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ORIGINAL RESEARCH ARTICLE

Operation performance test and analysis of 4GQ-1C sugarcane harvester

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ABSTRACT

4GQ-1C sugarcane harvester was designed to solve the current problems that large and medium-sized sugarcane harvesters had low adaptability in sloping, small row spacing, and small plots of sugarcane harvesting. In order to verify the adaptability and reliability of 4GQ-1C sugarcane harvester, field tests were carried out and compared with existing models. Results showed that the 4GQ-1C sugarcane harvester has good operation performance with a lower impurity rate and loss rate of sugarcane, stronger harvesting adaptability in small row spacing areas, and is more convenient in collecting sugarcane compared with sugarcane harvesters with power of 132 and 194 kw. Furthermore, 4GQ-1C sugarcane harvester is compact and flexible, with good adaptability and a good harvest effect in sugarcane growing areas with small and medium-sized planting scales, making it worth popularizing and applying to sugarcane harvest.

Keywords: sugarcane; harvester; operation performance; field test

1. Introduction

Sugarcane is an important sugar crop in China. In the 2018–2019 crop season, the planting area of sugarcane reached more than 1.2 million hm^2, mainly concentrated in Guangxi, Yunnan, and Guangdong, among which the planting area of sugarcane in Guangxi was about 870,000 hm^2, accounting for more than 60% of the total planting area in China[1–3]. The development of sugarcane mechanization in China is slow, mainly because sugarcane is planted in hilly and mountainous areas with undulating sugarcane fields, most of which are small and medium-sized sugarcane fields[4,5]. With the construction of the "double-high" base, the promotion of moderate-scale management routes, and the demonstration of agricultural machinery and agronomy integration, two mainstream planting modes, single-row planting and wide-narrow row planting, have gradually formed, with planting row spacings of 09, 12, and 14 m as the main ones[6,7]. At present, there are 74–257 kW sugarcane harvesters in the market, among which 132–189 kW sugarcane harvesters are the majority, with large matching power, large feeding amounts, and high harvesting efficiency[8,9]. Large and medium-sized sugarcane harvesters with an area of more than 130 kW have excellent working performance when planted in large enough areas with wide row spacing and relatively gentle sugarcane fields, but the working effect is not good when working in small plots with narrow row spacing and steep sugarcane fields. Therefore, the demand for small-sized sugarcane harvesters is urgent.

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In order to solve the above problems, a 4GQ-1C sugarcane harvester with a small body, light weight, and crawler-type walking chassis was developed. Its supporting power was 97 kW, which was suitable for sugarcane harvesting in small row spacing and small and medium plots. Taking this machine as the research object, the sugarcane harvester was harvested in a single row of sugarcane fields with a row spacing of 12 m. Compared with two types of sugarcane harvesters with 132 kW and 194 kW, the performance index and its fusion effect on sugarcane planting agronomy were studied and determined.

2. Structure and working principle of the whole machine

The 4GQ-1C sugarcane harvester adopts the design of a sugarcane collecting bucket device, a two-stage short conveying channel, and a crawler chassis walking device[10]. Its main structure includes a tip cutter, an inverted device, a root cutter, a primary conveying channel, a secondary conveying channel, a cutting device, a crawler walking device, a fan device, a sugarcane hopper device, etc. The structural schematic diagram of 4Q-1C sugarcane harvester is shown in **Figure 1**.

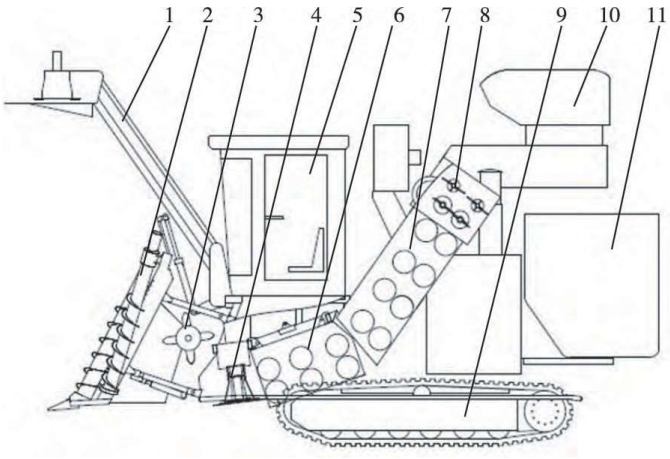

Figure 1. Structure of 4GQ-1C sugarcane harvester.
Note: 1. Tip cutter; 2. toppling device; 3. cane pressing roller; 4. root cutters; 5. cab; 6. primary conveying channel; 7. secondary conveying channel; 8. cutting device; 9. crawler walking chassis; 10. fan device; 11. cane collecting device.

During the harvesting operation, the tip of sugarcane above the growing point was cut off by the tip cutter, and the tip was flung to the harvested area by the rotation of the tip cutter blade to avoid the leaf tip being fed into the harvester again. The left and right pairs of spiral stabilizers rotating toward each other are used to straighten and branch the lying sugarcane so that sugarcane in the area to be harvested can enter the feeding entrance smoothly. The sugarcane was fed into the conveying channel at a certain angle by the pressing action of the sugarcane roller, and the root of the sugarcane was cut off by a pair of high-speed rotary root cutters. After adjusting the direction of sugarcane conveying through the primary conveying channel, the sugarcane was transported to the secondary conveying channel, and the sugarcane was cut into the sugarcane segment with a length of 20–30 cm by the cutting device. Under the action of the cutting cutter roller and sugarcane throwing roller, the sugarcane section was thrown into the negative pressure area of the fan in a parabolic trajectory, and impurities were removed by the fan air. Sugarcane leaves and impurities were blown out through the fan mouth, and the sugarcane section directly fell into the collecting device.

The 4GQ-1C sugarcane harvester is compact and can operate flexibly in the sugarcane field with small row spacing. The total mass of the harvester is 7 t, and the lightweight design of the fuselage can effectively reduce the crushing effect of the harvester on the cane field. The design of the “One” crawler walking device makes the whole machine have a low center of gravity, which can adapt to the environment of sugarcane harvesting, such as hilly and sloping land, soft ground after rain, and small plots. It has little influence on the

permanent root of sugarcane, a small turning radius at the head of the plowing road, and flexible turning. The sugarcane collecting device adopts two-stage hydraulic cylinders to realize rear lifting and tipping, respectively. It can carry about 1 t of sugarcane in one operation. When the sugarcane section is full, it can be unloaded with one click. The theoretical working efficiency of 4GQ-1C sugarcane harvester is 10 t/h, which can meet the needs of small and medium-sized sugarcane harvesting operations.

3. Materials and methods

3.1. Test site

The prototype test was carried out in April 2020 in the sugarcane planting base of Lenuo Village, Ningwu Town, Wuming District, Nanning City, Guangxi Province. The weather was clear, and the temperature was 23–25 ℃ during the test. The sugarcane planting area of the base is about 150 hm^2, the sugarcane undulation is gentle, the sugarcane ridge length is about 300 m, and the sugarcane area has a machine-cultivated road.

3.2. Test materials

The sugarcane variety is Guitang 55, which was sown by a sugarcane planter in June 2019. It is planted in a single row with a row spacing of 12 m. Most of the sugarcane is in an upright state, and the growth is good.

3.3. Test equipment

The experiment was carried out in the field, and the equipment mainly included the 4GQ-1C sugarcane harvester, 4GZQ-180 sugarcane harvester, and 4GZQ-260 sugarcane harvester independently developed by Guangxi Agricultural Machinery Research Institute Co., Ltd., as well as the robustness meter, soil cutting ring knife, canvas, tape measure, and electronic scale used in the determination of basic parameters.

3.4. Test method

Basic soil parameters such as firmness and moisture content are determined in accordance with GB/T 5262-2008 “General Provisions on Test Methods for Agricultural Machinery Test Conditions.” The basic parameters, lodging degree, and mechanical performance parameters of sugarcane were determined according to JB/T 6275-2007 Test Methods for Sugarcane Harvesting Machinery[11,12].

3.4.1. Basic soil parameters

Soil firmness and soil moisture content were determined by the 5-point method. According to the operation rules of agricultural machinery and agronomy integration, the depth of sugarcane mechanization planting is 10–15 cm, so the firmness of the 0–15 cm soil layer is measured by a firmness meter. The soil samples were obtained by a soil-taking ring knife, and the absolute moisture content of the soil was determined by the drying method.

3.4.2. Basic parameters of sugarcane

Five test points were randomly selected, and 10 m of sugarcane ridges were taken for each test point. The ineffective sugarcane plants (sugarcane shoots and sugarcane plants with heights < 65 cm) were removed. The number of effective sugarcane plants, non-lodging (sugarcane stalk with a vertical line between the base and the ground at 0°–30°), moderate lodging (30°–60°), severe lodging (>60°), and the degree of lodging were calculated. At one of the test points, 10 effective sugarcane plants were randomly selected to determine the basic parameters of sugarcane, including the length, mass, and diameter of sugarcane stalks, and calculate the ratio of leaf to stem. At the same time, sugarcane yield was estimated[13].

3.4.3. Performance indicators of machine operation

The operational performance test mainly measured the index parameters of the 4GQ-1C sugarcane harvester, the 4GZ-180 sugarcane harvester, and the 4GZ-260 sugarcane harvester operating at normal harvesting speed, according to JB/T 6275-2007. The "Test Method for Sugarcane Harvesting Machinery" measures operational performance indicators, such as qualified rate of cutting height, broken head rate of permanent root, qualified rate of sugarcane segment, impurity content rate, and total loss rate. Each type of machine is run three times, and the average value is calculated.

4. Test results and analysis

4.1. Basic soil parameters

The determination results of soil firmness and soil moisture content are shown in **Tables 1** and **2**.

Table 1. Soil compactness.

Depth/cm	Soil firmness /MPa					
	Test point 1	Test point 2	Test point 3	Test point 4	Test point 5	Average
0	0	0	0	0	0	0
2	38	16	56	14	67	38.2
4	103	77	82	135	126	104.6
6	188	151	196	283	245	212.6
8	204	286	340	361	258	289.8
10	276	455	448	680	509	473.6
12	550	800	650	861	740	720.2
15	996	1015	1232	1080	1355	135.6

Table 2. Soil moisture content.

Test point	Soil moisture content/%			
	Serial number 1	Serial number 2	Serial number 3	Average
1	15.32	13.64	14.56	14.51
2	16.88	14.33	17.31	16.17
3	14.17	13.96	15.44	14.52
4	12.98	15.14	15.08	14.4
5	13.24	16.65	17.11	15.67

It can be seen from **Table 1** and **Table 2** that the average firmness of the 0–15 cm soil layer in the sugarcane field in the experimental area is mainly 0–11356 MPa, and the deeper the soil layer, the greater the firmness. The average moisture content of the soil is 15%, which meets the conditions for sugarcane harvesting.

4.2. Basic situation of sugarcane

The determination results of the lodging degree of sugarcane are shown in **Table 3**. As can be seen from **Table 3**, the average lodging rate, moderate lodging rate, and severe lodging rate of sugarcane in this experimental area are 89.2%, 8.83%, and 1.98%, respectively, and the overall state is non-lodging, which is favorable for harvesting.

Table 3. Lodging degree of sugarcane.

Serial number	Effective plant number	No lodging plant number	Medium lodging plant number	Number of severely lodging plants	Non lodging rate/%	Medium lodging rate/%	Severe lodging rate/%
1	73	70	3	0	95.89	4.11	0.00
2	59	48	11	0	81.36	18.64	0.00
3	83	80	0	3	96.39	0.00	3.61
4	68	56	10	2	82.35	14.71	2.94
5	60	54	4	2	90.00	6.67	3.33
Average value	68.6	61.6	5.6	1.4	89.20	8.83	1.98

The measurement results of the basic parameters of sugarcane are shown in **Table 4**. As can be seen from **Table 4**, the average total weight of each sugarcane is 1932 kg, the weight of cane is 1568 kg, the length of cane is 2173 mm, the diameter of cane is 3271 mm, and the ratio of leaf to stem is 2386%. Based on the row spacing of 12 m, the yield of this sugarcane area is estimated to be 7596 t/hm^2.

Table 4. Basic parameters of sugarcane.

Number	Total sugarcane mass/kg	Cane mass/kg	Cane length/mm	Sugarcane diameter/mm	Leaf tip mass/kg	Leaf to stem ratio/%
1	1.440	1.125	1995	29.87	0.315	28.00
2	1.668	1.368	2300	28.41	0.300	21.93
3	1.845	1.465	2100	33.98	0.380	25.94
4	2.385	1.970	2360	36.48	0.415	21.07
5	1.845	1.560	2120	33.21	0.285	18.27
6	1.505	1.150	1845	29.56	0.355	30.87
7	2.500	2.050	2460	37.20	0.450	21.95
8	2.340	1.982	2315	34.88	0.358	18.06
9	1.767	1.385	1998	32.46	0.382	27.58
10	2.029	1.624	2236	31.08	0.405	24.94
Average value	1.932	1.568	2173	32.71	0.365	23.86

4.3. Analysis of measurement results of operational performance indicators

4.3.1. Determination results

In the harvesting test, three harvesters were used to harvest one after another. The 4Q-1C sugarcane harvester collects sugarcane in the form of a sugarcane hopper and then dumps the sugarcane section on the canvas after one operation; the 4GZ-180 sugarcane harvester and 4GZ-260 sugarcane harvester collect sugarcane by lifting and conveying, and the collected sugarcane segments are directly conveyed to the canvas during the operation.

Each group of tests was conducted for 3 times, and qualified sugarcane segments, leaves, and other impurities were sorted by hand, and the performance indexes were determined according to the sugarcane test method. The operation process is shown in **Figure 2**, the measurement results of operation performance indicators are shown in **Table 5**, the comparison of performance indicators is shown in **Figure 3**, and the data of three operations of each harvester is shown in **Figure 4**.

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

Figure 2. Field harvesting of sugarcane harvesters. **(a)** 4GQ-1c sugarcane harvester; **(b)** 4CZQ-180 sugarcane harvester; **(c)** 4GZQ-260 sugarcane harvester.

Table 5. Results of operation performance of sugar harvesters (unit: %).

Model	Serial No.	Cutting height qualification rate	Root breaking rate	Pass rate of sugarcane section	Impurity content	Total loss rate
4GQ-1C	1	100	4.11	96.4	4.01	0.13
	2	100	5.08	95.54	4.06	0.58
	3	100	2.41	96.86	4.45	1.24
	Average value	100	3.87	96.27	4.17	0.65
4GZQ-180	1	100	5.88	93.64	7.47	1.93
	2	100	6.94	95.87	5.22	1.46
	3	100	2.67	92.50	6.03	2.05
	Average value	100	5.16	94.00	6.24	1.81
4GZQ-260	1	100	6.67	88.39	8.14	0.87
	2	100	8.82	91.25	4.73	1.46
	3	100	6.85	94.88	5.78	1.87
	Average value	100	7.45	91.51	6.22	1.40

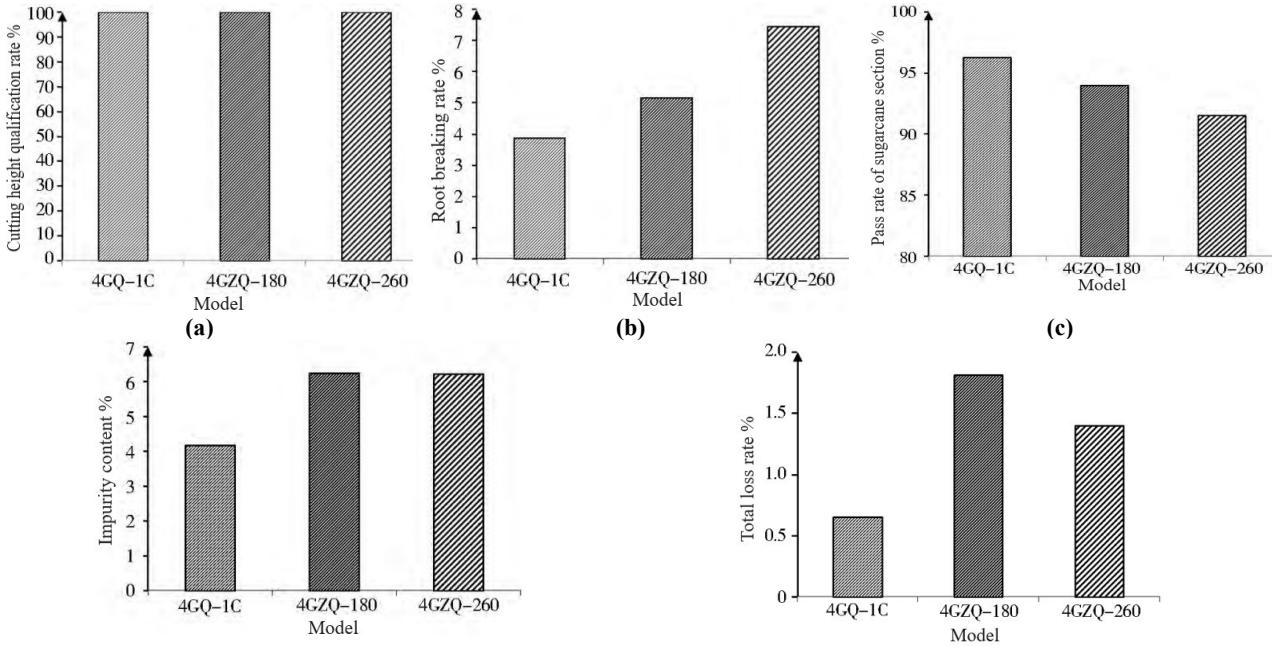

Figure 3. Comparison of operation performance of sugarcane harvesters.

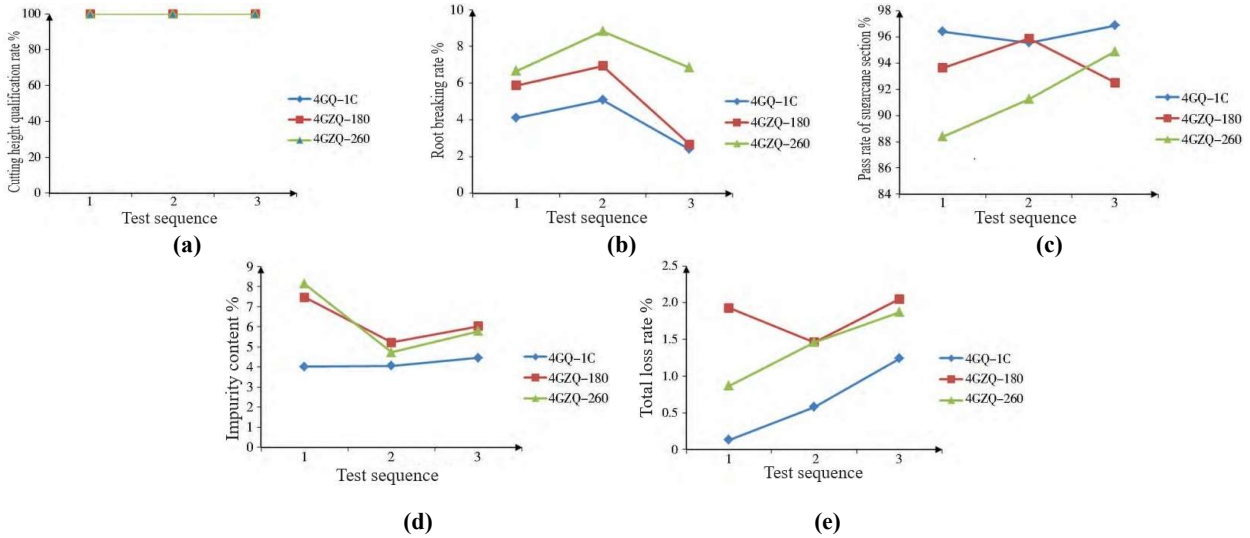

Figure 4. Comparison of three operation performance data of sugarcane harvester.

During the field harvest experiment with three harvesters, the 4GQ-1C sugarcane harvester can smoothly harvest because of its small overall model and its standard row spacing of 12 m. The branch effect is good, and the sugarcane in the harvest area will not rub with the sugarcane, which has good passability and high reliability. Because the sugarcane collection hopper is used to collect the sugarcane segments, the sugarcane segments directly fall into the sugarcane collection device after the impurities are removed by the fan, so the loss rate of the sugarcane segments is low; after harvest, the qualified rate and impurity rate of sugarcane segments are all good. The machine has a reasonable configuration and stable operation and meets the quality requirements of a sugarcane harvester.

Since the 4GZQ-180 and 4GZQ-260 sugarcane harvesters adopt the method of lifting and transporting sugarcane, the sugarcane section is transported to the canvas through the lifting scraper after being cleaned by the fan. It is inevitable that the sugarcane section will fall to the ground during the transportation process. Therefore, the loss rate of the sugarcane section is higher than that of the 4GQ-1C sugarcane harvester. In addition, due to the large size of the two machines, they scraped with the sugarcane in the area to be harvested to a certain extent when harvesting a 12-meter single row of sugarcane, which caused some sugarcane to tilt or fall, affecting the harvesting quality of the next round of machines. Therefore, 4 GZQ–180 and 4 GZQ–260 sugarcane harvesters are more suitable for harvesting in large row spacing or wide and narrow row sugarcane areas.

4.3.2. Result analysis

It can be seen from **Figure 3(a)** that the cutting height qualification rate of the three harvesters is 100%, which is closely related to the harvesting method of cutting in the soil during the test. After being cut into the soil, the sugarcane permanent roots not only have a high qualification rate in the height of the cutting section but also have loose soil on the upper layer of the sugarcane ridge due to the cutting into the soil, so the germination rate and germination quality of the sugarcane permanent roots can be well guaranteed.

It can be seen from **Figure 3(b)** that the root breaking rates of 4GQ-1C, 4GZ-180, and 4GZ-260 sugarcane harvesters are 3.87%, 5.16%, and 7.45%, respectively, which meet the industry standard that the root breaking rate is lower than 10%. In combination with **Figure 4(b)**, 4GQ-1C has the lowest rate of root breaking, followed by 4GZQ-180, which indicates that the small model has a lower degree of root breaking when harvesting sugarcane in 12 m row spacing.

It can be seen from **Figure 3(c)** that the qualification rates of sugarcane sections harvested by 4GQ-1C,

4GZQ-180 and 4GZQ-260 sugarcane harvesters are 96.27%, 94.00%, and 91.51%, respectively, which all meet the design standards of more than 90%.

In general, the sugarcane segment qualification rate of 4GQ-1C is better, but it can be seen from **Figure 4(c)** that the sugarcane segment qualification rate of the three models basically meets the requirements, and all have good sugarcane segment quality.

It can be seen from **Figure 3(d)** that the impurity rate of sugarcane harvested by 4GQ-1C, 4GZQ-180, and 4GZQ-260 sugarcane harvesters is 4.17%, 6.24%, and 6.22%, respectively, all of which meet the industry standard of impurity rate < 8%. It can be seen from **Figure 4(d)** that the impurity content in the three tests of the 4GQ-1C model is lower than that of the other two models, while the impurity content in the three tests of the 4GZQ-180 and 4GZQ-260 models is similar, indicating that the impurity content of the small model is good and the impurity removal effect of medium and large harvesters is similar.

It can be seen from **Figure 3(e)** that the total loss rates of sugarcane harvested by 4GQ-1C, 4GZQ-180, and 4GZQ-260 sugarcane harvesters are 0.65%, 1.81%, and 1.40%, respectively, all of which meet the industry standard of a total loss rate < 5%. As can be seen from **Figure 4(e)**, the total loss rate of model 4GQ-1C in three trials is lower than that of the other two models, which indicates that under the same or similar conditions, the sugarcane harvester with collecting bucket has less loss during harvesting. However, in the actual operation process, the related factors of the loss rate also include the sugarcane received by the transfer truck, the sugarcane loss during the connection between the sugarcane transfer truck and the sugarcane collection truck, lodging, missing cutting, and the level of the operators.

5. Conclusion

1) The 4GQ-1C sugarcane harvester adopts a 97 kW engine, a crawler-type walking system, and a sugarcane collecting hopper, which is small in size, flexible in operation, and adaptable and is suitable for sugarcane harvesting in small plots with narrow row spacing, large slope, and scattered.
2) Compared with 132 kW and 194 kW sugarcane harvesters, the adaptability and reliability of 4GQ-1C sugarcane harvesters for planting plots with small and medium row spacing were studied through field experiments. The results showed that the qualified rate of cutting height, the broken head rate of ratoon, the qualified rate of cane segments, the impurity content rate, and the total loss rate of the 4GQ-1C sugarcane harvester were 100%, 3.87%, 96.27%, 4.17%, and 0.65%, respectively, and all the performance indexes met the design requirements and industry standards. Compared with the mature large and medium-sized sugarcane harvesters, this harvester had better harvest quality in small row spacing sugarcane fields.

Conflict of interest

The authors declare no conflict of interest.

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