

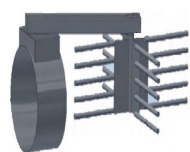


**Figure 14.** Throwing impeller.

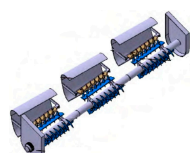


**Figure 15.** Straw breaking and diversion device.

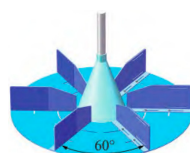


**Figure 16.** Active centrifugal rice straw spreading device.



**Figure 17.** Side-throwing device.

In total, before the start of the returning-to-field operation, the inclination angle and installation position of the guiding vane or the rotational velocity and inclination angle of the spreading disc are determined. Therefore, the spreading uniformity and widths of chopped straw in real-time can not be adjusted in real-time and the uniformity and widths are easily affected by the existence of side-wind in the field and uneven distribution of straw on the field surface. Therefore, the automatic distribution judgment of crop straw in the field and the mitigation of the impact of external disturbances on spreading uniformity should be the focus of future research.

## 5. Summaries and Recommendations

In general, extensive research has been conducted to design, optimize, and develop crop straw chopping and returning devices through computational simulations, theoretical analy-

ses, and empirical laboratory or field investigations. These efforts have substantially enhanced the chopped and returning quality of crop straw, establishing a foundation for subsequent agricultural practices such as tillage and seeding. Nevertheless, uneven straw distribution post-harvest remains a persistent challenge, with operational parameter adjustments still predominantly reliant on empirical human judgment.

Furthermore, when straw is directly spread on the field surface, the causal relationships among the straw's in-field mass and distribution, the operational parameters of the returning machine, and the quality of chopping and spreading remain unclear, often resulting in an uneven distribution of the chopped material.

Similarly, the soil–straw–tool interaction dynamics for buried or mixed straw demand deeper mechanistic understanding. These limitations contribute to operational inefficiencies, including elevated energy expenditure, suboptimal processing quality, and reduced operational throughput. Therefore, to address these challenges, advanced sensing and control technologies must be developed to dynamically monitor straw distribution and mass mulching on the field surface, autonomously calibrate machine parameters, and intelligently evaluate operational quality. To advance toward high-performance straw management systems with superior comminution consistency, reduced energy demands, and enhanced operational efficiency, six strategic recommendations are proposed:

- (1) Develop the intelligent field straw distribution mapping system. The heterogeneous spatial and mass distribution of straw necessitates adaptive parameter selection for blade rotational velocity, forward speed, and spreading device angles. A machine vision-based automated extraction system should be engineered to inform real-time parameter optimization during chopping and spreading operations.
- (2) Engineer the adaptive self-regulating mechanisms for chopping and returning equipment. Manual parameter adjustments (e.g., blade speed, ground clearance, and forward velocity) under dynamic field conditions often result in suboptimal blade kinematics and susceptibility to environmental disturbances (e.g., crosswinds and turbulent airflow). Closed-loop control systems, integrated with straw distribution data, should be developed to enable autonomous machine parameter modulation.
- (3) Elucidation of the mechanics and kinematics of straw during the chopping and returning processes. The interplay between straw biomechanical properties, kinematic tool forces, and aerodynamic/stochastic field conditions critically governs straw fragmentation length, energy efficiency, and spreading uniformity. High-fidelity computational modeling (e.g., CFD-DEM coupling) combined with high-speed imaging and sensor fusion technologies should be employed to examine the effects of operational and structural parameters of the chopping and returning machine, airflow distribution, and spatial and mass distortion of crop straw on the quality of chopped and spread straw.
- (4) Implement the real-time quality assessment systems for straw returning operations. Current quality assessment typically relies on manual labor, which is impractical for large-scale mechanized farming and introduces subjective bias. An integrated optical–electronic monitoring platform should be developed to autonomously quantify straw comminution metrics (e.g., length distribution and spread uniformity) and provide feedback for process optimization.
- (5) Pioneer the high forward-speed (>8 km/h) straw chopping and returning architectures. Conventional machines (1–4 km/h) prolong operational timelines, disrupt farming schedules, and compromise subsequent planting windows. While blade speed escalation might maintain comminution quality at higher forward speeds, this approach exponentially increases energy consumption. Innovative comminution principles (e.g., pulsed shear, counter-rotating blade arrays) must be explored to decouple forward speed from energy intensity to achieve high forward-speed operation.

- (6) Establish the context-specific straw residue management frameworks. While straw retention strategies (surface spreading, ditch burial, and soil mixing) enhance soil fertility and crop yields, optimal method selection hinges on agroecological contexts (soil type, crop rotation, and climate). Predictive models integrating agronomic requirements, machine capabilities, and economic constraints should be formulated to guide site-specific implementation of straw return protocols.

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

**Funding:** This thesis was funded by the National Natural Science Foundation of China (No. 32401714), the Natural Science Foundation of Henan Province (No. 242300421560), the Science and Technology Project of Henan Province (No. 232102110273), and the scientific research foundation for advanced talents of Henan University of Technology (No. 2022BS077).

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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