Comprehensive Evaluation of Different Sugar Beet Varieties by Using Principal Component and Cluster Analyses

Xiao-Hang Hu\(^{1,2}\), Jian-Chao Zhou\(^1\), Hong-Ze Yang\(^3,*\)

\(^1\)Crop Research Institute of Heilongjiang University, Harbin 150080, Heilongjiang, China
\(^2\)Inspection and Testing Center for Beet Quality, Ministry of Agriculture, Harbin 150080, Heilongjiang, China
\(^3\)Research Institute of Industrial Crops, Xinjiang Academy of Agricultural Sciences, Urumqi 830091, China

*Corresponding author e-mail: 80416913@qq.com

Abstract: This study aimed to examine the main qualities and differences among sugar beet, fodder beet, and edible beet of fourteen genotypes from a collection obtained from an experimental farm (black soil) in Heilongjiang University and make a comprehensive evaluation for these varieties on the basis of six quality indicators. Fourteen genetic varieties of sugar beet roots were used as experimental materials, and the quality indicators were the total amino acid (TAA), betaine, sugar, potassium, sodium, and Alfa amino N (\(\alpha-N\)) contents. Analysis of variance for the quality indicators showed significant differences among the genetic varieties. Principal component analysis (PCA) and cluster analysis (CA) were used to evaluate the variability in quality characteristic of the sugar beet roots and rank the contributions of the variables. According to PCA, the quality indicators of the fourteen genetic varieties were divided into four principal components with the cumulative variance contribution rate of 91.8%. The genetic varieties were again classified into four groups based on the CA method, which was in agreement with the results obtained using the PCA method. The results showed that multigerm genotypes including ‘S204’, ‘Xintian 3-12’, ‘Shi Tian No. 1’, and ‘Y7792’ were put in one group and had better qualities. The two methods were combined to establish a model to evaluate the qualities according to the comprehensive evaluation indicators. Therefore, combining the PCA and CA methods could be a feasible approach for the comprehensive quality evaluation of sugar beet genetic cultivars in China.

1 Introduction

Sugar beet (\textit{Beta vulgaris} L.), a member of the Chenopodiaceae family (\textit{Amaranthaceae}), is commonly known as sugar beet, edible beet, and fodder beet according to its purpose [1,2,3]. As one
of the most agro-economic sugar crops, sugar beet plays an important role worldwide and is mainly distributed in the northeast, northwest, and north China [4]. With the development of sugar industry and the increase in the awareness on quality, sugar beet breeders focus on not only the sugar content of the root and the total yield per unit but also the sugar beet variety with high quality and functional traits. Because of the rich nutritional contents in the leaves of fodder beet and edible beet, the planting and breeding of sugar beet have reached a peak in Europe and the United States [5,6,7]. The nutritional value receives significant consideration during the breeding and production of different varieties of sugar beet[8,9]. The internal indicators such as amino acids, betaine, sugar, potassium, sodium, and Alfa amino N (α–N) are significantly correlated with the nutrient and processing quality characters[10,11,12,13]. Quality evaluation involves the determination of the physiological functions of the internal indicators during the breeding of sugar beet varieties. Since the use of only one quality characteristic or agronomic trait such as root size, root weight, and root type can hardly meet the need of quality evaluation of sugar beet, establishing evaluation models by using powerful statistical methods is necessary to determine the differences in quality indicators, providing comprehensive and technical support for high-quality breeding and utilisation of sugar beet.

Some indicators of different varieties of sugar beet have been used to evaluate the quality of sugar beet and distinguish various cultivars [14,15,13]. However, developing methods to conduct more comprehensive assessment based on the quality indicators is necessary. For instance, during the bolting process, protein content and total amino acid level in sugar beet was found to increase, and such increases were reported to be related to the changes in several amino acids [16]. The differences in saccharose and amino acid contents between sugar beet with high and low sugar contents were found to be small and were mainly detected in the phloem of taproot after 9--12 weeks of growth [17]. Principal components analysis (PCA) is one of the crucial and popular multivariate techniques. Clustering analysis (CA) is usually performed to classify samples and variables into groups on the basis of their resemblance. Some studies have used the PCA and CA to analyse the qualities of sugar beet varieties. Jia et al.[18] conducted comprehensive quality evaluations on thirty-four sugar beet varieties from five different producing areas by using the methods of correlation—PCA and CA—for the contents of eleven elements, including potassium and sodium. In addition, analysis and comprehensive evaluations have been performed on the amino acid components in the roots of fourteen varieties of sugar beet by using the PCA method [13]. In recent years, although many studies focused on the analyses of agronomic traits of sugar beet varieties by using the PCA method [19,20,21], few studies revealed the composite nutritional quality indicators. Therefore, the present study aimed to evaluate the major nutrition quality indexes of sugar beet genotypes by using the PCA and CA methods. We determined the differences among sugar beet, fodder beet, and edible beet from a collection obtained from the experimental farm (black soil) in Heilongjiang University on the basis of six quality indicators. By conducting these analyses, we attempted to generate a reasonable evaluation system for the nutrition quality of sugar beet in China.

2. Materials and Methods

2.1 Plant Materials

Fourteen major cultivated sugar beet genetic varieties with different traits and origins that were collected from an experimental farm were evaluated (Table 1).
Table 1. Plant material, Genotype, Traits and Origin

| Genotype | Name       | Traits      | Origin       |
|----------|------------|-------------|--------------|
| S1       | Bi Jiu     | E, monogerm | Netherlands  |
| S2       | Aikesheng  | E, monogerm | England      |
| S3       | Auto       | E, monogerm | Italy        |
| S4       | Qing Feng  | E, monogerm | China        |
| S5       | Hong Xia   | E, multigerm| China        |
| S6       | Shi Tian No. 1 | E, multigerm| China      |
| S7       | Lvov       | E, multigerm| China        |
| S8       | Red feed   | F, monogerm | China        |
| S9       | S11-3      | F, multigerm| China        |
| S10      | Y7792      | F, monogerm | China        |
| S11      | S204       | F, multigerm| China        |
| S13      | BETA807    | S, monogerm | USA          |
| S14      | KWS0149    | S, monogerm | Germany      |
| S15      | Xintian No 12 | S, multigerm| China        |

E- edible beet, S-sugar beet, F-fodder beet

2.2 Experimental site and design

The experiments were performed at the experimental farm (black soil) in Heilongjiang University, Hulan District, Harbin City, Heilongjiang Province (45°49′--46°25′N, 126°11′--127°19′E), which is characterised by continental monsoon climate in the north temperate zone, with an annual average temperature of 4.6°C, a mean annual precipitation of 507.0 mm, an annual accumulated temperature (≥10°C) of 2972°C, and frost-free season of 144 days.

The field experiment was conducted for two years (2014-2015) in a randomised complete block design with three replications and plot size of 13m² (10 m length and 1.3 m wide), with two rows. The genotypes seeds were sowed on first ten days of May, with the density of plants being 65cm by 20cm. The roots were harvested on last week of September every year by manual method. During the growing season were applied conventional farming methods and fertilization.

Six replicate roots were collected from different rows in each spot and mixed together to make composite samples. Three composite samples were taken from the trial field. All composite root (central part of the whole root) samples were made into paste samples for chemical analysis by using a self-made machine.

2.3 Amino Acid Analysis

Amino acid analysis: eighteen components of amino acids were quantified using a Hitachi L-8800 Amino Acid Automatic Analyzer (Windows NT chromatography operating system, USA) according to Larher et al.[22] and Hecker et al. [23]. All amino acid data were calculated in percentage by dried beet root.

2.4 Betaine Analysis

Betaine analysis: the content of betaine in roots was measured using a colorimetric method
described by Grieve[24] and Abbas [25] by using a commonly used T6 UV visible spectrophotometer at 525nm. All betaine data were calculated in percentage by dried beet root.

2.5 Sugar, Potassium, Sodium and Alfa amino N (α–N)

Sugar, potassium, sodium, and α–N analysis: the potassium, sodium, and α–N contents were measured using a VENIMA sugar beet quality auto-analyzer, and sugar content was measured using an H8 spectropolarimeter. The α–N content was analysed using the fluorometric o-phthalaldehyde method according to Burba et al. [26]. All potassium, sodium, and α–N data were calculated in mmol per 100g fresh beet root, and sugar data were calculated in °S.

2.6 Statistical Analysis

All experiments were repeated three times, and the mean values were evaluated statistically (SPSS for windows, Chicago: SPSS Inc). One-way analysis of variance (ANOVA) was performed using Duncan’s multiple range test to measure significant differences between the data. The PCA method was used to provide a score, which correlated with the extent of quality variation found in each variable and reflected the relationship between quality indicators and sugar beet varieties [27]. The CA method allowed the classification of samples on the basis of the similarities of their qualities [28].

3. Result

3.1 Quality Analysis

The amount of major amino acids in the roots of the fourteen sugar beet varieties was measured (Table 2 and Figure 1-A). The result showed that all the varieties contained common amino acids, including essential amino acids (threonine, valine, methionine, isoleucine, leucine, phenylalanine, and lysine; Table 1). The total amino acid (TAA) content ranged between 0.30 and 0.62%, with the edible sugar beet ‘Hong Xia’ having the highest, whereas fodder sugar beet ‘S-11-3’ having the lowest value (Figure 1-A). The total essential amino acid (TEAA) content was within 0.10--0.20%, with ‘Hong Xia’ having the highest content. In addition, the ratio of ETAA/TAA was within 28.91--40.81% and ETAA/total non-essential amino acid (NETAA) was 43.00--68.95%, which were close to 40% and 60%, respectively, of the ratios recommended by the WHO/FAO, indicating that the protein contents in these roots are ideal [29].

The betaine contents in the roots of the fourteen sugar beet varieties varied from 0.14 to 1.09% (Figure 1-B). The average value was 0.66%, and the variable coefficient between the varieties was 8.33%. Clear differences were noted among the varieties, with ‘Shi Tian No. 1’ showing the highest value (1.21%), which was significantly different (p<0.01) from those of other samples, and ‘Auto’ showing the lowest value (0.14%). Other varieties containing high betaine were ‘Y7792’ and ‘S204’ and those with low betaine content were ‘Bi Jiu’ and ‘Aikesheng’. The differences in betaine contents of sugar beet roots might reflect the anti-saline capacity and determine the energy power, particularly in fodder beet [30].

The levels of sugar, potassium, sodium, and α–N are important quality indicators of sugar beet. Sugar refers to the content of usable components (mainly saccharose) in sugar beet root. Potassium and sodium in the root are in inorganic forms, whereas α–N is in organic form owing to the presence of acid amides and proteins.
Table 2. The amino acid composition and mass fraction of sugar beet root in different varieties

| Amio Acid Content (%) | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | S13 | S14 |
|-----------------------|----|----|----|----|----|----|----|----|----|------|------|------|------|------|
| Asp                   | 0.02| 0.02| 0.02| 0.03| 0.04| 0.03| 0.03| 0.04| 0.02| 0.04  | 0.04  | 0.04  | 0.04  | 0.02  |
| Thr                   | 0.01| 0.01| 0.01| 0.02| 0.02| 0.01| 0.01| 0.02| 0.01| 0.02  | 0.01  | 0.02  | 0.02  | 0.01  |
| Ser                   | 0.01| 0.01| 0.01| 0.02| 0.02| 0.02| 0.01| 0.02| 0.01| 0.01  | 0.01  | 0.02  | 0.01  | 0.01  |
| Glu                   | 0.09| 0.04| 0.10| 0.19| 0.18\(^1\)| 0.06| 0.12| 0.04| 0.15| 0.04  | 0.06  | 0.10  | 0.04  | 0.04  |
| Gly                   | 0.01| 0.01| 0.01| 0.02| 0.02| 0.02| 0.01| 0.02| 0.01| 0.01  | 0.01  | 0.02  | 0.02  | 0.01  |
| Ala                   | 0.02| 0.01| 0.03| 0.03| 0.03| 0.03| 0.03| 0.01| 0.03| 0.01  | 0.03  | 0.01  | 0.02  | 0.01  |
| Cys                   | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| Val                   | 0.02| 0.02| 0.02| 0.03| 0.03| 0.03| 0.03| 0.02| 0.03| 0.02  | 0.02  | 0.02  | 0.02  | 0.03  |
| Met                   | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00  | 0.00  | 0.01  | 0.00  | 0.00  |
| Ile                   | 0.01| 0.01| 0.01| 0.02| 0.02| 0.01| 0.01| 0.02| 0.01| 0.01  | 0.02  | 0.01  | 0.02  | 0.01  |
| Leu                   | 0.01| 0.02| 0.02| 0.03| 0.03| 0.03| 0.02| 0.01| 0.03| 0.01  | 0.02  | 0.02  | 0.03  | 0.03\(^3\) | 0.02 |
| Tyr                   | 0.00| 0.00| 0.00| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01  | 0.01  | 0.01  | 0.01  | 0.01  |
| Phe                   | 0.01| 0.01| 0.01| 0.01| 0.02| 0.01| 0.01| 0.01| 0.01| 0.01  | 0.01  | 0.02  | 0.01  | 0.01  |
| Lys                   | 0.02| 0.02| 0.02| 0.03| 0.04| 0.03| 0.03| 0.02| 0.04| 0.02  | 0.02  | 0.02  | 0.02  | 0.04  |
| NH\(_3\)              | 0.02| 0.00| 0.02| 0.02| 0.02| 0.01| 0.01| 0.00| 0.01| 0.00  | 0.00  | 0.00  | 0.01  | 0.00  |
| His                   | 0.00| 0.01| 0.01| 0.01| 0.01| 0.01| 0.00| 0.01| 0.00| 0.01  | 0.00  | 0.01  | 0.01  | 0.01  |
| Arg                   | 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01  | 0.01  | 0.02  | 0.01  | 0.01  |
| Pro                   | 0.01| 0.01| 0.01| 0.01| 0.02| 0.02| 0.01| 0.02| 0.01| 0.01  | 0.02  | 0.01  | 0.02  | 0.01  |
| TAA                   | 0.33| 0.29| 0.40| 0.57| 0.61| 0.41| 0.30| 0.51| 0.29| 0.49  | 0.29  | 0.47  | 0.45  | 0.33  |
| ETAA                  | 0.10| 0.11| 0.12| 0.17| 0.19| 0.15| 0.10| 0.18| 0.11| 0.14  | 0.11  | 0.19  | 0.16  | 0.13  |
| ETAA/TA               | 30.8| 39.8| 31.3| 30.0| 31.7| 37.5| 35.0| 35.0| 38.4| 28.9  | 37.7  | 40.8  | 36.4  | 40.0  |
| ETAA/NE               | 44.5| 66.3| 45.5| 43.0| 46.6| 60.2| 53.9| 53.8| 62.4| 40.6  | 60.6  | 68.9  | 57.4  | 66.7  |

TAA: total amino acid; ETAA: Essential amino acid; NETAA: Nonessential amino acid; Asp: Aspartic acid; Thr: Threonine; Ser: Serine; Glu: Glutamic acid; Gly: Glycine; Ala: Alanine; Cys: Cysteine; Val: Valine; Met: Methionine; Ile: Isoleucine; Leu: Leucine; Tyr: Tyrosine; Phe: Phenylalanine; Lys: Lysine; NH\(_3\): Ammonia peak; Histidine; Arg: Arginine; Pro: Proline; The name of the genotypes S1-S14 is the same to Table 1. Values are mean ± standard error of three replicates. Means followed by same letter within a column are not significantly different (P<0.01) according to Duncan’s multiple range test (DMRT).
Fig 1 The contents of Amino acid (A)、Betaine (B)、Sugar (C), Potassium (D), Sodium (E) and Alfa amino N(α–N) (F) of sugar beet roots in different varieties (series). The name of the species S1-S14 is the same as Table 1.

Sugar contents in the roots of different varieties varied from 3.37 to 11.24 ºS (Figure 1-C). The mean value was 6.80 ºS, with a variable coefficient of 2.54% between varieties, and significant differences were noted among the varieties. ‘KWS0149’ had the highest sugar (11.24 ºS), which was significantly different ($p<0.01$) from that of other samples. ‘Aikesheng’ had the lowest sugar (3.37 ºS).
Other varieties with high sugar content were ‘Xintian No 12’ and ‘BETA807’, and those with low sugar content were ‘Auto’, ‘Bi Jiu’, and ‘Lvov’.

Potassium contents of the different varieties were found to range from 3.41 to 4.79 mmol·100g⁻¹ with a mean value of 4.14 mmol·100g⁻¹ and a variable coefficient of 3.44% (Figure 1-D). ‘Red feed’ had the highest content (4.79 mmol·100g⁻¹), which was significantly different (p<0.01) from that of other varieties. ‘S11-3’ had the lowest content (3.41 mmol·100g⁻¹). Other sugar beet varieties with high potassium content included ‘Shi Tian No. 1’ and ‘Lvov’, and those with low potassium content were ‘Aotuo’ and ‘Hong Xia’.

Sodium contents of the different varieties ranged from 4.08 to 11.54 mmol·100g⁻¹ with an average value of 7.68 mmol·100g⁻¹ and a variable coefficient of 2.91% (Figure 1-E). ‘S11-3’ had the highest content (11.54 mmol·100g⁻¹) that differed significantly (p<0.01) from that of other varieties. ‘Auto’ had the lowest content (4.08 mmol·100g⁻¹). The content of sodium in the present study was lower than that found in Novi by Sklenar et al. (1999). This might be because of the differences in cultivar, soil type, and/or climatic conditions. Other beet varieties having high sodium content included ‘Qing Feng’ and ‘Aikesheng’, and those with a lower sodium content included ‘S204’ and ‘Y7792’.

The α−N contents of different varieties varied from 1.98 to 3.49 mmol·100g⁻¹ with a variable coefficient of 5.37% (Figure 1-F). The differences among varieties were significant. ‘Bi Jiu’ had the highest content (3.49 mmol·100g⁻¹) and showed significant differences (p<0.01) from those of other varieties. ‘BETA807’ had the lowest α−N content (1.98 mmol·100g⁻¹). The α−N content is reported to be correlated with the sugar beet maturity [31]. Other varieties containing high α−N included ‘Xintian No 12’ and ‘Y7792’, and those with low α−N were ‘Lvov’ and ‘S11-3’.

3.2 Principal Components Analysis (PCA)

The PCA method is a powerful statistical technique used to reduce high dimensional data to lower dimensional data by using different variables [32]. It allows the identification of variables and samples that are closer and contain analógical information [33]. In the present study, the PCA was conducted by considering the levels of TAA, betaine, sugar, potassium, sodium, and α−N in the fourteen varieties of sugar beet roots as indicators and dividing the data into four principal components according to the characteristic value of greater than 0.6 and accumulating contribution rate of greater than 85% (Table 3). The results showed that characteristic values and accumulating contribution rates for the first (PC1), second (PC2), third (PC3), and fourth (PC4) principal components were 2.336 (38.93%), 1.425 (23.75%), 1.066 (17.7%), and 0.681 (11.35%), respectively. The total accumulating contribution rate was 91.80%, indicating that the four principal components accounted for most of all the quality indicators’ information.

The vector quantity of characteristic value in each principal component was calculated as follows:

\[ ti = ai / \sqrt{\lambda i} \]  

(i=1, 2, 3), where \( \lambda i \) is the vector quantity of characteristic value of each principal value, and ‘ai’ is the vector quantity matrix of characteristic value that could be calculated using the content matrix. The vector quantity matrix of the characteristic values of principal components of the six quality indexes could reflect the influence level of the indexes on the principal components (Table 4). Except sodium, all other load weights in PC1 were positive. In addition, the two highest load weights were sugar (0.64) and betaine (0.63), which showed that, the higher the PC1, higher are the
sugar and betaine contents. The load weight for sodium was the highest (0.68) in PC2, where as it was negative (-0.34) in PC3, indicating that its influence on PC3 was negative and on PC2 was positive. Similarly, the load weight for TAA was the highest (0.90) in PC3, where a sit was negative (-0.15) in PC4, indicating that its influence on PC4 was negative and on PC3 was positive.

| Index/principal | PC1 | PC2 | PC3 | PC4 |
|----------------|-----|-----|-----|-----|
| TAA            | 0.09| 0.16| 0.90| -0.15|
| Betaine        | 0.63| 0.10| 0.02| 0.27 |
| Sugar          | 0.64| 0.10| 0.02| 0.27 |
| K              | 0.43|-0.05|-0.26|-0.84 |
| Na             | -0.04| 0.68|-0.34| 0.19 |
| a-N            | 0.13|-0.70|-0.10| 0.29 |

Considering that the rates of contribution of PC1 and PC2 are 39% and 24%, respectively, a sample score plot of PC1 and PC2 was generated to show the relationship between the quality indicators and varieties (Figure 2). In the plot of PC1 and PC2, a group containing S14 (‘Xintian No 12’), S6 (‘Shi Tian No. 1’), S10 (‘S204’), and S11 (‘Y7792’) were collected in the top right-hand of the PC space, and they were characterised by varieties rich in betaine. S7 (‘Lvov’), S12 (‘Red feed’), and S8 (‘BETA807’) were positioned in the positive interval of PC2, suggesting that sugar beet varieties had high content of potassium and TAA. S9 (‘S11-3’), S4 (‘Qing Feng’), S13 (‘KWS0149’), and S5 (‘Hong Xia’) were placed on the left side of PC2, indicating the high content of sodium. S1 (‘Bi Jiu’), S2 (‘Aikesheng’), and S3 (‘Auto’) were located in the negative interval of PC1, indicating their low sugar content among the varieties. Therefore, evaluating the varieties according to their locations on the basis of the quality indicators by using PCA plots might be a feasible approach.
Fig.2 Scatter diagram of the first principal component and the second main component of sugar beet roots in 14 varieties (series) (The name of the species S1-S14 is the same as Tab l. 3.3 Comprehensive evaluation on quality among fourteen varieties

The relative values of the six indicators—betaine, sugar, potassium, sodium, $\alpha$–N, and TAA concentrations—were chosen to evaluate and compare the quality of the fourteen sugar beet genetic varieties. After each sample’s principal component value was calculated, the comprehensive quality evaluation indicators could be calculated. Normally, the larger are the comprehensive indexes, the higher is the comprehensive quality. Considering each principal component’s variance rate of contribution as weight, comprehensive evaluation of the indicators was performed as follows:

$$F_{\text{comprehensive}} = 0.39F_1 + 0.24F_2 + 0.18F_3 + 0.11F_4$$

where $F_{\text{comprehensive}}$ was the comprehensive quality evaluation score of each sugar beet variety; $F_1$, $F_2$, $F_3$, and $F_4$ are PC1, PC2, PC3, and PC4, respectively. The varieties of sugar beet were ranked from high to low according to the comprehensive quality scores (Table 5). The results showed that, among the fourteen varieties, edible beet ‘Shi Tian No. 1’ showed the highest score and edible beet ‘Auto’ showed the lowest score in the first principal component (F1); fodder beet ‘S11-3’ showed the highest and ‘Bi Jiu’ showed the lowest scores in the second component (F2); edible beet ‘Hong Xia’ had the highest and edible beet ‘Lvov’ had the lowest scores in the third component (F3); and fodder beet ‘S11-3’ had the highest and sugar beet ‘BETA807’ had the lowest scores in the fourth component (F4). The top four varieties having the highest comprehensive quality scores were edible beet ‘Shi Tian No. 1’, sugar beet ‘BETA807’, fodder beet ‘Red feed’, and ‘Y7792’, suggesting that these four genetic varieties have higher comprehensive qualities and nutrition value.
Table 5. Quality principal component score and comprehensive score of sugar beet root in fourteen genotypes

| Genotype          | F₁  | F₂  | F₃  | F₄  | F   | Sequence |
|-------------------|-----|-----|-----|-----|-----|----------|
| Shi Tian No.1     | 3.99| -0.17| -0.41| 0.11| 1.45| 1        |
| BETA 807          | 1.97| 2.14| 0.35| -0.95| 1.24| 2        |
| Red feed          | 2.34| 0.21| 0.66| -0.96| 0.98| 3        |
| Y7792             | 2.40| -1.51| 1.09| 0.75| 0.85| 4        |
| Hong Xia          | -0.67| 0.79| 1.88| 0.64| 0.34| 5        |
| Lvov              | 0.50| 1.62| -1.47| -0.66| 0.25| 6        |
| S11-3             | -0.71| 2.32| -1.16| 1.43| 0.23| 7        |
| S204              | 1.28| -1.74| -0.56| 0.43| 0.03| 8        |
| KWS0149           | -0.85| 0.71| 0.49| 0.22| -0.05| 9        |
| Xintian No.12     | 0.73| -1.36| -0.96| -0.15| -0.23| 10       |
| Qing Feng         | -1.52| 0.51| 1.22| -0.31| -0.29| 11       |
| Aikesheng         | -2.30| -0.42| -1.11| 0.19| -1.18| 12       |
| Bi Jiu            | -2.61| -1.86| -0.91| -0.52| -1.68| 13       |
| Auto              | -4.12| -1.23| 0.90| -0.24| -1.77| 14       |

F₁-F₄ is the principal component score respectively, F is the comprehensive score.

3.4 Clustering Analysis (CA)

The relationship of quality indicators and principal components was used to perform CA for classifying the varieties into four categories (Figure 3). The top in the dendrogram named category I consisted of three genetic varieties ‘Bi Jiu’, ‘Aikesheng’, and ‘Auto’, which had poor quality; category II consisted of four genetic varieties ‘Qing Feng’, ‘Hong Xia’, ‘KWS0149’, and ‘S11-3’, which had average quality; category III consisted of three genetic varieties ‘Red feed’, ‘BETA807’, and ‘Lvov’, which had relatively good quality; and in the bottom of the dendrogram named category IV consisted of four genetic varieties ‘S204’, ‘Xintian No 12’, ‘Shi Tian No. 1’ and ‘Y7792’, which multigerm genotypes were put in one group and had the better quality.

Fig. 3 Dendrogram of fourteen genetic varieties of sugar beet roots based on six quality characteristics. Reconfigure the distance of clustering merge by using WARD method.
4. Discussion

Sugar beet is mainly planted in Europe, but to a lesser extent in Asia[34]. More than 95% of sugar beet varieties used are imported from other countries in China[35]. These sugar beet varieties are characterised by high yield and high sucrose content, but their nutritional and agronomic qualities are less clear. Therefore, elucidating the composite nutritional quality indicators of these varieties and establishing a comprehensive evaluation system for sugar beet in China are necessary. This might also provide important theoretical basis for breeding, cultivation, production, and utilisation of sugar beet. Both PCA and CA methods were used to classify the different varieties of sugar beet into groups, which might reflect the genetic relationship and geographical distribution[18]. In the present study, the quality parameters of fourteen varieties of sugar beet were measured and analysed, and the results showed that the TAA contents of roots ranged from 0.30 to 0.62%, with the edible sugar beet ‘Hong Xia’ and fodder sugar beet ‘S11-3’ having the highest and lowest scores, respectively. All the fourteen varieties contained the common amino acids with the edible beet ‘Hong Xia’ having the highest EAA content. The ETAA/TAA (-40%) and ETAA/NETAA (-60%) ratios were similar to those recommended by the WHO/FAO[29], indicating that the protein contents in these roots are ideal and consistent with those reported in a previous study [13]. The high betaine-containing varieties (e.g. ‘Shi Tian No. 1’, ‘Y7792’, and ‘S204’) can be used as natural raw materials for extracting betaine. ‘KWS0149’, ‘Xintian No 12’, and ‘BETA807’ have high sugar content and might be used as raw materials for sugar extraction. From the perspective of sugar production, potassium and sodium are inorganic, whereas α-N is organic non-sugar contents. During sugar production, the lower is the non-sugar content, the less are the ash content, waste, and cost [36]. ‘S11-3’ meets such a quality requirement; however, from the perspective of food usage, varieties with high potassium and low sodium contents (e.g. ‘Shi Tian No. 1’) could benefit individuals with hypertension. The mechanisms underlying these quality indicator differences among beet varieties need to be elucidated in the future.

Multiple indexes are available for evaluating the quality of sugar beet, and the differences in quality among varieties were attributed to many interacting factors [37]. Generally, variable indicators selected using the PCA method based on different quality characteristics could not only accelerate the breeding process but also allow scientific screening of high-quality varieties and avoiding of the waste of resources. Therefore, the PCA method has been widely applied in many crops [28,38,39]. In the study, we used the PCA method to extract four principal components based on total amino acid, betaine, sugar, potassium, sodium, and α-N content of sugar beet genetic roots. The combined rate of contribution was up to 91.8%, i.e. >90% of the information in the original data could be reflected, thus simplifying the calculations and avoiding data loss or interferences from irrelevant factors. A reasonable evaluation model was thus generated and used to rank the comprehensive quality indicator evaluation scores of different genetic varieties, and according to our results, ‘Xintian No 12’, ‘Shi Tian No. 1’, ‘S204’, and ‘Y7792’ can be used in breeding programs for high betaine content, ‘Lvov’ and ‘Red feed’ for high contents of potassium and TAA, ‘S11-3’, ‘Qing Feng’, and ‘Hong Xia’ for high content of sodium, ‘BETA807’ and ‘KW0149’ for high sugar content. In addition, the CA method was applied, and the results also indicated four categories based on the quality contents and four genetic varieties ‘S204’, ‘Xintian No 12’, ‘Shi Tian No. 1’and ‘Y7792’, which multigerm genotypes were put in one group and had the better quality. One of the reasons may be these selected multigerm genotypes did not have self-fertility gene. Therefore, the use of the PCA and CA methods allowed the simplification of the quality evaluation system. The combined use of these two methods could be useful for selecting high-quality sugar beet and providing important data for beet breeding and quality improvement.

5. Conclusion

In this study, the quality including the total amino acid (TAA), betaine, sugar, potassium, sodium, and Alfa amino N (α–N) varied significantly between the fourteen gentypes of sugar beet. The results of the satistics of sugar beet root could provide basic information for evaluating different sugar beet gentypes. Based on PCA analysis, total amino acid, betaine, sugar, potassium, sodium, and α–N
content of sugar beet genetic roots were extracted four principal components, while, the comprehensive quality indicator evaluation scores of different genetic varieties indicated that ‘Xintian No 12’, ‘Shi Tian No. 1’, ‘S204’, and ‘Y7792’ can be used in breeding programs for high betaine content, ‘Lvov’ and ‘Red feed’ for high contents of potassium and TAA, ‘S11-3’, ‘Qing Feng’, and ‘Hong Xia’ for high content of sodium, ‘BETA807’ and ‘KWS0149’ for high sugar content. The method of CA was applied to divided the fourteen genotypes into four clusters which multigerm genotypes were put in one group and had the better quality. It could be concluded from the result the PCA and CA methods were combined to establish a model to evaluate the qualities according to the comprehensive evaluation indicators and information from this study might provide a feasible approach for the comprehensive quality evaluation of sugar beet genetic cultivars in China.

Acknowledgement

This present study was supported by the grants from Science and technology innovation talent project of Harbin municipal science and technology bureau in China (2016RAQXJ042), Basic research operation fee of Heilongjiang province by Heilongjiang university special fund project (HDJCCX - 201613) and The national sugar industry system project (CARS - 170202, CARS-170204).

Compliance with Ethical Standards

Conflict of interest No conflict of interest declared.

References

[1] Ford-Lloyd BV, Williams JT. A revision of Beta section Vulgares (Chenopodiaceae), with new light on the origin of cultivated beets. Botanical Journal of the Linnean Society, 71(1975): 89--102.
[2] Oyen LPA. Beta vulgaris L. In: Grubben GBH, Denton OA (Eds.), Plant Resources of Tropical Africa ;2(2004). Vegetables:110--113. Backhyus, Netherlands.
[3] Kumar S, Brooks SL. Use of red beet (Beta vulgaris L.) for antimicrobial applications-a critical review. Food & Bioprocess , (2017);Technology2:1--26.
[4] Kong XW, Zhu GL, Jian ZP. Chinese quinoa plant. Journal of Plant Classification;16(1)(1978): 99-123.
[5] Lu BF, Gui G, Zhou Y. Development and application of edible beets. Sugar Crops of China, 2(2008): 67--69.
[6] Kapadia GJ, Rao GS. Anticancer effects of red beet pigments. Red Beet Biotechnology. Springer,New York, (2013):987-988.
[7] Maheshwari RK, Parmar V, Joseph L. Latent therapeutic gains of beet root juice. World Journal of Pharmaceutical Research, 2(4) (2013): 804--820.
[8] Kazimierczak R, Hallmann E, TreśClnska V, Rembiałkowska E. Estimation of the nutritive value of two red beet (Beta vulgaris L.) varieties from organic and conventional cultivation. Journal of Research & Applications in Agricultural Engineering, (2011);56:206-210.
[9] Almazan A M, Mortley D G, Grant P J. Sugar beet grown using nutrient film technique: yield and nutritional quality. J Sci. Food Agr., 70(3) (2015);369-372.
[10] Sklenar P, Kovacev L, Cacic N. Effect of potassium, sodium and alfa-amino-nitrogen content on recoverable sugar of some sugar beet hybrids. Acta Periodica Technologica (Yugoslavia), (1999).
[11] Mäck G, Hoffmann CM, Märländer B. Nitrogen compounds in organs of two sugar beet genotypes (Beta vulgaris L.) during the season. Field Crops Research, 102(3) (2007):210--218.
[12] Allison MF, Chapman JL, Garat CE, Todd AD. The potassium, sodium, magnesium, calcium and phosphate nutrition of sugar beet (Beta vulgaris) grown on soils containing incorporated straw. J Food Sci., 74(2) (2015):216--220.
[13] Hu XH, Wu YM, Wang XW. Principal component analysis and comprehensive evaluation of amino acid in different varieties of sugar beet. Chinese Agricultural Science Bulletin, 32(27)(2016):69--75.
[14] Rađivojevi S, Obradovi SP, Kabic DR, Došenović I. Biological and technological characteristic
of different sugar beet varieties used in sugar production during 1998. Acta Periodica Technologica, (2000):31.

[15] Ra’Eisiyan Zadeh M, Nuruzi M, Faza’Eli H, Racisiyan Zadeh R, Danesh Megaran M. Silage characteristics and nutritive value of sugar beet tops and crown harvested by three different methods. Journal of Dairyence, 93(1) (2010):621--621.

[16] Gu W, Li CF, Wang YB. Changes of fatty acid and amino acid components during the first year bolting of sugar beet (Beta vulgaris L.). Journal of Nuclear Agricultural Sciences, 8(2012): 023.

[17] Lohaus G, Burba M, Heldt HW. Comparison of the contents of sucrose and amino acids in the leaves, phloem sap and taproots of high and low sugar-producing hybrids of sugar beet (Beta vulgaris L.).Journal of Experimental Botany, 45(8)(1994): 1097--1101.

[18] Jia XF, Zhu SM, Wang Q, Long W, Zhang XL. Principal component analysis and cluster analysis of the elements in sugar beet roots of different geographical origins in Xinjiang. Modern Food Science and Technology, (7) (2015):302--308.

[19] Héberger K, Csomós E, Simon-Sarkadi E. Principal component and linear discriminant analyses of free amino acids and biogenic amines in Hungarian wines. J Agric Food Chem., 51(27)(2003): 8055--8060.

[20] Song JF, Liu CQ, Jiang XQ, et al. Comprehensive evaluation of vegetable soybean quality by principal component analysis and cluster analysis. Food Sci., 36(13)(2015):12--17.

[21] Đanojčević Đ, Curčić Z, Nagl N, Taški-Ađuković K, Boćanski J. Evaluation of sugar beet genotypes for root traits by principal component analysis and cluster analysis. Genetika, 48(1) (2016):339--348.

[22] Larher FR, Lugan R, Gagneuel D, Guyot S, Monnier C, Lespinasse Y, Bouchereau A. A reassessment of the prevalent organic solutes constitutively accumulated and potentially involved in osmotic adjustment in pear leaves. Environ. Exp. Bot. 66(2) (2009): 230--241.

[23] Hecker RJ, Ruppel EG, Maag GW, Rasmuson DM. Amino acids associated with Cercospora leaf spot resistance in sugar beet. Journal of Phytopathology, 82(2) (2010):175--181.

[24] Grieve CM, Grattan SR. Rapid assay for determination of water soluble quaternary ammonium compounds. Plant and Soil, 70(2) (1983): 303--307.

[25] Abbas W, Ashraf M, Akram NA. Alleviation of salt-induced adverse effects in eggplant (Solanum melongena L.) by glycine betaine and sugar beet extracts. Sci Hortic, 125(3)(2010):188--195.

[26] Burba M, Georgi B. Die fluorometrische Bestimmung der Aminosauren in Zuckerrohr- und Zuckerfabriksprodukten mit Fluoreszamin und o-Phthalaldehyd. Zuckerindustrie, 26(1976): 322--329.

[27] Lyu J, Liu X, Bi JF, Jiao Y, Wu XY, Ruan W. Characterization of Chinese white-flesh peach cultivars based on principle component and cluster analysis. J Food Sci., 4(2017):3818--3826.

[28] Dray S, Josse J. Principal component analysis with missing values: a comparative survey of methods. Plant Ecology, 216(5) (2016):1--11.

[29] Passmore R, Pellett PL, Young VR. Nutritional evaluation of protein foods. Experimental Agriculture, 18(2008):167.

[30] Svachula V, Pulkrbek J. Dependence of betaine content in sugar beet on the rainfall and air temperature during the prevalent organic solutes constitutively accumulated and potentially involved in osmotic adjustment in pear leaves. Environ. Exp. Bot. 66(2) (2009): 230--241.

[31] Wold S, Esbensen K, Geladi P. Principal component analysis. Chemometrics & Intelligent Laboratory Systems, 2(1–3) (1987):37--52.

[32] Kumar R, Pathak A D. Recent trend of sugar beet in world. Souvenir-IISR-industry interface on research and development initiatives for sugarbeet in India, 46--47(2013):28--29.

[33] Geng G, Yang J. Sugar beet production and industry in China. Sugar Tech., 17(1) (2015):13--21.

[34] Hoffmann CM. Root quality of sugar beet. Sugar Technology. 12(3-4) (2010):276--287.

[35] Xiao Y, Juan DU, Yang XM. Pu XY, Zeng YW, Yang T, Yang JZ, Yang SM, Chen ZY. Analysis of
functional ingredients in barley grains from different regions between Southwest China and ICARDA. Southwest China Journal of Agricultural Sciences, 30(8) (2017).

[38] Pérezloredo MG, Garciachoa F, Barragánhuerta BE. Comparative analysis of betalain content in fruits and other cactus fruits using principal component analysis. International Journal of Food Properties, 19(2)(2016):326--338.

[39] Li W, Gao H Y, Chen H J, Wu WJ, Fang XJ. Evaluation of comprehensive quality of different varieties of bayberry based on principal components. Analysis Journal of Chinese Institute of Food Science and Technology, 17(6) (2017).