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RESEARCH ARTICLE

PHENOTYPIC DIVERSITY OF *ACER GINNALA* (ACERACEAE) IN CHINA UNDER ENVIRONMENTAL CONDITIONS

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ABSTRACT

Acer ginnala (Aceraceae) is a multipurpose shrub with significant economic and ecological value in China. Considering the fact that various natural and anthropogenic pressures might bring about serious influences to morphological diversity of *Acer ginnala.* In this context, thirty-four phenotypic traits were analyzed to explore the phenotypic variation and pattern of 19 *Acer ginnala* populations by principal component analysis (PCA), nested analysis and cluster analysis. A correlations between phenotypic traits and environment factors were used pearson's correlation coefficient. The results showed that phenotypic traits were significantly different among 19 populations. Phenotypic variation coefficient (CV) and Shannon-Wiener index (H_{SW}) were 23.53% and 5.22 respectively. The phenotypic differentiation coefficient (Vst) among populations was 56.996%, which was more than that of within populations (43.004%). The total of four principal components was 87.30% in principal component analysis. Nineteen *A. ginnala* populations were divided into two groups based on cluster analysis. Absolute high temperature and Annual average temperature were negative correlated to leaf length of *A. ginnala*, while Annual precipitation had a positive correlation with length/width ratio of leaf. Environmental factors would affect the phenotypic variation and pattern of *A. ginnala* populations.

INTRODUCTION

Plants are vulnerable to rapid environmental changes due to changing climate influences on floral biodiversity including changed geographical distribution of species, in length of growing season for plants and so on (Iverson and Prasad., 2001; Lucas-Borja *et al*., 2016). So it is essential to gain a comprehensive idea of population genetic variability in order to provide a basis for conservation of the trees (Aitken *et al*., 2008). Phenotypic diversity and variation may reflect both genetic variability and adaption to local environmental characteristics (Ming *et al*., 2006). The relationships between plant phenotypic variation and environment have been reported in many articles (Li *et al*., 2014). *Acer ginnala* (Aceraceae) is a tree or shrub with bisexual flowers and key fruit (Hall, 1951; Bock *et al*., 1980). It is widely distributed in both Japan, North Korea, Russia and over most provinces in China from the northeast to the southwest (Huang *et al*., 2009). This speices is always used for landscaping with highly ornamental value, economic value for industry application, and medical value with its gallic acid (Wang, 2010; Yan *et al*., 2010; Huang *et al*., 2009). Meanwhile, with the increase of soil moisture content and soil total potassium, the leaves gradually became oval and the key fruit became shorter, *A. ginnala* have formed different types of phenotypic characteristics in wild community (Wang *et al*., 2010). Very few analyses have been conducted on the genetic diversity and variation of *A.ginnala.* The study on phenotypic diversity of *A.ginnala* in different environments will provide useful information for understand the genetic variation pattern and protection of *A.ginnala.* The objective of this study is to answer the following questions: Are there phenotypic diversity of *A.ginnala* populations? Which environmental factor play a role in these phenotypic diversity?

MATERIALS AND METHODS

Sample collection

From September 2015 to October 2015, A total of 380 samples were collected from 19 populations of *A. ginnala*, covering most of its distribution range in China. About 20 individuals per population were collected. The distances between sampled trees varied from 50 to100 meters depending on the population size, to ensure that the sampled trees truly represented their populations. Each population was positioned by GPS and meteorological factors were provided by the local weather bureau. The detailed locations and environmental factors were listed in Table 1.

Measurement of parameters

According to the method of Falkenhagen (1978), each trait was measured in three replicates and the mean value was used (liu

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et al., 2016). Eight phenotype traits, Leaf length (LL), blade length (BL), blade width (BW), Petiole length (PL), the high of leaf opex to left side (Hos), the length of leaf opex to left side (Los), the high of leaf opex to α (Hlα) and the length of leaf opex to α (Llα), were measured by ruler. Petiole width (PW), Petiole end width (PEW), leaf opex length (LOL), leaf opex width (LOW), caropodium length (CL), length of key fruit handle (KFHL), key fruit length (KFL), key fruit width (KFW), Bears the mark (BM), fruit length (FL), fruit width (FW), Fruit thickness (FT), seed length (SL), seed width (SW) and seed thickness (ST) were measured by vernier caliper. The angle of key fruit (KFIA) and angle on the left (α) were measured by the protractor. Length/width ratio of key fruit (KFLW), Length/width ratio of fruit (FLW), Length/width ratio of seed (SLW), leaf area (LA), leaf vein (LV), Length/width ratio of petiole (PLW), Length/width ratio of blade (BLW), Leaf length/Petiole length (KLP) and Length/width ratio of leaf opex (LLW) were calculated by EXCEL software.

Table 1. The locations and ecological factors of *A.ginnala* populations

Label	Location	Province	Longitude (E)	Latitude (N)	Altitude (m)	Slope (°)	Average Temperature of January (℃）	Average Temperature (℃）of July(℃）	Annual Average Temperature (℃）	Effective Accumulated (℃） Temperature (℃）	Effective Accumulated (℃） Temperature (℃）	Absolute High Temperature (℃）	Absolute Low Temperature (℃）	Annual Sunlight Hours (h)	Frost Free Period (d)	Annual Precipitation (mm)
BDG	Ba daogou Mountain	shanxi	114º08' 16.09"	41º08' 31.16"	1580	13	-7	21.9	6.4	3213.5	3213.5	33	-23	2889	125	450
HJG	Hao jiagou Mountain		111º26 '17.16"	38º32' 11.08"	1450	12	-5.5	24.5	7.8	3650	3650	33	-18	2855	150	350
HHG	Hou huigou Mountain		111º45' 05.51"	36º48' 01.16"	1200	19	-3.5	23.5	9.5	3641.5	3641.5	35	-16	2808	202	460
JMLC	Jie miaolinchang		111º56	36º49'	1450	24	-2	20.5	10	4124.5	4124.5	37	-14	2812	140	650
PQG	Pang quangou Mountain		111º27' 12.89"	37º52' 17.67"	1800	10	-2.5	25	7	3686.5	3686.5	34	-14	2743	156	576
QLY	Qi liyu Mountain		111º14'	36º36	1560	22	-0.5	26.5	12.2	4604.5	4604.5	38	-12	2265.1	235	437.3
XTS	Xing tangsi Mountain		111º46' 27.15"	36º25' 06.48"	1530	33	0	27	12.3	4753	4753	37	-12	2845	190	493.3
YDS	Yunding		111º34'	37º53'	1000	26	-5.5	22.5	7.9	3283.5	3283.5	33	-19	2872.6	134	428
BJ	Beijing	Beijing	115º49'	39º40'	1420	22	-4	27.5	13	4496.5	4496.5	37	-14	2680	189	483.9
MLG	Mai ligeng Mountain	Inner Mongolia	109º26' 29.39"	40º40' 16.10"	1273	36	-9.5	23.5	10.4	3504	3504	34	-24	2806	122	262.9
BYS	Bai yunshan Mountain	Henan	111º49' 50.34"	33º40' 13.43"	1479	21	1	28.5	16	5394	5394	39	-8	2150	176	1060
LJL	Lao jieling Mountain		111º43' 44.91"	33º37' 11.03"	1482	23	3	29	16.9	5732	5732	37	-7	2019	236.2	830
LJS	Lao junshan Mountain		111º38' 13.26"	33º44' 47.46"	952	26	-6	26.5	16.2	4716.5	4716.5	36	-11	2103	198	863.8
LTG	Long tangou Mountain		111º36' 43.34"	33º31' 01.88"	1560	27	2.8	28.7	16.6	5730	5730	37	-6.5	2018	236	828
TTZ	Tian tangzai Mountain	Anhui	115º46' 04.85"	31º10' 17.44"	560	32	4.5	30.5	17.4	5712	5712	41	-6	2020	211	1100
FZL	Fu ziling Mountain		116º16' 32.11"	31º20' 58.53"	700	28	3.5	30	16.8	5693.5	5693.5	41	-7	2010	230	960
WCLC	Wo chuanglingchang		115º50' 13.80"	31º14' 33.80"	760	37	4	30	17.2	5710	5710	40	-5	2020	212	1050
TBD	Tai baiding Mountain	Hubei	113º36' 40.67"	32º30' 50.50"	1440	27	3	30	17	5628	5628	39	-7	2026	230	1080
TBS	Tong baishan Mountain		113º18' 37.80"	32º23' 53.80"	960	27	3.5	31	17.1	5620	5620	38	-8	2030.5	228	969

Data analyze

Statistical analysis was performed with SPSS software for Microsoft Windows (SPSS17.0). Analysis of variance (ANOVA) was performed for morphological variables to find significant differences between studied populations. Principal component analysis (PCA) was used to assess contribution rate of variation. And Pearson's correlation coefficient was undertaken to further examine the correlations between phenotypic traits and environment factors. Coefficients of variation (*CV*) and phenotypic differentiation coefficient (V_{ST}) were determined as index of morphological variability. Coefficient of variation (*CV*) according to the formula *CV*=stdv/avg were calculated (the average quantity (avg) of target from the standard curve, the standard deviation of the average (stdv) (Zhou *et al*., 2010). Vst was calculated as *Vs*t=(δt/s2)/(δt/s2+δs2), where δt/s2is the variance component among regions, and δs2 is the variance component within regions (Ge *et al*., 1988). The phenotype diversity (Shannon-Wiener information index, *Hsw*) of each morphological trait and population was evaluated by BIO-Dap software (Liu *et al*., 2016). Cluster analysis was performed based on Euclidean distance using unweighted pair-group method of arithmetic averages (UPGMA) by cluster function in NTSYSps-2102a software.

Table 2. The ANOVE analysis of phenotypic traits among/within populations of *A. ginnala*

traits	Among populations F value	Within populations F value	traits	Among populations F value	Within populations F value
LL	65.034**	13.993**	$L_{L\alpha}$	99.207**	11.828**
BL	95.147**	16.057**	LA	97.826**	15.772**
BW	106.213**	15.089**	CL	58.922**	1.502
BLW	43.498**	1.784	KFHL	92.446**	1.907
PL	37.930**	6.159**	KFL	154.831**	1.708
PW	56.367**	10.920**	KFW	107.604**	1.157
PLW	36.226**	0.281	KFLW	69.372**	1.604
FLW	25.714**	13.837**	KFIA	29.134**	2.255*
KLP	61.162**	0.87	BM	80.550**	0.247
LOL	90.207**	6.940**	FL	207.473**	0.874
LOW	0.718	0.537	FW	4.822**	0.736
BLW	54.502**	2.116*	FT	95.057**	1.434
ɑ	33.619**	5.129**	PEW	16.801**	2.664**
lv	26.612**	16.402**	SL	143.480**	0.837
H_{OS}	196.823**	11.886**	SW	5.766**	0.791
Los	22.757**	9.544**	ST	104.487**	1.373
$H_{L\alpha}$	331.523**	11.334**	SLW	10.487**	3.001**

Not: LL: Leaf length; BL: blade length; BW: blade width; BLW: Length/width ratio of blade; PL: Petiole length; PW: Petiole width; PLW: Length/width ratio of petiole; PEW: Petiole end width; KLP: Leaf length/Petiole length; LOL: leaf opex length; LOW: leaf opex width; LLW: Length/width ratio of leaf opex; ɑ: angle on the left; LV: leaf vein; Los: the length of leaf opex to left side; $L_{l\alpha}$: the length of leaf opex to ɑ; LA: leaf area; CL: caropodium length; KFHL: length of key fruit handle; KFL: key fruit length; KFW: key fruit width; KFIA: angle of key fruit; BM: Bears the mark; FL: fruit length; FW: fruit width; FT: Fruit thickness; SL: seed length; SW: seed width; ST: seed thickness; SLW: Length/width ratio of seed; $H_{os:}$ the high of leaf opex to left side; $H_{l\alpha:}$ the high of leaf opex to ɑ; KFLW: Length/width ratio of key fruit; FLW: Length/width ratio of fruit.

F: means the value of Significant difference.

*mean significant difference at 0.05 level; ** mean significant difference at 0.01 level.

RESULTS

Phenotypic diversity

The *F* values of *A. ginnala* phenotypic traits among populations were significantly different (Table 2). Only 16 phenotypic traits (LL, BL, BW, PL, PW, LOL, LOW, ɑ, LV, HOS, $H_{L\alpha}$, $L_{L\alpha}$, KFIA, PEW and SLW) within the populations were significantly different. The distinct correlation in each phenotypic trait of *A. ginnala* from different populations was confirmed by analyzing coefficient of variation *(CV)*. The average *CV* of the seed length (SL) among the 19 populations exhibited the lowest variation (15.677%), while the leaf opex length (LLW) exhibited the highest variation (31.612%). The mean *CV* of 34 traits was 23.53%. The average variation among populations was lowest in population HJG (18.076%) and highest in FZL population (36.054%) (Table 3). Shannon-Wiener index (H_{SW}) of 34 traits was used for the estimation of phenotypic diversity. H_{SW} for 34 morphological traits was ranged from 4.18 to 6.26, and the mean was 5.22. The H_{SW} of 19 populations ranged from 2.18 to 2.43, with a mean value of 2.31. The highest phenotypic diversity was found in WCLC, BDG and LJS population (H_{SW} =2.43), while the lowest phenotypic diversity was in LTG population (H_{SW} =2.18) (Table 3). PCA analysis showed that the four principal components of the cumulative contribution rate were 87.300% (Table 4). The first principal component contribution rate was 39.825% with the main contributions from $H_{L\alpha}$, HOS, BL, BW, LA, LL and PW. The second principal component contribution rate was 22.522% with the main contributions from KLP, LLW, PL, KFL, FT and ST. The third principal component contribution rate was 16.499% with the main contributions from BM, KFW, KFHL, KFL and CL. The fourth principal component contribution rate was 8.454% with the main contributions from FLW, KFLW, SLW, FL, ST and SL.

Phenotypic differentiation

The phenotypic differentiation coefficients (*Vst*) value of 34 phenotypic traits ranged from 23.134% to 85.287% (Table 5). The *Vst* value of Length/width ratio of seed (SLW) exhibited the lowest value (23.134%), while Length/width ratio of leaf opex (LLW) exhibited the highest value (85.287%). The phenotypic differentiation coefficients (*Vst*) among populations was 56.996%, and that within populations was 43.004%. This result revealed that phenotypic variation among populations was higher than within populations. Nineteen *A. ginnala* populations were mainly divided into two groups (Fig. 1). Ten populations from north of China (MLG, BJ, HHG, BDG, QLY, XTS, JMLC, YDS, HJG and PQG) and four populations

Table 3. Shannon-Wiener indices and variation coefficient based on phenotypic traits of *A. ginnala* populations

Traies	CV	Shannon-Wiener(Hsw)	traies	CV	Shannon-Wiener(Hsw)	Populations	CV	Shannon-Wiener(Hsw)
LL	22.09	6.17	$L_{L\alpha}$	27.388	5.81	FZL	36.054	2.34
BL	23.084	6.26	LA	28.346	5.87	BDG	21.719	2.43
BW	21.058	6.23	CL	21.76	4.99	BYS	24.341	2.33
BLW	24.953	5.29	KFHL	24.257	4.98	BJ	18.805	2.23
PL	25.483	5.26	KFL	25.915	4.99	HJG	18.076	2.33
PW	23.8	5.26	KFW	20.297	4.99	HHG	18.231	2.26
PLW	27.657	5.23	KFLW	19.853	4.99	JMLC	19.645	2.25
PEW	27.019	6.26	KFIA	20.775	5	LJL	22.803	2.2
KLP	28.156	5.25	BM	21.979	5	LJS	23.844	2.43
LOL	29.938	6.25	FL	22.046	4.87	LTG	20.703	2.18
LOW	27.392	4.91	FW	23.122	4.86	MLG	21.057	2.35
LLW	31.612	5.22	FT	20.84	5.21	PQG	18.984	2.33
α	22.755	5.27	PEW	19.031	4.98	QLY	20.77	2.33
LV	24.661	5.27	SL	15.677	4.68	TBD	26.787	2.33
H_{OS}	25.688	5.14	SW	19.705	4.68	TTZ	33.768	2.3
L_{OS}	24.251	4.95	ST	16.963	4.18	TBS	28.327	2.3
$H_{L\alpha}$	24.163	4.86	SLW	18.454	4.21	WCLC	34.54	2.43
Mean CV of phenotypic traits	23.53					XTS	19.792	2.35
						YDS	18.907	2.28
Mean Hsw of phenotypic traits	5.22					Mean	23.53	2.31

Not: LL: Leaf length; BL: blade length; BW: blade width; BLW: Length/width ratio of blade; PL: Petiole length; PW: Petiole width; PLW: Length/width ratio of petiole; PEW: Petiole end width; KLP: Leaf length/Petiole length; LOL: leaf opex length; LOW: leaf opex width; LLW: Length/width ratio of leaf opex; α: angle on the left; LV: leaf vein; Los: the length of leaf opex to left side; $L_{l\alpha}$: the length of leaf opex to α; LA: leaf area; CL: caropodium length; KFHL: length of key fruit handle; KFL: key fruit length; KFW: key fruit width; KFIA: angle of key fruit; BM: Bears the mark; FL: fruit length; FW: fruit width; FT: Fruit thickness; SL: seed length; SW: seed width; ST: seed thickness; SLW: Length/width ratio of seed; $H_{os:}$ the high of leaf opex to left side; $H_{l\alpha:}$ the high of leaf opex to α; KFLW: Length/width ratio of key fruit; FLW: Length/width ratio of fruit.

BDG : Ba daogou Mountain; HJG: Hao jiagou Mountain; HHG: Hou huigou Mountain; JMLC: Jie miaolinchang; PQG: Pang quangou Mountain; QLY: Qi liyu Mountain; XTS: Xing tangsi Mountain; YDS: Yunding Mountain; BJ: Beijing; MLG: Mai ligeng Mountain; BYS: Bai yunshan Mountain; LJS: Lao junshan Mountain; LJL: Lao jieling Mountain; LTG: Long tangou Mountain; TTZ: Tian tangzai Mountain; FZL: Fu ziling Mountain.; WCLC: Wochuanglingchang; TBD: Tai baiding Mountain; TBS: Tong baishan Mountain.

Table 4. Analysis on feature value of principal component, contribution rate and accumulation contribution

	Principal component				Phenotypic	Principal component			
Phenotypic	1	2	3	4		1	2	3	4
LL	0.810	0.346	-0.098	0.284	$L_{I\alpha}$	-0.456	0.453	-0.021	-0.026
BL	0.922	0.149	0.082	0.184	LA	0.858	0.29	0.103	0.180
BW	0.907	0.218	0.025	0.230	CL	0.181	0.234	0.519	-0.093
BLW	-0.502	-0.137	0.222	-0.222	KFHL	-0.073	0.308	0.643	-0.357
PL	0.119	0.719	-0.274	0.369	KFL	0.127	-0.563	0.630	-0.301
PW	0.793	0.015	0.241	0.157	KFW	-0.464	0.341	0.669	0.206
PLW	-0.450	0.434	-0.482	0.205	KFLW	0.568	-0.01	-0.235	-0.476
PEW	0.637	-0.242	-0.024	0.180	KFIA	0.013	-0.025	0.245	-0.150
KLP	0.578	-0.793	0.250	-0.071	BM	0.118	-0.088	0.721	-0.045
LOL	0.731	-0.367	0.052	-0.105	FL	-0.719	-0.054	0.359	0.446
LOW	0.025	-0.096	-0.007	-0.026	FW	-0.319	-0.291	0.109	0.133
LLW	0.475	-0.774	0.124	-0.035	FT	-0.017	-0.56	0.058	0.389
α	0.514	0.097	0.312	0.144	FLW	-0.350	0.243	0.36	0.592
LV	0.705	-0.183	-0.174	0.302	SL	-0.423	-0.38	0.279	0.426
HOS	0.929	0.044	0.093	0.054	SW	-0.243	-0.446	0.189	0.176
LOS	0.269	0.420	0.088	0.305	ST	-0.042	0.50	0.058	0.440
$H_{L\alpha}$	0.939	0.032	0.065	-0.104	SLW	0.067	0.184	-0.019	0.452
Eigen value		8.762			4.955		3.630		1.860
Contribution rate		39.825			22.522		16.499		8.454
Cumulative Contribution		39.825			62.347		78.846		87.300

Not: LL: Leaf length; BL: blade length; BW:blade width; BLW: Length/width ratio of blade; PL: Petiole length; PW: Petiole width; PLW: Length/width ratio of petiole; PEW: Petiole end width; KLP: Leaf length/Petiole length; LOL: leaf opex length; LOW: leaf opex width; LLW: Length/width ratio of leaf opex; α: angle on the left; LV: leaf vein; Los: the length of leaf opex to left side; $L_{l\alpha}$: the length of leaf opex to α; LA: leaf area; CL: caropodium length; KFHL: length of key fruit handle; KFL: key fruit length; KFW: key fruit width; KFIA: angle of key fruit; BM: Bears the mark; FL: fruit length; FW: fruit width; FT: Fruit thickness; SL: seed length; SW: seed width; ST: seed thickness; SLW: Length/width ratio of seed; $H_{os:}$ the high of leaf opex to left side; $H_{l\alpha:}$ the high of leaf opex to α; KFLW: Length/width ratio of key fruit; FLW: Length/width ratio of fruit.

Table 5. Variance components and differentiation coefficients *(V_{ST})* of phenotypic traits among and within populations of *A. ginnala*

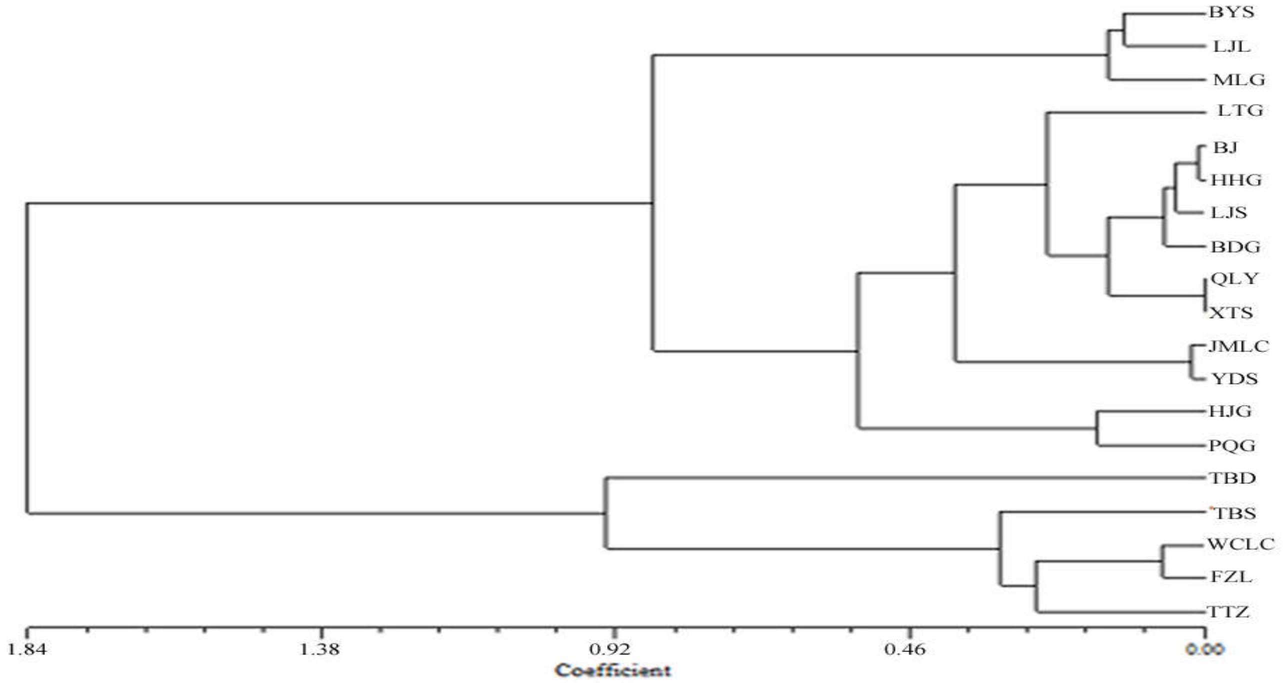
Phenotype	Variance components			Percentage of variance portion		VST	Phenotype	Variance components			Percentage of variance portion		VST
	Within populations	Among populations	Random errors	Within populations	Among populations			Within populations	Among populations	Random errors	Within populations	Among populations	
LL	194.840	186.328	52.596	44.918	42.956	51.117	L_{La}	83.893	44.453	14.8457	58.588	31.044	65.365
BL	150.339	112.758	27.739	51.692	38.770	57.142	LA	9268.695	6641.612	1663.324	52.742	37.793	58.256
BW	161.201	101.781	26.6443	55.658	35.142	61.297	CL	2.670	0.302	0.7956	70.870	8.015	55.840
BLW	1.378	0.251	0.5563	63.064	11.484	84.596	KFHL	0.911	0.083	0.1729	78.063	7.115	44.009
PL	28.425	20.514	13.1563	45.777	33.036	58.083	KFL	2.073	0.102	0.2351	86.015	4.231	49.311
PW	2.437	2.098	0.759	46.034	39.629	53.739	KFW	0.974	0.047	0.159	82.547	3.982	26.744
PLW	56.612	1.954	27.4353	65.827	2.272	79.664	KFLW	4.430	0.455	1.121	73.759	7.576	54.686
PEW	4.718	11.282	3.2207	24.544	58.699	59.633	KFIA	1009.598	347.372	608.3721	51.370	17.675	74.401
KLP	16.197	1.024	4.649	74.060	4.682	66.054	BM	4.485	0.061	0.9774	81.199	1.104	46.658
LOL	3.441	1.177	0.6697	65.077	22.258	74.514	FL	0.974	0.018	0.0824	90.654	1.676	47.185
LOW	0.628	2.088	15.3551	3.477	11.554	70.647	FW	0.241	0.163	0.8768	18.804	12.728	50.487
LLW	31.239	5.389	10.0623	66.907	11.542	85.287	FT	4.595	0.308	0.8487	79.890	5.355	38.718
α	6197.875	4202.204	3236.454	45.451	30.816	59.595	FLW	1.019	0.718	1.0646	36.370	25.629	58.662
L_V	111.411	305.179	73.4955	22.733	62.271	66.398	SL	0.543	0.014	0.0664	17.105	12.245	29.485
Hos	242.079	64.971	21.5922	73.660	19.770	78.840	SW	0.294	0.179	0.8938	21.481	13.101	48.116
L_{os}	24.803	46.229	19.1337	27.508	51.271	55.478	ST	5.081	0.297	0.8537	6.536	4.766	34.918
Hla	329.538	50.071	17.4505	82.995	12.610	69.810	SLW	2.107	2.680	3.5265	22.340	20.239	23.134
Mean											56.933	20.736	56.996

Not: LL: Leaf length; BL: blade length; BW:blade width; BLW: Length/width ratio of blade; PL: Petiole length; PW: Petiole width; PLW: Length/width ratio of petiole; PEW: Petiole end width; KLP: Leaf length/Petiole length; LOL: leaf opex length; LOW: leaf opex width; LLW: Length/width ratio of leaf opex; α: angle on the left; LV: leaf vein; Los: the length of leaf opex to left side; L_{la}: the length of leaf opex to α; LA: leaf area; CL: caropodium length; KFHL: length of key fruit handle; KFL: key fruit length; KFW: key fruit width; KFIA: angle of key fruit; BM: Bears the mark; FL: fruit length; FW: fruit width; FT: Fruit thickness; SL: seed length; SW: seed width; ST: seed thickness; SLW: Length/width ratio of seed; $H_{os:}$ the high of leaf opex to left side; $H_{la:}$ the high of leaf opex to α; KFLW: Length/width ratio of key fruit; FLW: Length/width ratio of fruit.

Table 6a. Correlation coefficient between phenotypic characters and meteorogical factors

Traits	longitude	Latitude	Altitude	Slope	Absolute High Temperature	Absolute Low Temperature	Average Temperature of January	Average Temperature of July	Annual Average Temperature	Annual Precipitation	Annual Sunlight Hours	Frost Free Period	≥10℃ Effective Accumulated Temperature
LL	-0.426	-0.457*	0.163	-0.104	-0.55*	-0.47*	-0.398	-0.358	-0.496*	-0.491*	0.576**	0.331	-0.478*
BL	-0.576**	-0.424	-0.025	0.399**	-0.197	-0.063	0.038	-0.179	-0.146	-0.13	0.163	0.0.84	-0.121
BW	-0.489*	-0.462*	-0.010	-0.148	-0.274	-0.144	-0.038	-0.295	-0.252	-0.218	0.274	-0.027	-0.216
BLW	0.228	-0.446**	0.022	0.252	0.544**	0.474*	0.42	0.627*	0.606**	0.522*	-0.614**	0.554*	0.548*
PL	0.339	-0.299	0.563*	-0.124	-0.442	-0.05**	-0.282	-0.344	-0.48*	-0.528*	0.605**	-0.266	-0.409
PW	-0.562*	-0.245	-0.137	-0.284	-0.47*	-0.347	-0.272	-0.423	-0.46*	-0.472*	0.556*	-0.264	-0.264
PLW	-0.275	-0.452	-0.135	-0.134	-0.342	-0.474	0.233	0.342	-0.45	-0.432	0.522	-0.266	-0.254
KLP	-0.719**	0.000	-0.451	-0.123	-0.153	0.029	0.097	-0.12	-0.089	-0.06	0.106	0.104	-0.047
LOL	-0.606**	0.074	-0.575*	0.370*	-0.711**	-0.612**	-0.575*	-0.706**	-0.76**	-0.713**	0.81**	-0.515**	0.709**
LOW	-0.36	0.130	-0.247	-0.071	-0.579**	-0.438	-0.357	-0.403	-0.585**	-0.522**	0.594**	-0.333	-0.503*
BLW	-0.626**	0.117	-0.61**	0,405**	-0.548*	-0.559*	-0.582**	-0.664**	-0.631**	-0.647**	0.709**	-0.54*	-0.624**
α	-0.544*	-0.485*	-0.231	0.221	-0.111	0.014	-0.003	0.266	0.052	-0.026	-0.11	-0.029	0.103
LV	-0.612**	-0.021	-0.437	-0.256	-0.456*	-0.286	-0.198	-0.288	-0.394	-0.362	0.469*	-0.27	-0.323
H_{OS}	-0.615**	-0.488**	-0.053	0.048	-0.473*	-0.443	-0.36	0.644**	-0.581**	-0.542*	0.677**	-0.283	-0.573*
L_{0S}	0.063	-0.203	0.191	-0.351	0.097	0.279	0.36	0.259	0.25	0.251	-0.256	0.342	0.29
H_{La}	-0.614**	-0.444	-0.03	0.095	-0.519*	-0.542*	-0.478*	-0.753**	-0.686**	-0.635**	0.723**	-0.401	-0.684**
L_{La}	-0.623**	0.169	0.289	-0.284	0.234	0.414	0.473*	0.431	0.415	0.411	-0.426	0.429	0.45

LA													
CL	-0.038	-0.384	-0.215	-0.268	0.545*	0.617**	0.647**	0.583**	0.563*	0.672**	-0.672**	0.514*	0.648**
KFHL	0.251	-0.349	0.076	0.119	0.217	0.342	0.359	0.318	0.286	0.187	-0.185	0.385	0.332
KFL	0.12	-0.412	0.189	0.37	-0.043	0.175	0.082	0.162	0.108	0.142	-0.168	0.027	0.106
KFW	0.224	-0.246	0.317	0.157	0.332	0.562*	0.535*	0.372	0.339	0.366	-0.412	0.576**	0.426
KFLW	-0.157	-0.012	-0.206	-0.166	-0.329	-0.507*	-0.498*	-0.285	-0.263	-0.287	0.31	-0.578**	-0.362
KFIA	-0.197	-0.219	0.057	0.411**	-0.522*	-0.39	-0.267	-0.534*	-0.563*	-0.473*	0.582**	-0.334	-0.499*
BM	-0.501*	-0.324	-0.243	0.575**	-0.356	-0.548*	-0.423	0.599**	-0.615**	-0.556*	0.511*	-0.525*	-0.574*
FL	0.371	0.042	-0.079	0.193	0.23	0.377	0.309	0.006	0.255	0.325	-0.351	0.343	0.281
FW	0.306	0.097	-0.369	-0.094	-0.576**	-0.632**	-0.592**	-0.445	-0.599**	-0.535*	0.547*	-0.637**	-0.559*
FT	-0.57*	0.27	-0.66**	-0.142	0.286	0.376	0.253	0.176	0.317	0.261	-0.241	0.431	0.293
PEW	-0.45	0.24	-0.58	-0.144	0.276	0.289	0.143	0.174	0.278	0.172	-0.230	0.389	0.287
LA	-0.45	-0.554*	0.033	-0.002	0.448	0.568*	0.51*	0.243	0.477*	0.487*	-0.508*	0.555*	0.471*
SL	0.172	0.18	-0.446	-0.005	0.133	0.029	0.157	-0.054	0.057	0.155	0.027	-0.054	0.058
SW	-0.044	0.164	-0.567*	-0.277	-0.339	-0.344	-0.142	-0.45	-0.483*	-0.406	0.312	-0.209	-0.352
ST	-0.527*	0.22	-0.631**	-0.107	0.275	0.363	0.24	0.16	0.3	0.245	-0.224	0.42	0.277
SLW	0.276	-0.344	-0.093	0.248	0.321	0.244	0.2	0.27	0.358	0.37	-0.192	0.113	0.273



Note: BDG: Ba daogou Mountain; HJG: Hao jiagou Mountain; HHG: Hou huigou Mountain; JMLC: Jie miaolinchang; PQG: Pang quangou Mountain; QLY: Qi liyu Mountain; XTS: Xing tangsi Mountain; YDS: Yunding Mountain; BJ: Beijing; MLG: Mai ligeng Mountain; BYS: Bai yunshan Mountain; LJS: Lao junshan Mountain; LJL: Lao jieling Mountain; LTG: Long tangou Mountain; TTZ: Tian tangzai Mountain; FZL: Fu ziling Mountain.; WCLC: Wochuanglingchang; TBD: Tai baiding Mountain; TBS: Tong baishan Mountain.

Fig.1. UPGMA-derived dendrogram based on Euclidean distances showing of the 34 phenotype traits of *A. ginnala*

(LJL, LTG, BYS.LJS) from south of China Fourteen populations were gathered into group I, other five populations (WCLC, FZL, TTZ, TBD and TBS) from south of China were gathered into group II.

Correlation analysis

The correlation analysis showed in Table 6. FSL, KFW and LA had a positive correlation with the average temperature of January and absolute low temperature, respectively. Nine phenotypic traits (LL, PW, LOL, LOW, LALW, HOS, $H_{I\alpha}$, KFIA and FW) had a negative correlation with absolute high temperature and annual average temperature, respectively. Annual Precipitation had positive correlation with BLW, CL, and LA, had a negative correlation with eleven phenotypic traits (LL, PL, PW, LOL, LOW, LLW, HOS, $H_{I\alpha}$, KFIA, BM and FW). Nine phenotypic traits (LL, BLW, PW, LOL, LOW, LLW, LV, HOS and $H_{L\alpha}$) had a positive correlation with annual sunlight hours, while CL and BLW had a negative correlation with annual sunlight hours. Eleven phenotypic traits (BL, BW, PW, PL, LOL, LLW, HOS, $H_{L\alpha}$, BM, FT and ST) had a negative correlation with latitude.

DISCUSSION

Phenotypic diversity

A. ginnala existed high phenotypic diversity and variation in populations (Table 2). Similar results were obtained in previous studies (Yang *et al*., 2011). The same genus tree *Acer mono* also occuured a high level of phenotypic variation (Zhang *et al*., 2015). The high phenotypic diversity of *A. ginnala* was related to the broad geographical distribution, selection of cultivator and long evolutionary history of species. First, *A. ginnala* mainly inhabit in Northeast, North, Northwest of China, the environmental conditions in these inhabits were different (Huang *et al*., 2009 such an annual precipitation and annual average temperature in different regions). Futhermore, due to the ornamental and economic value, *A. ginnala* is widely planted in many place, farmers give priority to the amelioration of more attractive characteristics through introducing and maintaining phenotypic with different (Li *et al*., 2007; Wang *et al*., 2013). In addition, *A. ginnala* has been reportd to possess millions years of evolutionary history (Yan *et al*., 2010). Thus, it can be inferred that such a long history, broad distribution range and selection of cultivator may have rendered it possible to accumulate a large amount of phenotypic variability. Analysis of population-level diversity revealed that the phenotypic diversity of WCLC population was higher than those of other populations. Population size of WCLC was the largest and individuals were found to be thriving, which may harbor more phenotypic diversity within this population. LTG population had the lowest diversity. Human activities have been an important cause of population size reduction in LTG in the past years through over-exploitation and habitat loss. Reduction in population size may lead to increase inbreeding depression and lower fitness (Ellstrand and Elam, 1993; Frankham *et al*., 1997). This in turn would lower the diversity of LTG population, and also lower its ability to compete with introduced species, to cope with disturbed habitats, and to adapt to natural changes in the environment (Frankham *et al*., 1997).

Phenotypic differentiation: The phenotypic differentiation of *A. ginnala* main came from among populations, which was affected by biological characteristics or geographically isolation of populations. *A. ginnala* has hermaphodite flower and low rate of seed maturity, which reduced pollen flow between populations (Liang *et al*., 2007). Furthermore, the geographical location in the distribution range of *A. ginnala* is complex, with neighboring populations frequently separated by geographic barriers such as high mountains and broad rivers. Under these conditions, pollens or seeds can seldom expand successfully from one population to another. Cluster analysis showed that 19 populations gathered into two distinct groups (Fig.1). Plant species may respond to suitable environment conditions through phenotypic plasticity (Fiorani and Schurr, 2013). In our study, the nine south populations had the similar temperature and precipitation, however, the content of elements in soil is different. Five populations (TBS, TBD, WCLC, TTZ and FZL) located in Dabie Mountain (E: 113°16′~116°45′, N: 30°57′~32°43′）, the C, N and P content of soil in Dabie Mountain were 249mg/kg ~ 780.10mg/kg, 59.27mg/kg ~ 190.10mg/kg, 30.95mg/kg ~ 107.10 mg/kg, respectively (Wang *et al*., 2014; Zhang *et al*., 2010). The other four populations (LJL, LTG, BYS, LJS) located in Funiu Mountain (E: 110°30′~113°05′, N:32°45′~34°00′), N content in Funiu Mountain were 26 mg/kg ~220mg/kg (Zheng *et al*., 2011), which possibly lead to that four southern populations of *A.ginnala* were not clustered into a class with the other five southern populations.

Conclusion

In summary, high genetic diversity and high genetic differentiation were detected among the *A. ginnala* populations in China. A large proportion of the genetic variation (56.996%) resides among the populations. Significant correlation was found between phenotypic traits and environmental factors. The strategy of conservation for *A. ginnala* should in-situ methods. In-situ method pays more attention to restore the suitable habitats and the effective population size. Based on the results, in-situ conservation strategies should be adopted to protect and restore all existing populations of *A. ginnala*.

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Conflict of interest

The authors declare they have no conflict of interest.

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