Genetic diversity analysis of fruit characteristics of hawthorn germplasm

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ABSTRACT. One hundred and six accessions of hawthorn intraspecific resources, from the National Germplasm Repository at Shenyang, were subjected to genetic diversity and principal component analysis based on evaluation data of 15 fruit traits. Results showed that the genetic diversity of hawthorn fruit traits varied. Among the 15 traits, the fruit shape variable coefficient had the most obvious evaluation, followed by fruit surface state, dot color, taste, weight of single fruit, sepal posture, peduncle form, and metula traits. These are the primary traits by which hawthorn could be classified in the future. The principal component demonstrated that these traits are the most influential factors of hawthorn fruit characteristics.

Key words: Hawthorn; Genetic diversity; Principal component

INTRODUCTION

Hawthorn (*Crataegus* spp) is native to China, and over the past 3000 years, by both natural and artificial (human) selection, it has developed to form abundant germplasm. In 1982, the unique professional hawthorn germplasm resource-keeping garden was constructed in Shenyang, China. Four hundred accessions, contained in 11 *Crataegus* species, have been collected and saved in this repository; most resources belong to the intraspecific cultivar of hawthorn. As the scale of the collecting resource increases, research and appraisal of basic traits of hawthorn are possible. Germplasm resource evaluation has been carried out on the majority of fruit tree species in China, especially with respect to the study of fruit traits. Data has been widely reported for most species, including macadamia nut (Wang et al., 2011); loquat (Lin et al., 2009; Zhang et al., 2009); jack fruit (Wang et al., 2009); mango (Zhu et al., 2010); longan (Huang et al., 2010); Jujube (Yang et al., 2006); strawberry (Yang et al., 2007); apple (Wang et al., 2007); cherry (Qi et al., 2008); and peach (Wang et al., 2005). The evaluation of hawthorn germplasm resource, however, has not been reported. In the current study, genetic diversity and principal component was analyzed to evaluate fruit traits for 106 accessions of Chinese hawthorn. The study provides practical guidance and theoretical basis for the future collection, development, and variety breeding of hawthorn.

MATERIAL AND METHODS

Plants

Accessions of hawthorn intraspecific resources (N = 106), maintained in the Shenyang National Hawthorn Germplasm Nursery were used (Table 1). The picking date was October of 2012. For each specimen, 15 fruit traits were evaluated.

Table 1. Hawthorn (*Crataegus pinnatifida* Bge.) cultivars included for analysis.

Resource name	Resource name	Resource name	Resource name	Resource name	Resource name
Anshanzirou	Fushantieqiu	Liaohong	Pingyitianhongzi	Waibahong	Yiduxiaohuang
Baili	Guajiayu No. 1	Liaoyangzirou	Pingyiyinhongzi	Wanqiushanlihong	Yinyeling No. 2
Bairangmian	Haitangshanzha	Linxianshangkou	Qingyuanmopan	Wanbaodidajinxing	Yinyeling No. 9
Baihuayudahong	Hanfeng	Linfen No. 1	Qiufeng	Wanbaodishisheng	Zaohong
Baihuayushanzha	Hezedashanzha	Lufu No. 1	Qiuhong	Xifen No. 1	Zimuhong
Beijingshanzha	Huabeixiaoshanzha	Luojiagoushanzha	Qiujinxing	Xifen No. 4	Zizhenzhu
Benxi No. 7	Hengrenxiangyang	Maershanlihong	Qiuli	Xifen No. 5	Fengshuishanzha
Chaojixing	Huangbaoyu No. 1	Magangzaohong	Shandongdajinxing	Xifenshisheng	Laiwuheihong
Dahuang	Huangguo	Majiadadui	Shanxitiansheng	Xifenghong	Pingyishanzha
Dahuo	Huixiandahongkongqi	Majiafenrou	Shangzhuanbaizha	Xihong	Tongtaibaiyesheng
Damianqiu	Jiguanshanshanzha	Mengyinbanyexiaojinxing	Shenglizirou	Xiajinxing	Yiduchangkou
Datangqiu	Jilinyehe	Mengyindajinxing	Shisheng No. 1	Xianpingzhenmu No. 1	Feixiandamianqiu
Dawangmiao	Jianzirou	Mengyinxiaojinxing	Shuanghong	Xiaomianqiu	Kaiyuanruanzi
Dawang	Jianchangshanzha	Muhuli	Songshancunshisheng	Xinghong No. 3	Pingyifuhongzi
Donglingqingkou	Jinxiandahongshanzha	Niejiayu No. 2	Taianshiliu	Xinglongshisheng	Tongliaohong
Donglingshanzha	Jinxiantianshanzha	Niuxintai No. 1	Tangchi No. 2	Xingshiliu	Yepu No. 1
Duanzhihanluhong	Jinxianxiaoye	Piposhi	Tianshui	Yanrangqing	
Fakushishengshanlihong	Jiuzhaishanzha	Pingyidahongzi	Tielingshanzha	Yangjiabaodahong	

Data collection, trimming, and analysis

Based on the Hawthorn Germplasm Resource Description and Data Standard, basic trait and identification data were collected for each accession, including 14 fruit classification traits

(peduncle form and trait; sepal form and posture; fruit form, surface color and surface state; fruit dot quantity, color, and size; pulp color and texture, and fruit flavor and fragrance) and a single numeric trait (fruit weight). The classification code used is shown in Table 2. All data were analyzed using SPSS statistical software.

Table 2. Hawthorn (*Crataegus pinnatifida* Bge.) fruit characteristics and classifications.

Characteristic	No. of cultivars	Grade code							
		1	2	3	4	5	6	7	8
Peduncle form	106	Wide shallow	Flat	Upheaval					
Metula trait	106	Expanded	Tumor in one side						
Sepal shape	106	Triangular	Lanceolate	Ligulate					
Sepal posture	93	Open, sepal apex upright	Half open, sepal apex upright	Half open, sepal apex warped	Opening, sepal apex flat	Opening, sepal apex warped	Sepal folding	Folding, sepal apex warped	
Fruit shape	100	Sub-rounded	Oblate	Ovate	Obovate	Oblong	Wide ovate	Squarish	Irregular
Surface color	99	Yellow	Orange red	Red					
Surface state	99	Rough	Smooth matte	Smooth glossy					
Fruit dot quantity	94	None	Few	Medium	Many				
Fruit dot color	95	Ashen	Golden	Tawny	Brown				
Fruit dot size	87	Small	Medium	Large					
Sarcocarp color	106	Green	White	Yellow	Pink	Red	Purple		
Fruit texture	106	Hard	Compact	Mellow-soft	Soft				
Fruit flavor	106	Sweet	Sour and sweet	Sweet and sour	Sour	Sourest	Thin	Bitter	
Fruit fragrance	106	None	Thin	Thick					

RESULTS

Genetic diversity analysis of hawthorn germplasm fruit characteristics

Results are shown in Tables 3 and 4. The variable coefficient of the fruit form (100 accessions) had the highest value (54.88%); fruit form was diverse and included suborbicular, flat circular, ovate, obovate, oblong, oval, wide ovate and square forms. The variable coefficient of the fruit surface state (99 accessions) was 42.87%; this trait included rough, smooth glossy, and smooth matte classifications. The variable coefficient of fruit dot color was 42.29%, including ashen, golden, tawny, and brown classifications (95 accessions). The variable coefficient of the peduncle form was 37.74%; wide-shallow, flat and upheaval forms were described in the 106 accessions. The variable coefficient of sepal posture was 37.42% and included open-upright, half open-upright, half open-warped, open-flat, open-warped, folding, and folding-warped classifications. The variable coefficient of metula trait was 35.51%, including the classifications expanding, and a tumor in one side. The variable coefficient of fruit dot size was 31.75%, including small, medium, and large. The variable coefficient of sepal trait was 23.54%, including trilateral, lanceolate, and ligulate forms. The variable coefficient of fruit dot number was 20.56%, including few, medium, and many. The variable coefficient of fruit surface color was 17.22%, including yellow, red, and orange red. The variable coefficient of fruit fragrance was 41.39%, including thick, thin, and without smell. The variable coefficient of pulp color was 34.18%, including green, white, yellow, pink, and red. The variable coefficient of fruit fragrance was 26.51% including thin, thick, and without fragrance. The variable coefficient of fruit texture was 23.87%, including hard, compact, mellow soft, and soft. The variable coefficient of single fruit weight was 36.15%; the amplitude of variation was 1.5-16.5 g. Significant variable coefficients were those of fruit shape, fruit surface, fruit dot color, fruit flavor, single fruit weight, sepal posture, peduncle form and the trait of metula. Based on these results, we suggest that these be the major traits for hawthorn categorization in the future.

Table 3. Genetic diversity analysis of hawthorn (*Crataegus pinnatifida* Bge.) fruit traits.

Character	No. of cultivars	Min	Max	Mean	SD	CV
Peduncle form	106	1.00	3.00	1.4057	0.53056	37.74
Metula trait	106	1.00	2.00	1.3208	0.46898	35.51
Sepal shape	106	1.00	3.00	2.3585	0.55530	23.54
Sepal posture	93	1.00	7.00	3.9785	1.48893	37.42
Fruit shape	100	1.00	8.00	4.8200	2.64529	54.88
Surface color	99	1.00	3.00	2.8384	0.48879	17.22
Surface state	99	1.00	3.00	1.4141	0.60626	42.87
Fruit dot quantity	94	2.00	4.00	3.2447	0.66698	20.56
Fruit dot color	95	1.00	4.00	2.6105	1.1041	42.29
Fruit dot size	87	1.00	3.00	1.9425	0.61675	31.75
Sarcocarp color	106	1.00	5.00	2.8491	0.97387	34.18
Fruit texture	106	1.00	4.00	2.8585	0.68227	23.87
Fruit flavor	106	1.00	7.00	3.1226	1.29249	41.39
Fruit fragrance	106	1.00	3.00	2.2264	0.59013	26.51
e	106	1.50	16.25	7.6963	2.78245	36.15

Table 4. Frequency distribution of hawthorn fruit characteristics.

Character	No. of cultivars	Frequency							
		1	2	3	4	5	6	7	8
Peduncle form		106.0	61.32	36.79	1.88				
Metula trait	106	67.92	32.07						
Sepal shape	106	3.77	56.60	39.62					
Sepal posture	93	7.52	6.45	17.20	38.70	18.27	3.22	8.60	
Fruit shape	100	5.0	37.0	1.0	2.0	1.0	8.0	29.0	17
Surface color	99	5.05	6.06	88.88					
Surface state	99	64.64	29.29	6.06					
Fruit dot quantity	94	0.0	12.76	50.0	37.23				
Fruit dot color	95	17.89	33.68	17.89	30.52				
Fruit dot size	87	21.83	62.06	16.09					
Sarcocarp color	106	16.98	3.77	57.54	20.75	0.94			
Fruit texture	106	2.83	22.64	60.37	14.45				
Fruit flavor	106	6.60	25.47	37.73	17.92	6.60	2.83		
Fruit fragrance	106	8.49	60.37	31.31					

Analysis of frequency distribution of hawthorn traits

Genetic diversity of fruit traits in 10 hawthorn germplasm resource (Table 4) demonstrated that the peduncle form for most fruits was wide-shallow (61.32%), followed by open and flat; upheaval was the least common form. For the majority of accessions, the metula trait was expanded. The most common sepal state was triangular (56.6% of cases), followed lanceolate and then ligulate. The most common sepal posture was open and flat, followed by half open warped and open warped; open straight, half open straight and folded were less common, and folded warped was the least common. The majority of accessions had oblate fruit, and the most common fruit color was red (in 88.88% of cases). The most common fruit surface trait rough. All fruit examined had dots; the most common classification for the number of dots was medium, the majority of dots were golden and brown, and the majority of dots were medium sized. The most common sarcocarp color was yellow. The most common fruit texture was soft; the majority of fruit had a sour sweet or sweet sour flavor, and a thin fragrance (60.37%).

Principal component analysis

Principal component analysis demonstrated the effect of each factor in form diversity; the cumulative contributive percentage of the first six principal components was 65.472%, containing the vast majority of messages (Table 5). The contributive percentage of the first principal component was 19.004%, of which, single fruit weight had a significant capacity, being the main factor of fruit economic traits. The second principal component included peduncle depression, metula and fruit dot color; these traits had abundant genetic diversity (Table 3). The third principal component included fruit texture, fruit flavor and sarcocarp color; these may reflect the correlated character of fruit texture in which fruit flavor is a negative factor. The fourth principal component included sepal posture and fruit surface traits; the fifth included fruit and sepal shape, with sepal shape being a negative factor; the sixth included fruit surface color, dot size, and dot numbers, with the latter being a negative factor.

Table 5. Results of analysis of principal components in hawthorn.

		Principal component					
		Prin1	Prin2	Prin3	Prin4	Prin5	Prin6
Eigen value		2.661	1.687	1.433	1.316	1.058	1.011
Contributive percentage		19.004	12.052	10.234	9.397	7.559	7.224
Total contributive percentage		19.004	31.057	41.291	50.688	58.247	65.472
Eigenvectors	Single fruit weight	0.4653	-0.1414	-0.0443	0.0463	-0.0375	-0.0569
	Sarcocarp color	-0.1976	-0.3248	-0.3492	-0.1843	0.3000	0.3225
	Fruit texture	-0.1958	-0.1429	0.3877	-0.3611	0.2452	-0.2951
	Fruit flavor	0.1371	0.2248	-0.4402	0.3824	-0.1548	-0.0922
	Fruit fragrance	-0.1910	-0.3556	0.2180	0.3157	-0.1125	-0.1412
	Peduncle form	-0.2054	0.4263	0.2934	0.2509	-0.0077	0.2088
	Metula trait	-0.1922	0.4414	-0.0885	0.1491	0.3106	0.0294
	Sepal shape	0.3048	0.0609	0.2033	-0.1676	-0.4346	0.0088
	Sepal posture	0.2713	-0.1135	0.3992	0.3954	-0.0750	0.0863
	Fruit shape	0.2042	0.0887	0.1598	0.2093	0.5721	-0.4333
	Surface color	0.2485	0.0579	0.0475	0.1287	0.3404	0.4892
	Surface state	-0.3138	-0.1789	0.1082	0.3222	0.0125	-0.0912
	Fruit dot quantity	0.3012	-0.2143	0.2057	-0.0426	0.2442	0.3922
	Fruit dot color	0.1269	0.4459	0.2008	-0.3926	0.0019	-0.0284
	Fruit dot color	0.3581	-0.0602	-0.2664	-0.0231	0.1779	-0.3775

DISCUSSION

Analysis of fruit genetic diversity demonstrated that fruit traits reflect abundant genetic variation, with variable coefficients between 17.22 and 54.88%. Fruit shape, which had the highest variable coefficient, is an important indicator to reflect the external character of fruit, as is fruit surface state, which had the next highest variable coefficient. Fruit color had the smallest variable coefficient indicating that the color of the hawthorn is relatively uniform. Based on this result, we recommend increasing the number of yellow and orange cultivars within the hawthorn collection. For the majority of accessions, the sarcocarp was yellow, and followed by pink and green, with white and red cultivars (including Damianqiu, Datangqiu, Hengrenxiangyang, Niejiayu No. 2) being very rare. For the majority of the fruit, the sarcocarp texture was mellow. Hard sources are reportedly very rare (Dong, 2013) and in the current study, hawthorn cultivars that were very hard (including Pingyidahongzi, Shanxitiansheng, and Xifenshisheng) were outstanding resources. The majority of cultivars had a fruit that was sour-sweet or sweet-sour in flavor. Hawthorns which taste

very sour, sweet, and with thin fragrance were very rare, so the sour-sweet and the sweet-sour are the outstanding resources, and there are 67 shares totally in 106 shares. Thin fruit fragrance was common, and fruits without fragrance were very rare. Based on analysis of frequency distribution of fruit traits in germplasm resources, the quantitative traits sepal posture, fruit shape, fruit dot color, and the number of fruit dots are abundant. There were seven classifications for sepal posture, but the majority of cultivars examined were classified as open and flat; fruit shape had eight classifications, and oblate was the most common; the majority of fruits had a rough surface; hawthorns with a smooth, glossy surface were very rare; and the majority of cultivars had a red fruit color, which species bearing yellow fruits being very rare.

These results demonstrate that hawthorn fruit peduncle, metula, sepal, fruit surface, the fruit dot form, and fruit flavor have genetic diversity. The data presented here provide abundant information on parent materials for hawthorn breeding, and improved scope for the development of hawthorn resources.

Conflicts of interest

The authors declare no conflict of interest.

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