

# Identification and Cluster Analysis of Sweet Corn Based on Grain Textural Properties

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**Abstract:** The edible qualities are crucial factors for quality of Fresh-eating sweet Corn. However, the research of the edible quality at the milking stage remains largely ambiguous in sweet corn. To identify phenotypes and classify genotypes via principal component analysis and cluster analysis, the textural properties of the grain of 51 sweet corn varieties in regional tests were measured by texture analyzer. The results showed that there was high genetic variation and diversity in the grain textural properties (hardness, springiness, cohesiveness, adhesiveness, chewiness, resilience, gumminess) between the 51 sweet corn varieties. Among the variation in these textural properties, the variation in adhesiveness was the greatest, and the variation in cohesiveness was the smallest; the variation ranges were 1.145~18.190 and 0.126~0.253, respectively. There were very significantly positive relationships between hardness, cohesiveness, chewiness and gumminess; the correlation coefficients were greater than 0.783. However, no significant correlation between resilience and the other traits was observed. According to principal component analysis (PCA), the above seven textural characteristics were governed by three independent principal components. The per cent contributions of the variance of the three independent principal components were 54.656%, 15.814% and 14.737%. Hardness, springiness and resilience were the dominant factors affecting the textural properties of the sweet corn grain. According to systematic cluster analysis, the 51 sweet corn varieties could be classified into 2 groups based on their hardness values, and group 1 could be further classified into 3 subgroups based on the values of springiness and resilience. These results indicated that significant genetic differences exist in the textural properties of sweet corn grain and provided useful information for improving the edible quality of sweet corn.

**Keywords:** Sweet Corn, Textural Properties, Principal Component Analysis, Cluster Analysis

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## 1. Introduction

Sweet corn is a subspecies of *Zea mays*. Compared with common corn, sweet corn carries one or more recessive gene mutations that increase the amount of polysaccharides in the endosperm [1, 2]. As a recently introduced food, sweet corn is commonly consumed as fruits and vegetables, and it is harvested at the immature stage of endosperm development – 20-24 days after pollination [3, 4]. Sweet corn grain has a desirable taste; a unique nutrient composition; and a high-quality phyto-nutrition profile comprising water-soluble phytoglycans, sucrose, fructose, dietary fibre, vitamins, antioxidants and minerals [5]. In addition, sweet corn has advantages of a short production cycle, good market

conditions and high economic benefits. With the economic development and the improvement of people's living standards, the fresh corn industry is developing rapidly. During 2011, global imports of frozen sweet corn were valued at \$393 million, and preserved sweet corn was valued at \$968 million [6]. Countries such as the US, France, Hungary and Thailand are the main export countries of sweet corn products. On the other hand, Japan, Germany, the UK, Spain, the Russian Federation and China are the main import countries of sweet corn, and the demand for sweet corn has displayed a sharp increase in the last few years. From 1998 to 2016, the global sweet corn planting area increased from 66.67 to 147 million hectares, with the total planting area increased by nearly 2.2 times in the past eighteen years [7, 8].

Fresh sweet corn quality involves commercial quality, nutrient quality, end-use quality and edible quality. The commercial quality involves ear shape and size, grain size and uniformity, and pericarp colour, which can be measured by visual observations. The nutrient quality includes the composition and content of sugar, starch, proteins, amino acids, vitamins, and minerals, which can be identified by chemical analysis. The end-use quality mainly consists of grain depth, pericarp thickness, and bract colour, and the edible quality mainly involves waxiness, sweetness, hardness, fragrance and other factors that can be measured by sensory evaluation. The sensory evaluation method is subjective and influenced by cultivation practices, environmental conditions, harvest time and taste personnel preferences. Therefore, it is difficult to ensure the accuracy of the evaluation results and consistency between years [9].

A texture analyser is the main instrument that can evaluate the edible quality objectively. This type of instrument is widely used in the food industry. Its working principle involves simulated mastication through double compressions of a sample. The changes in the positions and weight of samples over time can be measured accurately, and textural properties such as hardness, springiness, adhesiveness, cohesiveness, gumminess, chewiness and resilience can be calculated [10-12]. By constantly exploring correlations between sensory evaluation and texture analysis results, researchers have developed a texture evaluation system. Zhan et al. (2007) proposed that the hardness, viscosity, adhesiveness and springiness from a texture analysis can indirectly reflect the edible quality of rice [13]. Chang et al. (2009) studied the creep properties of four varieties of cooked japonica rice by a dynamic mechanical analyser and found a positive significant relationship between the viscosity coefficient and sensory evaluation ( $r=0.973$ ) [14]. Chauvin et al. (2010) evaluated the relationships between compressive forces, tensile forces and sensory perception of apple and pear harvested in two different years. The texture measurements of apples ( $r = 0.78\sim 0.83$ ) and pears ( $r = 0.83$ ) showed a significant correlation with sensory results for hardness, and tensile data could predict crispness of apples ( $r = 0.88$ ) and pears ( $r = 0.85$ ) [15]. Texture analysis has the following advantages: large application range, convenient operation, and suitability for mass analysis. In this study, we measured the grain textural properties of 51 sweet corn varieties by a texture analyser, and then conducted a principal component analysis (PCA) and cluster analysis. The results of this study provide a theoretical basis for the edible quality evaluation of sweet corn.

## 2. Materials and Methods

### 2.1. Plant Materials and Field Evaluation

A total of 51 sweet corn varieties from 14 provinces were obtained from provincial seed management stations (Table 1). The varieties were planted at the Zhejiang Experimental Station of the Institute of Maize and Featured Upland Crops,

Zhejiang Academy of Agricultural Sciences, China (29.16°N, 120.13°E) in late March of 2020. The soil was a clayey loam and had moderate level of fertility. The soil consisted of approximately 15.4 g/kg organic matter, 1.66 g/kg total nitrogen, 120.6 mg/kg available nitrogen, 7.08 mg/kg available phosphorus and 86.5 mg/kg soil available potassium. The experiment was conducted in accordance with a completely random block design. Artificial bagging pollination was carried out at the flowering stage, and the samples were harvested 21 days after pollination. Planting was performed in two rows per plot, with 15 plants per row; the plants were spaced 28 cm apart, and the row spacing was 67.5 cm. The field management practices were performed according to the conventional requirements.

### 2.2. Sampling Methods

To ensure the consistency of ear growth and grain filling, the 51 sweet corn varieties were subjected to bagging treatments before the silking stage. Artificial self-pollination was then performed in the full-bloom stage. At 21 days after pollination, three ears were harvested in the early morning, and texture profile analysis (TPA) was carried out after cooking.

### 2.3. Test Methods

After removing the bracts, the sweet corn ears were cooked for 20 min in an electric pot. When the temperature of the sweet corn ears was 60°C by natural cooling, eight complete grains from the same vertical row in the middle part of the corn ear were selected for texture profile analysis (TPA). TPA was performed via a TVT-300XP texture analyser, and the parameters were as follows: the probe was a P/36R device; the speed of the probe was 1 mm/s before the test; the speed of the probe was 5 mm/s in the test; the speed of the probe was 5 mm/s after the test; the back embryo side of the grain faced upward, with degree of compression of 90%; the interval time between two compressions was 5 s; and the trigger force was 5 g. The textural properties included hardness, springiness, cohesiveness, adhesiveness, chewiness, resilience and gumminess.

### 2.4. Statistical Analysis

Descriptive statistics, principal component analysis (TPA) and cluster analysis of the textural properties were performed using SPSS 13.0.

## 3. Results

### 3.1. Phenotypic Analysis of Textural Properties of Sweet Corn

The textural properties of the 51 sweet corn varieties showed a wide range of variation (Table 2). Among these textural properties, adhesiveness, chewiness, resilience and gumminess presented a coefficient of variation greater than 30%. Adhesiveness showed the highest coefficient of

variation (52.425%) and ranged from 1.145 to 18.19035.9, with an average of  $6.454 \pm 3.383$ . Resilience and chewiness showed the next highest coefficients of variation (39.713% and 37.849%, respectively) ranged from 0.065 to 0.283 and 202.172 to 871.398, respectively. The high coefficient of variation suggested that there were high degrees of discreteness and large genetic variations for adhesiveness, resilience and chewiness of the 51 sweet corn varieties. Cohesiveness showed the lowest coefficient of variation (14.187%) and ranged from 0.126 to 0.253, with an average of  $0.168 \pm 0.024$ , it suggested that the discrete degree of cohesiveness of the 51 sweet corn varieties was low. In addition, hardness and springiness ranged from 3715.378 g to 7880.488 g and 0.281 to 0.597, respectively.

Phenotypic correlations were analysed between the seven textural properties, and most of them exhibited significant positive correlations with each other ( $p < 0.05$ ; Table 3). Highly significant positive correlations were observed between hardness, gumminess, chewiness and cohesiveness, with phenotypic correlation coefficients ( $r_p$ ) greater than 0.783. Springiness showed a significant positive correlation with chewiness ( $r_p = 0.617$ ), but there was no significant correlation observed between resilience and the other properties. These results suggest that the larger the sweet corn grain hardness and springiness are, the greater the grain chewiness increase, and the greater the sweet corn grain gumminess is, the larger the grain cohesiveness increase.

**Table 1.** Genotypic differences in grain textural properties among 51 sweet corn varieties.

Code	Origin	Variety	Hardness	Springiness	Cohesiveness
1	He Bei	Wan Tian 2015	6108.550	0.471	0.180
2	Bei Jing	Shuang Se Tian 1606	7142.643	0.594	0.183
3	Bei Jing	Si Da Tian 221	6368.714	0.579	0.166
4	Bei Jing	Sheng tian Ai Fei	3893.917	0.454	0.144
5	Shan Dong	SWRB6D05	6539.717	0.594	0.182
6	He Nan	Zheng Tian 66	6424.586	0.363	0.168
7	Hu Bei	Tai Mei Tian Er Hao	5699.500	0.500	0.170
8	Jiang Su	Cui Tian 628	6984.929	0.466	0.197
9	Jiang Su	Jing Tian 14	5066.667	0.413	0.158
10	Shang Hai	He Tian n 3 Hao	5171.307	0.518	0.170
11	Shang Hai	He Li 1 Hao	5702.521	0.595	0.162
12	Shang Hai	Hu Tian 13	6507.371	0.538	0.177
13	Shang Hai	Hu Tian 16	5939.500	0.500	0.170
14	Shang Hai	Shen Ke Tian 516	6467.714	0.591	0.193
15	Shang Hai	Shen Ke Tian 810	5607.167	0.454	0.177
16	Shang Hai	Shen Ke Tian 811	4716.000	0.476	0.142
17	Shang Hai	Bai Mei Ren	4315.429	0.557	0.144
18	Shang Hai	Mei Guo 1 Hao	4098.000	0.428	0.137
19	Shang Hai	Yun Tian 60	4916.188	0.444	0.154
20	Chong Qing	YT710	3793.292	0.404	0.147
21	Si Chuan	Rong Yu Tian Jiu Hao	4505.167	0.389	0.133
22	Si Chuan	Rong Yu Tian Liu Hao	6343.536	0.479	0.157
23	Gui Zhou	Qian Tian 201	5623.813	0.484	0.159
24	Zhe Jiang	Zhe Tian 11	4890.554	0.373	0.156
25	Zhe Jiang	Jin Yu Tian 2 Hao	6052.667	0.597	0.154
26	Zhe Jiang	Pu Tian 1 Hao	5750.017	0.444	0.186
27	Zhe Jiang	Sheng Tian 169	5710.400	0.281	0.167
28	Zhe Jiang	Sheng Tian Bai Zhu	4864.643	0.488	0.155
29	Zhe Jiang	Shu Mei Tian 10 Hao	5477.131	0.380	0.154
30	Zhe Jiang	Zhe Tian 20	6306.383	0.376	0.150
31	Zhe Jiang	Zhe Tian 358	4672.983	0.535	0.159
32	Zhe Jiang	Zhe Tian 67	3715.378	0.473	0.141
33	Zhe Jiang	Zhe Ke Tian 6 Hao	3859.455	0.475	0.130
34	Zhe Jiang	Cui Tian 258	5061.679	0.499	0.136
35	Zhe Jiang	Cui Tian 321	5780.083	0.576	0.168
36	Zhe Jiang	Jin Yin 305	4294.167	0.371	0.126
37	Zhe Jiang	Zhe Tai Tian 928	7167.333	0.526	0.253
38	Fu Jian	Hua Tai Tian 328	5398.844	0.368	0.174
39	Fu Jian	Yong Zhen 7 Hao	6839.798	0.465	0.183
40	Fu Jian	Wan Xian Tian 178	7880.488	0.446	0.203
41	Fu Jian	Hui Tian 192	6623.810	0.523	0.224
42	Guang Dong	Guang Liang Tian 27 Hao	6855.229	0.514	0.187
43	Guang Dong	E Tian 28	6515.500	0.378	0.172
44	Guang Dong	Jiang Tian 018	6299.170	0.453	0.200
45	Guang Xi	Zhong Miao Bai Tian 107	3854.750	0.331	0.148
46	Guang Xi	Hei Shen	7654.000	0.340	0.200
47	Guang Xi	Gui Tian 612	5867.800	0.427	0.167
48	Guang Xi	Gui Tian 568	6329.521	0.478	0.161

Code	Origin	Variety	Hardness	Springiness	Cohesiveness
49	Guang Xi	Gui Tian 569	5792.357	0.315	0.170
50	Guang Xi	Zhong Xian Tian 3 Hao	6222.400	0.329	0.190
51	Guang Xi	Jin Mei Tian 616	5576.729	0.539	0.170

Table 1. Continued.

Code	Origin	Variety	Adhesiveness	Chewiness	Resilience	Gumminess
1	He Bei	Wan Tian 2015	3.159	530.177	0.085	1130.974
2	Bei Jing	Shuang Se Tian 1606	6.493	783.691	0.136	1340.288
3	Bei Jing	Si Da Tian 221	8.469	632.240	0.088	1068.286
4	Bei Jing	Sheng tian Ai Fei	4.500	247.675	0.065	575.521
5	Shan Dong	SWRB6D05	7.133	844.456	0.088	1231.720
6	He Nan	Zheng Tian 66	6.844	414.360	0.093	1090.562
7	Hu Bei	Tai Mei Tian Er Hao	9.209	518.388	0.084	981.058
8	Jiang Su	Cui Tian 628	9.591	648.387	0.121	1426.879
9	Jiang Su	Jing Tian 14	2.556	352.320	0.078	824.254
10	Shang Hai	He Tian n 3 Hao	4.031	453.792	0.094	901.204
11	Shang Hai	He Li 1 Hao	14.902	544.740	0.087	978.220
12	Shang Hai	Hu Tian 13	8.094	750.555	0.283	1199.863
13	Shang Hai	Hu Tian 16	6.284	523.538	0.162	1020.720
14	Shang Hai	Shen Ke Tian 516	7.616	744.845	0.126	1283.040
15	Shang Hai	Shen Ke Tian 810	1.632	425.700	0.085	1050.771
16	Shang Hai	Shen Ke Tian 811	6.319	328.446	0.139	675.387
17	Shang Hai	Bai Mei Ren	10.984	368.862	0.092	654.856
18	Shang Hai	Mei Guo 1 Hao	5.965	230.635	0.244	565.449
19	Shang Hai	Yun Tian 60	4.746	348.393	0.221	768.793
20	Chong Qing	YT710	3.800	208.945	0.072	575.437
21	Si Chuan	Rong Yu Tian Jiu Hao	2.234	248.970	0.076	620.423
22	Si Chuan	Rong Yu Tian Liu Hao	6.808	486.848	0.108	1020.451
23	Gui Zhou	Qian Tian 201	5.669	447.251	0.157	898.722
24	Zhe Jiang	Zhe Tian 11	3.348	304.116	0.077	769.669
25	Zhe Jiang	Jin Yu Tian 2 Hao	12.019	571.119	0.092	936.487
26	Zhe Jiang	Pu Tian 1 Hao	1.741	496.224	0.095	1076.093
27	Zhe Jiang	Sheng Tian 169	9.147	279.259	0.100	961.907
28	Zhe Jiang	Sheng Tian Bai Zhu	7.719	355.124	0.074	820.023
29	Zhe Jiang	Shu Mei Tian 10 Hao	5.527	324.155	0.109	865.210
30	Zhe Jiang	Zhe Tian 20	9.142	375.454	0.072	951.842
31	Zhe Jiang	Zhe Tian 358	4.730	382.151	0.073	747.046
32	Zhe Jiang	Zhe Tian 67	4.074	282.583	0.104	544.827
33	Zhe Jiang	Zhe Ke Tian 6 Hao	2.238	252.697	0.087	506.212
34	Zhe Jiang	Cui Tian 258	3.407	331.877	0.177	696.543
35	Zhe Jiang	Cui Tian 321	7.838	587.449	0.110	985.530
36	Zhe Jiang	Jin Yin 305	4.673	202.172	0.086	548.599
37	Zhe Jiang	Zhe Tai Tian 928	1.145	871.398	0.136	1814.431
38	Fu Jian	Hua Tai Tian 328	5.020	350.102	0.181	983.042
39	Fu Jian	Yong Zhen 7 Hao	6.656	580.419	0.116	1280.172
40	Fu Jian	Wan Xian Tian 178	18.190	739.427	0.116	1635.538
41	Fu Jian	Hui Tian 192	3.083	763.709	0.129	1497.976
42	Guang Dong	Guang Liang Tian 27 Hao	8.437	622.655	0.129	1316.172
43	Guang Dong	E Tian 28	1.546	424.978	0.094	1127.074
44	Guang Dong	Jiang Tian 018	9.412	562.111	0.101	1276.701
45	Guang Xi	Zhong Miao Bai Tian 107	6.313	222.261	0.069	580.906
46	Guang Xi	Hei Shen	9.549	583.199	0.100	1577.265
47	Guang Xi	Gui Tian 612	4.143	425.214	0.108	979.891
48	Guang Xi	Gui Tian 568	9.146	533.337	0.092	1040.357
49	Guang Xi	Gui Tian 569	10.299	319.581	0.087	1021.100
50	Guang Xi	Zhong Xian Tian 3 Hao	7.274	404.308	0.103	1215.999
51	Guang Xi	Jin Mei Tian 616	7.713	513.930	0.098	965.882

**Table 2.** Statistical analysis of textural properties of the grain of 51 sweet corn varieties.

Trait	Mean	Max.	Min.	Range	SD	CV (%)
Hardness	5666.314	7880.488	3715.378	4165.110	1034.024	18.249
Springiness	0.461	0.597	0.281	0.316	0.082	17.822
Cohesiveness	0.168	0.253	0.126	0.127	0.024	14.187
Adhesiveness	6.454	18.190	1.145	17.045	3.383	52.425
Chewiness	463.352	871.398	202.172	669.226	175.375	37.849
Resilience	0.113	0.283	0.065	0.218	0.045	39.713
Gumminess	992.085	1814.431	506.212	1308.219	300.306	30.270

SD Standard deviation, CV (%) Coefficient of variation (%)

**Table 3.** Correlation analysis of textural properties of 51 sweet corn varieties.

Trait	Hardness	Springiness	Cohesiveness	Adhesiveness	Chewiness	Resilience	Gumminess
Hardness	1.000						
Springiness	0.176	1.000					
Cohesiveness	0.783**	0.154	1.000				
Adhesiveness	0.388**	0.178	0.110	1.000			
Chewiness	0.824**	0.617**	0.787**	0.303*	1.000		
Resilience	0.113	0.107	0.102	-0.025	0.175	1.000	
Gumminess	0.942**	0.176	0.939**	0.283*	0.857**	0.118	1.000

\* Significant at  $P < 0.05$ , \*\* Significant at  $P < 0.01$

### 3.2. Principal Component Analysis of Grain Textural Properties of Sweet Corn

Principal component analysis (PCA) is a kind of statistical method that is used to reduce multidimensional data to fewer dimensions while retaining most of the information [16]. PCA was performed to study the grain textural properties of sweet corn. The eigenvalues and contributions of the principal components are shown in Table 4. There are three principal components (PCs) with eigenvalues greater than 1.0, and their eigenvalues are 3.826, 1.107 and 1.032. The cumulative contribution rate of the first three principal components to the total variance is 85.206%, which means that the first three principal components represent more than 80% of the information of all grain textural properties of the sweet corn.

After the standardization of the initial data, the principal component scores of the first three principal components could be obtained (Table 5). The first principal component (PC. 1) could be calculated with the formula  $Y_1 =$

$0.384 \cdot X_1 - 0.166 \cdot X_2 + 0.323 \cdot X_3 - 0.031 \cdot X_4 + 0.165 \cdot X_5 - 0.002 \cdot X_6 + 0.319 \cdot X_7$ , it explained 54.656% of the total variance. The representative variables of the first principal component included hardness, cohesiveness and gumminess, which displayed significantly positive correlations with each other. The first principal component mostly reflected the grain hardness of sweet corn during taste. The second principal component (PC. 2) could be calculated with the formula  $Y_2 = -0.062 \cdot X_1 + 0.735 \cdot X_2 - 0.201 \cdot X_3 + 0.373 \cdot X_4 + 0.365 \cdot X_5 + 0.129 \cdot X_6 - 0.131 \cdot X_7$  and represented 15.814% of the total variance; the representative variables were springiness, adhesiveness and chewiness. The second principal component mostly reflected the grain springiness of sweet corn. The formula of the third principal component (PC. 3) is  $Y_3 = -0.095 \cdot X_1 + 0.107 \cdot X_2 + 0.080 \cdot X_3 - 0.555 \cdot X_4 + 0.065 \cdot X_5 + 0.791 \cdot X_6 - 0.014 \cdot X_7$ . The third principal component mainly represented the grain resilience of sweet corn and explained 14.737% of the total variance. These results suggested that the hardness, springiness and resilience were important textural properties for evaluating the edible quality of sweet corn.

**Table 4.** Eigenvalues and contribution percentages of the principal components.

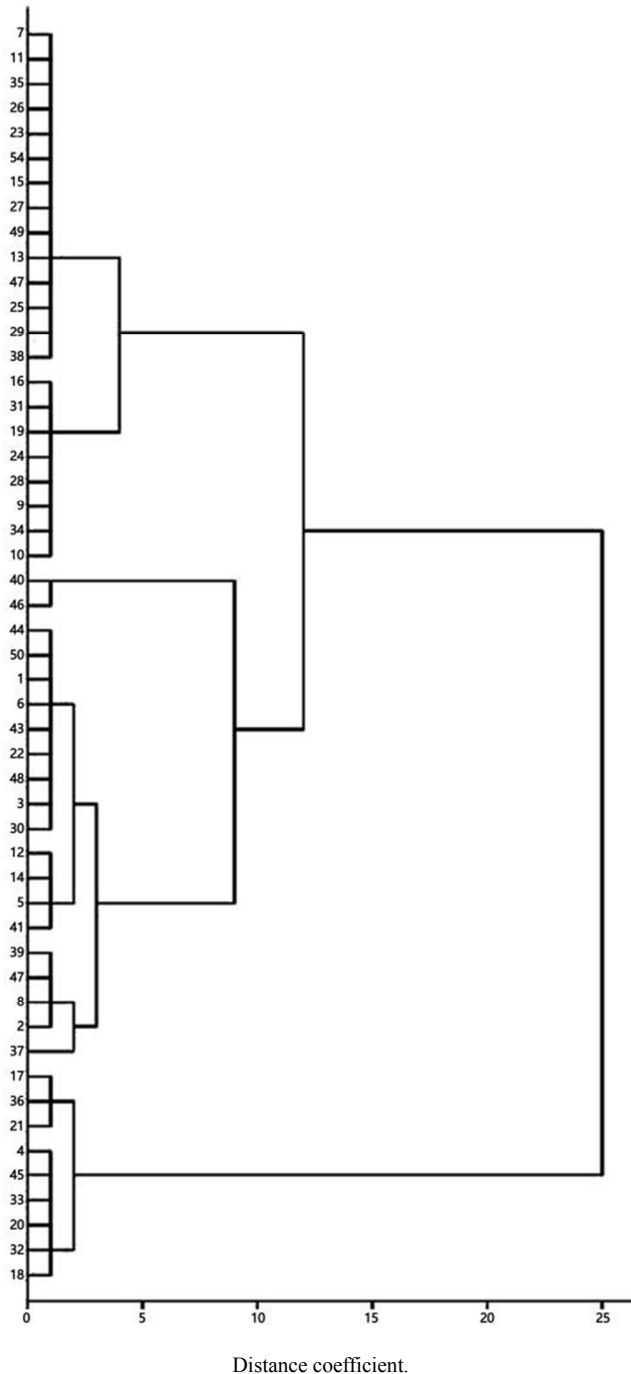
Principal components	Eigenvalue	Contribution percentage of the variance (%)	Cumulative contribution percentage of the variance (%)
1	3.826	54.656	54.656
2	1.107	15.814	70.469
3	1.032	14.737	85.206
4	0.836	11.941	97.147
5	0.167	2.386	99.533
6	0.028	0.401	99.934
7	0.005	0.066	100.000

**Table 5.** Principal component scores after standardization.

Trait	PC. 1	PC. 2	PC. 3
Hardness	0.384	-0.062	-0.095
Springiness	-0.166	0.735	0.107
Cohesiveness	0.323	-0.201	0.080
Adhesiveness	-0.031	0.373	-0.555
Chewiness	0.165	0.365	0.065

Trait	PC. 1	PC. 2	PC. 3
Resilience	-0.002	0.129	0.791
Gumminess	0.319	-0.131	-0.014

### 3.3. Cluster Analysis of Grain Textural Properties of Sweet Corn



**Figure 1.** Clustering analysis of 51 sweet corn varieties based on textural properties.

Cluster analysis is a nonparametric statistical method that classifies groups based on the degree of similarity of samples. On the basis of PCA, cluster analysis is carried out by using the unweighted pair group method of arithmetic mean

(UPGMA). The similarity of the varieties was displayed by the euclidean distances between them (Figure 1). According to the key variable hardness of PC. 1, the 51 sweet corn varieties could be divided into two groups with a euclidean distance of 25. Group 1 includes forty-four varieties with a high average hardness of approximately 6021.903 g. Group 2 contained only seven varieties, whose average hardness was 4036.617 g. At a euclidean distance of 8.84, group 1 could be further classified into three subgroups on the basis of springiness and resilience. Subgroup 1 contained twenty-two varieties: 9 varieties from Zhejiang, 6 varieties from Shanghai, 3 varieties from Guangxi, 1 variety from Jiangsu, 1 variety from Fujian, 1 variety from Hubei, and 1 variety from Guangzhou. All the varieties of subgroup 1 had high hardness, medium springiness and medium resilience. Subgroup 2 included only two varieties: Wan Xian Tian 178 from Fujian and Hei Shen from Guangxi. These varieties have characteristics that include high hardness, low springiness and resilience. Subgroup 3 comprised twenty varieties that mainly originated from provinces such as Guangdong, Zhejiang, Guangxi, and Fujian. All the varieties of subgroup 3 had high hardness, high springiness and high resilience.

## 4. Discussion

A texture analyser is a kind of instrument that can quickly, scientifically and objectively evaluate the textural properties of food. A large number of studies have confirmed that a texture analyser-based evaluation is a good supplement and substitute for sensory evaluations [17, 18]. Texture analysers have been applied extensively in the agriculture and food industries [19, 20]. However, there are few studies on the textural properties of sweet corn. Sun et al. determined the optimum test conditions of the textural properties of ready-to-eat corn with a texture analyser and established a prediction model of sensory evaluation that could explain 69.7%~98.7% of the total variation [21]. Lu et al calculated the TPA comprehensive evaluation (D) values of seven sweet corn varieties at different harvest times; there was a significant difference between sweet corn varieties, and an increasing D value could be observed with the delay of harvest time [22]. Significant differences in textural properties were also observed between 91 waxy corn varieties. For these textural properties, the CV of adhesiveness was the highest, and the CV of cohesiveness was the lowest [23]. In this study, the CV of adhesiveness was 52.425%, and the CV of cohesiveness was 14.187%, which was consistent with the results of previous studies.

The quality of fresh corn mainly involves the edible quality, commercial quality, end-use quality and nutrition quality, among which the edible quality is the key of the quality evaluation standard of fresh corn. The application of texture analysers in the evaluation of edible quality is very

important for the quality improvement of fresh corn. In a previous study, 40 sweet corn varieties were investigated via texture analysis, and the variation ranges of hardness, springiness and resilience were 5075.86~9847.38 g, 0.28~0.47 and 0.13~0.23, respectively, their average values were 7175.67 g, 0.37 and 0.18 [24]. In our study, the variation ranges of hardness, springiness and resilience were 3715.378~7880.488 g, 0.281~0.597 and 0.065~0.283, respectively; the average values were 5666.314 g, 0.461 and 0.113. It suggested that there was greater genetic variation for springiness and resilience of the 51 sweet corn varieties, compared with the previous study, and many new sweet corn varieties which had low hardness, high springiness and low resilience could be found in this study. These results were consistent with the improving targets of low-hardness breeding in sweet corn.

## 5. Conclusion

In this study, there were significant positive correlations between the majority of textural properties. The phenotypic correlation coefficient (*rp*) ranged from 0.283 to 0.942. According to PCA, there were three principal components (PCs) with eigenvalues greater than 1.0. The cumulative contribution percentage of the first three principal components to the total variance was 85.206%. Hardness, springiness and resilience were important textural properties for evaluating the edible quality of sweet corn. Via cluster analysis, 51 sweet corn varieties were classified into 2 groups according to the values of hardness, and group 1 was further classified into 3 subgroups based on the values of springiness and resilience. The results of this study provide useful information for improving the edible quality of sweet corn.

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