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Main Quality Traits Analysis and Evaluation of Potato Germplasms

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Abstract To improve the utilization efficiency of potato germplasm resources, the quality traits of 172 potato germplasms were analyzed. The results indicated that: (1) The variation coefficient of reducing sugar was the largest (66.67%), and the range was 0.093~1.11 g/100g; The variation coefficient of crude protein was larger (21.11%), and the range was 1.12~3.57 g/100 g; The variation coefficient of dry matter was the smallest (12.85%), and the range was 14.6%~30.6%. (2) The results of correlation analysis showed, it was very significantly negative correlation between reducing sugar and dry matter, crude protein or crude starch, a significantly negative correlation with vitamin C, other quality traits were significantly positively correlated. (3) principal component analysis showed that the cumulative contribution rate of the four factors reached 97.75%. as followed dry matter (47.98%), reducing sugar (26.42%), vitamin C (16.54%) and crude protein (6.81%). (4) All potato germplasms were classified into three groups at the level of D=23. Class I had the highest dry matter and vitamin C, class IV contained crude protein. The above conclusions will be beneficial to improve the utilization efficiency of potato germplasm and accelerate quality breeding.
Keywords Potato germplasm; Quality traits; Principle component analysis; Clustering analysis

Potato (*Solanum tuberosum*) is known as "second bread" and "underground apple" (Pan, 2019), which is an important grain and vegetable crop. The protein and vitamin C in tuber are 10 times that of apple. Potato is rich in dietary fiber, sylvite, lysine and tryptophan (Zhao, 2019), which is of great significance to ensure China's food security and people's balanced dietary nutrition. Since the staple food strategy was put forward, potato breeding has gradually changed from traditional fresh food type and starch processing type to special processing type, and the quality requirements of potato have become more detailed. The research on the evaluation and utilization of special processing quality traits has become the focus of new variety breeding (Wang et al., 2016; Qiu et al., 20119; Liu, 2018; Xu and Jin, 2017). To fully understand the main quality characteristics of germplasm resources and explore the utilization value of core germplasm resources of different quality types will be beneficial to improve the selection efficiency of parents and speed up the process of special quality breeding. Liu (2006) analyzed and determined the starch content of 382 introduced potato resources, and comprehensively evaluated the agronomic characters of 40 selected high starch resources. Luo et al. (2019) analyzed the contents of protein, vitamin C, starch and total amino acids in 6 samples of colored potatoes. Yu (2018) evaluated and analyzed the contents of reducing sugar, soluble sugar and starch as well as the color difference and texture traits of tuber and whole powder from 119 germplasm materials with rich genetic background and excellent comprehensive evaluation of phenotypic traits. Pan (2019) conducted correlation analysis, principal component analysis and cluster analysis on 8 quality traits of 53 materials and defined the use and classification of the tested varieties.

At present, most of the studies have focused on the evaluation and analysis of the quality of potato starch processing, potato chips processing and whole powder processing, but there are few data on the systematic analysis of quality traits. Therefore, correlation analysis, principal component analysis and cluster analysis were used to analyze the 5 main quality traits of 172 potato germplasm resources in this study, to clarify the differences of quality traits among different germplasm resources, and to screen the specific core germplasm resources that meet the requirements of different quality improvement parents, so as to provide technical reference for potato breeding.

1 Results and Analysis

1.1 Variation analysis of quality traits

The coefficient of variation (CV) represents the discrete feature of traits, which can be used to analyze the genetic variation of different quality traits in germplasm resources. The CV of reducing sugar, crude protein, crude starch, vitamin C and dry matter of the 172 tested materials were significantly different (Table 1), with relatively rich genetic variation information. And the CV of the 5 quality traits is in the following order: reducing sugar>crude protein>crude starch>vitamin C>dry matter. Among them, reducing sugar is 66.67%, crude protein is 21.11%, and dry matter is 12.85%. The results showed that the diversity index of reducing sugar and crude protein was higher, which provided a good genetic basis for the improvement of reducing sugar and crude protein quality traits.

Table 1 Variations of main quality traits of tested potato resources

Trait	Mean	Max	Min	Variability	Variance	SD	CV (%)
Dry matter (g/100 g)	21.86	30.6	14.6	16	7.88	2.81	12.85
Crude protein (g/100 g)	1.99	3.57	1.12	2.45	0.17	0.42	21.11
Vitamin c (mg/100 g)	12.91	20.4	6.74	13.66	8.53	1.92	14.87
Crude starch (%)	15.7	23.22	8.56	14.66	5.68	2.39	15.22
Reducing sugar (g/100 g)	0.33	1.2	0.093	1.11	0.05	0.22	66.67

1.2 Correlation analysis of quality traits

The results of correlation analysis of 5 quality traits showed that 6 pairs of quality traits were positively correlated (Table 2). Among them, dry matter and crude starch, dry matter and vitamin C, vitamin C and crude protein, vitamin C and crude starch showed extremely significant positive correlation, and the correlation coefficient between dry matter and crude starch was the highest, which was 0.83. 4 pairs of quality traits showed a negative correlation. Among them, reducing sugar and crude protein, reducing sugar and dry matter, reducing sugar and crude starch showed extremely significant negative correlation, and the correlation coefficient between reducing sugar and crude protein was the highest (-0.63).

Table 2 Correlation coefficient among 5 quality traits of potato

Trait	Dry matter	Crude protein (g/100 g)	Vitamin C (mg/100 g)	Reducing sugar (g/100 g)	Crude starch (%)
Dry matter (g/100 g)	1	-	--	-	-
Crude protein (g/100 g)	0.18*	1	-	-	-
Vitamin c (g/100 g)	0.25**	0.24**	1	-	-
Reducing sugar (g/100 g)	-0.33**	-0.63**	-0.18*	1	-
Crude starch(g/100 g)	0.87**	0.08	0.37**	-0.27**	1

Note: * and ** indicate significant level at 5% and 1% probability respectively

1.3 Principal component analysis of quality traits

It can be seen that the cumulative contribution rate of the first three eigencalues reached 90.94% (Table 3), indicating that the first three principal components contain most of the quality information of germplasm resources. The eigencalue of the first principal component is 2.4 with the contribution rate of 47.98%. According to the eigenvector analysis of the 5 principal components (Table 4), the eigencalue of dry matter is the largest in the first principal component, followed by crude starch, crude protein and vitamin C, indicating that dry matter has the greatest influence on the first principal component. Therefore, the dry matter factor is the first principal component. The eigencalue of the second principal component is 1.32, contribution rate is 26.42%, and comulative contribution rate is 74.4%. In the second principal component, the eigencalue value of reducing sugar is the largest, followed by crude starch, dry matter and vitamin C, indicating that reducing sugar makes the greatest contribution to the second principal component, so reducing sugar factor is the second principal component. The eigencalue of the third principal component is 0.83, contribution rate is 16.54%, and comulative contribution rate is 90.94%. In the third principal component, the eigencalue value of vitamin C is the largest, followed by reducing sugar and crude protein, indicating that vitamin C makes the greatest contribution to the third principal component, so vitamin C is the third principal component. The eigencalue of the fourth principal component is 0.34, the contribution rate is 6.81%, and the cumulative contribution rate is 97.75%. In the fourth principal component, the eigencalue of reducing sugar is the largest, followed by crude protein. As we known, reducing sugar is the second principal component factor, and crude protein has the greatest influence on the fourth principal component, so the crude protein factor is the fourth principal component. In a word, the traits of quality evaluation and analysis of potato germplasm resources were dry matter, reducing sugar, vitamin C and crude protein in turn.

Table 3 Principal component analysis of quality traits

Component	Eigencalue	Contribution rate (%)	Comulative contribution rate (%)
1st	2.4	47.98	47.98
2nd	1.32	26.42	74.4
3rd	0.83	16.54	90.94
4th	0.34	6.81	97.75
5th	0.11	2.25	100

Table 4 5 principal components of corresponding eigenvectors

Trait	1st	2nd	3rd	4th	5th
Dry matter (g/100g)	0.54	0.36	-0.28	0.22	-0.67
Crude protein (g/100g)	0.35	-0.65	0.01	0.66	0.14
Vitamin C (mg/100g)	0.35	0.04	0.92	-0.13	-0.13
Reducing sugar (g/100g)	-0.43	0.5	0.25	0.71	0.04
Crude starch (%)	0.53	0.44	-0.12	0.01	0.71

1.4 Cluster analysis of germplasm resources

DPS16.05 software and Squared Euclidean distance were used to conduct systematic cluster analysis on 5 quality traits of 172 potato germplasm resources, including dry matter, reducing sugar, crude protein, vitamin C and crude starch. At the Euclidean distance of 23, 172 germplasm resources were divided into 4 groups (Figure 1). The average dry matter content and vitamin C content of 42 germplasm resources in the class I were the highest (Table 5). The dry matter content was 20.8~30.6 g/100 g, vitamin C content was 7.6~20.4 mg/100 g, crude protein content was 1.35~3.57 g/100 g, reducing sugar content was 0.093~0.74 g/100 g, crude starch content was 14.68%~23.22%. This group includes domestic selected varieties (lines), CIP materials and other introduced materials, which can be used as improved parent materials for varieties with high dry matter and high vitamin C. There are 52 resources in class II, the average contents of dry matter, crude protein and vitamin C were lower than those of class I, in which the contents of dry matter, vitamin C, crude protein, reducing sugar and crude starch were 19.7~27.9 g, 6.9~19.3 mg/100 g, 1.29~2.6 g, 0.093~0.52 g and 13.48%~19.29%, respectively. Class III contains 41 resources, and the highest average reducing sugar content was 0.61 g/100 g., in which reducing sugar content was 0.34~1.2 g/100 g, dry matter content was 14.6~23.9 g/100 g, vitamin C content was 6.74~14.9 mg/100 g, crude protein content was 1.12~2.08 g/100 g, crude starch content was 8.56%~17.04%. This group can be used as parents for variety improvement by referring to other traits, such as 11 (Black beauty) can be used as an intermediate material for color potato variety improvement. Class IV contains 37 resources, and the average value of crude protein content is the highest, which was 2.27 g/100 g. Among them, crude protein content was 1.69~3.05 g/100 g, dry matter content was 14.6~22.6 g/100 g, vitamin C content was 7.8~17.8 mg/100 g, reducing sugar content was 0.093~0.56 g/100 g, crude starch content was 10.96%~16.22%. This group showed high crude protein, which could be used as parents to improve high crude protein varieties.

2 Discussion

Broadening the genetic basis of potato and fully exploiting the utilization value of quality traits of germplasm resources are of great significance to the breeding of new potato varieties. According to different quality breeding needs, three quality types of resource groups were evaluated and selected. First one is suitable to be used as high dry matter and low reducing sugar resources for processing quality breeding parents or processing potatoes. 20 resources with dry matter content ≥ 25 g/100 g, 20 resources with reducing sugar content < 0.15 g/100 g, and 5 resources with two traits, namely, Root Potato 2, Root Potato 1, Root Potato 5, CIP396029.205 and Root Potato 4, respectively. Second one is suitable for starch processing varieties to select high starch resources of parents or intermediate materials. Among the 26 resources with crude starch content ≥ 18%, Эалева had the highest crude starch content (23.22%), followed by E15 (22.09%). Third one with high vitamin C and high crude protein resources, which were suitable for breeding parents or intermediate materials of nutritional quality (fresh potato and food processing potato). 43 resources with vitamin C content ≥ 15 mg/100 g, 20 resources with crude protein content ≥ 2.5 g/100 g, and 4 resources with two traits, namely 'Ganyin2', 'CIP396236.2',' Spunta' and 'Flava', respectively.

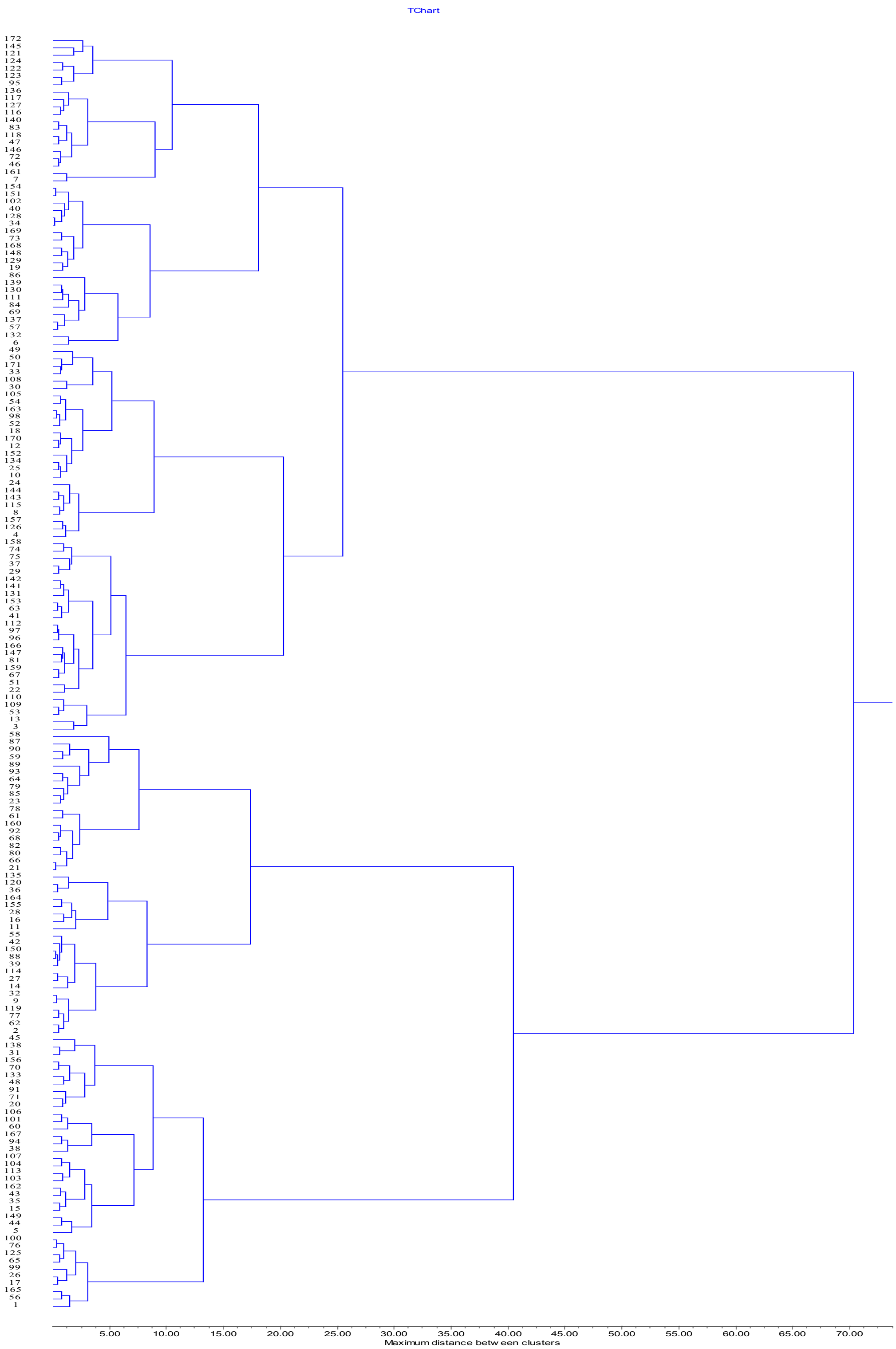

Figure 1 Dendrogram of cluster analysis of 172 potato germplasms

Table 5 Average Values of 5 quality traits in 5 potato groups

Trait	I	II	III	IV
Dry matter (g/100 g)	25.19	22.21	20.24	19.40
Crude protein (g/100 g)	2.13	1.97	1.60	2.27
Vitamin C (mg/100 g)	14.81	13.54	11.04	11.89
Reducing sugar (g/100 g)	0.26	0.24	0.61	0.24
Crude starch (%)	18.59	16.04	14.14	13.64

In this study, it was found that there was a negative correlation between reducing sugar and dry matter, crude protein, crude starch and vitamin C, and a positive correlation among dry matter, crude starch, crude protein and vitamin C, which was consistent with the conclusion of Pan (2019). There was a very significant positive correlation between crude starch content and dry matter content, and the correlation coefficient was 0.87, indicating that crude starch is the main component of dry matter. Combined with the results of principal component analysis, if it is not the breeding of starch processing varieties, the crude starch content can be ignored, and the parents of other special processing varieties such as whole powder, fried slices, fried strips or cooking can be selected, mainly based on low reducing sugar and high dry matter, while referring to other agronomic and quality traits (Yu, 2018). There was a very significant negative correlation between reducing sugar content and crude protein content, with a correlation coefficient of 0.63. This is mainly due to the Maillard reaction between reducing sugar and amino acids in the process of high temperature deep frying, resulting in brown matter, which leads to darker color after deep frying (Da Pereira and Da Costa, 1995; Liu, 2018). Therefore, the higher the crude protein content, the darker the color of French fries after high temperature deep frying.

The main quality traits of potato are mostly quantitative traits controlled by minor polygenes (Sun, 2003). Potato dry matter content and starch content are greatly affected by genetic factors (Pan, 2019), and the inheritance is mainly gene additive effect (Slattery et al., 2000). When breeding varieties with high dry matter or high starch, the parents or intermediate materials must be high dry matter or high starch materials on the basis of selecting other agronomic traits (Sun, 2010). In the breeding of low-reducing sugar varieties, the selection of parents or intermediate materials must consider the combining ability of parents on the basis of comprehensive consideration of other agronomic traits such as low-temperature storage resistance and inheritance of crude protein. Loiselle et al. (1990) found that combining ability of parents affected the process ability and color stability of potato chips.

3 Materials and Methods

3.1 Test site

The test site is located in Longde Guanzhuang Base of Guyuan Branch of Ningxia Academy of Agriculture and Forestry Sciences (35°70’N, 106°18’E), with altitude of 2 300 m, annual average temperature of 8.4°C, frost-free period of 135 d, sunshine of 2 988 h and average annual rainfall of about 603 mm. And the soil of the test site is light black loessial soil, with pH value of 7.6～8.6, content of organic matter of 2.69%, hydrolyzed nitrogen of 96.9 g/kg, available phosphorus of 34.9 g/kg, and available potassium of 202 g/kg.

3.2 Test materials

172 potato germplasm resources, including 116 foreign materials and 56 domestic varieties (Table 6).

3.3 Test methods

From 2017 to 2018, the seeds were sown in numbered order at the Longde Guanzhuang base of Guyuan Branch of Ningxia Academy of Agriculture and Forestry Sciences without repetition. The planting area of each material is 40 m^2, the row spacing is 90 cm, and the plant spacing is 30 cm. 7～14 d after harvest, crude protein (Kjeldahl determination was used in GB/T 5009.5-2010), crude starch (Polarimetry was used in NY/T 11-1985), reducing sugar (Direct titration was used in GB/T 5009.7-2008) and Vitamin C (Fluorometry was used in GB/T 5009.86-2003) were determined, and the samples to be tested were treated according to NY/T1303-2007(AppendixI).

Table 6 172 potato germplasms used in this experiment

No.	Name	Origin	No.	Name	Origin
1	Ailan 1	China	87	CIP396008.104	CIP
2	Ba 72 South Yuxun	China	88	CIP396009.24	CIP
3	White Purple potato	China	89	CIP396009.258	CIP
4	Beishu 1	China	90	CIP396012.266	CIP
5	Chuan 117	China	91	CIP396018.241	CIP
6	Gan71-19-19	China	92	CIP396026.101	CIP
7	Ganyin2	China	93	CIP396026.103	CIP
8	Plateau 6	China	94	CIP396027.205	CIP
9	Plateau 7	China	95	CIP396029.205	CIP
10	Netherlands 15	China	96	CIP396029.25	CIP
11	Black beauty	China	97	CIP396031.108	CIP
12	Red beauty	China	98	CIP396031.119	CIP
13	Tiger head	China	99	CIP396033.102	CIP
14	Ji Zhangshu 12	China	100	CIP396034.103	CIP
15	Zhangshu 20	China	101	CIP396034.268	CIP
16	Jinshu15	China	102	CIP396036.201	CIP
17	Jinshu16	China	103	CIP396037.215	CIP
18	Jinshu18	China	104	CIP396038.101	CIP
19	Jinshu4	China	105	CIP396038.107	CIP
20	Jinshu7	China	106	CIP396043.226	CIP
21	Kexin12	China	107	CIP396046.105	CIP
22	Kexin4	China	108	CIP396236.2	CIP
23	Landan	China	109	CIP396240.2	CIP
24	Liangshu 3	China	110	CIP396240.23	CIP
25	Linshu16	China	111	CIP396241.4	CIP
26	Longshu10	China	112	CIP396244.17	CIP
27	Longshu 11	China	113	CIP396247.15	CIP
28	Longshu 13	China	114	CIP397077.16	CIP
29	Longshu6	China	115	Pasqueflower	Germany
30	Mengshu10	China	116	Baiyin 1	Unknow
31	Mini potato	China	117	Atlantic	American
32	Ningshu12	China	118	Favorita	Holland
33	Ninghu4	China	119	Mira	Germany
34	Ningshu8	China	120	Baron Potato	American
35	Qingshu168	China	121	Root Potato 1	Japan
36	Qingshu2	China	122	Root Potato 2	Japan
37	Tianshu12	China	123	Root Potato 4	Japan
38	Tianshu9	China	124	Root Potato 5	Japan
39	Tong7405-235	China	125	Anti-epidemic White	Unknow
40	Wei178 of 2	China	126	A19	Unknow
41	Wu zao yangyu	China	127	Colmo	Holland
42	Xiyutou	China	128	D52	Unknow
43	Xiazhai	China	129	D74	Unknow
44	Yanshu 9	China	130	Desiree	Holland
45	Miscellaneous single 38	China	131	E13	Unknow
46	Early rose	China	132	E15	Unknow
47	Zhengshu 2	China	133	E86-694	Unknow
48	Zoomlion Red	China	134	EBA	Holland
49	Zhongshu 20	China	135	F16	Unknow
50	Zhongshu 22	China	136	Flava	Germany
51	Zhongshu 5	China	137	GB13-8	Unknow
52	Zhongshu 9	China	138	H29	Unknow
53	Zhongshu D540	China	139	Herbstgelbe	Germany
54	Zhongshu D5682	China	140	I46	Unknow
55	Center 24	China	141	IDIAP92(381381.13)	Unknow
56	Ziyun 1	China	142	INIA310; Chucmarina(393371.58)	Unknow
57	CIP378711.5	CIP	143	J21	Unknow
58	CIP391046.14	CIP	144	K3	Unknow

Continued Table 6

No.	Name	Origin	No.	Name	Origin
59	CIP393075.54	CIP	145	K6	Unknow
60	CIP393077.159	CIP	146	LK99	Unknow
61	CIP393077.54	CIP	147	M12	Unknow
62	CIP393079.24	CIP	148	Multa	Holland
63	CIP393248.55	CIP	149	N14	Unknow
64	CIP393280.57	CIP	150	N8	Unknow
65	CIP393280.82	CIP	151	NS51-5	Unknow
66	CIP393371.157	CIP	152	NS78-1	Unknow
67	CIP393385.57	CIP	153	NS78-21	Unknow
68	CIP395011.2	CIP	154	NS78-78-1	Unknow
69	CIP395015.6	CIP	155	NS880407	Unknow
70	CIP395017.14	CIP	156	P4	Unknow
71	CIP395017.227	CIP	157	P7	Unknow
72	CIP395017.229	CIP	158	PAMPEANA-INTA	Unknow
73	CIP395017.242	CIP	159	S41956	Unknow
74	CIP395037.107	CIP	160	SERRANITA(391691.96)	Unknow
75	CIP395077.12	CIP	161	Spunta	Holland
76	CIP395084.9	CIP	162	Tacan	Unknow
77	CIP395096.2	CIP	163	Tawa	American
78	CIP395109.29	CIP	164	Vester	Denmark
79	CIP395109.34	CIP	165	Victoria (381381.2)	Unknow
80	CIP395111.13	CIP	166	wilia	Holland
81	CIP395112.19	CIP	167	Zeisig	Germany
82	CIP395112.32	CIP	168	Голубиэна	Unknow
83	CIP395112.36	CIP	169	Малиновка	Unknow
84	CIP395112.6	CIP	170	Никунеенский	Unknow
85	CIP395114.5	CIP	171	Удача	Unknow
86	CIP395123.6	CIP	172	Эалева	Unknow

3.4 Data analysis

DPS16.5 data processing system and Excel2010 were used for statistical analysis. Euclidean distance and sum of squares of deviation were used for systematic cluster analysis.

Authors' contributions

XRX is the experimental designer and executor of this study. ZXC participated in data collation and drafted the manuscript. ZGH and YBQ participated in part of experiments. WLK and GZQ conceived of the project, directed the design of the study, data analysis, draft and revision. All authors read and approved the final manuscript.

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