

# DESIGN AND THRESHING OUTPUTS STUDY OF INTERNAL AND EXTERNAL ROTARY ROLLER BUCKWHEAT THRESHER

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## 内外滚筒旋转式荞麦脱粒装置设计与脱出物研究

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### ABSTRACT

In order to study the distribution of buckwheat threshing outputs, on the self-designed internal and external rotary roller buckwheat threshing device test bench, the feeding amount was 0.5 kg/s, the internal roller speed was 380 r/min, and the external roller speed was +50 r/min (same direction as the internal roller), 0 r/min and -50 r/min (reverse direction compared to the internal roller) for threshing test. By analysing the overall condition of the threshing outputs, the content of each component in the threshing outputs, and the axial distribution of the threshing roller, it was found that the receiving box below the rasp bar roller mainly contained grains and chaff, leaves and petals, and the receiving box below the spike tooth roller mainly contained short stalks. Under the three conditions, the proportion of chaff in the threshing outputs was 40-45%, the proportion of leaves and petals was 23-29%, the proportion of grains was 13-19%, the proportion of short stalks was 14-16%. Grains, chaff, leaves and petals were mainly concentrated at the front, and short stalks were mainly distributed at the rear of the threshing roller, providing a theoretical basis for the design of the cleaning system.

### 摘要

为研究荞麦脱出物分布情况,在自行设计的内外滚筒旋转式荞麦脱粒装置试验台上,选取喂入量为 0.5 kg/s,内滚筒转速为 380 r/min,外滚筒转速分别为+50 r/min (与内滚筒同向)、0 r/min 和-50 r/min (与内滚筒反向)进行脱粒试验。通过对脱出物整体情况和脱出混合物中各成分含量以及沿脱粒滚筒轴向分布进行分析,纹杆滚筒下方接料盒中主要以籽粒和细小的糠、叶子和花瓣居多,钉齿滚筒下方接料盒中以短茎秆居多,三种条件下脱出物中糠所占比例最大为 40%-45%,叶子和花瓣所占比例次之为 23%-29%,籽粒所占比例为 13%-19%,短茎秆所占比例为 14%-16%,籽粒、糠、叶子和花瓣主要集中在前端位置,短茎秆主要分布在脱粒滚筒后端,因此脱粒装置前端清选负荷较大,而外滚筒不转情况下整体分布优于另外两种情况,外滚筒与内滚筒转向相反时脱出混合物中杂余质量略低于另外两种情况,为后续清选系统的设计提供理论依据。

### INTRODUCTION

Buckwheat has an infinite raceme with long flowering period and extremely inconsistent grain maturation time and maturity, which brings some difficulties to its mechanized harvesting (Huang Xiaona et al., 2018). When buckwheat is harvested, there are many withered petals, the stems are brittle and easy to break, and the leaves have not withered. Therefore, there is a large number of things such as chaff, short straws, leaves, and petals in the mixture, which brings some difficulties to the selection of buckwheat (Farooq et al., 2016; Ren Changzhong et al., 2018).

The existing threshing device mainly adopts a form in which the threshing drum is matched with the concave grate. The rubbing, brushing and impacting of the threshing drum complete the separation of grain and straw (Barac et al., 2011; Dhananchezhyan et al., 2013; Chuan-udom et al., 2011). When the threshing drum rotates at a high speed, the kernel crushing rate and kernel loss rate are large, and it is difficult to adapt to the buckwheat mechanized harvesting operation (Govindaraj et al., 2017; Maertens et al., 2000).

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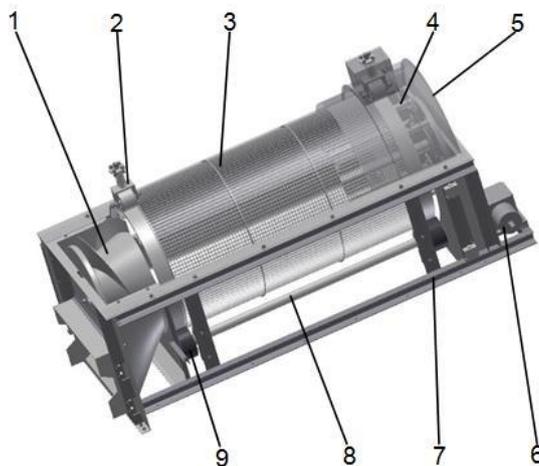
In recent years, scholars at home and abroad have conducted a lot of research on the distribution of threshing outputs. *Ni Chen et al. (2013)* and *Bohai Li et al. (2005)* based on the simulation of the spline interpolation method of MATLAB digital signal processing software, a mathematical model of rice threshing outputs was established, which provided a basis for improving the distribution. *Shujuan Yi et al. (2008)* studied the axial distribution of threshing outputs in the nail-type axial flow threshing and separation device, and provided a theoretical basis for further research of the device. *Yaoming Li et al. (2008)* and *Yanhe Zhang et al. (2011)* compared the uniformity of the threshing outputs distribution on the short-rasp-bar tooth cylinder and the spike tooth cylinder; it was found that the short-rasp-bar tooth cylinder can reduce the load of the cleaning device and improve the overall machine quality. *Taibai Xu et al. (2019)* studied the distribution of the extracts after leaving the concave plate in the multi-roller bench test; it was found that the axially-distributed extracts were unevenly distributed in the horizontal roller, and the cleaning loss was serious. *Zhenwei Liang et al. (2019)* studied the distribution of extracts from spiral blade plate-tooth combination and nail-type axial flow separation devices; the axial and circumferential distribution curves and equations of the extracts from the two devices were obtained. *Yaoming Li et al. (2014)* and *Yan Guo et al. (2011)* studied the distribution of the threshing mixture under the shear roller and the longitudinal axial roller; they provided the basis for the design and optimization of the cleaning device. *Liquan Yang et al. (2018)* studied the distribution of corn threshing kernels and provided a scientific basis for the design of the corn kernel harvester threshing system. *Lijun Wang et al. (2015)* analysed the corn exfoliation composition and established the simulation models of different compositions to study the movement law of corn threshing outputs. *Nan Jiang et al. (2013)* with the help of high-speed camera equipment, photographed online the falling process of the ejection from the device; the falling process of the ejection from the nail-type axial flow threshing and separating device was analysed.

Considering the above points, an internal and external rotary roller buckwheat threshing device was designed, and a threshing test was performed on test bench to analyse the distribution of the threshing outputs, which provided a basis for the design of the cleaning device.

## MATERIALS AND METHODS

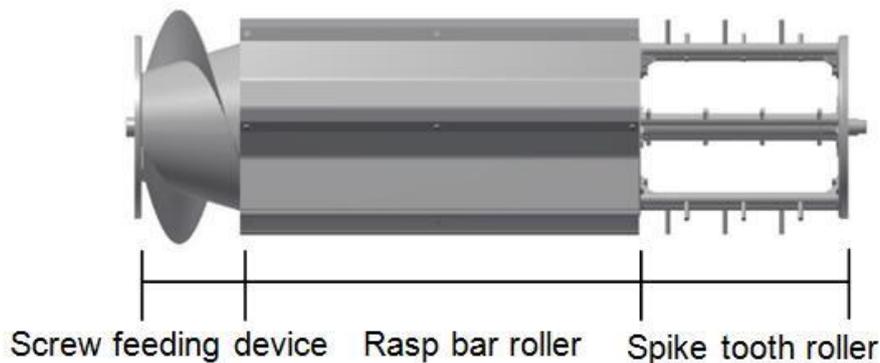
### Internal and external rotary roller buckwheat threshing device

The structure of the internal and external rotary roller buckwheat threshing device is shown in Fig. 1. It mainly includes frame, threshing roller, concave grate roller, screw feeding device, top cover, pressing wheel, friction wheel, transmission shaft, reducer and other components, where the concave grate roller is the external roller, the threshing roller is the internal roller, and both of them can rotate independently. During work, the materials from the feeding inlet, enters the concave grate roller under the function of the screw feeding device, and completes the separation of the grain from the stalk under the rubbing and brushing action of the internal and external rollers, and the grain and debris fall through the concave grate roller, straw is discharged from the trash export. The concave grate roller is rotated by the friction wheel, and compacted by the pressing wheel to prevent slipping.



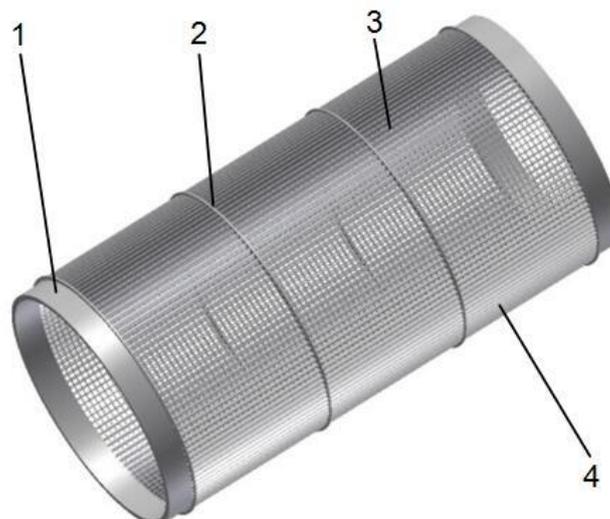
**Fig. 1 - Structure of internal and external rotary roller buckwheat threshing device**  
 1- Screw feeding device; 2- Pressing wheel; 3- Concave grate roller; 4- Threshing roller; 5- Top cover;  
 6- Reducer; 7- Frame; 8- Transmission shaft; 9- Friction wheel

The structure of the threshing roller is shown in Fig. 2. It is composed of screw feeding device, rasp bar roller, spike tooth roller and shaft. The screw feeding device adopts the design of double spiral cone blades and cone cylinder, and the material can be pushed into the concave grate roller during the rotation. The rasp bar roller adopts 6 D-shaped left rods with a fully closed design and length of 988 mm, the rubbing effect with the external roller completes the separation of grain and stalk and the backward push of the material. The spike tooth roller uses 6 rows of nails, each row of nails is arranged with 3 spirals and has the length of 494 mm, the grains are further threshed by the action of impacting and combing, the straws are pushed back and thrown out of the machine.



**Fig. 2- Structure of threshing roller**

The structure of the concave grate roller is shown in Fig. 3. The two ends are support drive plates, and 120 ribs are evenly arranged in the middle circumferential direction; the ribs are reinforced by the ring plate. Wire rings are fixed on the roller longitudinal each 15 mm, and a series of grids with a hole length 14 mm and a hole width 12 mm are formed. The surface of rib is higher than the iron wire 5 mm, in order to block the crop and improve the impact and vibration of the roller on the crop. The working diameter of the concave grate roller is  $\text{Ø}636$  mm.



**Fig. 3 - Structure of concave grate roller**  
1- Support drive plate; 2- Ring plate; 3- Rib; 4- Wire ring

### **Buckwheat threshing device performance test bench**

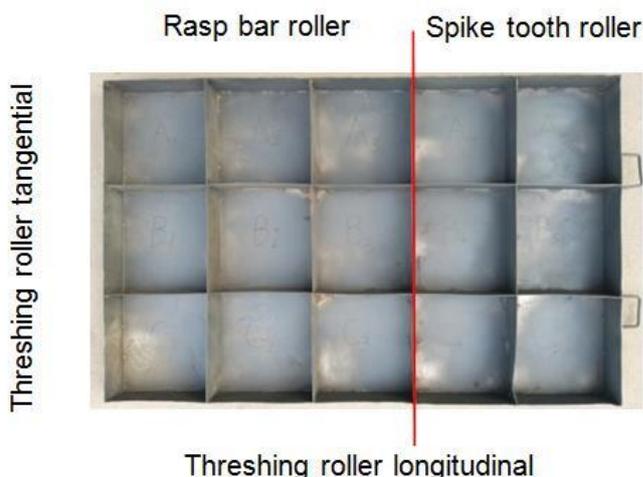
The structure of the buckwheat threshing device performance test bench is shown in Fig. 4. It is mainly composed of conveyor belt, feeding bridge, internal roller reducer, threshing device, external roller reducer, control box, receiving box, motor of 1.5 kW, frame, and motor of 7.5 kW. During work, the material enters the threshing device through the feeding bridge. After threshing, grains and debris fall into the receiving box, and the straw is discharged from the machine.



**Fig. 4 - Performance experiment unit of buckwheat threshing device**

1- Conveyor belt; 2- Feeding bridge; 3- Internal roller reducer; 4- Threshing device; 5- External roller reducer; 6- Control box; 7- Receiving box; 8- Motor of 1.5 kW; 9- Frame; 10- Motor of 7.5 kW

The conveyor belt is 0.4 m high, 10 m long and 1 m wide, it is driven by a motor of 40 W, and the speed range is 0-60 m/min. The receiving box is placed under the threshing device. The structure is shown in Figure 5. It is divided into five rows along the threshing roller longitudinal, each row is 258 mm wide. The 1-3 rows correspond to the rasp bar roller and 4-5 rows correspond to the spike tooth roller. It is divided into three columns tangential to the threshing roller, and each column is 274 mm wide.

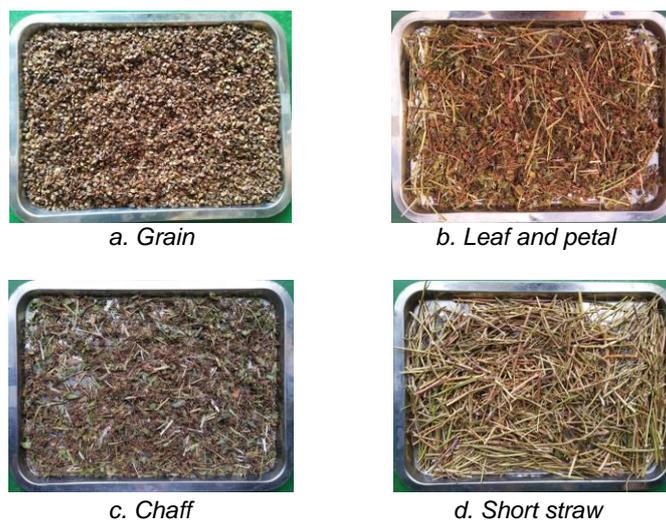


**Fig. 5 - Receiving box**

### **Test materials and test methods**

The buckwheat used in the experiment is red mountain buckwheat grown in Taigu, Shanxi, 78-92 cm height, the grain moisture content is 10.9%, the stalk moisture content is 45.1%, the grass-valley ratio is 1:2.38, and the thousand-grain weight is 25.4 g, which are harvested manually for testing.

This experiment mainly studied the distribution of threshing outputs under different external roller conditions when the feeding amount was 0.5 kg/s and the rotation speed of the internal roller was 480 r/min. During the test, 6 kg buckwheat were evenly spread on the conveyor belt, the speed of the belt was adjusted to 0.833 m/s and the feeding amount was 0.5 kg/s, the speed of the internal roller was adjusted to 480 r/min by the motor inverter, the rotation speed of the external roller was adjusted to + 50 r/min, 0 r/min, and -50 r/min through the motor inverter (“+” means that the rotation direction of the external roller is the same as that of the internal roller, and “-” means that the rotation direction of the external roller is opposite to that of the internal roller). Three groups of tests were performed, and each group of tests was repeated three times. After the test, we took out the receiving box, manually sorted and weighed the materials in each cell. The threshing outputs mainly consisted of grains, leaves, petals, chaff and short stalks, the size of the short stalks being 10-30 mm, as shown in Fig. 6.



**Fig. 6 - Threshing outputs components**

## RESULTS

### Analysis of the overall situation of the threshing outputs

The output mixtures in the receiving box, after the test, are shown in Fig. 7. It can be seen that there are more mixtures in the receiving box below the rasp bar roller, mainly leaves, petals, chaff and grains, mixed with a small number of short straws; there are fewer mixtures in the receiving box below the spike tooth roller, most are short stalks, mixed with a small amount of grains, leaves and petals. It showed that in the buckwheat threshing process, the main grains are threshing under the rubbing effect of the rasp bar roller and the concave grate roller, and with the further impacting of the spike tooth roller and the concave grate roller, the threshing of hard to separated grain is completed, and the straws are more likely to be broken by the spike tooth roller.



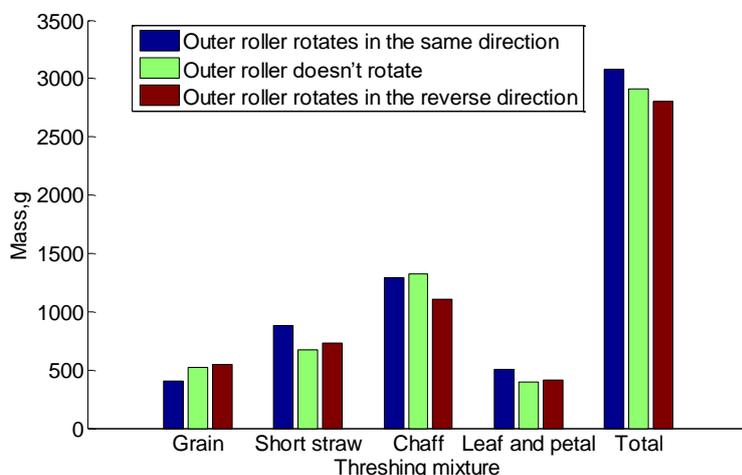
**Fig. 7 - Overall situation of the threshing outputs**

### Analysis of threshing outputs components under different external roller rotation conditions

#### **Components weight analysis**

Under the three rotating conditions of the external roller, grains, short stalks, chaff, leaves and petals in the threshing outputs and the total mass of the mixtures are shown in Fig. 8. It can be seen the grains weight when the external roller rotates in the same direction with the internal roller is slightly smaller than that when the external roller doesn't rotate or rotates in the reverse direction of the internal roller. The reason is that when the external roller and the internal roller rotate in the same direction, the kneading and squeezing effect of the material between them is small, the threshing is insufficient, and the grain loss is large. The short straws weight when the external roller rotates in the same direction with the internal roller is bigger than that when the external roller doesn't rotate or rotates in the reverse direction of the internal roller. The reason is that when the external roller and the internal roller rotate in the same direction, the movement of the materials between them is more complicated than in the other two cases, and the stems are more likely to be broken and fall into the receiving box.

The chaff weight when the external roller rotates in the reverse direction of the internal roller is slightly smaller than that when the external roller doesn't rotate or rotates in the same direction of the internal roller. The reason is that when the rotation of the internal and external roller is reversed, the relative rotation speed of them increases, the residence time of the materials between the rollers is short, and the number of stalks broken into chaff is reduced. The leaves and petals' weight, when the external roller rotates in the same direction of the internal roller, is bigger than that when the external roller doesn't rotate or rotates in the reverse direction of the internal roller. The reason is that when the external roller and the internal roller turn in the same direction, the relative rotation speed of them decreases, but the movement of the material between them is complicated, and more leaves and petals fall into the receiving box without being broken. The total mass of mixtures is the biggest when the external roller and the internal roller rotate in the same direction; the total mass of the mixtures is the smallest when the external roller and the internal roller rotate in the opposite direction, and the total mass of the mixtures is in the middle when the external roller doesn't rotate. The reason is that when the external roller and the internal roller rotate in the opposite direction, the relative rotation speed of them is the highest, and the materials stay between the rollers for the shortest time, and there are minimal mixtures falling into the receiving box through the external roller. The situation is exactly the opposite when the external roller and the internal roller rotate in the same direction.



**Fig.8 - Mass of components under different outer roller rotation conditions**

### **Components proportion analysis**

The proportions of the mass of grains, short stalks, chaff, leaves and petals in the threshing outputs under the three rotation conditions of the external roller are showed in Fig. 9. The maximum proportion of grains is 19% when the external roller and the internal roller rotate in the opposite direction. The minimum proportion of grains is 13% when the external roller and the internal roller rotate in the same direction. The middle proportion of grains is 18% when the external roller doesn't rotate and it is close to the situation of the external roller and the internal roller rotating in the opposite direction. The maximum proportion of short straws is 19% when the external roller and the internal roller rotate in the same direction. The minimum proportion of short straws is 14% when the external roller doesn't rotate. The middle proportion of short straws is 15% when the external roller and the internal roller rotate in the opposite direction. The proportion of short straws is close under the three conditions. The maximum proportion of chaff is 45% when the external roller doesn't rotate. The minimum proportion of short chaff is 40% when the external roller and the internal roller rotate in the opposite direction. The middle proportion of chaff is 42% when the external roller and the internal roller rotate in the same direction. The proportion of chaff is a little different under the three conditions. The maximum proportion of leaves and petals is 29% when the external roller and the internal roller rotate in the same direction. The minimum proportion of leaves and petals is 23% when the external roller doesn't rotate. The middle proportion of leaves and petals is 26% when the external roller and the internal roller rotate in the opposite direction. The proportion of leaves and petals is a little different under the three conditions.

Comprehensive analysis shows that the proportion of chaff in the three conditions is 40%-45%, the proportion of leaves and petals is 23%-29%, the proportion of grains is 13%-19%, and the proportion

of short straws is 14%-16%. This shows that the proportion of grains is close to that of short straws. The reason is related to the physical properties of buckwheat: at buckwheat maturity, the leaves have withered, and there are many withered petals, they are easily broken during the threshing process and mixed with chaff, so the proportion of chaff in the threshing mixtures is the largest. Buckwheat hollow stalks have high moisture content during harvest, they are brittle and easy to be broken, so there are a few short straws in the threshing mixtures, which also brings some difficulties to the cleaning of buckwheat threshing outputs.

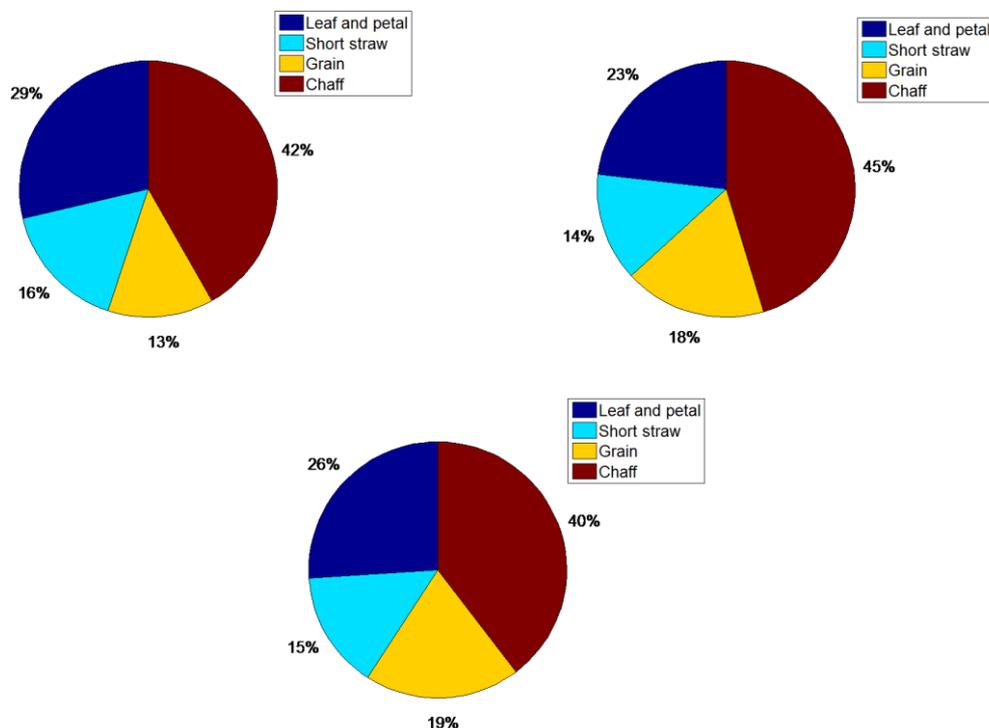


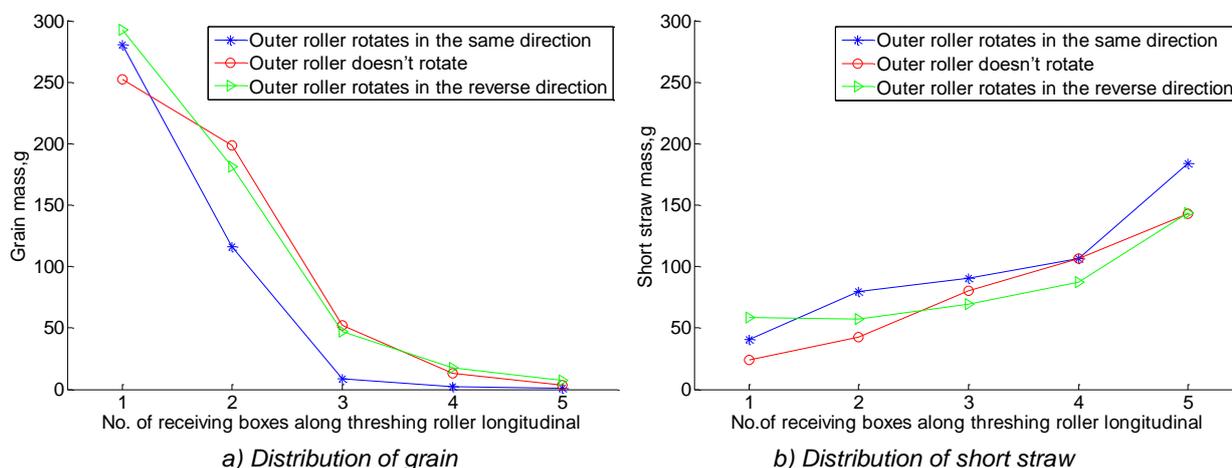
Fig. 9 - The components proportion under different conditions of external roller rotation

#### ***Analysis of the components' distribution along longitudinal axis of the threshing roller***

The grains' distribution along longitudinal axis of the threshing roller under the three rotation conditions of the external roller is showed in Figure 10(a). Grains gradually decrease along the threshing roller longitudinal, and the decline trend is obvious in 1-3 rows, and the 3-5 rows are gradually flattened, and they are mainly concentrated below the rasp bar roller. It shows that the threshing of the main grains is completed under the rubbing effect of the rasp bar roller and the concave grate roller, and the threshing of the hard to separate grains is further completed under the impact of the spike tooth roller and the concave grate roller. The grains of the first row are the most numerous when the external roller and the internal roller rotate in the opposite direction, and the least numerous when the external roller doesn't rotate. The grains of second and third rows are the most numerous when the external roller doesn't rotate, and the least numerous when the external roller and the internal roller rotate in the same direction. The grains of fourth and fifth rows are the most numerous when the external roller and the internal roller rotate in the opposite direction, and the least numerous when the external roller and the internal roller rotate in the same direction. Comprehensive analysis shows that when the internal and external rollers rotate in the same direction, the grains are quickly dropped into the receiving box, and the grains distribution at rear-end is smaller, and when the external roller doesn't rotate, the overall distribution of the components is relatively good.

The short straws' distribution along longitudinal axis of the threshing roller under three rotation conditions of the external roller is showed in Figure 10(b). The short straws gradually increase along the threshing roller longitudinal, and are mainly concentrated below the spike tooth roller. It shows that the spike tooth roller has a greater impact on the material than the rasp bar roller, and it is easy to break the stalks into the receiving box. The short straws in the first row are the most numerous when the external roller and the internal roller rotate in the opposite direction, and the least numerous when the external

roller doesn't rotate. The short straws in the second row are the most numerous when the external roller and the internal roller rotate in the same direction, and the least numerous when the external roller doesn't rotate; the grains in third to fifth rows are the most numerous when the external roller and the internal roller rotate in the same direction, and the least numerous when the external roller and the internal roller rotate in the opposite direction. Comprehensive analysis shows that when the internal and external rollers rotate, the rasp bar roller and concave grate roller are more likely to break the stalks into the receiving box, and when the external roller and the internal roller rotate in the opposite direction, the distribution of short straws is relatively good.



**Fig.10 - The components proportion under different conditions of external roller rotate**

The chaff distribution along longitudinal axis of the threshing roller under three rotation conditions of the external roller is showed in Figure 11(a). The chaff gradually decreases along the threshing roller longitudinal, and the downward trend of 1-3 rows is obvious, the 3-5 rows are gradually flattened, and they are mainly concentrated in 1-2 rows, and 3-5 rows towards to zero, it shows that during the threshing process, the chaff are easily separated from the crops and fall into the receiving box, and the cleaning pressure of front-end is greater. The chaff of first row are the most when the external roller and the internal roller are rotated in the same direction, and the least when the external roller is not rotated; the chaff of second row are the most when the external roller is not rotated, and the least when the external roller and the internal roller are rotated in the opposite direction; the chaff of third row are the most when the external roller is not rotated, and the least when the external roller and the internal roller are rotated in the same direction; the chaff of fourth and fifth rows are close in three cases, and almost zero. Comprehensive analysis, when the internal and external rollers are rotated, a large amount of chaff are quickly separated and fall into the receiving box, and when the external roller is not rotated, the overall distribution is relatively good.

The leaves and petals distribution along longitudinal axis of the threshing roller under three rotation conditions of the external roller is showed in Figure 11(b). When the external and internal rollers are rotated in the same direction, the leaves and petals increase, then decrease, and then increase, and each row is higher than the other two cases, it shows that when the external roller and the internal roller are rotated in the same direction, the movement of the materials between the rollers is more complicated, the kneading and squeezing effect is more obvious, and a large number of leaves and petals are separated and fall into the receiving box. When the external roller and the internal roller rotated in the opposite direction, the leaves and petals decrease and then increase, it shows that after the materials enter the internal and external rollers, a large number of leaves and petals are separated, and the kneading effect of the rasp bar roller and concave grate roller is small, so the leaves and petals gradually decrease, when they reach the spike tooth roller, due to the large impacting of the spike tooth roller, leaves and petals are knocked down and gradually increasing. Comprehensive analysis shows that the pressure for the selection of leaves and petals is mainly concentrated on the front and back ends, and the distribution of leaves and petals is relatively good when the external roller is not rotated.

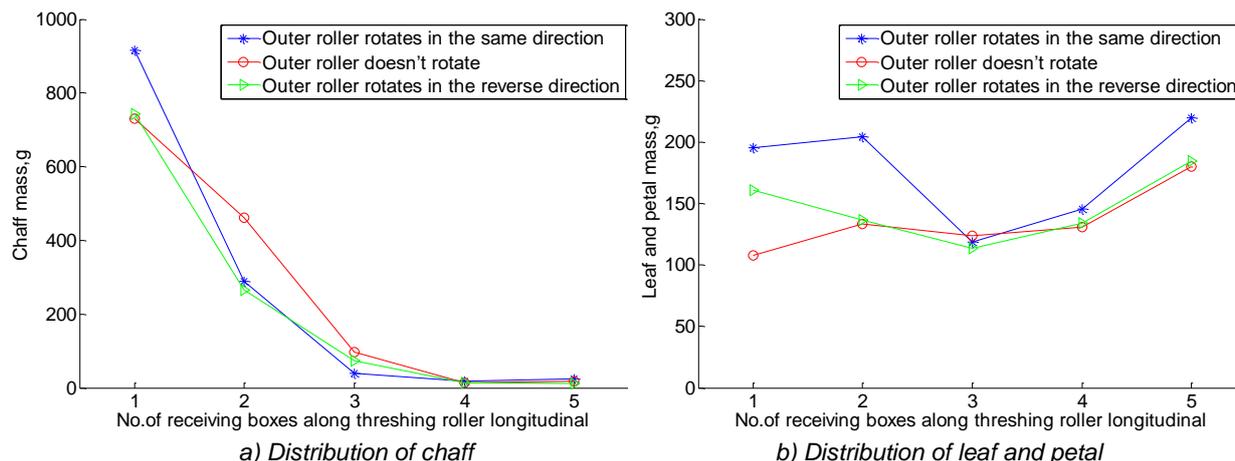


Fig.11 - The components proportion under different conditions of external roller rotate

## CONCLUSIONS

(1) The buckwheat threshing test was performed on self-designed internal and external rotary roller buckwheat threshing device test bench. The feeding amount was 0.5 kg/s, the internal roller speed was 480 r/min, and the external roller was +50 r/min (same direction as the internal roller), 0 r/min and -50 r/min (opposite direction of the internal roller), which provided a theoretical basis for the design of subsequent cleaning systems.

(2) Analysing the overall situation of the threshing outputs, it was found that there were more mixtures in the receiving box below the rasp bar roller, mainly leaves, petals, chaff and grains, with a small number of short straws. There were fewer mixtures in the receiving box below the spike tooth roller, most of which were short stalks, mixed with a small amount of grains, leaves and petals.

(3) By analysing the mass of threshing outputs under the three rotation conditions of the external roller, it was found that when the external roller and the internal roller rotated in the opposite direction, the debris mass in the mixtures was slightly smaller than the other two cases, and the grain loss was greater when the external roller and the internal roller rotated in the same direction.

(4) By analysing the proportion of the components of the threshing outputs under the three rotation conditions of the external roller, it was found that the proportion of chaff was 40-45%, and the proportion of leaves and petals was 23-29%, the proportion of grains was 13-19%, the proportion of short straws was 14-16%. The proportion of grains was close to the proportion of short straws.

(5) By analysing the distribution of the threshing outputs along the threshing roller longitudinal under the three rotation conditions of the external roller, it was found that the grains, chaff, leaves and petals were mainly concentrated at the front position, and the short straws were mainly distributed at the rear of the threshing roller, so the cleaning load of the front-end was large, but the overall distribution was better than in the other two cases when the external roller didn't rotate.

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