Research Article

Evaluation of Edible Quality of Sorghum Based on Principal Component Analysis

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Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important cereals in the Northeast China. The physicochemical, pasting, texture, and cooking properties of 21 sorghum varieties were determined, which were mainly cultivated in Northeast China. Then, the evaluation of edible quality of sorghum was based on principal component analysis and fitted with the score of sensory evaluation. Five principal components (PCs) with a cumulative contribution rate of 86.19% could be picked out to describe the taste, pasting, flavor, cooking, and variety of sorghum, respectively. And a comprehensive equation of sorghum edible quality in Northeast China was constructed which was $Z = 0.45F_1 + 0.25F_2 + 0.12F_3 + 0.10F_4 + 0.08F_5$. The edible quality of No. 14 and No. 15 was the best. The sensory evaluation was used to verify the above equation with the fitting coefficient of 0.81, which indicated that the equation could be more accurate to evaluate the edible quality of sorghum in Northeast China.

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most produced cereal after wheat, rice, maize, and barley [1, 2] and is drought tolerant, resistant to water logging, and grows in various soil conditions [3]. In recent years, sorghum cultivation has been concentrated in Northeast China, and the yield accounted for 62% of the National Sorghum Yield in 2016 (data source: Department of Market and Economic Information, Ministry of Agriculture, China). Because sorghum is rich in starch and protein, it can be regarded as a substitute for the common cereals such as rice, wheat, millet, and soybean. The consumption of whole sorghum grains would contribute toward health benefits through bioactive compounds such as fiber and phenolics [4]. In Western countries such as the United States, Australia, and Brazil, sorghum is developed and cultivated primarily for animal feeding, while in semiarid regions of the world, it is mainly used in human feeding as coarse grains [5–7]. In China, the history of Kaoliang Spirit has been more than 2500 years [8]. With the short of pure water resources, sorghum which is an

ecologically friendly and tolerant crop will become an important crop in the future. As sorghum is one of the three main grains in China, how to evaluate its edible quality scientifically and realize its value better is a question worthy of in-depth study.

Nowadays, the evaluation of the edible quality of cereals is mainly focused on the fine grains such as rice and wheat. Evaluation methods include sensory evaluation and instrumental analysis. Sensory evaluation was affected by the regional eating habits, environment of the participants, and difficulty in quantitatively describing the food taste [9]. Some scholars have made comprehensive analysis of cereal quality by means of instrument and physicochemical characteristics that include the texture tester and the rapid viscosity analyser (RVA). The hardness and stickiness in the texture characteristics can be used to evaluate the softness and looseness of rice, while the pasting temperature and setback viscosity of gelatinized flour starch pastes can be used to evaluate the cooking time and the texture of meal [10, 11]. Based on the analysis of the correlation among the gelatinization properties, texture properties, and sensory

evaluation of cereals, a method for predicting the texture of rice can be established [12]. In addition, physicochemical components are often used to analyse the quality of rice taste. The composition content and structure of starch were the important factors of edible quality, while protein, moisture, and ash content were significantly correlated with taste, appearance, and comprehensive score of rice [13–15]. Literature review shows the varieties of rice with better taste quality had a shorter cooking time, higher iodine blue value, and lower water absorption [16]. So far, principal component analysis, cluster analysis, and discriminant analysis are the main methods used in the comprehensive analysis of cereals. However, principal component analysis is the most commonly method for cereal quality evaluation.

Principal component analysis (PCA) is an analytical method for transforming multiple indexes into fewer new ones [17]. PCA combined with the determination of cereal quality characteristics can simplify the cereal quality index into several principal components with a cumulative contribution rate of more than 80% and then analysed the edible quality of cereals to study the effects of physicochemical components and quality characteristics of cereals on edible quality [18, 19]. The principal component analysis (PCA) was used to study the edible quality of rice, the suitable processability of sweet waxy corn, and the physical properties and processing characteristics of oat grains [18, 20, 21]. Besides, it can be used to establish the evaluation model of edible quality which included Indica rice cake, Japonica rice, and Indica rice [22–24]. There are relatively few studies on the evaluation of sorghum edible quality.

The aim of the paper was to evaluate the edible quality of sorghum. 21 sorghum varieties which were mainly cultivated in Northeast China were selected to analyse their physicochemical, pasting, texture, and cooking properties and edible quality. Then, the properties of sorghum were analysed by PCA, and the evaluation equation was obtained. Finally, the equation was fitted with the score of sensory evaluation. The results showed it was more intuitive and objective and provided a theoretical basis for the edible quality of sorghum.

2. Materials and Methods

2.1. Materials. Nos. 1–13 sorghum (*Sorghum bicolor* (L.) Moench) varieties were provided by Jilin Academy of Agricultural Sciences (Jilin province, China), which were Z1001—Z1013. Nos. 14–21 were provided by Heilongjiang Academy of Agricultural Sciences (Heilongjiang Province, China), which were 16-5071, 16-5072, Dragon Miscellaneous 17, Dragon Miscellaneous 18, Dragon Miscellaneous 16, Dragon Glutinous 13-2, Dragon Rice Grain 2, and Dragon Rice Grain 1. All chemicals were analytical grade reagents.

2.2. Proximate Analysis. Moisture content was determined according to the procedure in AACC (44-19,2000). Ash content was determined by dry ashing in a furnace oven at 550°C (AACC 8-01,2000). The crude protein was calculated by converting the nitrogen content determined by the

Kjeldahl method ($N \times 6.25$) (AACC 46-12,2000). Crude lipid, using a Soxhlet apparatus (AACC 30-25,2000), was also determined. Starch content was determined according to the procedure in AACC (76.13.2000). Tannin content was determined referring to the method of Maxson by spectrophotometry [25].

2.3. RVA Pasting Properties. Sorghum pasting properties were determined using a Rapid Visco Analyser (RVA, Super3, Newport Scientific, Warriewood, Australia). Flour (3.00 g, based on 12% moisture) was mixed with 25 g of distilled water in an RVA sample canister. The RVA was run using Thermocline for Windows software (Version 1.2). The Rice Method 1 program was used with heating and cooling cycle set as follows: (1) holding at 50°C for 1 min, (2) heated to 95°C in 3.8 min, (3) holding at 95°C for 2.5 min, (4) cooling to 50°C in 3.8 min, and (5) holding at 50°C in 1.4 min. The pasting temperature (PT), peak viscosity (PV), breakdown (BD), and setback (SB) were recorded from the Thermocline for Windows software (Version 1.2) [26].

2.4. Cooking Characteristics

2.4.1. Preparation of Sorghum Rice. Experiments were conducted with an automatic rice cooker (CFXB4003-A1, 4.0 L, 700 W, 220 V, 50 Hz, Guangzhou domestic appliance Ltd., China). 1000 g sorghum rice was soaked in a pot for 30 min with 1500 mL of tap water. After the sorghum rice cooked for 40 min, the thermostat coupled with microswitch automatically switched off the automatic rice cooker. The cooked sorghum rice samples were held in the rice cooker for an additional 20 min. Finally, the cooked sorghum rice was obtained.

2.4.2. Water Absorption Rate. The sorghum sample of a certain mass was weighed and recorded as M_1 , which was placed in a beaker. Then, a certain volume of distilled water was added, cooked in a boiling water bath for 20 minutes, and finally cooled to room temperature, and the weight of M_2 was recorded. The calculation formula is as follows [27]:

$$\text{Water absorption rate (\%)} = \frac{M_2}{M_1} \times 100\%. \quad (1)$$

2.4.3. Volume Expansion Ratio. The volume of sorghum rice sample before and after cooking was measured by the drainage method, as described in [16]. The sample of sorghum rice of certain mass was poured into the measuring cylinder that contains 50 mL distilled water, and the volume V_1 was recorded. Then, the sorghum rice sample was cooked in a boiling water bath for 20 minutes. After cooking, the sample was poured into the same measuring cylinder as above, and the volume V_2 was recorded. The formula is as follows:

$$\text{Volume Expansion ratio} = \frac{V_2 - 50}{V_1 - 50} \times 100\%. \quad (2)$$

2.4.4. Iodine Blue Value. The rice soup was cooled to room temperature and diluted to 100 mL. After [27] centrifugation (Allegra X-30R Multifunctional Centrifuge, American Beckman Coulter, USA), 1.0 mL rice soup was added to 50 mL distilled water and then 5 mL of 0.5 mol/L HCl solution and 1 mL of 0.2 g/100 mL of iodine reagent were added; finally, the volume was adjusted to 100 mL. The absorbance was measured at a wavelength of 660 nm by Ultraviolet visible spectrophotometer (UVmini-1240, Shimadzu Co., Ltd, Japan). The iodine blue value of rice soup is expressed by absorbance [28].

2.5. Textural Profile Analysis. Textural profile analysis (TPA) of the cooked sorghum rice was performed using a texture analyser (TA.XT.plus, Texture Technologies Corp., UK). The hardness, stickiness, adhesiveness, chewiness, and responsiveness were determined. The texture was determined according to the method of Yu et al. [29] with minor modifications. The texture analyser was linked to a computer that recorded the data via a software program called Texture Expert Excede Version 1.0 (Stable Micro Systems Software). The P50 probe was used to compress 3 sorghum rice grains, under the compression distance of 1.4 mm and the trigger point force of 10.0 g, with pretest speed, test speed, and posttest speed of 10.0 mm/s, 0.5 mm/s, and 5.0 mm/s, respectively. All textural analyses were replicated six times per sample, and the results are presented as mean values.

2.6. Sensory Evaluation. The sensory analysis of the cooked sorghum rice was carried out in laboratory conditions. Sensory assessments were determined by 20 trained panelists (staff aged from 30 to 40 years old and graduate students aged from 20 to 30 years old): ten females and ten males. The evaluation was carried out using the 100-point scale test with the distinctions of quality (smell, appearance, taste, texture, and acceptability) [30, 31], and the results are shown in Table 1. In the process of sensory quality evaluation, 4 servings of sorghum rice were tasted each time, and the evaluation time was arranged 1 hour before and 2 hours after meal. The average value of each evaluator was calculated as the comprehensive evaluation value of sorghum rice, and the edible quality of sorghum was measured.

2.7. Principal Component Analysis. Principal component analysis (PCA) converts observations of correlated variables into a set of linearly uncorrelated orthogonal variables (principal components, PCs), ordered in such a way that each PC has the largest possible variance under the constraint of being orthogonal to all preceding components [32].

The p variables of n samples ($X_1, X_2, \dots, X_p$) was transformed into k ($k < p$) complex variables ($F_1, F_2, \dots, F_k$), which was the linear combination of original variables. Comprehensive variables $F_1, F_2, \dots, F_k$ were called the first, second, $\dots$, the k_{th} PC of the original variable, respectively:

$$\begin{aligned} F_1 &= a_{11}X_1 + a_{21}X_2 + \dots + a_{p1}X_p \\ F_2 &= a_{12}X_1 + a_{22}X_2 + \dots + a_{p2}X_p \\ &\dots \\ F_k &= a_{1k}X_1 + a_{2k}X_2 + \dots + a_{pk}X_p. \end{aligned} \quad (3)$$

The quantized values of each sample are weighted by the ratio β_i ($i = 1, 2, \dots, k$) of the k PCs of different eigenvalues, and the comprehensive evaluation function: $Z = \beta_1F_1 + \beta_2F_2 + \dots + \beta_kF_k$ was used to calculate the scores of sorghum rice samples [33].

2.8. Statistical Analysis. SPSS software (Version 17.0, SPSS Inc., Chicago, USA) was used to analyse the data. The means were compared using Pearson's test at a 5% level of significance using the analysis of variance (ANOVA). Analyses of the samples were completed in triplicate, and the data were expressed as the mean $\pm$ standard deviation.

3. Results and Discussion

3.1. Proximate Analysis of Sorghum. There were significant differences in physicochemical components among different sorghum grain varieties ($P < 0.05$), as shown in Table 2. Starch and protein were the main components of sorghum grains and played an extremely important role in the cooking process. The starch content of 21 sorghum varieties ranged from 68.15% to 79.39%, with an average content of 73.24%, which was lower than the average starch content in other cereals (78% of rice and 75% of corn) [34]. The protein content varied from 6.75% to 11.23%. Most of them were higher than 8.25% except for No. 2 and Nos. 18–21. The result showed there were regional differences of the starch content and protein content, and sorghum planted in Heilongjiang are generally lower than those in Jilin. Therefore, the difference in starch and protein content among different varieties may be one of the main factors causing the difference in taste quality [35].

The moisture and tannin in sorghum were 9.46%~14.42% and 0.00%~0.12%, respectively. Water can bind to macromolecules such as protein and starch, which has an important effect on starch gelatinization and edible quality of cereals. Especially, the content of tannin in No. 13 was 0, which may have a positive effect on the good taste quality of sorghum rice. The range of the oil content was 1.30%~3.93%, with the highest content in No. 15 Sorghum of 3.93%, which was much higher than that in rice (0.24%~0.67%). The oil in sorghum can improve the edible quality of rice and give the special flavor of rice. However, the oil forms the complex with starch, which inhibits the gelatinization of starch and affects the taste quality of rice [36].

3.2. Pasting Properties. The significant differences in pasting properties among different varieties are shown in Table 2 ($P < 0.05$). Gelatinization is one of the physicochemical properties of starch, and it is an important indicator to de-

TABLE 1: The sensory evaluation of sorghum rice.

Variety	Smell (20)	Color (7)	Appearance (20) Glossiness (8)	Rice grain integrity (5)	Stickiness (10)	Acceptability (30) Elasticity (10)	Soft and hard degree (10)	Taste (25)	Texture (5)	Score (100)
1	14.00	5.50	5.00	4.50	5.50	5.00	6.50	18.00	3.80	67.80
2	16.20	5.65	6.50	3.30	6.00	6.00	7.50	18.00	3.80	72.95
3	15.00	5.00	5.25	4.25	5.40	4.50	6.50	17.50	3.50	66.90
4	16.40	4.50	6.80	3.60	5.60	4.50	6.20	18.00	3.00	68.60
5	16.50	5.00	4.80	4.30	5.50	5.00	7.20	17.00	3.75	69.05
6	13.60	4.50	5.80	3.20	5.75	4.00	6.30	19.00	3.50	65.65
7	13.65	3.80	5.75	3.50	6.80	5.50	7.20	18.00	3.50	67.70
8	13.80	6.00	5.75	3.00	6.50	4.50	6.50	18.00	3.50	67.55
9	15.00	4.50	5.00	3.50	5.80	5.50	6.00	17.50	4.00	66.80
10	16.40	5.60	5.25	4.25	4.50	5.00	5.80	18.00	3.35	68.15
11	15.00	4.50	5.30	3.30	4.20	5.50	6.50	16.50	3.90	64.70
12	15.00	5.00	5.40	3.40	4.00	5.50	6.50	16.50	3.50	64.80
13	16.70	6.80	5.60	4.30	3.80	3.00	6.20	17.00	2.85	66.25
14	15.00	4.50	7.00	4.80	8.20	6.50	8.50	20.00	4.50	79.00
15	17.00	4.50	7.00	4.80	8.25	7.00	8.20	21.00	4.50	82.25
16	16.50	5.00	6.50	4.30	6.00	6.00	7.50	18.50	3.75	74.05
17	15.00	5.85	5.30	3.80	6.00	4.75	6.50	17.00	3.50	67.70
18	14.00	6.20	7.00	2.80	5.80	4.00	8.00	16.50	3.80	68.10
19	14.60	4.00	6.80	4.30	8.30	6.00	7.25	19.00	4.85	75.10
20	14.50	6.70	6.50	3.40	7.80	7.00	8.75	18.00	4.50	77.15
21	14.50	6.60	5.70	4.00	7.50	5.50	7.50	20.00	3.50	74.80

termine the cooking quality and edible quality of rice. The PT of 21 sorghum varieties ranged from 71.1°C to 80.7°C, and the PT of sorghum from Jilin (74.8°C~80.7°C) was significantly higher than that of Heilongjiang (71.1°C~74.4°C) ($P < 0.05$), which indicated that sorghum from Jilin was not easy to gelatinize. Compared to the analysis of protein content in different sorghum varieties, the protein content of sorghum planted in Jilin was generally high, which was consistent with the results of Chandrashekar and Kirleis [37] that higher protein content would inhibit gelatinization of sorghum starch [37, 38].

The PV of 21 sorghum varieties was concentrated in the range of 3000~4000 cP, while the PV of sorghum varieties Nos. 14, 15, and 19 from Heilongjiang was 2491 cP, 2691 cP, and 2498 cP, respectively, which were much lower than that of other varieties. The results indicated that the starch granules of the three varieties were easy to expand during cooking and gelatinization and easy to be softened and break during the thickening process [39].

The BD is a measure of the difficulty of particle structure disintegration in the heating process of starch [40]. The BD varied from 539 cP to 2918 cP, which indicated that the effect of starch on the taste quality of sorghum was different. The SB of different varieties varied widely, ranging from 387 to 2061 cP. The SB of sorghum varieties Nos. 14, 15, and 19 was 387 cP, 422 cP, and 627 cP, respectively, while the SB of other sorghum varieties was above 1500 cP. This may be related to the starch content; that is, the varieties with a lower amylose content have lower SB. After cooking and gelatinization, the aging rate of starch is slower, and the taste quality of rice is better [29].

3.3. Cooking Characteristics. The significant differences in volume expansion ratio, water absorption rate, and iodide

blue value among different varieties ($P < 0.05$) are shown in Figure 1. It can be seen from Figures 1(a) and 1(b) that the volume expansion ratio and the water absorption rate of Nos. 4, 8, 9, and 12 were 270.85%, 276.23%, 288.23%, and 279.28% and 242.95%, 242.19%, 241.86%, and 236.52%, respectively, which were significantly higher than other varieties ($P < 0.05$). The water absorption rate and the volume expansion ratio of rice grains were the important indicators of cooking characteristics. And the bigger the grains are, the higher the fluffy quality of rice is; more likely, it was that rice grains appear to explode [15]. So that the acceptability of Nos. 4, 8, 9, and 12 with high water absorption rate and volume expansion ratio may be poor (Table 1). It could be seen from Figure 1(c) that the iodine blue value of sorghum ranged from 0.071 to 1.561, and most of the varieties were concentrated in the range of 0.650 to 0.850. However, the iodine blue value of Nos. 14, 15, 19, 20, and 21 in Heilongjiang was 0.122, 0.123, 0.297, 0.161, and 0.071, respectively, which were significantly lower than those of other varieties ($P < 0.05$). At the same time, compared with Table 3, it was found that the PV and SB of Nos. 14, 15, and 19 with a lower iodine blue value were also significantly lower than other sorghum varieties ($P < 0.05$). It indicated that the starch granules of these varieties were easily to be broken, easy to gelatinize, and not easy to regenerate during the cooking process and with better edible quality. Some studies have shown that the cooking quality of sorghum was mainly affected by the composition and gelation of starch. The gelation humidity of amylose is high, so that the water absorption and the expansion rate was large, which led to the dryness of cooked rice. Meanwhile, the more the amylose content, the more the starch content dissolved in the cooking process, resulting in the larger iodine blue value of

TABLE 2: Physicochemical components, pasting properties, and textural properties of sorghum.

Variety	Moisture (%)	Protein (%)	Starch (%)	Oil (%)	Tannin (%)	Ash (%)	PT (°C)	PV (cP)	BD (cP)	SB (cP)	Hardness (g)	Stickiness (gm ⁻¹)	Adhesiveness	Chewiness	Responsiveness
1	10.05 ± 0.034klm	8.28 ± 0.230gh	70.81 ± 1.136abc	1.83 ± 0.135efgh	0.049 ± 0.005cdef	0.53 ± 0.075efg	75.7 ± 0.26def	3749 ± 33.56d	1451 ± 13.05cde	1875 ± 20.66b	429.770 ± 55.52ghij	-10.174 ± 0.157a	266.177 ± 37.68efgh	258.076 ± 41.87defgh	0.365 ± 0.030cd
2	11.19 ± 0.076ce	6.75 ± 0.114k	69.49 ± 0.929bc	2.25 ± 0.250cde	0.038 ± 0.006efgh	0.44 ± 0.047gh	75.2 ± 0.23efg	3801 ± 86.32d	1462 ± 67.73cd	1770 ± 50.51bcde	386.419 ± 57.27ghij	-1.497 ± 0.371a	229.890 ± 29.32efgh	211.348 ± 29.90efgh	0.353 ± 0.010cd
3	10.61 ± 0.064gh	9.80 ± 0.161c	72.86 ± 1.872abc	1.84 ± 0.207dgh	0.053 ± 0.007cde	0.81 ± 0.040ab	76.0 ± 0.15def	3059 ± 22.65gh	1151 ± 23.50efgh	1651 ± 63.13efgh	529.797 ± 31.45defghij	-0.796 ± 0.559a	368.286 ± 19.25bcde	313.355 ± 20.22cde	0.450 ± 0.025abc
4	10.75 ± 0.033fg	9.39 ± 0.108cd	77.21 ± 0.925abc	2.58 ± 0.183bc	0.058 ± 0.004c	0.7 ± 0.032bcd	76.7 ± 0.32cde	3135 ± 35.92d	1093 ± 15.01ghij	1744 ± 12.53cdef	689.326 ± 38.83bcd	-0.644 ± 0.372a	482.189 ± 27.29bc	440.334 ± 15.82abc	0.469 ± 0.017ab
5	10.38 ± 0.122hij	8.97 ± 0.014def	71.36 ± 5.129abc	2.23 ± 0.212cde	0.088 ± 0.006b	0.85 ± 0.069a	74.8 ± 0.10ghi	3462 ± 30.51ef	1269 ± 50.30efg	1843 ± 4.04bc	455.143 ± 147.17fghij	-0.334 ± 0.102a	322.299 ± 99.77defg	267.377 ± 92.46defg	0.479 ± 0.046a
6	10.16 ± 0.074ijk	9.08 ± 0.049de	76.8 ± 3.286abc	1.63 ± 0.043ghi	0.046 ± 0.004cdefg	0.52 ± 0.051fg	76.2 ± 0.60def	3490 ± 50.48e	1331 ± 101.53def	1699 ± 63.63defg	710.490 ± 55.29bcd	-3.907 ± 0.717a	444.294 ± 77.57bcd	348.042 ± 69.33bcd	0.377 ± 0.059bcd
7	9.88 ± 0.103klm	8.79 ± 0.2ef	75.27 ± 1.964abc	1.87 ± 0.066efgh	0.056 ± 0.002cd	0.52 ± 0.026efg	75.6 ± 0.36efg	3440 ± 32.25ef	1208 ± 34.65efgh	1734 ± 13.45cdef	330.941 ± 32.34ij	-0.662 ± 0.403a	201.869 ± 3.61gh	165.963 ± 6.08gh	0.379 ± 0.030bcd
8	12.19 ± 0.041c	9.07 ± 0.019de	76.7 ± 2.347abc	2.12 ± 0.114def	0.042 ± 0.006defg	0.44 ± 0.048gh	76.5 ± 0.1de	3424 ± 59.48ef	1023 ± 29.57ijkl	1747 ± 32.56cdef	517.364 ± 43.95defghij	-12.019 ± 0.190a	331.832 ± 21.25defg	316.207 ± 24.07cde	0.392 ± 0.037abcd
9	9.77 ± 0.050lmn	10.35 ± 0.135b	74.79 ± 0.857abc	1.30 ± 0.089i	0.057 ± 0.008cd	0.68 ± 0.034cd	78.2 ± 0.87b	2997 ± 35.44gh	941 ± 117.75ijkl	1751 ± 34.59bcddef	780.384 ± 11.04b	-1.004 ± 0.402a	502.311 ± 26.55ab	459.876 ± 12.35ab	0.408 ± 0.011abcd
10	10.10 ± 0.097kl	10.4 ± 0.147b	74.15 ± 1.584abc	2.35 ± 0.110bcd	0.006 ± 0.001j	0.32 ± 0.020hi	78.1 ± 0.15b	3374 ± 28.57ef	791 ± 4.04i	1783 ± 36.91bcd	825.757 ± 74.10b	-1.033 ± 0.525a	501.149 ± 45.78ab	465.248 ± 38.09ab	0.379 ± 0.01abcd
11	10.46 ± 0.285ghi	9.03 ± 0.2de	71.76 ± 1.113abc	1.78 ± 0.175fgh	0.076 ± 0.008b	0.64 ± 0.020cde	76.7 ± 0.40cd	3052 ± 20.22gh	1078 ± 23.44hijk	1601 ± 18.01ghi	630.415 ± 36.47bcdef	-6.874 ± 1.587b	285.404 ± 39.10efgh	232.949 ± 17.29defgh	0.228 ± 0.031efg
12	11.83 ± 0.051d	10.56 ± 0.207b	74.95 ± 2.013abc	1.55 ± 0.039hi	0.12 ± 0.008a	0.53 ± 0.058defg	77.6 ± 0.31bc	3331 ± 37.10f	905 ± 62.92kl	1520 ± 65.90i	575.257 ± 16.23cdefg	-0.380 ± 0.183a	353.720 ± 21.29cdef	291.039 ± 26.58def	0.371 ± 0.044bcd
13	9.46 ± 0.094n	11.23 ± 0.014a	79.39 ± 0.801a	2.33 ± 0.190cd	0 ± 0.001fj	0.82 ± 0.060ab	80.7 ± 0.21a	2962 ± 17.62h	539 ± 57.0hijk	2061 ± 50.74a	1039.629 ± 165.83a	-1.441 ± 0.497a	639.617 ± 110.54a	525.244 ± 110.37a	0.390 ± 0.009abcd
14	10.37 ± 0.253hij	9.73 ± 0.153c	69.8 ± 1.1065bc	2.59 ± 0.079bc	0.031 ± 0.005gh	0.55 ± 0.014efg	72.4 ± 0.21k	2491 ± 32.16j	1079 ± 57.0hijk	387 ± 21.17k	630.070 ± 22.03bcdef	-0.73183 ± 9.619d	249.144 ± 15.51efgh	215.052 ± 16.53defgh	0.176 ± 0.020fg
15	9.70 ± 0.118mn	9.74 ± 0.143c	68.15 ± 2.619c	3.93 ± 0.278a	0.033 ± 0.003fgh	0.48 ± 0.026fg	74.4 ± 0.35hij	2691 ± 69.48i	1065 ± 46.32ijkl	422 ± 14.98k	655.698 ± 17.47bcde	-73.924 ± 6.34hc	222.242 ± 22.03defgh	222.066 ± 42.10defgh	0.189 ± 0.022fg
16	11.04 ± 0.013ef	8.92 ± 0.21def	78.07 ± 2.79ab	1.98 ± 0.055defgh	0.048 ± 0.004cdefg	0.51 ± 0.017fg	73.5 ± 0.15j	3666 ± 41.58d	1282 ± 42.23def	1561 ± 43.92hi	471.276 ± 21.33efghij	-13.040 ± 1.474a	263.025 ± 51.59efgh	232.006 ± 42.10defgh	0.313 ± 0.078de
17	12.35 ± 0.067bc	8.53 ± 0.258fg	71.34 ± 5.82abc	2.79 ± 0.119b	0.046 ± 0.007cdef	0.64 ± 0.043cde	73.8 ± 0.21ij	3478 ± 25.51ef	1255 ± 11.59fgh	1573 ± 6.81hi	732.777 ± 17.97bc	-0.958 ± 0.084a	285.888 ± 9.15efgh	228.509 ± 2.52defgh	0.337 ± 0.074ef
18	14.42 ± 0.032a	7.19 ± 0.074jk	74.44 ± 0.846abc	2.28 ± 0.067cde	0.040 ± 0.002cdefgh	0.75 ± 0.023abc	73.6 ± 0.15j	4071 ± 41.88c	1607 ± 54.05c	1584 ± 42.93ghi	465.250 ± 22.11efghij	-7.602 ± 0.481a	245.135 ± 20.32efgh	188.748 ± 18.56efgh	0.357 ± 0.011cd
19	10.01 ± 0.138klm	7.42 ± 0.27ij	68.93 ± 1.469bc	2.02 ± 0.056defg	0.091 ± 0.009b	0.6 ± 0.027def	71.1 ± 0.36l	2498 ± 58.92j	1061 ± 52.66ijkl	627 ± 23.69i	536.816 ± 21.92defgh	-59.164 ± 9.732bc	168.578 ± 9.37b	138.518 ± 7.07gh	0.136 ± 0.015g
20	12.63 ± 0.103b	7.15 ± 0.134k	69.85 ± 4.243bc	2.62 ± 0.056bc	0.023 ± 0.003bi	0.27 ± 0.031i	71.7 ± 0.15kl	4622 ± 120.09b	2918 ± 81.07b	1664 ± 43.51defgh	375.310 ± 58.96hij	-65.696 ± 17.021c	155.624 ± 17.28h	126.917 ± 16.68h	0.189 ± 0.028fg
21	10.47 ± 0.084ghi	7.91 ± 0.154hi	71.92 ± 0.851abc	1.73 ± 0.091fgh	0.014 ± 0.013ij	0.46 ± 0.021g	72.0 ± 0.60kl	4999 ± 47.08a	2655 ± 122.41a	1642 ± 63.86ghi	315.927 ± 88.82j	-0.281 ± 0.173a	217.263 ± 61.70fgh	204.781 ± 56.77efgh	0.448 ± 0.009abcd

*Different letters in the same column indicate significant difference ($P < 0.05$).

FIGURE 1: Cooking characteristics of sorghum: (a) water absorption rate; (b) volume expansion ratio; (c) iodine blue value.

TABLE 3: The loadings of the individual variables as calculated during PCA.

Individual variable	F_1	F_2	F_3	F_4	F_5
X_1	-0.250	0.563	-0.176	0.289	0.631
X_2	0.733	-0.503	0.075	0.094	-0.129
X_3	0.796	0.264	0.043	0.114	0.134
X_4	-0.367	-0.480	0.323	0.138	0.490
X_5	0.058	0.050	-0.902	0.027	-0.276
X_6	0.430	-0.139	-0.429	-0.457	0.219
X_7	0.489	0.450	-0.388	-0.045	0.525
X_8	0.675	0.253	-0.129	0.614	-0.080
X_9	0.400	0.394	-0.134	0.741	-0.208
X_{10}	0.900	-0.120	0.105	-0.062	-0.039
X_{11}	-0.270	0.842	0.411	-0.025	-0.012
X_{12}	-0.625	0.590	0.351	0.121	-0.138
X_{13}	0.570	0.673	0.205	-0.229	-0.010
X_{14}	0.666	-0.578	0.175	0.164	0.236
X_{15}	0.641	0.604	-0.003	-0.327	0.017
X_{16}	0.926	-0.215	0.241	0.020	0.040
X_{17}	0.913	-0.191	0.284	0.035	-0.016
X_{18}	0.648	0.496	0.114	-0.348	-0.171

soup and the worse grain integrity and acceptability (stickiness and elasticity) of sorghum rice [41]. On the contrary, the sorghum rice with more amylopectin content was wet, and the taste was better [42].

3.4. Textural Characteristics. The significant differences in textural properties among different varieties ($P < 0.05$) are shown in Table 2. The hardness of sorghum rice ranged from 315.93 to 1039.63 g, and most of the varieties were concentrated in the range of 300 g to 600 g. It was not difficult to find that the stickiness of 21 varieties of sorghum is generally very low, only the Jilin No. 11 and Heilongjiang Nos. 14, 15, 19, and 20 with higher stickiness, which are $-45.874 \text{ g} \cdot \text{m}^{-1}$, $-103.183 \text{ g} \cdot \text{m}^{-1}$, $-73.924 \text{ g} \cdot \text{m}^{-1}$, $-59.164 \text{ g} \cdot \text{m}^{-1}$, and $-65.696 \text{ g} \cdot \text{m}^{-1}$, respectively. The stickiness of No. 14 was the highest, which was significantly higher than that of other sorghum varieties ($P < 0.05$). Stickiness of rice was related to the composition of starch; that is, the varieties with a lower amylose content have higher stickiness [43]. The results also verified the experimental iodine blue value; that is, in sorghum varieties with a low iodine blue

FIGURE 2: Scree plot of the eigenvalues of PCA.

value, the rice soup will be more viscous, steamed rice stickiness was higher, and acceptability was better [44]. The hardness and stickiness were the main indicators to evaluate the quality of sorghum rice. The rice with a lower hardness and higher stickiness had shorter cooking time and better taste quality [15]. The chewiness is a comprehensive embodiment of adhesiveness and elasticity, which is related to the content of protein and starch [45]. No. 13, for example, which has the highest chewiness and adhesiveness, also has the highest protein content. In addition, there were significant differences in responsiveness among different varieties ($P < 0.05$).

3.5. Principal Component Analysis. The PCA was carried out with 18 quality indexes of 21 sorghum varieties, including moisture, protein, starch, fat, tannin, ash, iodine blue value, expansion volume, water absorption rate, PT, PV, BD, SB, hardness, stickiness, adhesiveness, chewiness, and responsiveness which were expressed by X_1 – X_{18} , respectively.

A scree plot that identifies the major groups of variables was done. The scree plot is shown in Figure 2. The first five principal components F_1 – F_5 had a high total variability equal to 86.19% and were considered representative of the data and further investigated. The component F_1 is clearly the most significant principal component.

The loadings of the individual variables in each PC were done (Table 3), in order to investigate the correlations among the five main variables F_1 – F_5 and their components. The contribution rate of each index variable X_i to F_j was calculated and sorted. The first n index variables with a cumulative contribution rate of more than 85% to F_j were selected for the interpretation and analysis of F_j [46]. The results are shown in Table 4. Combining Tables 3 and 4, it could be seen that X_{16} , X_{17} , X_{10} , X_3 , X_2 , X_8 , X_{14} , X_{18} , X_{15} , X_{12} , and X_{13} were grouped within F_1 and can be treated as one variable. And so on, the

relationship between other variables and principal components could be obtained. Among them, F_1 mainly synthesized the variation information of protein content X_2 , starch content X_3 , PT X_{10} , adhesiveness X_{16} , and chewiness X_{17} with the variance of 0.54, 0.63, 0.81, 0.86, and 0.83, respectively, which were more than 50% and related to the texture of sorghum rice. F_2 was mainly characterized in PV X_{11} , SD X_{12} , SB X_{13} , hardness X_{14} , and stickiness X_{15} , which were related to the change of the gelatinization property in the sorghum cooking process. The tannin content X_5 and ash content X_6 have the largest contribution rate to F_3 , while the high tannin content will produce bitter taste, mainly affecting the flavor of sorghum. Volume expansion ratio X_8 and water absorption ratio X_9 are the main contribution variables to F_4 , which were related to cooking characteristics. The moisture X_1 and iodine blue value X_7 have the largest contribution rate to F_5 , and these two indexes were related to the waxy and nonwaxy varieties of sorghum. Therefore, F_5 mainly reflected the quality of sorghum varieties.

According to the results of PCA, the eigenvectors of the five PC were further calculated, as shown in Table 5. Then, the linear relationship was obtained as follows:

$$Z = 0.45F_1 + 0.25F_2 + 0.12F_3 + 0.10F_4 + 0.08F_5. \quad (4)$$

21 kinds of sorghum were evaluated by the equation, and the two varieties with the highest score were No. 14 and No. 15 cultivated in Heilongjiang.

Finally, in order to verify the accuracy and practicability of the equation, the sensory evaluation was taken as the ordinate and the comprehensive evaluation equation as the horizontal coordinate, and the linear regression analysis was used to verify the edible quality of sorghum rice. The formula was obtained, as follows:

$$y = 3.42x + 70.24 (r^2 = 0.81), \quad (5)$$

TABLE 4: Contribution rate (CR) and cumulative contribution rate (CCR) of individual variables (IV) to PC.

IV	F_1		IV	F_2		IV	F_3		IV	F_4		IV	F_5	
	CR (%)	CCR (%)		CR (%)	CCR (%)		CR (%)	CCR (%)		CR (%)	CCR (%)		CR (%)	CCR (%)
X_{16}	12.30	12.30	X_{11}	18.35	18.35	X_5	43.89	43.89	X_9	34.53	34.53	1	32.38	32.38
X_{17}	11.94	24.24	X_{13}	11.72	30.07	X_6	9.92	53.81	X_8	23.74	58.27	7	22.41	54.79
X_{10}	11.62	35.86	X_{15}	9.44	39.50	X_{11}	9.12	62.93	X_6	13.14	71.41	4	19.51	74.30
X_3	9.08	44.94	X_{12}	9.01	48.51	X_7	8.14	71.07	X_{18}	7.61	79.02	5	6.20	80.50
X_2	7.71	52.65	X_{14}	8.63	57.15	X_{12}	6.65	77.72	X_{15}	6.73	85.74	14	4.54	85.04
X_8	6.54	59.18	X_1	8.20	65.34	X_4	5.62	83.33						
X_{14}	6.35	65.53	X_2	6.54	71.89	X_{17}	4.37	87.70						
X_{18}	6.02	71.56	X_{18}	6.37	78.26									
X_{15}	5.90	77.45	X_4	5.96	84.22									
X_{12}	5.59	83.05	X_7	5.24	89.46									
X_{13}	4.66	87.71												

TABLE 5: Eigenvector of primary components.

Individual variable	Principal component function				
	F_1	F_2	F_3	F_4	F_5
X_1	-0.095	0.286	-0.129	0.229	0.569
X_2	0.278	-0.256	0.055	0.074	-0.116
X_3	0.301	0.134	0.031	0.090	0.121
X_4	-0.139	-0.244	0.237	0.109	0.442
X_5	0.022	0.025	-0.663	0.021	-0.249
X_6	0.163	-0.071	-0.315	-0.362	0.197
X_7	0.185	0.229	-0.285	-0.036	0.473
X_8	0.256	0.129	-0.095	0.487	-0.072
X_9	0.152	0.201	-0.098	0.588	-0.188
X_{10}	0.341	-0.061	0.077	-0.049	-0.036
X_{11}	-0.102	0.428	0.302	-0.020	-0.011
X_{12}	-0.237	0.300	0.258	0.096	-0.124
X_{13}	0.216	0.342	0.150	-0.181	-0.009
X_{14}	0.252	-0.294	0.129	0.130	0.213
X_{15}	0.243	0.307	-0.002	-0.259	0.015
X_{16}	0.351	-0.109	0.177	0.016	0.036
X_{17}	0.346	-0.097	0.209	0.028	-0.014
X_{18}	0.245	0.252	0.084	-0.276	-0.154

and the fitting coefficient was greater than 0.80, which indicated that the equation can accurately evaluate the edible quality of sorghum rice.

4. Conclusions

One-way ANOVA analysis of 18 indicators of 21 kinds of sorghum from the Northeast China revealed that there were significant differences among the quality characteristics of different varieties. Meanwhile, it could be seen that there were regional differences of the starch content, protein content, and PT. And the above indicators of sorghum varieties from Heilongjiang are generally lower than those from Jilin. Then, five principal components with a cumulative contribution rate of 86.19% could be picked out by PCA to describe the taste, pasting, flavor, cooking, and variety of sorghum, respectively. According to the results of PCA, a comprehensive equation was constructed, which is $Z = 0.45F_1 + 0.25F_2 + 0.12F_3 + 0.10F_4 + 0.08F_5$, and two sorghum varieties with the highest score were obtained: No. 14 and No. 15. Meanwhile, the sensory quality analysis was used to verify the equation with the fitting coefficient of 0.81

(>0.80), which indicated that the five principal components (F_1 – F_5) could be more accurate to evaluate the edible quality of sorghum.

Data Availability

The data used to support the findings of this study are included within the article.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent

Informed consent was obtained from all individual participants included in the study.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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