Effect of cut tobacco size and distribution on critical cigarette quality characteristics of "slim cigarette" processing technology

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Abstract: To further improve the stability of quality control on the processing technology of slim cigarettes in the process of cigarette manufacturing. In this study, based on the blending formula of product A, the cut tobacco screened out by different sieves was rolled according to different proportions. The cigarette structure, physical properties, tobacco loss from cigarette-end, dust content, and density of tobacco rod were systematically evaluated. The results showed that the proportion of medium and short cut tobacco (1.0 mm ~ 3.35 mm) ≥ 62%, and the whole cut tobacco ratio in the cigarette was less than 40%, which could effectively improve the fluctuation of slim cigarette physical properties and the distribution stability of cut tobacco in tobacco rod.

1. Introduction
The category of "slim cigarette" has developed rapidly in recent years. In June 2014, the State Tobacco Monopoly Administration issued "the notice on standardizing and supporting the development of slim cigarette," encouraging enterprises to effectively promote the standardized development of slim cigarettes through reasonable layout and technical research and development. At present, the research on slim cigarettes mainly focuses on the influence of cigarette auxiliary material parameters on the physical and chemical properties of cut tobacco and smoke [1-7]. However, the industry has made significant problems in the production and processing of slim cigarettes. For example, The significant fluctuation of critical physical indicators and unstable distribution of cut tobacco in tobacco rod are exposed. Simultaneously, there are relatively few studies on the quality stability control of the physical properties of slim cigarettes by the processing and rolling process [8]. Therefore, in order to further improve the stability of the quality control of slim cigarettes at the processing technology, this study combined with the current industry requirements analyzed the control ideas of the critical parameters of cut tobacco size and distribution and carried out a systematic evaluation on the industry's representative "slim cigarette" products. The results can effectively improve the fluctuation of the physical properties of slim cigarettes and the distribution stability of cut tobacco in the tobacco rod.
2. Materials and Methods
Test materials: Cut tobacco of product A; Test equipment: PROTOS 2C cigarette maker; Test equipment: AS400 vibrating sieve (screen size: 3.35mm-2.5mm-1.0mm; rotational speed: 210rpm; time: 4min), Comprehensive test bench for slim cigarettes, Hardness tester for slim cigarettes and densitometer.

Test method: the blending cut tobacco was screened by vibrating sieve, and the cut tobacco in each layer of sieve mesh was collected. The cut tobacco collected from different sieves is rolled in regular production according to different proportions. The cigarette structure, physical properties, and density of tobacco rod were detected after cigarette rolling; the weight of sample cigarette was screened with 550 ± 5mg single gram weight before the density of tobacco rod detection.

Test scheme: see table 1.

Table 1 Blending test scheme of the cut tobacco size distribution

| Test group | 3.35(mm) | 2.5(mm) | 1.0(mm) | <1.0(mm) | Total |
|------------|----------|---------|---------|----------|-------|
| Test 1     | 100.00%  | 0.00%   | 0.00%   | 0.00%    | 100.00% |
| Blending weight kg | 10 |
| Test 2     | 48.50%   | 29.50%  | 20.50%  | 1.50%    | 100.00% |
| Blending weight kg | 4.85 |
| Test 3     | 38.50%   | 36.00%  | 24.00%  | 1.50%    | 100.00% |
| Blending weight kg | 3.85 |
| Test 4     | 28.50%   | 42.50%  | 27.50%  | 1.50%    | 100.00% |
| Blending weight kg | 2.85 |
| Test 5     | 18.50%   | 49.00%  | 31.00%  | 1.50%    | 100.00% |
| Blending weight kg | 1.85 |
| Test 6     | 8.50%    | 55.50%  | 34.50%  | 1.50%    | 100.00% |
| Blending weight kg | 0.85 |

3. Results and Analysis

3.1. The Structure of Cut Tobacco in the Tobacco Rod
The structure of cut tobacco was analyzed for six groups of test samples. According to table 2 and Fig. 1, the reduction of the whole cut-tobacco ratio in tobacco blending is affected by reducing the whole cut-tobacco ratio in tobacco-rod. The higher the whole cut-tobacco ratio in tobacco blending is, the higher the reduction value is; the medium and short cut-tobacco ratio(1.0 mm-3.35 mm) of 6 groups of test samples is gradually increased, from 42.85% to 70.73%; the small particle (1.0mm) content of six groups of samples is almost the same, but test 1 is slightly higher.

Table 2 The Structure of cut tobacco rolled after blending

| Test group | Total sample weight g/% | Screen size | Whole cut-tobacco ratio% | Medium and short cut-tobacco ratio% | Small particle content% |
|------------|-------------------------|------------|--------------------------|------------------------------------|------------------------|
| Test 1     | 50.08                   | 19.14      | 6.95                     | 14.51                              | 9.47                   | 52.10% | 42.85% | 18.92% |
| Test 2     | 99.98%                  | 38.22%     | 13.88%                   | 28.97%                             | 18.92%                 | 42.29% | 50.45% | 18.75% |
| Test 3     | 99.17%                  | 29.97%     | 12.32%                   | 38.13%                             | 18.75%                 | 39.13% | 53.75% | 18.65% |

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### 3.2. Physical Properties of Cigarettes

It can be seen from table 3 to table 5 that under the condition of no significant difference in single gram weight (P = 0.99 > 0.05), the standard deviation of cigarette weight of six groups of test samples showed a downward trend, from 20.2 to 15.0; the standard deviation of draw resistance of six groups of test samples was basically consistent; the standard deviation of total ventilation rate of six groups of test samples showed a downward trend, from 2.9 to 2.7; the standard deviation of the hardness of six groups of test samples showed a downward trend. The length and circumference standard deviation of the six groups of test samples have no noticeable change and keep the same.
### Table 3 Analysis of variance of single gram weight of six groups of test cigarettes

| Source   | DF  | SS   | MS  | F    | P    |
|----------|-----|------|-----|------|------|
| Factor   | 5   | 5.40 | 1.08| 0.12 | 0.987|
| Residual | 54  | 487.25 | 9.02|      |      |
| Total    | 59  | 492.65 |    |      |      |

### Table 4 Statistics of physical properties in the tobacco rod

| Test group | Number | Single gram weight | Length | Circumference | Total ventilation rate | Draw resistance |
|------------|--------|--------------------|--------|---------------|------------------------|-----------------|
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
| Test 1     |        |                    |        |               |                         |                 |                 |
| 1          | 549.7  | 24                 | 99.9   | 0.135         | 17.0                    | 0.08            | 45.6            | 2.7            | 1202            | 62              |
| 2          | 553.8  | 17                 | 99.9   | 0.188         | 17.0                    | 0.05            | 46.3            | 3.3            | 1229            | 45              |
| 3          | 554.9  | 25                 | 99.9   | 0.149         | 17.0                    | 0.06            | 46.5            | 2.5            | 1217            | 68              |
| 4          | 561.7  | 20                 | 99.9   | 0.160         | 17.0                    | 0.07            | 47.7            | 3.2            | 1212            | 74              |
| 5          | 566.3  | 22                 | 100.0  | 0.187         | 17.0                    | 0.06            | 44.0            | 3.2            | 1188            | 61              |
| Test 2     |        |                    |        |               |                         |                 |                 |
| 6          | 558.7  | 16                 | 99.9   | 0.130         | 17.1                    | 0.06            | 44.8            | 2.4            | 1218            | 46              |
| 7          | 554.3  | 23                 | 99.9   | 0.104         | 17.0                    | 0.04            | 45.5            | 3.2            | 1200            | 67              |
| 8          | 555.9  | 19                 | 99.9   | 0.134         | 17.0                    | 0.05            | 45.8            | 2.3            | 1202            | 58              |
| 9          | 553.0  | 19                 | 100.0  | 0.309         | 17.0                    | 0.05            | 45.4            | 2.5            | 1196            | 49              |
| 10         | 552.0  | 17                 | 100.1  | 0.232         | 17.0                    | 0.05            | 45.3            | 3.5            | 1193            | 52              |
| Average    | 555.0  | 20.2               | 99.9   | 0.173         | 17.0                    | 0.06            | 45.7            | 2.9            | 1206            | 58              |

| Test group | Number | Single gram weight | Length | Circumference | Total ventilation rate | Draw resistance |
|------------|--------|--------------------|--------|---------------|------------------------|-----------------|
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
|            |        | Mean               | SD     | Mean          | SD                      | Mean            | SD              |
| Test 2     |        |                    |        |               |                         |                 |                 |
| 1          | 556.8  | 18                 | 100.0  | 0.134         | 17.0                    | 0.05            | 46.9            | 3.3            | 1258            | 44              |
| 2          | 560.5  | 18                 | 99.9   | 0.125         | 17.0                    | 0.05            | 47.5            | 1.9            | 1234            | 48              |
| 3          | 554.7  | 21                 | 99.9   | 0.105         | 17.0                    | 0.06            | 45.9            | 3.0            | 1249            | 66              |
| Test 2     |        |                    |        |               |                         |                 |                 |
| 4          | 550.5  | 17                 | 100.0  | 0.179         | 17.0                    | 0.04            | 47.6            | 3.9            | 1245            | 70              |
| 5          | 550.7  | 15                 | 99.9   | 0.164         | 17.0                    | 0.06            | 46.2            | 3.0            | 1230            | 67              |
| 6          | 556.9  | 21                 | 99.9   | 0.123         | 17.1                    | 0.06            | 46.8            | 2.4            | 1256            | 64              |
| 7          | 552.8  | 20                 | 99.9   | 0.172         | 17.0                    | 0.07            | 46.1            | 3.1            | 1250            | 59              |
| Test | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | Value 6 | Value 7 | Value 8 | Value 9 | Value 10 | Average |
|------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|---------|
| 1    | 557.6   | 99.8    | 0.155   | 17.0    | 0.05    | 47.7    | 2.1     | 1246    | 55      |
| 2    | 559.7   | 140.0   | 0.226   | 17.0    | 0.07    | 49.1    | 4.3     | 1326    | 61      |
| 3    | 554.0   | 99.9    | 0.167   | 17.0    | 0.05    | 46.9    | 2.6     | 1246    | 63      |
| 4    | 549.5   | 99.9    | 0.137   | 17.0    | 0.05    | 46.6    | 3.5     | 1324    | 45      |
| 5    | 554.6   | 99.9    | 0.189   | 17.0    | 0.05    | 47.3    | 2.6     | 1324    | 50      |
| Test 3 | 6    | 552.2   | 170.0   | 0.201   | 17.0    | 0.05    | 48.2    | 2.2     | 1218    | 65      |
| 7    | 555.5   | 99.9    | 0.150   | 17.0    | 0.05    | 47.2    | 2.8     | 1328    | 59      |
| 8    | 555.3   | 99.9    | 0.150   | 17.0    | 0.05    | 47.9    | 2.8     | 1328    | 69      |
| 9    | 554.8   | 99.9    | 0.135   | 17.0    | 0.05    | 47.0    | 3.3     | 1324    | 58      |
| 10   | 555.0   | 99.9    | 0.121   | 17.0    | 0.06    | 48.0    | 3.1     | 1324    | 50      |
| Average | 554.8 | 99.9    | 0.163   | 17.0    | 0.05    | 47.6    | 2.9     | 1236    | 59      |
| 1    | 550.1   | 170.0   | 0.106   | 17.0    | 0.05    | 47.5    | 2.5     | 1263    | 55      |
| 2    | 556.4   | 99.9    | 0.167   | 17.1    | 0.05    | 48.4    | 2.9     | 1243    | 63      |
| 3    | 555.3   | 99.9    | 0.117   | 17.1    | 0.04    | 48.3    | 3.6     | 1262    | 50      |
| 4    | 555.0   | 100.0   | 0.111   | 17.1    | 0.03    | 48.3    | 1.5     | 1298    | 62      |
| Test 4 | 5    | 554.0   | 99.9    | 0.167   | 17.0    | 0.04    | 48.0    | 3.8     | 1293    | 45      |
| 6    | 553.7   | 99.9    | 0.165   | 17.1    | 0.05    | 47.9    | 2.3     | 1284    | 67      |
| 7    | 551.1   | 99.9    | 0.148   | 17.0    | 0.05    | 47.4    | 3.0     | 1272    | 66      |
| 8    | 559.6   | 99.9    | 0.109   | 17.1    | 0.04    | 50.0    | 3.1     | 1313    | 58      |
| 9    | 557.4   | 99.9    | 0.146   | 17.1    | 0.05    | 46.4    | 3.6     | 1279    | 51      |
|    | Value | Time | Detection Rate | Width | Height | Position | Width | Height | Width | Height | Position |
|----|-------|------|----------------|-------|--------|-----------|-------|--------|-------|--------|-----------|
| 10 | 555.5 | 19   | 99.9           | 0.347 | 17.1   | 0.04      | 49.2  | 1.2    | 1313  | 66     |
| Average | 554.8 | 17.6 | 99.9           | 0.158 | 17.1   | 0.04      | 48.1  | 2.8    | 1282  | 58     |
| 1  | 557.8 | 16   | 100.0          | 0.105 | 17.0   | 0.07      | 49.2  | 2.7    | 1252  | 66     |
| 2  | 555.4 | 17   | 100.0          | 0.164 | 17.0   | 0.06      | 49.5  | 2.9    | 1239  | 54     |
| 3  | 554.4 | 18   | 100.0          | 0.173 | 17.0   | 0.05      | 49.0  | 3.5    | 1234  | 51     |
| 4  | 552.8 | 14   | 99.9           | 0.100 | 17.0   | 0.07      | 48.8  | 2.4    | 1238  | 39     |
| 5  | 551.0 | 18   | 99.9           | 0.098 | 17.0   | 0.07      | 48.5  | 2.6    | 1247  | 76     |
| Test 5 | 6  | 549.3 | 15   | 99.9           | 0.139 | 17.1   | 0.08      | 49.1  | 2.0    | 1227  | 54     |
| 7  | 559.9 | 18   | 99.9           | 0.103 | 17.0   | 0.06      | 50.2  | 3.0    | 1255  | 60     |
| 8  | 555.8 | 17   | 99.9           | 0.114 | 17.0   | 0.06      | 49.7  | 2.5    | 1222  | 59     |
| 9  | 556.9 | 17   | 100.0          | 0.295 | 17.0   | 0.07      | 49.1  | 2.9    | 1239  | 47     |
| 10 | 554.5 | 19   | 99.9           | 0.090 | 17.0   | 0.06      | 48.5  | 2.5    | 1241  | 54     |
| Average | 554.8 | 16.9 | 99.9           | 0.138 | 17.0   | 0.06      | 49.2  | 2.7    | 1239  | 56     |
| 1  | 555.5 | 17   | 99.9           | 0.135 | 17.1   | 0.05      | 48.1  | 1.9    | 1220  | 52     |
| 2  | 557.8 | 13   | 99.9           | 0.175 | 17.1   | 0.06      | 47.3  | 2.6    | 1236  | 62     |
| 3  | 551.0 | 15   | 99.9           | 0.119 | 17.0   | 0.06      | 47.5  | 3.7    | 1232  | 75     |
| 4  | 553.7 | 14   | 99.8           | 0.100 | 17.0   | 0.05      | 48.1  | 2.3    | 1239  | 51     |
| 5  | 557.1 | 15   | 99.9           | 0.107 | 17.1   | 0.05      | 47.4  | 2.1    | 1235  | 49     |
| Test 6 | 6  | 552.0 | 16   | 99.9           | 0.181 | 17.1   | 0.04      | 47.9  | 2.2    | 1226  | 63     |
| 7  | 553.2 | 15   | 99.9           | 0.143 | 17.1   | 0.06      | 46.3  | 3.8    | 1220  | 48     |
| 8  | 555.8 | 13   | 99.8           | 0.117 | 17.1   | 0.05      | 47.8  | 2.7    | 1228  | 50     |
| 9  | 559.9 | 18   | 99.8           | 0.581 | 17.1   | 0.06      | 47.5  | 3.0    | 1242  | 41     |
| 10 | 554.3 | 14   | 99.9           | 0.158 | 17.0   | 0.06      | 47.9  | 2.7    | 1255  | 61     |
| Average | 553.6 | 15.0 | 99.9           | 0.182 | 17.1   | 0.05      | 47.6  | 2.7    | 1233  | 55     |
| Test group | Testing number | Mean of hardness | SD of hardness |
|------------|----------------|-----------------|----------------|
| Test 1     |                |                 |                |
|            | 1              | 58.1            | 2.9            |
|            | 2              | 59.4            | 2.4            |
|            | 3              | 60.2            | 2.8            |
|            | 4              | 61.7            | 3.2            |
|            | 5              | 58.5            | 4.3            |
|            | Average        | 59.58           | 3.12           |
| Test 2     |                |                 |                |
|            | 1              | 58.1            | 3.1            |
|            | 2              | 59.3            | 2.7            |
|            | 3              | 60.3            | 3.4            |
|            | 4              | 61.5            | 2.4            |
|            | 5              | 60.5            | 3.3            |
|            | Average        | 59.94           | 2.98           |
| Test 3     |                |                 |                |
|            | 1              | 59.8            | 3              |
|            | 2              | 58.4            | 2.8            |
|            | 3              | 59.4            | 3.3            |
|            | 4              | 59.6            | 2.7            |
|            | 5              | 60.6            | 2.1            |
|            | Average        | 59.56           | 2.78           |
| Test 4     |                |                 |                |
|            | 1              | 59.3            | 2.6            |
|            | 2              | 60              | 2.6            |
|            | 3              | 60.7            | 2.4            |
|            | 4              | 61              | 2.2            |
|            | 5              | 60.5            | 2.8            |
|            | Average        | 60.3            | 2.52           |
| Test 5     |                |                 |                |
|            | 1              | 60              | 2.4            |
|            | 2              | 59.1            | 3              |
|            | 3              | 59.4            | 3.1            |
|            | 4              | 59.9            | 2.1            |
|            | 5              | 59.5            | 1.5            |
|            | Average        | 59.58           | 2.42           |
| Test 6     |                |                 |                |
|            | 1              | 59.2            | 1.9            |
|            | 2              | 60              | 2.6            |
|            | 3              | 60.1            | 2.5            |
|            | 4              | 60.4            | 2.6            |
|            | 5              | 61.7            | 2.3            |
|            | Average        | 60.28           | 2.38           |
3.3. Dust Content and Tobacco Loss from Cigarette-end
It can be seen from Fig.3 that the tobacco loss from the cigarette-end of 1#-6# test sample gradually increases, from 1.29 mg/pc to 3.9 mg/pc; the dust content of the 1#-6# test sample also increases gradually, from 1.02% to 2.42%.

3.4. Distribution for the density of tobacco rod
All cigarettes were screened by weight (555 ± 5mg / cigarette) to ensure that the weight of each cigarette was equal. It can be seen from table 6 that under the condition of the same single gram weight, there is no significant difference in the mean (density of tobacco rod) among six groups of test samples; however, the standard deviation of test 1 sample is the largest, and that of test 6 sample is the smallest. Also, as shown in Fig.4, the standard deviation distribution curve of test 6 is lower than that of other test
samples, which indicates that the fluctuation of the mean (density of tobacco rod) within groups of each measuring point in test 6 is small, and the stability of distribution for the density of tobacco rod is well controlled.

| Test group | The density of tobacco rod $X_{mean}$ | The standard deviation $S_{mean}$ |
|------------|--------------------------------------|----------------------------------|
|            | Within groups (20pc) | Between groups $X_{mean}$ | Within groups (20pc) | Between groups $X_{mean}$ |
| Test 1     | $245.01$ | $242.04$ | $243.53$ | $13.04$ | $15.03$ | $14.03$ |
| Test 2     | $241.72$ | $243.96$ | $242.84$ | $13.62$ | $11.39$ | $12.50$ |
| Test 3     | $245.78$ | $243.48$ | $244.63$ | $12.99$ | $10.13$ | $11.56$ |
| Test 4     | $242.80$ | $243.02$ | $242.91$ | $9.15$ | $12.51$ | $10.83$ |
| Test 5     | $244.12$ | $239.92$ | $242.02$ | $11.14$ | $7.82$ | $9.48$ |
| Test 6     | $243.55$ | $244.36$ | $243.96$ | $7.62$ | $9.12$ | $8.37$ |

Figure 4 Standard deviation distribution curve of the mean (density of tobacco rod)

4. Conclusion and discussion
Among them, the proportion of medium and short cut tobacco (1.0 mm ~ 3.35 mm) $\geq$ 62%, and the whole cut tobacco ratio in the cigarette is less than 40%, which can effectively improve the fluctuation of slim cigarette physical properties and improve the distribution stability of cut tobacco in tobacco rod. However, dust content and tobacco loss from cigarette-end will increase with the decrease of the whole cut-tobacco ratio. Aim at this problem, the filling performance of cut tobacco can be improved accordingly. To sum up, increasing the proportion of medium and short cut tobacco and reasonably reducing the whole cut tobacco ratio are conducive to improving the quality of slim cigarettes.

Based on the work carried out under the special topic "Research on control technology of cut tobacco length" in the "tobacco processing technology" research section under the systematic research route of
"slim cigarette" blending formula, this study mainly evaluated the influence trend of different cut tobacco length, quality indicators and economic performance indicators, and determined the suitable cut tobacco length control for "slim cigarette" rolling. Finally, the improved adaptability between the cut tobacco length and the slim cigarette was completed, which provided important support for "the final blending formula of the system of tobacco processing control technology for the compatibility of cut tobacco characteristics and slim cigarettes."

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