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QUALITY EVALUATION OF TIBETAN HIGHLAND BARLEY BY GREY RELATIONAL GRADE ANALYSIS

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Abstract

To evaluate comprehensively the varietal differences in quality, ten highland barley varieties were analyzed by employing grey system theory. The concentrations of nutritional compounds were found to be 0.14 ~ 0.42% for flavones, 2.65 ~ 6.52% for β-glucan, and 2.27 ~ 64.97 mg/100 g for anthocyanin. The results indicated that Zangqing 85 possessed excellent quality considering those compounds, followed by purple highland barley, black highland barley and blue highland barley with high content of anthocyanin. The results of this study provide the key support for highland barley breeding, harvest, application and quality analysis.

Introduction

Highland barley adapts poor soil, high altitude and cold weather, and it has characteristic of short growth duration and wide adaptability (Yang *et al.* 2000, Tang *et al.* 2017). It is a symbolic crop cultivated in Tibetan Plateau which is one crop a year. The highland barley is not only the irreplaceable staple food of Tibetan farmers, but also the significant raw material of feedstuff processing and brewing industry (Yuan *et al.* 2018). Therefore, the development of highland barley production is the basic factor that influences agriculture growth, the improvement of people's living standard and social stability. Highland barley owns high protein, high fiber, high vitamins, low fat and low sugar. It also contains minerals, amino acids and vitamins more than other grains. It can alleviate the deficiency of nutrition, improve immunity, effectively reduce blood lipids and anti-tumor effect under long term consumption (Newman and Newman 2006, Ames and Rhymer 2008, Pins *et al.* 2006). Tibetan compatriots are able to survive mostly on highland barley in cold areas where there is lack of fruits and vegetables. Therefore, highland barley has become the world's widely favoured health food which can promote health and prevent diseases; and also it has special medical functions (Colombo 2010, Poutanen 2012). At present, the studies on functional components of highland barley are mostly concentrated on ß-glucan ((Bhatty 1993, Wang *et al.* 2000, Zhang *et al.* 2002, Papageo *et al.* 2005), and a few on the content of flavonoids and anthocyanin. This study employed the grey relational comprehensive evaluation for analyzing the comprehensive quality of barley, *viz.* basic nutritional quality including trace elements, and also specific quality, *viz.* β-glucan, flavonoids, and anthocyanins in order to select high quality barley varieties for developing barley functional health food.

Materials and Methods

Survey area: Lhasa city: Nyemo County, Quxur County, Linzhou County; Shannan Prefecture: Long Zi county, Naidong County, ChaNang County, Gongga County; Shigatse city: Jiangzi County, Lazi County, Panam County, Sangzhu Zi area; Linzhi city, Pakistan Yi District, Kampot

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Jomda county; Chang Du city, Karub district, Lhorong county, Bainbar county, Mangkam county; Ngari Prefecture, Burang county, Zada county. The investigation is located in between 90°03′～90°38′ east longitude and 28°27′～29°34′ north latitude, including six districts and nineteen counties in Tibet city, covering different types of ecological regions and the production area of Tibet highland barley.

Selection of varieties (strain): ordinary barley: white barley, Zangqing 85, Xila 22, Zangqing 2000, Mingma, Zangqing 320, Zangqing 13, Colored highland barley, blue highland barley, purple highland barley and black highland barley. All the selected barley were harvested in 2017.

Experimental analysis method: Crude protein determination method refers to GB5009.5-2010. Coarse fiber determination method bases in GB/T 5009.10-2003. Starch use GB/T 5009.9-2009. Phosphorus, potassium, calcium, iron, magnesium, manganese, copper and zinc were determined by ICP-MS. The data of ß-glucan, flavone and anthocyanin were determined in Northwest Plateau Biological Institute of Chinese Academy of Sciences. SPSS was used for variance analysis and multiple comparisons and comprehensive evaluation were applied to grey relational analysis.

Results and Discussion

The range of flavonoids content in Tibetan highland barley was 0.14 ~ 0.42% with an average of 0.23%, while ß-glucan content was in the range of 2.65 ~ 6.52% with an average content of 4.59%. Anthocyanin content in colored barley varied greatly in the range of 2.27 ~ 64.97 mg/100g with a mean value of 13.32 mg/100 g (Table 1). Compared to the common highland barley, the content of flavonoids in colored highland barley increased by 8 ~ 36%, the content of anthocyanin by 6.9 ~ 19.8 mg/100 g, though the content of ß-glucan was lower than that of common highland barley. There were significant differences in nutritional quality regarding crude protein content between the two kinds of barley.

The content of the trace elements in colored highland barley was generally low, especially Mn, Cu and Zn, which were significantly lower than that of common highland barley. Compared to other studies copper, iron, manganese, and zinc content in highland barley were higher than those in others area (Sager *et al.* 2005, Zhu 2006, Bleidere *et al.* 2013, Jākobsone *et al.* 2018). The result indicated that the content of three trace elements, *viz.* iron, zinc and copper in Tang Yawei Tibetan area's highland barley was significantly higher than that in imported materials. However, compared to the findings of Tang (2015) the average content of iron and manganese in this study was noticeably higher, though the zinc and copper content was lower.

Since the quality traits considered in this study were too many and various performance indicators were not the same single index's comparison and analysis was not appropriate to evaluate the comprehensive quality of barley, the grey relational grade analysis method presumably overcome the problem. It is a comprehensive description and quantitative evaluation of the main target characters of varieties. Professor Deng Julong established the grey system theory in 1982. The method is simple, convenient, practical, accurate and reliable. It has attracted more and more researchers' attention. The method was used successfully for analysis of quality parameters in new oat varieties in Tibet (Wei *et al.* 2013). According to the grey system theory, all the tested highland barley material was regarded as a grey system, and each trial barley was one of the factors in the system. According to the development and production of the actual requirement, the main quality parameters of barley varieties constitute together into an "ideal variety", all traits of the "ideal variety" sequence as the reference series, and all the tested varieties constitute index sequence as comparison sequence. In order to comprehend the quality of different varieties of highland barley, and to facilitate enterprises, farmers and herdsmen, the comprehensive quality and specific quality of highland barley were evaluated accordingly. The basic nutritional index

(crude protein, crude starch, crude fiber, P and K), trace element index (calcium, iron, magnesium, manganese, copper and zinc), and specific quality (ß-glucan, flavonoids, and anthocyanin) were used for the comprehensive quality evaluation. Nonetheless, 14 indexes in three categories were considered for correlation analysis and the weighted correlation coefficient was used to determine the order of varieties.

The establishment of ideal varieties and the determination of their weight coefficients are the key to evaluate crop quality with grey relational grade method. The research on comprehensive evaluation and specific evaluation accomplish the maximum nutritional index of variety as an ideal index (Table 1). Different weight coefficients were given to the main characters of each variety. This research was mainly about the specific quality, so it was set to the maximum as the sum of coefficients was 0.51. And for the specific quality ß-glucan developed the greatest contribution on product functional, the weight coefficient was slightly higher than that of other specific indicators, another indicators' weight coefficient is shown in Table 1. Similarly, ß-glucan was the highest in specific evaluation, as 0.40, and the coefficients of flavone and anthocyanin were 0.30.

Because the dimension of each performance index was different, it was necessary to do the dimensionless processing of the original data of each index. Using the initial value method, the data in the table was compressed into the range of (0 to 1), that is, the index values of the tested varieties were divided by the corresponding indexes of the ideal varieties, and the data are listed in Table 2. Then, according to the data obtained from the dimensionless treatment, the absolute difference between the corresponding characters of the tested varieties and the ideal varieties was obtained (Table 3). Then, according to the following formula, the corresponding correlation coefficients were calculated. The weighted correlation degree is the average value of the row correlation coefficient, and the weighted correlation degree is the sum of the product of each correlation coefficient and the corresponding weight coefficient.

$$\xi_{i(k)} = \frac{\min\limits_{i}\min\limits_{k}|\Delta_{i(k)}| + \rho\max\limits_{i}\max\limits_{k}|\Delta_{i(k)}|}{|\Delta_{i(k)}| + \rho\max\limits_{i}\max\limits_{k}|\Delta_{i(k)}|}$$

In the formula, $\xi_{i(k)}$ as the correlation coefficient, $|\Delta_{i(k)}|$ as the absolute difference of the reference sequence and the comparative sequence in k points, $\min_{k}|\Delta_{i(k)}|$ as a first grade minimum difference, means minimum differential reference sequence index of each character in the corresponding index, $\min_{i}\min_{k}|\Delta_{i(k)}|$ as a second grade minimum difference, means the minimum difference based on the first grade minimum difference. Table 3 shows that second minimum difference is 0. $\max_{i}\max_{k}|\Delta_{i(k)}|$ is the second-grade largest difference, and the meaning is similar to the second-grade minimum difference (Table 3 shows that the second grade largest difference is 1). ρ is resolving coefficients, the range is from zero to one, usually 0.5.

The comprehensive evaluation correlation value of the participants varieties is shown in Table 4. The weighted correlation coefficient from high to low was Zangqing 85 > purple highland barley > black highland barley > blue highland barley > Zangqing 320 > Zangqing 2000 > Xila 22 > white barley > Mingma > Zangqing 13. According to the principle of multi-dimensional comprehensive evaluation of grey relational grade, the comprehensive evaluation of the correlation degree reflects the quality of the tested varieties, and the greater the correlation degree is, the better the corresponding varieties are, and vice versa. The results indicated that the Zangqing 85, having the best quality of various nutritional indicators ranked the first; and purple barley and black barley due to high content of anthocyanins were ranked second and the third,

Table 1. Nutritional quality content in highland barley, and reference sequence and weight coefficient.

Varieties	CS (%)	CP (%)	CF (%)	Ca (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	K (mg/kg)	Mg (mg/kg)	Mn (mg/kg)	P (mg/kg)	Zn (mg/kg)	β-glucan (%)	EGB (%)	OPC (mg/100g)
White barly	49.93	10.73	2.64	324.77	3.16	43.36	5855.85	987.85	10.96	3200.15	16.83	4.20	0.34	0
Zangqing320	48.55	13.10	3.06	342.38	5.31	107.35	6320.09	1008.21	15.27	4009.20	28.19	4.554	0.194	0
Zangqing2000	48.88	12.80	2.98	420.18	5.24	85.33	5694.92	1116.65	15.51	3726.41	24.43	4.527	0.215	0
Blue barley	49.85	10.22	2.73	299.18	3.47	46.91	5000.62	809.85	9.27	3650.68	17.82	4.043	0.303	7.62
Xila22	49.01	11.81	3.11	383.29	4.93	82.84	5653.12	1052.02	14.86	4225.93	25.56	4.405	0.237	0
Purple barly	50.02	12.58	2.53	444.01	2.61	76.81	5907.46	1005.98	11.99	3544.67	18.48	3.962	0.285	7.60
Black barley	50.98	12.80	3.12	482.30	3.82	45.87	5764.02	1191.37	14.80	3899.34	19.50	4.815	0.285	3.82
Mingma	51.53	8.89	4.00	36.49	5.09	28.14	7532.72	759.89	9.73	7189.41	36.11	2.830	0.190	0
Zangqing85	47.81	15.59	3.66	742.81	4.23	73.84	5822.72	1158.29	18.27	3727.63	21.40	5.360	0.250	0
Zangqing13	48.71	17.71	3.23	572.37	3.38	42.79	5695.47	1112.85	13.75	3636.25	13.79	3.770	0.200	0
Mean	49.03	12.55	2.96	408.04	4.95	81.12	5686.14	1083.05	14.82	3761.30	23.76	4.459	0.227	/
Reference sequence	51.53	17.71	4.00	6320.09	7189.41	742.81	5.31	107.35	1191.37	18.27	36.11	5.36	0.34	7.62
W_K weight	0.05	0.05	0.03	0.03	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.21	0.15	0.15

Table 2. Initialization values of main factor.

Varieties	CS	CP	CF	K	P	Ca	Cu	Fe	Mg	Mn	Zn	β-glucan	EGB	OPC
White barly	0.96895	0.60561	0.65996	0.43722	0.59441	0.40392	0.92655	0.82917	0.59955	0.44512	0.46623	0.78312	1.00000	0.00000
Zangqing320	0.94217	0.73983	0.76382	0.46092	1.00000	1.00000	1.00000	0.84627	0.83549	0.55765	0.78087	0.84963	0.56642	0.00000
Zangqing2000	0.948532	0.72262	0.74459	0.56566	0.98561	0.79492	0.90108	0.93729	0.84868	0.51832	0.67669	0.84465	0.62866	0.00000
Blue barley	0.96743	0.57692	0.68276	0.40277	0.65287	0.43704	0.79123	0.67976	0.50717	0.50779	0.49341	0.75435	0.88321	1.00000
Xila22	0.951096	0.66662	0.77786	0.51600	0.92799	0.77173	0.89447	0.88304	0.81324	0.58780	0.70784	0.82174	0.69277	0.00000
Purple barly	0.970697	0.71028	0.63220	0.59775	0.49176	0.71557	0.93471	0.84439	0.65601	0.49304	0.51177	0.73912	0.83212	0.99724
Black barley	0.98923	0.72241	0.77897	0.64929	0.71911	0.42732	0.91201	1.00000	0.80978	0.54237	0.54008	0.89832	0.83212	0.50048
Mingma	1	0.50180	1.00000	0.04912	0.95722	0.26218	1.19187	0.63783	0.53266	1.00000	1.00000	0.52799	0.55474	0.00000
Zangqing85	0.927809	0.88044	0.91388	1.00000	0.79649	0.68789	0.92130	0.97223	1.00000	0.51849	0.59279	1.00000	0.72993	0.00000
Zangqing13	0.945275	1.00000	0.80731	0.77055	0.63690	0.39863	0.90117	0.93409	0.75252	0.50578	0.38205	0.70336	0.58394	0.00000

Table 3. The absolute difference of characteristics of experimental varieties and reference variety.

Varieties	CS	CP	CF	K	P	Ca	Cu	Fe	Mg	Mn	Zn	β-glucan	EGB	OPC
White barly	0.03105	0.39439	0.34004	0.56278	0.40559	0.59608	0.07345	0.17083	0.40045	0.55488	0.53377	0.21688	0.00000	1.00000
Zangqing320	0.05783	0.26017	0.23618	0.53908	0.00000	0.00000	0.00000	0.15373	0.16451	0.44235	0.21913	0.15037	0.43358	1.00000
Zangqing2000	0.05147	0.27738	0.25541	0.43434	0.01439	0.20508	0.09892	0.06271	0.15132	0.48168	0.32331	0.15535	0.37134	1.00000
Blue barley	0.03257	0.42308	0.31724	0.59723	0.34713	0.56296	0.20877	0.32024	0.49283	0.49221	0.50659	0.24565	0.11679	0.00000
Xila22	0.04890	0.33338	0.22214	0.48400	0.07201	0.22827	0.10553	0.11696	0.18676	0.41220	0.29216	0.17826	0.30723	1.00000
Purple barly	0.02930	0.28972	0.36780	0.40225	0.50824	0.28443	0.06529	0.15561	0.34399	0.50696	0.48823	0.26088	0.16788	0.00276
Black barley	0.01077	0.27759	0.22103	0.35071	0.28089	0.57268	0.08799	0.00000	0.19022	0.45763	0.45992	0.10168	0.16788	0.49952
Mingma	0.00000	0.49820	0.00000	0.95088	0.04278	0.73782	-0.19187	0.36217	0.46734	0.00000	0.00000	0.47201	0.44526	1.00000
Zangqing85	0.07219	0.11956	0.08612	0.00000	0.20351	0.31211	0.07870	0.02777	0.00000	0.48151	0.40721	0.00000	0.27007	1.00000
Zangqing13	0.05473	0.00000	0.19269	0.22945	0.36310	0.60137	0.09883	0.06591	0.24748	0.49422	0.61795	0.29664	0.41606	1.00000

Table 4. The correlation coefficient and weighting association of experimental varieties.

Varieties	CS	CP	CF	K	P	Ca	Cu	Fe	Mg	Mn	Zn	β-glucan	EGB	OPC	CWRV	SWRV
White barly	0.9415	0.5590	0.5952	0.4705	0.5521	0.4562	0.8719	0.7453	0.5553	0.4740	0.4837	0.6975	1.0000	0.3333	0.6429	0.6872
Zangqing320	0.8963	0.6577	0.6792	0.4812	1.0000	1.0000	1.0000	0.7648	0.7524	0.5306	0.6953	0.7688	0.5356	0.3333	0.6705	0.5306
Zangqing2000	0.9067	0.6432	0.6619	0.5351	0.9720	0.7091	0.8348	0.8886	0.7677	0.5093	0.6073	0.7630	0.5738	0.3333	0.6580	0.5375
Blue barley	0.9388	0.5417	0.6118	0.4557	0.5902	0.4704	0.7054	0.6096	0.5036	0.5039	0.4967	0.6706	0.8107	1.0000	0.6974	0.8152
Xila22	0.9109	0.6000	0.6924	0.5081	0.8741	0.6866	0.8257	0.8104	0.7281	0.5481	0.6312	0.7372	0.6194	0.3333	0.6472	0.5514
Purple barly	0.9446	0.6331	0.5762	0.5542	0.4959	0.6374	0.8845	0.7627	0.5924	0.4965	0.5060	0.6571	0.7486	0.9945	0.7145	0.8010
Black barley	0.9789	0.6430	0.6935	0.5877	0.6403	0.4661	0.8504	1.0000	0.7244	0.5221	0.5209	0.8310	0.7486	0.5002	0.7019	0.6575
Mingma	1.0000	0.5009	1.0000	0.3446	0.9212	0.4039	1.6227	0.5799	0.5169	1.0000	1.0000	0.5144	0.5290	0.3333	0.6094	0.5316
Zangqing85	0.8738	0.8070	0.8531	1.0000	0.7107	0.6157	0.8640	0.9474	1.0000	0.5094	0.5511	1.0000	0.6493	0.3333	0.7495	0.5893
Zangqing13	0.9013	1.0000	0.7218	0.6855	0.5793	0.4540	0.8350	0.8835	0.6689	0.5029	0.4472	0.6276	0.5458	0.3333	0.6065	0.5152

CWRV: Comprehensively weighted relevancy value，SWRV: Specifically weighted relevancy value.

respectively. Although blue barley had the highest anthocyanin content and high flavonoid content, but due to having low contents of trace elements ranked the fourth; the quality of Zangqing 320 and Zangqing 2000 were general.

In specific quality evaluation, correlation degree from high to low was: blue highland barley > purple highland barley > white barley > black highland barley > Zangqing 85 > Xila 22 > Zangqing 2000 > Mingma > Zangqing 320 > Zangqing 13. The special component of colored barley showed advantages, and the blue barley was the most obvious advantage, ranked first; ß-glucanin purple barley was relatively low, ranked second. Although the white barley showed relatively lower nutrients in the comprehensive evaluation, but because of having high yellow ketone content it was ranked third; while, because of black barley's anthocyanin content was significantly lower than that of other colored barley, it ranked fourth.

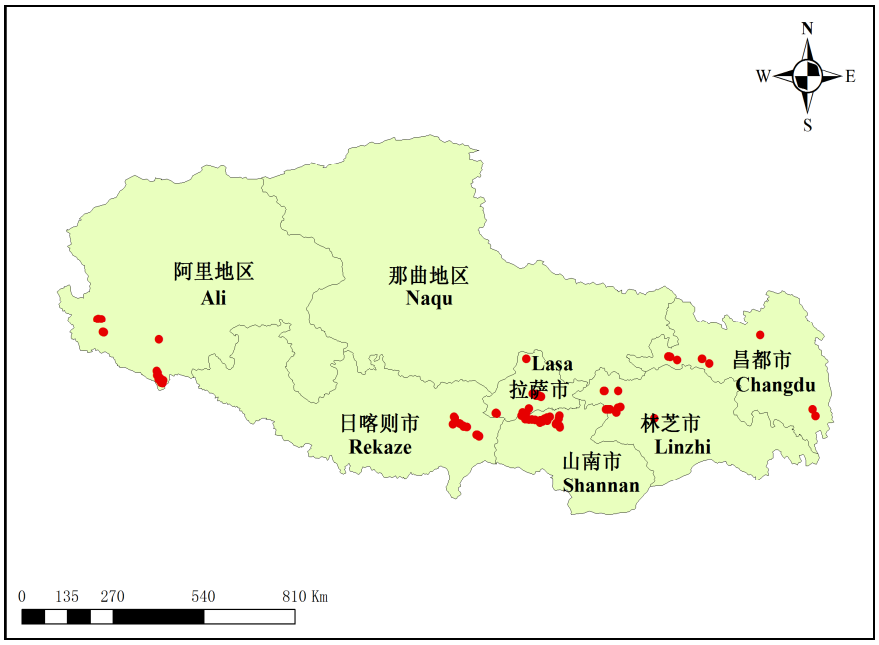

Fig. 1. Distribution of sampling sites.

Table 5. The correlation coefficient and weighting association of experimental varieties in 2016.

Varieties	CWRV	SWRV	Varieties	CWRV	SWRV
Zangqing2000	0.7218	0.6425	Blue barley	0.7309	0.7346
Zangqing320	0.7028	0.7053	Pinbi13	0.7275	0.7119
Zangqing85	0.8323	0.7840	Xila19	0.6861	0.6320
Guoluo	0.7520	0.7302	Xila22	0.7643	0.6634
Black barley	0.7877	0.9082	Purple barly	0.7320	0.7743

CWRV: Comprehensively weighted relevancy value SWRV: Specifically weighted relevancy value.

Since all the varieties used for the study in 206 and 2017 were not the same, the results of only the common varieties were compared in order to make the conclusion more accurate and reliable, and the weighted correlation coefficient from high to low were : Zangqing 85 > black barley > purple highland barley > blue highland barley > Zangqing 2000 > Zangqing 320, the comprehensive evaluation results are the same as in 2017, which shows the superiority of grey correlation evaluation and the stability of fine inheritance varieties. Based on the analysis of multiple quality characters of highland barley, the grey relational grade analysis method was used to provide a scientific basis for the breeding and quality evaluation of highland barley in Tibet.

The key for a comprehensive evaluation method is to select a proper evaluation index and determine the weight coefficients of indices. To avoid considering only the disadvantages of partial factors and ignoring other factors and to best reflect the true status (or value) of the evaluated varieties, this study selected five basic nutrition types, 6 trace elements as well as three specific quality indices as criteria in combination with an equalized weight index value based production practices for evaluating various varieties of highland barley of different production areas and ecosystems in Tibet region to improve the accuracy and validity of a comprehensive evaluation. Kim *et al. (*2007) showed that colored barley contains abundant phenolic compounds, which have strong antioxidant activity and can prevent coronary heart disease and cancer (Holtekjolen *et al.* 2006). However, this study did not evaluate the phenolic compounds, which are suggested to investigate further in the follow-up study in order to evaluate the quality of Tibetan highland barley varieties more comprehensively and objectively.

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