Off-field Transportation and Storage of Corn Stover with Medium-high Moisture Content Based on the Multistage Continuous Cold Roll Forming Method

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The moisture content of corn stover during the harvest season in the Huang-Huai-Hai region of China is approximately 50%. To achieve rapid off-field transportation and to prolong its shelf life, a method suitable for corn stover with medium-high moisture content was considered based on the stover multistage continuous cold roll forming method. An orthogonal experiment was adopted by taking the moisture content, sterilization method, and inhibitor addition method as experimental factors and taking the shelf life, percent rebound, and density of the molding blocks as the experimental indices. It was found that the steam sterilization method can prolong the shelf life of the molding block the most. The percent rebound and the density were primarily affected by the moisture content, followed by the sterilization method. A comprehensive analysis indicated that the optimal treatment mode was a moisture content of 45%, and the optimal sterilization method was steam sterilization with no inhibitor. In this mode, the molding block can be stored for 72 h without mildew with an average temperature of 32 °C and an average humidity of 48% during the day. The percent rebound was 24.3%, and the density can reach 310 kg/m^3 after the completion of rebound.

Keywords: Corn stover; Roll forming; Rapid off-field; Shelf life; Orthogonal experiment

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INTRODUCTION

China's corn stover resources represent a large output, accounting for 46.6% of China's agricultural residues (Tan *et al*. 2019). In China, the off-field utilization of corn stover primarily consists of feed and fuels. According to the moisture content of the harvest season, corn stover can be divided into four categories: high moisture content (> 60%) (Wu *et al*. 2016), medium-high moisture content (40% to 60%), medium-low moisture content (20% to 40%), and low moisture content (< 20%). Among these categories, corn stover with high moisture content is primarily used for silage, while stover with medium-low moisture content and low moisture content is primarily made into briquettes or fuels through solidification technology (Bi *et al*. 2019). China's corn-growing areas are primarily distributed in the Northeast and Huang-Huai-Hai regions (Zuo *et al*. 2015). The Huang-Huai-Hai region primarily adopts the planting mode of summer corn and winter wheat twice a year, and the moisture content of corn stover in the harvest season is approximately 50% (Zhai 2013). Because the output of corn stover is too large, on-site drying not only consumes considerable manpower and space but additionally affects subsequent planting. Therefore, corn stover needs to be removed from the field quickly. Corn stover with this moisture content has low bulk density, has high transportation costs, and decays easily, making it difficult to guarantee the storage quality and safety of corn stover when it is transported to the pastoral region of Northwest China (Xiong *et al*. 2010; Wu *et al*. 2016). This difficulty in transportation has led to the problem of high corn stover yields that are difficult to handle in China's planting areas, while the feed gap in the northwestern pastoral areas is large and difficult to address (Dong *et al*. 2018).

The key to efficient utilization of stover resources is to rely on biomass compacting technology to reduce volume and increase density. Of the compaction methods, mechanical compaction is the most effective (Tumuluru *et al*. 2011; Guo *et al*. 2016). According to the molding density of the material, the existing compression can be divided into three types: high density, medium-low density, and low density. Among these types, the compression molding of the die roller type biomass material is used for high-density molding, and the molding density is usually above 600 kg/m^3 (Ouyang *et al*. 2011), but this mode is only suitable for the molding of straw with low moisture content (Xia *et al*. 2014; Ning *et al*. 2016). The square baler is a medium-low density molding technique. The molding density achieved by the square baler is usually greater than 180 kg/m^3 according to the moisture content of the straw (Wang *et al*. 2009). The piston reciprocating punching affects the efficiency of this baler, and the equipment investment cost is high (Qian *et al*. 2019). The round baler is used for low-density molding. The molding density is usually above 125 kg/m^3 depending on the moisture content of the straw (Liu *et al*. 2017). However, the intermittent operation mode of the round baler causes round bales to exhibit low productivity and poor density uniformity (Guo *et al*. 2018; Xie *et al*. 2019). In the straw multistage continuous cold roll forming method described in this article, according to the different moisture contents of straw, the forming density is mainly within the range 250 to 400 kg/m^3, which is classified as medium density forming (Liu *et al*. 2016).

Scholars from various countries have performed considerable research in the field of stover biomass formation and storage. Kaliyan *et al*. (2013) studied the effects of different materials (corn stover and perennial grasses), particle size, and roller force on the density and durability of the molding blocks. The results showed that the roller force had the strongest effect on the density and durability of the molding blocks. The density of briquettes produced by the roller press was greater than 240 kg/m^3, and the briquettes exhibited good durability. Gao *et al*. (2015) designed a round bale forming device for corn stover silage with high moisture content based on the logarithmic spiral round bale forming principle. It tested the effect of the pressure angle of the feeding precompression mechanism and stover moisture content on the baling performance of the device. The results showed that the use of a logarithmic spiral round bale forming device with a certain pressure angle can solve the congestion problem and reduce the baling time. Cong *et al.* (2009a, 2009b) developed the 4YQK-2 corn harvester of stalk silage bundled based on the existing corn harvesting and forage silage mechanization technology and tested the performance of the prototype. The results of the study showed that the prototype can effectively complete the work of collecting, shredding, conveying, and bundling stover with high moisture content.

Corn stover with medium-high moisture content easily deteriorates under natural conditions without treatment. There are usually two ways to store this biomass. One approach is to make silage or yellow feed, which can be stored for a long time, and the other method is to reduce the moisture content of the stover by air drying followed by stacking or compression storage. Przybył *et al*. (2018) explored the effects of different treatment technologies on the quality of corn stover silage, and their results showed that silage can effectively improve the quality and storage time of corn stover feed. The corn stover silage in a flexible silo exhibited the best quality. Shinners *et al*. (2003) studied the effects of different storage methods on the storage quality of dry and wet corn stover, and their results showed that both bagging and film-coated silage of high-moisture stover were beneficial to storage, and film-coated silage was less prone to mold. Tian *et al*. (2015) explored the effects of three different storage methods (open-air, covered, and sealed) on the long-term storage of low-moisture corn stover with such pretreatment methods as whole plant, baling, and crushing. The results showed that the whole plant or baled stover were preferable, and the environment should be well ventilated when storing large quantities of stover. However, all the above methods require considerable time and labor, which are not conducive to the efficient and rapid transportation and reuse of corn stover from the fields in the Huang-Huai-Hai region of China.

Therefore, this research had the following objectives: (a) Verify the feasibility of the multistage continuous cold roll forming method for corn stover with medium-high moisture content; (b) Employ the experimental prototype to prolong the shelf life of corn stover with medium-high moisture content; (c) Explore the influence of moisture content, sterilization method and inhibitor addition method on the storage capacity of stover molding blocks; and (d) Obtain a treatment method suitable for the rapid off-field transportation of corn stover with medium-high moisture content to solve the problem of processing corn stover with medium-high moisture content in the Huang-Huai-Hai region of China.

EXPERIMENTAL

Materials

Corn stover was obtained from Gaocheng District, Shijiazhuang city, Hebei Province, China, in late June 2020, and it was crushed by the 9FS5-5500 straw kneading and crushing machine produced by China Shijiazhuang Liang New Energy Technology Co., Ltd. (Shijiazhuang, China) (Fig. 1).


(a) (b)

Fig. 1. Corn stover for experiment: (a) untreated corn stover; (b) corn stover after being crushed

The study was conducted by China Hebei Nongle New Energy Technology Co., Ltd. (Shijiazhuang, China) in July 2020. The average temperature of the experimental environment was 32 °C, and the average humidity was 48%.

Devices

Structure and working principle of a stover multistage continuous cold roll forming machine

The assembly drawing and prototype of the molding machine are presented in Fig. 2. The prototype of this molding machine was independently developed by China Agricultural University.

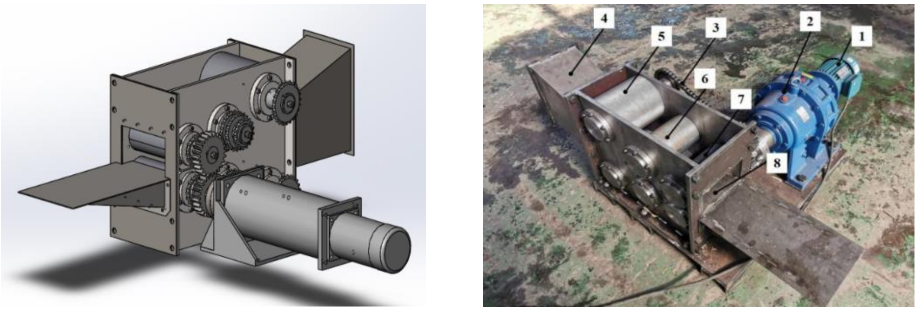

Fig. 2. Assembly drawing and prototype of a stover multistage continuous cold roll forming machine: 1: motor; 2: reducer; 3: transmission system; 4: feeding port; 5: one-stage compression roller; 6: two-stage compression roller; 7: three-stage compression roller; and 8: outlet

The working principle is shown in Fig. 3.

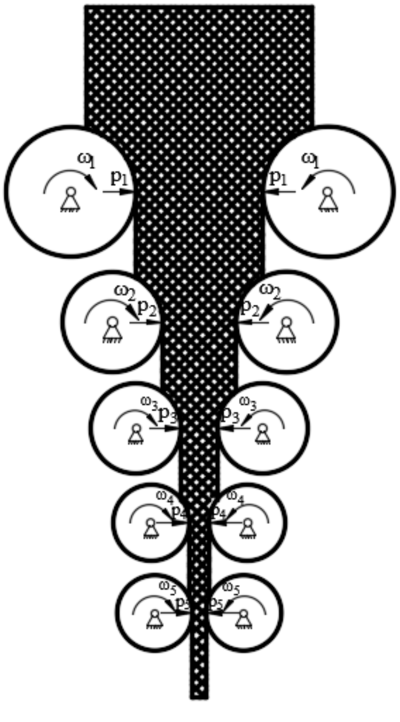

Fig. 3. Schematic diagram of the design scheme of a stover multistage continuous cold roll forming machine

The crushed corn stalks are fed in from one end and are continuously compressed by multistage symmetrically arranged compression rollers and are then discharged from the other end. The pressure at each compression stage during the compression process of the stover material is represented by $p_{1\text{-}5}$. The rotation directions of the compression rollers at each stage are ω_1, ω_2, ω_3, ω_4, and ω_5. Continuous roll forming of the crushed corn stover is employed to improve the productivity of compression forming and realize the efficient continuous cold compression forming of corn stover. The compression roller interacts with the stover material in the working process by rolling friction, and the stover material is cold-compressed, which can reduce the energy consumption of the machine. Finally, the symmetrical arrangement of the compression rollers can offset the axial force, improve the stability of equipment operation, reduce the wear of various working parts, and increase the life of the whole machine.

According to the relationship between the total rolling ratio ε, the number of compression stages n, and the compression roll radius r, the machine follows the open compression characteristics of corn stover and the design method of steel rolling machinery (Huang *et al*. 2007; Wang *et al*. 2016a,b; Liu *et al*. 2019). At the same time, to conserve experimental prototype consumables and to reduce the size of the experiment prototype, the prototype machine only produces the third-stage compression molding part, and the front-end feeding and precompression part are completed by the precompression device. Finally, the parameters of the molding machine are optimized, as shown in Table 1.

Table 1. Parameters of the Stover Multistage Continuous Cold Roll Forming Machine

Name	Value
Compression stages (n/level)	3
Thickness of the first-stage compression roller enters the material (s_0/mm)	200
Thickness of the final-stage compression roller presses out the material (s_n/mm)	20
Diameter of the first-stage compression roller (d_1/mm)	180
Diameter of the second-stage compression roller (d_2/mm)	125
Diameter of the third-stage compression roller (d_3/mm)	100
Feeding angle of the first-stage compression roller (α_1°)	63.61
Feeding angle of the second-stage compression roller (α_2°)	53.13
Feeding angle of the third-stage compression roller (α_3°)	45.57
Total rolling ratio (ε)	10
First-stage compression ratio (ε_1)	2
Second-stage compression ratio (ε_2)	2
Third-stage compression ratio (ε_3)	2.5

Other experimental equipment and instruments

Other equipment and instruments required for the experiment included a homemade precompression device (China Agricultural University, Beijing, China), an OHAUS MB23 moisture analyzer (OHAUS Co., Parsippany, NJ, USA), a ZF-C10002 electronic balance

(Hardware Weighing Apparatus Co., Hanghai, China), a LDR0.004-0.4 steam generator (Baishen Washing Equipment Co., Hanghai, China), a TUV ultraviolet germicidal lamp (Philips Investment Co., Amsterdam, Netherlands), a 3000-mL beaker, a temperature and humidity meter (Deli Group Co., Ningbo, China), a spray bottle, and a scale.

Methods

Experimental preparation

To explore the factors that affect the storage performance of corn stover blocks with medium-high moisture content, as well as to obtain a better processing mode that is convenient for transportation to different regions and adapts to this molding machine, an experimental study was conducted. Corn in the Huang-Huai-Hai area of China is generally harvested from the late wax maturity stage to the early maturity stage, and the moisture content of the harvested stover is approximately 50%. According to a previous experiment, it was observed that when the corn stover material is watered too much or the corn stover moisture content is higher than 50%, after being compressed by the stover multistage continuous cold roll forming machine, 'juice' appears (Fig. 4). It was found through calculation that the moisture content is largely stable at approximately 50% after the compression is completed. Therefore, this study chose three levels of moisture content: 40%, 45%, and 50%. To avoid the influence of the 'juice' on the experimental results and utilization of corn stover, this experimental study reduced the single stover feeding amount.

Fig. 4. 'Juice' appears in the compression process of corn stalks with moisture content higher than 50%

Due to the large quantity of stover required for the experiment and to establish conditions closer to the natural situation, the moisture content of the corn stover used in the experiment was controlled by natural air drying. Three samples were randomly selected from each group, and the moisture content was measured with the MB23 moisture analyzer. The average value was calculated, and the maximum error between the measured moisture content and the target moisture content (40%, 45%, and 50%) was controlled to not exceed 1.0%. The measurement of the MB23 moisture analyzer follows the principle of Eq. 1,

$$MC = \frac{m_0 - m_1}{m_0} \times 100\% \tag{1}$$

where MC is the moisture content (%), m_0 is the initial mass of samples (g), and m_1 is the mass of samples (g) after drying.

Orthogonal experimental design

To explore the effects of moisture content, sterilization methods, and inhibitor addition methods on the compression and storage performance of corn stover with medium-high moisture content, this study selected orthogonal table L9 (3^4) for experiments. The various factors and levels are shown in Table 2.

Table 2. Experimental Factors and Levels

Levels	**Factors**			
	Moisture Content (A)	Sterilization Methods (B)	Inhibitor Addition Methods (C)	Empty Column (D)
1	40%	No processing	None added	D_1
2	45%	Steam sterilization	Spray evenly before compression	D_2
3	50%	UV sterilization	Surface spray after molding	D_3

The goal of this research was to explore the optimal processing mode for rapid off-field transportation and storage of corn stover with medium-high moisture content. Therefore, under the premise of ensuring work efficiency, the materials should be sterilized as much as possible. Comprehensive considerations include steam sterilization, a steam temperature at the outlet above 120 °C, a sterilization time of 1 min (Iskakov *et al*. 2019), UV sterilization, a UV wavelength of 253.7 nm, and a sterilization time of 15 min (Murata *et al*. 2008). The chemical composition of the inhibitor was potassium sorbate, which could effectively inhibit the activities of mold, yeast, and aerobic bacteria. Following the instruction manual, 2 g of inhibitor was added to 1 kg of material.

Experimental indices

(1) Shelf life: The shelf life of the stover molding block refers to the storage time of the naturally stacked stover compression molding block without mildew and odor. The shelf life of the molding block has a considerable influence on its transportation and storage capacity. Therefore, the molding block is naturally stacked in a dry and dark environment, the three-component blocks are randomly selected after the compression is completed, and the quality of the compressed blocks is manually checked every 4 h. When there was clear mold visible to the naked eye, it was regarded as mold. The time interval between the moment when mold became apparent and the initial moment was defined as the shelf life of the molding block was measured, and the average value t was obtained.

(2) Percent rebound: The percent rebound of the stover molding block refers to the change in the thickness of the molding block with time after the compression was completed. The rebound of the molding block is known to have a great impact on transportation. When the compression molding machine was in normal operation, the 3 molding blocks were randomly selected after the compression was completed at the exit of the molding machine, and the thickness of the molding block is checked every 5 min until the thickness no longer changed. The percent rebound was calculated according to Eq. 2, and the average value was obtained,

$$\lambda = \frac{s''-s'}{s''} \times 100\% \tag{2}$$

where λ is the percent rebound of the forming block (%), s'' is the thickness of the forming block after rebound (mm), and s' is the thickness of the forming block after compression (mm).

(3) Density: When the compression molding machine operated normally, 3 groups of molding blocks were randomly selected after rebounding, their edges and corners were trimmed, parts with uniform density were left for weighing, and their length, width, and height were measured for volume calculation. The density was calculated according to Eq. 3, and then the average value is determined,

$$\rho = \frac{m}{V} \tag{3}$$

where ρ is the density of the forming block (kg/m^3), m is the mass of the forming block (kg), and V is the volume of the forming block (mm).

Statistical analysis

In each experiment, three sets of replicates were carried out under the same working condition, and the average value was obtained. Statistical tests were performed using the analysis of range and variance (ANOVA). The goal was to obtain the optimal combination. Statistical data analysis was conducted using SPSS 19.0 (IBM Corporation, Armonk, NY, USA).

RESULTS AND DISCUSSION

Range Analysis of the Orthogonal Experiment Results

Figure 5 shows the typical speciments of the molding block after the compression was completed, and the rebound was stable in the 9 groups of orthogonal experiments.

Fig. 5. Compression molding block samples

The results of the orthogonal experiment are shown in Table 3. The three factors of corn stover moisture content, sterilization method, and inhibitor addition method were found to have different effects on the shelf life, percent rebound, and density of the compression molding block in the natural state. The range value reflects the effects of various factors on the index. From the range analysis, the sterilization method had a significant impact on the shelf life and density of the molding block. The moisture content of the material had a significant effect on the percent rebound and density of the molding block. The range analysis method was used to analyze the influence of the three factors on the three indices of the compression molding block's shelf life, percent rebound, and density. The effect of the error column on the test indexes was not considered temporarily.

Table 3. Orthogonal Experiment Results and Range Analysis

Serial Number		**Factors**				**Experimental Indices**		
		A	B	C	D	Shelf Life (h)	Percent Rebound	Density (kg/m^3)
1		2	1	2	3	44	30.93	255.46
2		2	2	3	1	64	30.27	299.35
3		3	2	1	3	56	32.63	314.12
4		3	1	3	2	40	34.93	275.13
5		1	1	1	1	32	25.60	232.79
6		1	2	2	2	76	24.67	266.52
7		3	3	2	1	48	33.42	289.64
8		2	3	1	2	44	30.80	269.11
9		1	3	3	3	48	24.10	236.13
Shelf Life (h)	K_1	52.000	38.667	44.000	48.000			
	K_2	50.667	65.333	56.000	53.333			
	K_3	48.000	46.667	50.667	49.333			
	R	4.000	26.667	12.000	5.333			
Percent Rebound (%)	K_1	24.790	30.487	29.677	29.763			
	K_2	30.667	29.190	29.673	30.133			
	K_3	33.660	29.440	29.767	29.220			
	R	8.870	1.297	0.094	0.913			
Density (kg/m^3)	K_1	245.147	254.460	272.007	273.927			
	K_2	274.64	293.330	270.540	270.253			
	K_3	292.963	264.960	272.203	268.570			
	R	47.816	38.87	1.663	5.357			

Note: A means corn stover moisture content; B means sterilization method; C means inhibitor addition method; D means empty column; K_i (m column) means the average value of the sum of the numbers in the m column and the index value corresponding to "i"; R means range.

(1) Factors affecting the shelf life. From the range of the shelf life (R value) in Table 3 of the orthogonal experiment, it can be observed that the material sterilization method had the greatest impact on the shelf life of the molding block; the second was the inhibitor addition method. The moisture content of the material had the least impact on it. The experiment to obtain the longest shelf life was experiment No. 6, and the process conditions were $A_1B_2C_2$.

(2) Factors affecting the percent rebound. From the value of the percent rebound (R value) in Table 3 of the orthogonal experiment, the moisture content of the material had the strongest impact on the percent rebound of the molding block. The second was the material sterilization method. The inhibitor addition method had the least impact on the

percent rebound of the molding block. The experiment that obtained the lowest percent rebound was experiment No. 9, and the process conditions were $A_1B_3C_3$.

(3) Factors affecting density. From the value of the density (*R* value) in Table 3 of the orthogonal experiment, it can be observed that the moisture content of the material had the strongest impact on the density of the molding block. The second was the material sterilization method. The inhibitor addition method had the least impact on the density of the molding block. The experiment to obtain the highest density was experiment No. 3, and the process conditions were $A_3B_2C_1$.

Variance Analysis of Orthogonal Experiment Results

To explore the degree of influence of various factors on the experimental results, the analysis of variance was introduced on the basis of the range analysis, and SPSS 19.0 was employed to analyze the variance of the orthogonal test results with the shelf life, percent rebound, and density as indicators. The analysis results are shown in Table 4.

Table 4. Orthogonal Experiment Analysis of Variance

Indices	Factors	Sum of Squared Deviations	Degree of Freedom	Mean Square	F Ratio	P
Shelf Life (h)	A	24.889	2	12.444	0.538	0.650
	B	1123.556	2	561.778	24.308	0.040*
	C	216.889	2	108.444	4.692	0.176
	Error	46.222	2	23.111		
Percent Rebound (%)	A	122.172	2	61.086	96.480	0.010*
	B	2.839	2	1.420	2.242	0.308
	C	0.017	2	0.008	0.013	0.987
	Error	1.266	2	0.633		
Density (kg/m^3)	A	3492.035	2	1746.017	77.565	0.013*
	B	2425.984	2	1212.992	53.886	0.018*
	C	5.516	2	2.758	0.123	0.891
	Error	45.021	2	22.510		

Note: * means significant, which means $P < 0.05$

Table 4 shows that the method of material sterilization had a significant impact on the shelf life of the molding block ($P < 0.05$). The moisture content of the material and the method of inhibitor addition had no significant impact on the shelf life of the molding blocks. However, material moisture content had a significant effect on the percent rebound of the molding block ($P < 0.05$). The material sterilization method and inhibitor addition method had no significant impact on the percent rebound of the molding block, while the material moisture content and material sterilization methods did have significant effects on the density of the molding block ($P < 0.05$). The method of inhibitor addition had no significant effect on the density of the molding block.

Normally, the greater the moisture content of the stover was, the more likely it was to develop mildew (Fig. 6). Zhang *et al.* (2016) found that for corn stover with different moisture contents in the same treatment, the number of observed moldy sites increased rapidly in the 25% moisture content group after aerobic storage for 5 d, which was significantly higher than the 20% moisture content group. However, it was found in this experiment that the moisture content of the material had no significant effect on the shelf life of the molding block. In particular, the 50% moisture content molding block and the 45% moisture content molding block had a similar shelf life, and the surrounding positions of the 50% moisture content forming block were the first to exhibit mildew. The reason for this phenomenon may be that the 50% moisture content is the critical point of "juice extraction" in the compression operation of this stover multistage continuous cold roll forming machine. After the 50% moisture content of the stover forming block was squeezed, the moisture flowed from the center to the surroundings, which caused the surrounding parts of the stover forming block to be more moist than the central part after the compression was completed (Fig. 7). The central part had a moisture content of less than 50%. The moisture content of the surrounding parts was higher than 50%, but due to better ventilation around the forming block, the moisture content decreased faster, with the result being that the shelf life of the stover forming block with 50% moisture content was not significantly different from that of the 45% moisture content stover.

Fig. 6. Moldy stover forming block

Fig. 7. A 50% moisture content stover compression molding block with more humid surroundings

Determination of the Optimal Processing Mode

Analysis of the comprehensive balance method

The general principle of the comprehensive balance method is as follows: when the importance of each index is different, the selection level should ensure the importance of the index; when the importance of each index is similar, the selection level should grant priority to the main factors or the tendency of the majority. Through the analysis of the comprehensive balance method, the main sequence of the influence of the three factors is sterilization method > material moisture content > inhibitor addition method (Table 5).

Table 5. Comprehensive Balance Analysis

Indexes	Order of the Influence of Three Factors on Each Index		
Shelf Life	B	A	C
Percent Rebound (%)	A	B	C
Density	A	B	C

Note: The order of precedence is from left to right.

This study relied on a stover multistage continuous cold roll forming machine to continuously cold press corn stover with medium-high moisture content without bundles. The purpose was to solve the problem of rapid processing and storage of corn stover with medium-high moisture content. The shelf life index was the most important indicator for this study. For this molding machine, steam sterilization can maximize the shelf life of the molding block. Therefore, the sterilization method factor level was determined as steam sterilization (B_2). When the sterilization method was determined, the material moisture content had little effect on the shelf life. Therefore, steam sterilization is applicable to corn stover materials with moisture contents of 40% to 50%. This finding can guide the subsequent optimization and improvement of the forming machine. For example, the machine can be equipped with a steam generator, and a feeding device with a high-temperature steam nozzle installed to carry out high-temperature steam sterilization while feeding the material to improve the quality of the forming block.

The percent rebound and density indicators primarily affect the transportation process of corn stover from the field. The lower the percent rebound is and the higher the density is, the better the transportation performance of the molding block. The moisture content of the material had a significant impact on the density and percent rebound of the molding block. After a comprehensive analysis was conducted, the moisture content of the material was selected as 45% (A_2).

In the experiment, it was found that the inhibitor addition method had no significant effect on the shelf life, percent rebound, and density. Considering that the corn stover forming block at this moisture content stage is mainly used for feed application after being transported to different regions and considering the feed safety and economic cost, the factor level of the inhibitor addition method was determined to be no addition (C_1).

In summary, based on the stover multistage continuous cold roll forming machine, the optimal processing mode for off-field transportation and storage of the forming blocks is $A_2B_2C_1$. In other words, the moisture content is 45%, the sterilization method is steam sterilization, and no inhibitor is added.

Each index of the forming block in the better processing mode

To verify the reliability of the analysis results, experiments were conducted under a combination of better processing methods. Continuous cold rolling was performed on corn stover materials with a moisture content of 45%, steam sterilization, and no inhibitors. The compressed molding blocks were naturally stored in an environment with an average temperature of 32 °C and an average humidity of 48%. The specific values of each index are presented in Table 6.

Table 6. Each Index of the Forming Block in the Better Processing Mode

Indexes	After Crushing	After Molding
Shelf Life (h)	-	72
Percent Rebound (%)	-	24.28
Density (kg/m^3)	67.25	309.76

The experimental results showed that the shelf life of the molding block is 72 h, the percent rebound was 24.3%, and the density was 310 kg/m^3. Considering the characteristics of the arid and semiarid continental climate in the pastoral region in northwestern China, the relative humidity in summer is low, and the water loss of the molding block is therefore faster. In actual transportation, as the molding is transported increasingly far into the pastoral area in the northwest, this drying effect is more conducive to prolonging the storage time of the molding block. Therefore, the optimal processing mode $A_2B_2C_1$, obtained through orthogonal experiments, can largely meet the medium-long distance transportation requirements of more than 2000 km. Thus, corn stover from the Huang-Huai-Hai region of China can be transported to pastoral areas in northwestern China.

CONCLUSIONS

1. Based on the stover multistage continuous cold roll forming method, a method suitable for the transportation and storage of corn stover with medium-high moisture content was proposed, and the feasibility of this method was verified. This approach provides a new method for rapid off-field transportation and storage of corn stover in the Huang-Huai-Hai area of China.
2. Orthogonal experimental results showed that the steam sterilization method can increase the shelf life of the molding block. The percent rebound and density of the molding block are primarily affected by the moisture content of the material followed by the effect of the sterilization method.
3. The molding block can be stored for 72 h without mildew in an environment with an average temperature of 32 °C and an average humidity of 48% during the day. The percent rebound was 24.3%, and the density can reach 310 kg/m^3 after the completion of rebound. The molding block can meet the requirements of medium-long distance transportation.
4. The continuous cold roll forming of corn stover with medium-high moisture content without bundles was realized, which provides a theoretical basis and reference for further research investigating the rapid and low-cost off-field transportation of biomass stover and efficient medium-long distance transportation, storage, and reuse.

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