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RESEARCH ARTICLE

# Experimental Study of the Seed-Filling Uniformity of Sugarcane Single-Bud Billet Planter

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**Abstract** In this paper, a single-bud sugarcane seed-metering device was proposed to reduce the labor intensity of sugarcane planting and also to improve its automation and efficiency. In the research, single-bud billets were expelled by rake bars of rake bar chain in the seed box. A lateral plate of the seed box was removed and replaced by a transparent plastic plates in order to observe the seed-filling process. Single-factor tests and orthogonal tests were conducted in order to study the seed-filling uniformity of the single-bud billet planter. The results showed that the angle of the rake bar chain, the number of billets and the interactions between them had significant effects on the qualification filling rate $S_q$, the excess filling rate $S_m$ and the miss out filling rate $S_e$. According to the orthogonal and dual-factor tests data, the optimal combination of the structural parameters of the seed-metering device was determined as follows: rake bar chain angle of 117°, a number of billets of 700 and the rotary speed of the rake bar chain of 90 rpm. In this study, the value of $S_q$ was maximized (85.06%) and the value of $S_e$ was minimized (7.03%). This study can serve as a reference for optimizing the design of seed-metering devices of single-bud sugarcane planter.

**Keywords** Single-bud billet planter · Seed filling · Uniformity

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## Introduction

Sugarcane is the main raw material of sugar in China, and the main domestic planting regions are Guangxi, Yunnan, Guangdong and Hainan Provinces. In total, 13.3 billion $m^2$ of sugarcane was planted annually in China, which was more than 85% of the total area of the sugar crop in China. The sugar production from sugarcane accounts for more than 90% of the total sugar production in China (Ou 2019, 2013). Planting is one of the most labor-intensive and most important procedures in the production of sugarcane. Traditionally, sugarcane was planted by with a efficiency of 0.03 hectares per day per person (Liu 2011).

At present, the main types of sugarcane planters were whole-stalk planters, real-time cutting planters and pre-cutting planters. Both whole-stalk and real-time cutting planters were studied (Naquin 2014; Mandal and Maji 2008; Yadav 2003; Patil 2004; Khedkar 2008; Kumar 2012; Robotham 2004). However, the process of those planters was very labor-intensive and low efficient, and they were prone to miss seeding (Wang 2018; He 2020). Hence, there was an urgent need to develop a high efficiency and low labor-intensive sugarcane planter.

Han et al. (2019) proposed a pre-cutting sugarcane planter; herein, a U-shaped grooved wheel seed-grab mechanism and a chain sugarcane conveyor were included to enhance the uniformity of the intervals. He et al. (2019) designed an electromagnetic vibration-type single-bud sugarcane seed-metering device, and bud damage was avoided by automatic metering of the vibration. Moslem et al. (2014) designed another billet planter in which plant billets with an overlapping planting pattern were fabricated. In this research, an array of cupboards that were attached to a chain conveyor was used to transport the billets from the two metering devices to the furrows. Naik et al. (2012) developed a planting tractor for sugarcane bud chips; the optimum speed of operation was experimentally determined to be 1.4 km/h, and the miss rate was found to be 2.33%. Thienyaem et al. (2014) designed a cleated conveyor belt on the wall of the container for use as a metering device for the testing unit. It aimed to find the appropriate arrangement of the metering devices for the prevailing conditions in Thailand. Their stationary experiments were completed using a testing unit that was driven by an electric motor. Javad et al. (2013) investigated a capacitive sensor method for measuring the billet spacing uniformity for a sugarcane billet planter, and an electronic device, based on a capacitive sensor, was designed and developed to predict the ideal planting spacing of sugarcane billets.

In this study, a seed-metering device of a pre-cutting sugarcane single-bud billet planter was proposed. Herein, the rake bar chain in the seed box was used to drive the rake bar to expel the single-bud sugarcane billets. For a pre-cutting sugarcane planter, the key problem is the planting uniformity. Hence, the seed-filling uniformity of the seed-metering device was tested in order to ascertain the best combination of structural parameters that will provide the theoretical basis for the optimal design of the seed-metering device of the sugarcane single-bud billet planter.

## Materials and Method

### Principles of the Seed-Metering Device

Sugarcane is a crop that reproduces asexually, and it breeds using the buds on the nodes of the stem; sugarcane billets with different numbers of buds were used as the seeds during sugarcane planting. The seed-metering device that was designed in this paper adopted a single-bud billet with a length of 60 mm, hereinafter referred to as a billet (Fig. 1).

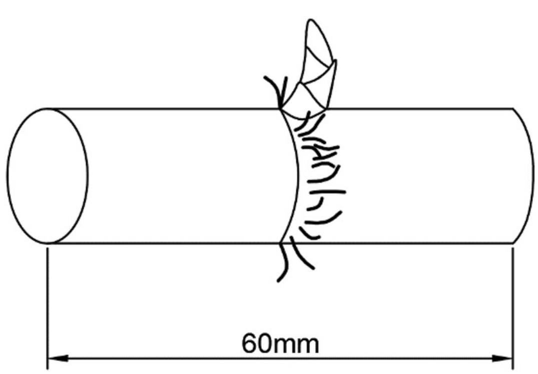



**Fig. 1** Sugarcane single-bud billet

Figure 2 shows the structure of the seed-metering device of the sugarcane single-bud billet planter. The device consists of a seed box, a seed quantity adjustment plate, a rake bar chain, the driving and driven wheels of the rake bar chain, a rake bar, a seeding channel and a seeding flap. During its operation, a hydraulic motor drove the rake bar chain using the driving wheels, and the billets were driven by the rake bar to move along the wall of the seed box. The sugarcane billets filled the rake bar and moved toward the inlet of the seeding channel. Further, the billets gradually left the rake bar under the action of both the centripetal force and gravity and then fell through the seeding channel. The sugarcane billets that did not entered the rake bar were driven to a certain height, due to their interaction with the rake bar and the other billets, and then slid down. The seeding flap is able to control the final drop position of the billets. The seed quantity adjustment plate is able to adjust the number of billets in the seed box. The driving and driven wheels of the rake bar chain can be adjusted by the spring.

Figure 3 illustrates the design of the rake bar; it was a hollow, semi-circular structure with an internal diameter of 30 mm, a length of 60 mm and a diameter of 30 mm on the side. This rake bar can satisfy the needs of a single sugarcane billet (diameter of 15–35 mm, length of 60 mm) that are either placed horizontally or vertically. There were different quantities and locations of billets on the rake bar during the seed-filling process, as shown in Fig. 4. Ideally, there would only be one billet on each rake bar (Fig. 4a, b). Sometimes two billets sat on the rake bar in a mutually perpendicular or mutually parallel position (Fig. 4 c, d). The rake bar can drive three or four billets by pushing them occasionally (Fig. 4e, h); however, the rake bar rarely drove more than four billets. During the seed-filling process, 1172 rake bars with billets were counted: the cases where there were 1, 2, 3 or 4 billets on the rake bar accounted for 78.7%, 16.6%, 3.6% and 1.1% of the total, respectively; it indicated that the current rake bar design can meet the need of sugarcane seed.

### Sugarcane Single-Bud Billets

The sugarcane variety used in this experiment was "Tai tang F66." The sugarcane plants with upright stems and which were disease and pest-free were selected. Sugarcane billets with a length of 60 mm were cut from the selected sugarcane specimens; 800 samples were taken so that the results were statistically significant. The average diameter of the sugarcane billets was 28.7 mm, and the average weight for 100 sugarcane billets was 3.075 kg.

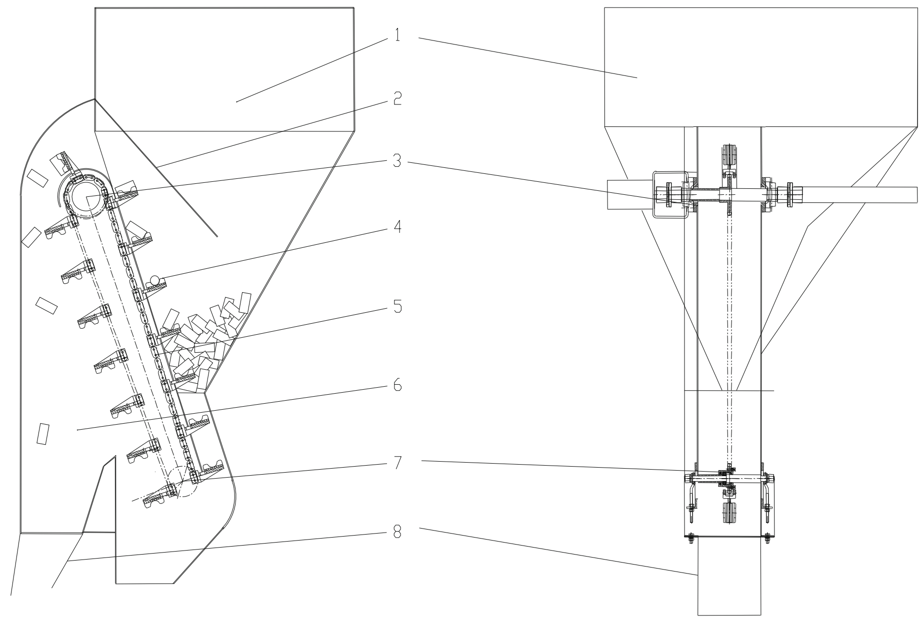



**Fig. 2** Structural diagram of the seed-metering device. 1 Seed box, 2 seed quantity adjustment plate, 3 rake bar chain driving wheel, 4 rake bar, 5 rake bar chain, 6 seeding channel, 7 rake bar chain driven wheel, 8 seeding flap

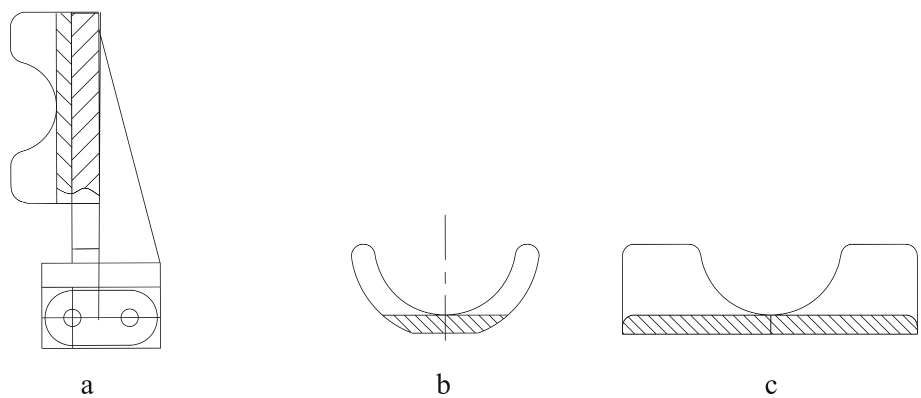



**Fig. 3** Structural diagram of a rake bar. (**a**) rake bar mounted on chain, (**b**) front view of the rake bar, (**c**) side view of the rake bar

## Experimental Method

Figure 5a shows the experimental setup for the seed-metering device. In order to better observe the seed-filling process, lateral plate of the seed box was removed and replaced by a transparent plastic plate. The billets were filled in the seed box of the seed-metering device during the experiment. A SONY HDR-CX550E digital camcorder was used to record the seed-filling process, and a tungsten iodine lamp was used to provide light. The test factors were the rotational speed of the rake bar chain, the angle of the rake bar chain, the number of billets and the diameter of the sugarcane billet. Hall sensors were used to measure the rotational speed of the rake bar chain wheel. The angle of the rake bar chain was the angle that is formed by the rake bar chain and a horizontal line; as shown in (Fig. 5b), it was adjusted using a hydraulic cylinder. The test indicators were described in detail in the following section.

## Parameters

During sugarcane planting, the number of sugarcane billets per unit length must be kept within a certain range. Thus, during the seed-filling process of a sugarcane single-bud billet planter, one rake bar with one or two sugarcane billets was considered to be normal seed filling. The cases of no billets or more than two billets on the rake bar were considered to be abnormal. The following test indicators for the uniformity of the sugarcane seed filling were proposed.

### Qualification Filling Rate ($S_q$)

The number of billets in the rake bar is counted when the total number of billets entering the seeding channel is 100; the number of rake bars begins from the first rake bar that emerges from the billets in the seed box. In addition, the

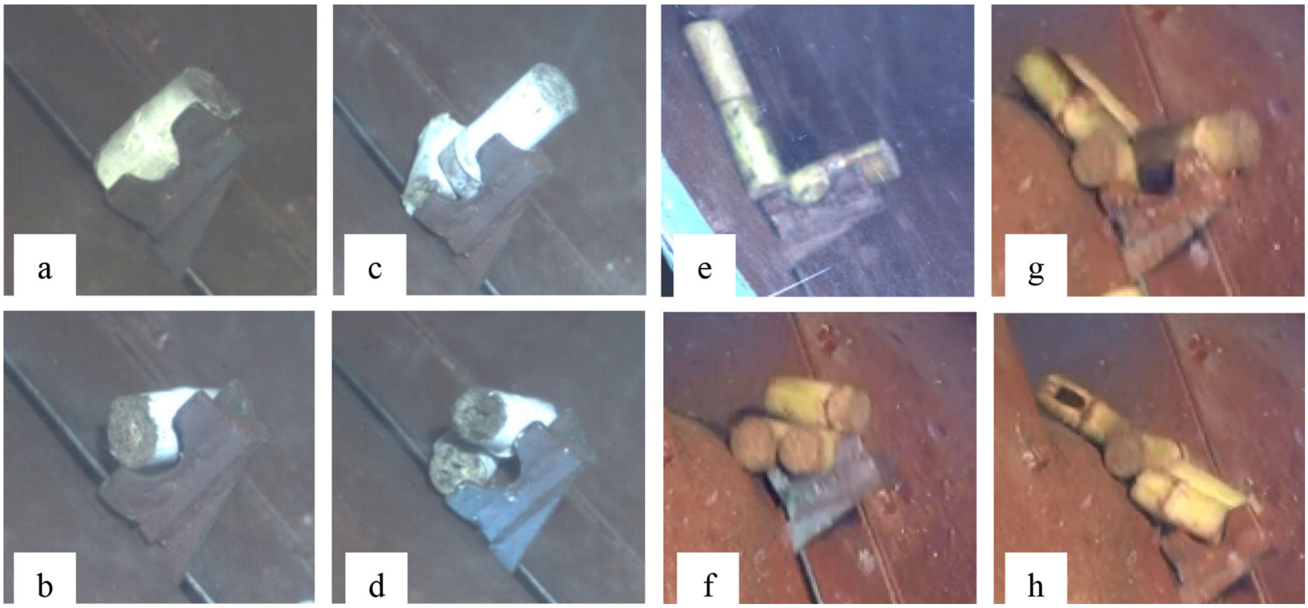



**Fig. 4** The number and position of the sugarcane billets on the rake bar. (**a**) vertical single billet, (**b**) horizontal single billet, (**c**) two billets directionally crossed, (**d**) two billets paralleled, (**e**) three billets of attitude 1, (**f**) three billets of attitude 2, (**g**) four billets of attitude 1, (**h**) four billets of attitude 2

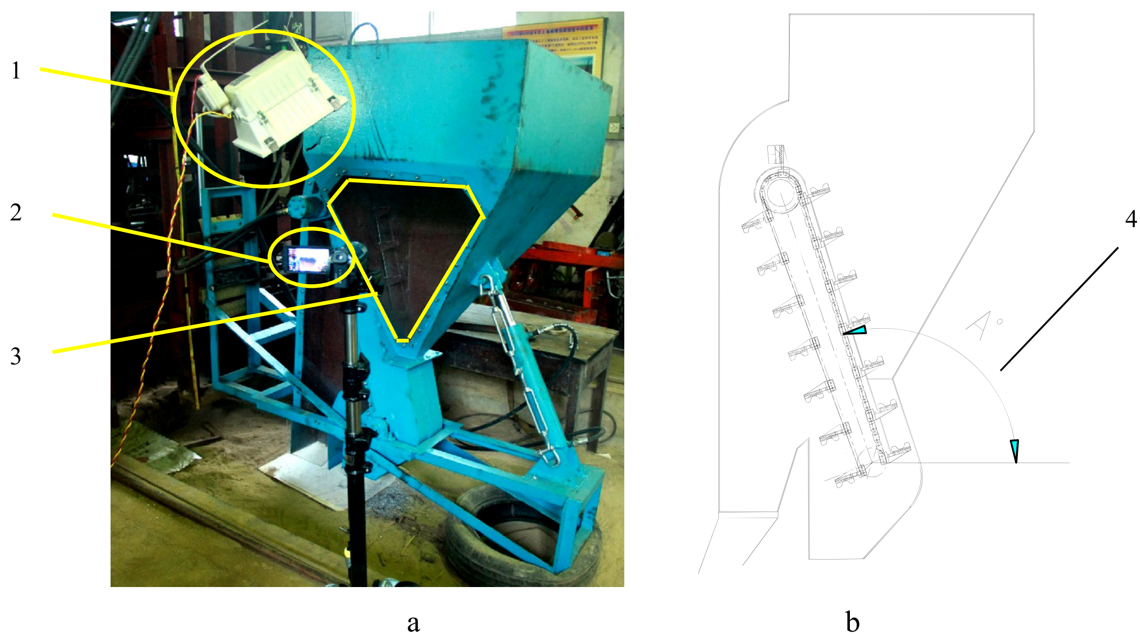



**Fig. 5** Experimental setup for the seed-metering device. 1 Tungsten iodine lamp, 2 camera, 3 filming area of the seed-filling process, 4 the angle of the rake bar chain being measured

ratio between the number of rake bars with 1–2 billets and the total number of rake bars is the qualification filling rate. This parameter mainly reflects the proportion of the number of rake bars with normal seed filling. When the value increases, the planter has superior seed-filling uniformity.

### Excess Filling Rate ($S_m$)

The ratio between the number of rake bars with more than 2 billets and the total number of rake bars, is the excess filling rate. A higher value indicates lower controllability and uniformity of the seed filling.

**Table 1** Test factor level

| No | Rotational speed of rake bar chain (rpm) | Angle of rake bar chain (°) | Number of billets | Diameter of billet (mm) |
|---|---|---|---|---|
| 1 | 90 | 117 | 200 | 15–20 |
| 2 | 90 | 117 | 200 | 20–25 |
| 3 | 90 | 117 | 200 | 25–30 |
| 4 | 90 | 117 | 200 | 30–35 |
| 5 | 50 | 117 | 500 | — |
| 6 | 60 | 117 | 500 | — |
| 7 | 70 | 117 | 500 | — |
| 8 | 80 | 117 | 500 | — |
| 9 | 90 | 117 | 500 | — |
| 10 | 100 | 117 | 500 | — |
| 11 | 110 | 117 | 500 | — |
| 12 | 120 | 117 | 500 | — |
| 13 | 130 | 117 | 500 | — |
| 14 | 90 | 97 | 500 | — |
| 15 | 90 | 107 | 500 | — |
| 16 | 90 | 117 | 500 | — |
| 17 | 90 | 127 | 500 | — |
| 18 | 90 | 117 | 100 | — |
| 19 | 90 | 117 | 200 | — |
| 20 | 90 | 117 | 300 | — |
| 21 | 90 | 117 | 400 | — |
| 22 | 90 | 117 | 500 | — |
| 23 | 90 | 117 | 600 | — |
| 24 | 90 | 117 | 700 | — |
| 25 | 90 | 117 | 800 | — |
| 26 | 90 | 117 | 900 | — |
| 27 | 90 | 117 | 1000 | — |

### Miss Out Filling Rate ($S_e$)

The ratio between the number of rake bars with no billets and the total number of rake bars is the miss out filling rate. A higher $S_e$ value indicates that the planting quality of the planter is lower, which leads to inferior performance.

$S_q$ is the leading indicator of the seed-filling uniformity of a single-bud billet planter, while $S_m$ and $S_e$ serve as secondary indicators. These parameters can be calculated from the following equations:

$$S_q = \frac{n_1}{n_1 + n_2 + n_3} \times 100\% \quad (1)$$

$$S_m = \frac{n_2}{n_1 + n_2 + n_3} \times 100\% \quad (2)$$

$$S_e = \frac{n_3}{n_1 + n_2 + n_3} \times 100\% \quad (3)$$

where $n_1$ refers to the number of rake bars with 1–2 billets, $n_2$ refers to the number of rake bars with more than 2 billets, $n_3$ refers to the number of rake bars with no billets.

### Experimental Design

First, single-factor tests (the factors and levels are shown in Table 1) were conducted to study the influence mechanism of each factor on the test's indicators. The effective ranges were selected to provide optimal parameters for the orthogonal tests. In order to verify the effect of the rotational speed of the rake bar chain, the angle of the rake bar chain was kept constant, and the single-factor tests on the rotational speed of the rake bar chain were performed when the number of billets was in the range of 200 to 700. Each test was repeated three times, and the results of the variance analysis are presented in Table 2. SPSS19.0 software was used to analyze the variance of the test data.

## Results and Discussion

### Single-Factor Test

When the angle of the rake bar chain was 117° and the number of billets was 500, the rotational speed of the rake bar chain had no significant effect on the values of $S_q$, $S_m$ or $S_e$ in the 95% confidence interval. When the number was less than 500, the rotational speed had a large impact on both $S_q$ and $S_e$; however, when the number was 500, the values of sig for $S_q$, $S_m$ and $S_e$ were 0.535, 0.228 and 0.892, respectively. When the number was 600, the values of sig for $S_q$, $S_m$ and $S_e$ were 0.320, 0.268 and 0.469, respectively. When the number was 700, the values of sig for $S_q$, $S_m$ and $S_e$ were 0.528, 0.630 and 0.192, respectively. This demonstrated that when the number was greater than 500, the rotational speed had no significant effect on $S_q$, $S_m$ and $S_e$. As shown in Fig. 6a, b, when the number was less than 500, $S_e$ increased with the rotational speed and $S_q$ decreased. As shown in Fig. 6c, if the number was greater than 500, the value of $S_q$ was higher overall; thus, the

**Table 2** Variance analysis of the test results for the rotational speed of the rake bar chain

| Number of billets | $S_q$ | | $S_m$ | | $S_e$ | |
|---|---|---|---|---|---|---|
| | F | Sig | F | Sig | F | Sig |
| 200 | 7.574 | 0.000** | 0.737 | 0.658 | 7.706 | 0.000** |
| 300 | 2.740 | 0.025* | 0.666 | 0.716 | 3.380 | 0.009** |
| 400 | 7.494 | 0.000** | 2.445 | 0.037 | 9.936 | 0.000** |
| 500 | 0.901 | 0.535 | 1.474 | 0.228 | 0.426 | 0.892 |
| 600 | 1.231 | 0.320 | 1.338 | 0.268 | 0.985 | 0.469 |
| 700 | 0.906 | 0.528 | 0.773 | 0.630 | 1.558 | 0.192 |

"**" means a significant impact within 99% confidence interval, "*" indicates a significant impact within 95% confidence interval

number of billets in the seed box should not be less than 500.

It can be seen that the angle of the rake bar chain had a large effect on the values of $S_q$, $S_m$ and $S_e$ in the 99% confidence interval. As shown in Fig. 6d, when the rake bar chain was rotating at a speed of 90 rpm and the number was 500, as the angle increased, the value of $S_q$ increased and $S_e$ decreased. $S_q$ reached a maximum value of 75.05% when the angle was 117°.

When the rake bar chain was rotating at 90 rpm and the angle was 117°, the number had a significant effect on the values of $S_q$, $S_m$ and $S_e$ in the 99% confidence interval. As shown in Fig. 6e, when the number was between 100 and 500, $S_q$ increased and $S_e$ decreased as the number increased. When the number was in the range of 500–700, $S_q$ slightly increased as the number increased. When the number ranged from 700 to 1000, $S_q$ decreased as the number increased, whereas the excess filling rate $S_m$ increased.

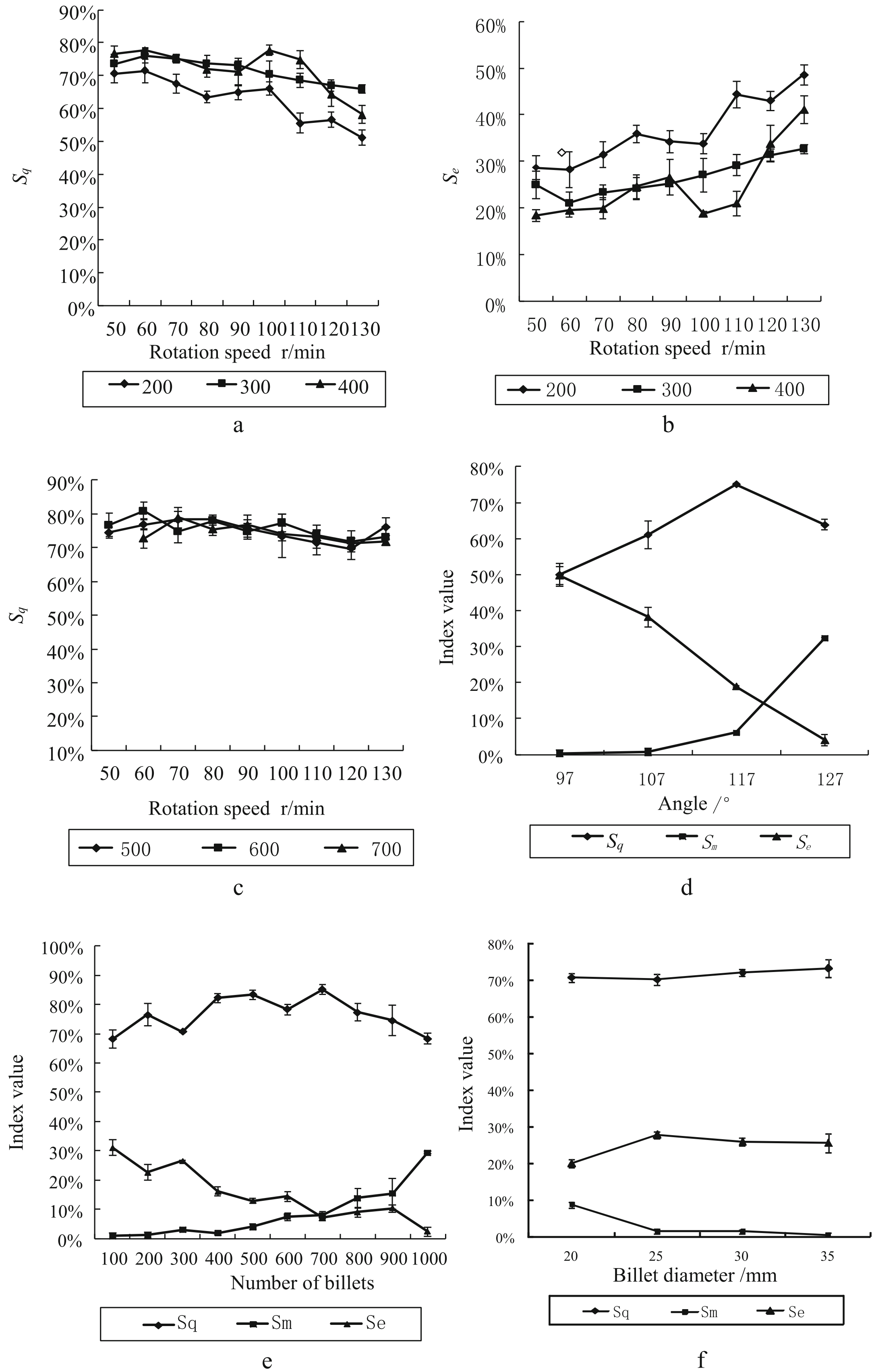
When the rake bar chain was rotating at 90 rpm, the angle of the rake bar chain was 117° and the number of billets was 200; the diameter of the sugarcane billets significantly affected $S_m$ and $S_e$, but it had no obvious influence on $S_q$. The effects of the diameter on the test indicators are demonstrated in Fig. 6f. When the diameter was greater than 20 mm, $S_m$ decreased significantly, $S_q$ remained unchanged, and $S_e$ showed a large increase.

## Orthogonal Test

According to the results of the single-factor tests, three values were chosen for factor A (the rotational speed of the rake bar chain) such as 70 rpm, 90 rpm and 130 rpm. Since the value of $S_q$ was too low when factor B (the angle of the rake bar chain) was set as 97°, three levels of 107°, 117° and 127° were selected to be used. Three levels of factor C (the number of billets) such as 200, 500 and 800 were selected the diameter of the sugarcane billets had no significant effect on the qualification filling rate $S_q$, and the sugarcane billets were not graded during planting. Hence, the diameter of the sugarcane billets was not taken as an influencing factor in the orthogonal test. The orthogonal test was arranged and carried out as per the values listed in Table 3.

## Analysis of the Results of the Orthogonal Tests

An average value was taken from the results of three tests in Table 3. The results of the analysis of the variance of the orthogonal tests are shown in Table 4. It can be seen that factor A significantly affected the value of $S_e$, whereas it had no significant effect on either $S_q$ or $S_m$ in the 95% confidence interval. Both factor B and factor C and the interactions between them B*C had evident effects on the values of $S_q$, $S_m$ and $S_e$. The interaction between factor B and factor C changed the number of rake bars that were covered by billets in the seed box. When the billets covered more rake bars, the billets had a greater chance of filling the rake bar, and the distance from the rake bar to the



Sq
Rotation speed r/min
200 300 400
a
Se
Rotation speed r/min
200 300 400
b
Sq
Rotation speed r/min
500 600 700
c
Index value
Angle /°
Sq Sm Se
d
Index value
Number of billets
Sq Sm Se
e
Index value
Billet diameter /mm
Sq Sm Se
f

◀ **Fig. 6** Effects of the rotational speed of the rake bar chain, the angle of the rake bar chain, the number of billets and the diameter of the sugarcane billets on $S_q$, $S_m$ and $S_e$

seeding channel after passing through the billets would be short. In addition, the extra billets had a lower probability of falling back into the seed box due to an imbalance during operation.

**Table 3** Arrangements and results of the orthogonal test

| Test no | Rotational speed of the rake bar chain A | Angle of the rake bar chain B | Number of billets C | $S_q$ | $S_m$ | $S_e$ |
|---|---|---|---|---|---|---|
| 1 | 70 | 107 | 200 | 74.54% | 0.60% | 24.85% |
| 2 | 70 | 107 | 500 | 67.62% | 2.13% | 30.25% |
| 3 | 70 | 107 | 800 | 82.66% | 2.44% | 14.90% |
| 4 | 70 | 117 | 200 | 74.70% | 1.54% | 23.76% |
| 5 | 70 | 117 | 500 | 79.25% | 3.64% | 17.11% |
| 6 | 70 | 117 | 800 | 76.98% | 16.43% | 6.59% |
| 7 | 70 | 127 | 200 | 74.31% | 3.69% | 22.00% |
| 8 | 70 | 127 | 500 | 71.23% | 21.42% | 7.36% |
| 9 | 70 | 127 | 800 | 49.61% | 49.71% | 0.68% |
| 10 | 90 | 107 | 200 | 70.40% | 1.11% | 28.49% |
| 11 | 90 | 107 | 500 | 71.47% | 1.48% | 27.06% |
| 12 | 90 | 107 | 800 | 80.36% | 2.38% | 17.26% |
| 13 | 90 | 117 | 200 | 71.22% | 0.86% | 27.92% |
| 14 | 90 | 117 | 500 | 77.22% | 5.84% | 16.94% |
| 15 | 90 | 117 | 800 | 69.08% | 19.74% | 11.18% |
| 16 | 90 | 127 | 200 | 67.68% | 2.25% | 30.07% |
| 17 | 90 | 127 | 500 | 69.31% | 26.43% | 4.27% |
| 18 | 90 | 127 | 800 | 41.53% | 56.61% | 1.86% |
| 19 | 110 | 107 | 200 | 57.46% | 0.00% | 42.54% |
| 20 | 110 | 107 | 500 | 71.70% | 1.11% | 27.18% |
| 21 | 110 | 107 | 800 | 72.90% | 1.61% | 25.49% |
| 22 | 110 | 117 | 200 | 65.29% | 0.24% | 34.47% |
| 23 | 110 | 117 | 500 | 76.19% | 4.10% | 19.71% |
| 24 | 110 | 117 | 800 | 83.69% | 7.18% | 9.13% |
| 25 | 110 | 127 | 200 | 73.22% | 2.67% | 24.11% |
| 26 | 110 | 127 | 500 | 72.31% | 22.22% | 5.47% |
| 27 | 110 | 127 | 800 | 36.99% | 61.23% | 1.77% |

**Table 4** Variance analysis of the results of the orthogonal tests

| | $S_q$ | | $S_m$ | | $S_e$ | |
|---|---|---|---|---|---|---|
| Source | Sig | Eta$^2$ | Sig | Eta$^2$ | Sig | Eta$^2$ |
| A | 0.208 | 0.325 | 0.489 | 0.164 | 0.045* | 0.541 |
| B | 0.002** | 0.796 | 0.000** | 0.973 | 0.000** | 0.928 |
| C | 0.062 | 0.5 | 0.000** | 0.962 | 0.000** | 0.95 |
| B × C | 0.001** | 0.887 | 0.000** | 0.959 | 0.028* | 0.706 |
| A × C | 0.553 | 0.288 | 0.894 | 0.116 | 0.155 | 0.528 |
| A × B | 0.599 | 0.266 | 0.452 | 0.338 | 0.229 | 0.469 |

** means a significant effect within 99% confidence interval, * means a significant effect within 95% confidence interval. Eta2 is the contribution rate of factors to test indicators

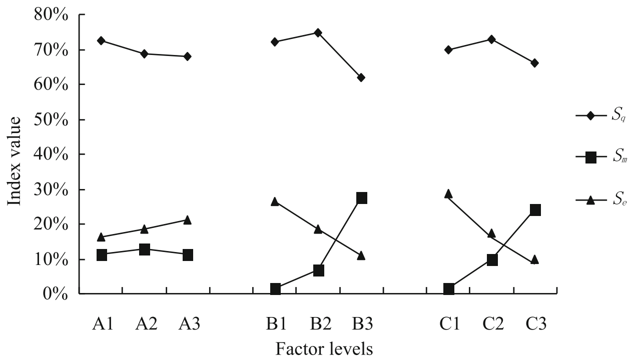



**Fig. 7** Trends of different factors

Referring to the estimates of the magnitude of the effects abbreviated as $\text{Eta}^2$ in Table 4, the order of significance of the factors from largest to smallest was B × C > B > C > A for $S_q$, B > C > B × C > A for $S_m$, and C > B > B × C > A for $S_e$.

Among the test indicators, $S_q$ was the primary indicator that can best reflect the uniformity of seed filling. However, the comprehensive analysis of $S_m$ and $S_e$ was referred to. The interaction between factor B and factor C had a significant effect on $S_q$; hence, this interaction should be given priority. According to Table 3, the best combination was B1C3 with an average value for $S_q$ of 82.66%. Considering the influence of the various factors on the test index, as shown in Fig. 7, the influence of factor A on $S_q$ was the highest when factor A was at the first level. Thus, the best combination of the test for the seed-filling uniformity is A1B1C3.

According to the orthogonal tests, the values of $S_q$, $S_m$ and $S_e$ for A1B1C3 were 82.66%, 2.44% and 14.90%, respectively, and the values of $S_q$, $S_m$ and $S_e$ for A3B2C3 were 83.69%, 7.18% and 9.13%, respectively. For verification of the orthogonal test, the best combination requires a dual-factor test of factor B and factor C.

**Table 5** Variance analysis of the dual-factor tests

| Source | $S_q$ | | $S_m$ | | $S_e$ | |
|---|---|---|---|---|---|---|
| | F | Sig | F | Sig | F | Sig |
| C | 6.194 | 0.000** | 40.109 | 0.000** | 72.783 | 0.000** |
| B | 79.238 | 0.000** | 247.013 | 0.000** | 319.617 | 0.000** |
| B*C | 20.179 | 0.000** | 27.002 | 0.000** | 2.547 | 0.005** |

** means a significant impact within 99% confidence interval, * indicates a significant impact within 95% confidence interval

## Dual-Factor Test for the Angle of the Rake Bar Chain and the Number of Billets

In order to verify the interaction between the angle of the rake bar chain B and the number of billets C and to obtain the best combination according to the influence mechanism, the rake bar chain was set at 90 rpm, and factor B was set at four levels: 97°, 107°, 117° and 127°. Factor C was divided into ten levels between 100 and 1000, and each test was repeated three times.

Table 5 shows the variance analysis of the dual-factor test. As observed, B and C and the interactions between them B*C had a significant effect on the values of $S_q$, $S_m$ and $S_e$ in the 99% confidence interval (sig = 0 < 0.05).

As shown in Fig. 8, when the number of sugarcane billets varied in the range of 100 to 1000 and at an angle of the rake bar chain of 117°, the value of $S_q$ was higher than that at angles of the rake bar chain of 107° and 127°; it can also be seen that the overall trends of the values of $S_m$ and $S_e$ were lower. The test results of the number of billets, when the angle of the rake bar chain was 117°, are shown in Table 6. When the number of billets = 700, the value of $S_q$ was maximized (85.06%), $S_e$ was minimized (7.03%) and $S_m$ = 7.91%. Therefore, when the angle of the rake bar chain was 117° and the number of billets was 700, the seed-filling uniformity displayed the best performance.

## Conclusions

Due to the peculiarity of sugarcane billets and the structure of the seed-metering devices of the sugarcane single-bud billet planter, the qualification filling rate $S_q$, the excess filling rate $S_m$ and the miss out filling rate $S_e$ had been proposed as indicators that can be used to measure sugarcane seed-filling uniformity. If the number of sugarcane billets (C) was less than 500, the rotational speed of the rake bar chain (A) had a significant effect on the test indicators; if the number of billets (C) was equal to or greater than 500, the rotational speed of the rake bar chain (A) had no significant effect on the test indicators. The angle of the rake bar chain (B), the number of billets (C) and the interactions between them (B*C) had a sig-

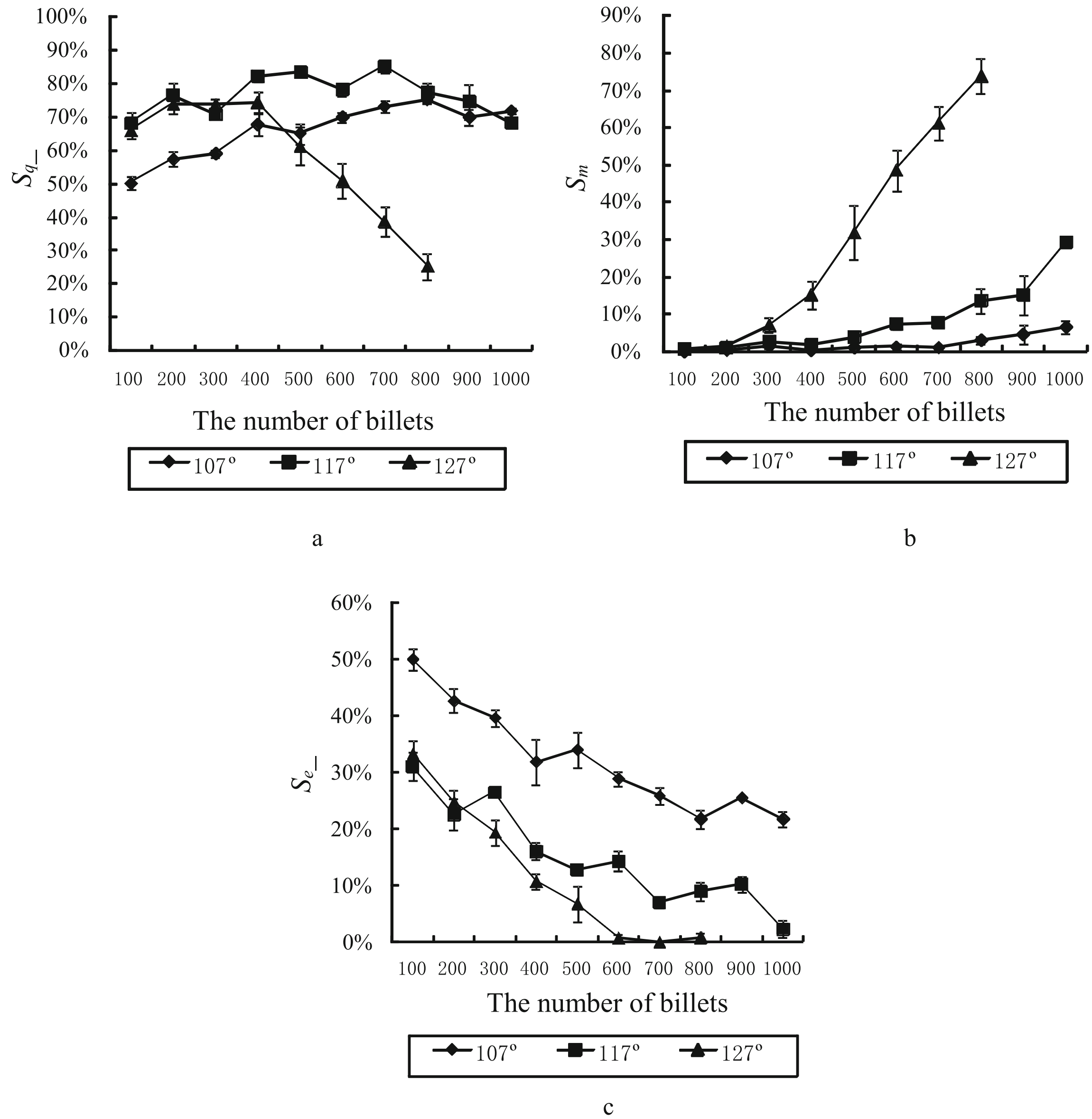



**Fig. 8** Effects of the angle of the rake bar chain and the number of billets on $S_q$, $S_m$ and $S_e$

**Table 6** Test results for different numbers of billets

| Number of billets | $S_q$ | $S_m$ | $S_e$ |
|---|---|---|---|
| 100 | 68.07% | 0.87% | 31.06% |
| 200 | 76.40% | 1.07% | 22.53% |
| 300 | 70.70% | 2.87% | 26.43% |
| 400 | 82.16% | 1.77% | 16.07% |
| 500 | 83.29% | 3.91% | 12.80% |
| 600 | 78.26% | 7.43% | 14.31% |
| 700 | 85.06% | 7.91% | 7.03% |
| 800 | 77.30% | 13.74% | 8.95% |
| 900 | 74.52% | 15.26% | 10.22% |
| 1000 | 68.31% | 29.34% | 2.35% |

nificant effect on the values of $S_q$, $S_m$ and $S_e$. The orthogonal tests and dual-factor tests had shown that the optimized parameters for the seed-metering device were: angle of the rake bar chain = 117° and the number of billets = 700. In this case, the value of $S_q$ was maximized and the value of $S_e$ was minimized.

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