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Geographical Variation in the Growth and Nutritional Traits of Leaf Powder from *Broussonetia papyrifera* (L.) L'Hér. ex Vent. from Different Provenances

Peng Zhou [1,2], Qingmin Que [1], Biying Ke [2], Siming Cui [1], Xiaoyang Chen [3,4,*] and Wei Zhou [1,*]

1 College of Forestry and Landscape Architecture, South China Agricultural University, Wushan Road 483, Tianhe District, Guangzhou 510642, China; zhoupeng1209zm@163.com (P.Z.); qmque@scau.edu.cn (Q.Q.); simingcui@163.com (S.C.)
2 Guangdong Eco-Engineering Polytechnic, Guangshan 1st Road 297, Tianhe District, Guangzhou 510520, China; kebiying2022@163.com
3 State Key Laboratory for Conservation and Utilization of Subtropical Agro-Bioresources, South China Agricultural University, Wushan Road 483, Tianhe District, Guangzhou 510642, China
4 Guangdong Key Laboratory for Innovative Development and Utilization of Forest Plant Germplasm, Wushan Road 483, Tianhe District, Guangzhou 510642, China
* Correspondence: xychen@scau.edu.cn (X.C.); wzhou@scau.edu.cn (W.Z.)

Abstract: *Broussonetia papyrifera* (L.) L'Hér. ex Vent., a perennial deciduous tree, is used in feed, medicine, papermaking, environmental protection, and ecological restoration. This paper ttook 33 provenances from the natural distribution as the research objects, observes their growth and nutritional traits, and analyzes the laws of geographical variation. The repeatability was 0.80–0.88 and 0.48–0.91, respectively. The correlation was significant (the correlation coefficient was 0.764). The variation is greatly affected by the latitudinal direction. Through clustering, the 33 provenances were clustered into 4 groups and most provenances with relatively close geographical origins were clustered together, showing differences between different geographical regions. Using leaf biomass (0.4662 g) and crude protein content (14.39%) as the selection index, the Sichuan Mianyang (SCMY), Chongqing Kaizhou (CQKZ), Shanghai (SH), and Fujian Nanping (FJNP) provenances were selected as fast-growing, high-yield, and high-quality paper mulberry provenances. This study provides the basis for the selection of excellent paper mulberry trees.

Keywords: paper mulberry; feed materials; growth traits; genetic variation; provenance selection

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1. Introduction

Broussonetia papyrifera (L.) L'Hér. Ex Vent., also known as peach, valley tree, and shell tree, is a perennial deciduous tree of the genus Broussonetia and the family Moraceae. It is distributed in China, the Malay Peninsula, the Korean Peninsula, Japan, Southeast Asia, the Pacific Islands, and other places. *Broussonetia papyrifera* resources are abundant in China and are widely distributed around the Yellow River, Yangtze River, Pearl River Basin, and Taiwan, where the plant grows wild or is planted in wastelands, the countryside, and ditches near villages [1,2]. Paper mulberry is a positive tree species with strong adaptability, stress resistance, and pollution resistance. It has the characteristics of fast growth, wide distribution, easy reproduction, high heat tolerance, and short rotation period. It has important economic value, and the whole plant can be used as a medicine with high medicinal value, while the leaves and fruits are rich in flavonoids, alkaloids, and coumarins [3,4]. Extracts of paper ketones, lignans, and terpenoids have antibacterial, anti-oxidation, and anti-cancer effects, relieve fatigue, and improve human immunity and are used in the treatment of breast cancer, diabetes, obesity, gout, and cardiovascular diseases [5–9]. The phloem fiber of paper mulberry bark is slender and represents 43.06% of contents. It can be used as a high-quality raw material for papermaking, rayon, advanced blending. Naxi Dongba paper, and the Dai nationality handmade paper, the latter two of which were selected for the first batch of submission to the national intangible cultural heritage list and are mainly made from paper mulberry [10–12]. The seeds are rich in fatty oils and can be used as raw materials for the production of paint, soap, and lubricating oil. It has the unique characteristics of thick leaves, a rough surface, and pilose on the back. It has a very strong ability to absorb harmful gases and dust, so it is often used as a greening and pollution-resistant tree species for planting [13,14]. Paper mulberry is widely used and plays an important role in poverty alleviation industries, environmental protection, and ecological restoration [15–18].

The crude protein content in the leaves of paper mulberry can reach more than 20%, which is higher than that of plants such as alfalfa (*Medicago sativa*, Shi S L). Research shows that using *B. papyrifera* as a raw material to produce feed for cattle, sheep, and pigs can greatly improve the quality of the meat and as a high-quality feed it can greatly reduce the cost of feed [19–23]. If it can be developed into a new type of feed material, it can not only increase the added value of paper mulberry but also reduce the cost of feed and promote the development of industry. At present, there is no clear understanding of the geographical differences in the growth and nutritional properties of *B. papyrifera* from different provenances in China. During its promotion, it became impossible to accurately obtain excellent provenances with fast growth and high nutritional value, resulting in the slow growth or low nutritional value of artificially planted *B. papyrifera*, which greatly reduces its economic value. Therefore, the study of the variation in growth and nutritional traits in the leaf powder of different provenances of paper mulberry can provide a basis for the selection of excellent provenances. In this study, the leaf powder of 33 provenances of paper mulberry was used as the research object, the growth amount and conventional nutrient components in the growth period were determined, and the differences in the feed traits of the paper mulberry leaf powder of different provenances were studied. Taking the biomass and crude protein content of the leaves as the main selection indexes, the excellent provenances were selected. This study can provide a reference for the selection and breeding of paper mulberry.

2. Materials and Methods

2.1. Materials

We collected paper mulberry seeds with 33 provenances (Table 1 and Figure 1) and raised seedlings in the greenhouse of the College of Forestry and Landscape Architecture, South China Agricultural University, Guangzhou.

Figure 1. Distribution map of seed collection points of *B. papyrifera* in China.

Table 1. Geographic locations and ecological factors of *B. papyrifera*.

Provenance	Longitude (°N)	Latitude (°E)	Altitude (m)	Annual Temperature (°C)	Annual Precipitation (mm)	Frost-Free Period (d)	Sunshine Duration (h)	Number of Samples
B J	E116.23	N39.54	54	11.5	640	193	2400	30
SXYQ	E113.28	N40.08	981	10.0	500	155	2696	30
HBWA	E114.12	N36.41	194	12.0	560	196	2297	30
SDQD	E120.22	N36.04	6	12.7	662	196	2643	30
SXYC	E111.00	N35.01	369	13.3	525	212	2040	30
GSTS	E105.43	N34.34	1169	11.0	492	185	2100	30
SXXA	E108.56	N34.20	385	13.5	620	216	1880	30
HNZZ	E113.37	N34.44	110	15.6	542	209	1870	30
AHHB	E116.49	N33.59	32	14.5	863	202	2316	30
HNTB	E113.25	N32.22	142	15.0	1168	231	2027	30
S H	E121.28	N31.13	16	17.6	1173	228	1886	30
SCMY	E104.40	N31.28	473	17.9	823	252	1172	30
CQKZ	E108.23	N31.09	255	15.3	1300	275	1463	30
HBYC	E111.17	N30.41	59	16.9	1216	275	1700	30
HBSS	E112.15	N30.18	34	16.6	1200	250	2006	30
ZJHZ	E119.57	N30.03	21	17.8	1454	255	1765	30
SCDY	E103.31	N30.35	524	16.1	1096	284	1077	30
SCNC	E106.06	N30.50	338	17.1	1034	290	1369	30
HNXX	E109.44	N28.18	200	16.0	1400	242	1440	30
JXJDZ	E117.10	N29.16	35	17.8	1805	247	2009	30
JXNC	E115.51	N28.41	16	17.3	1650	260	1770	30
GZZY	E106.55	N27.43	865	15.1	1100	284	1163	30
FJNP	E118.07	N27.19	87	19.3	1609	268	1802	30
GZKY	E107.54	N26.54	825	15.1	1308	268	1105	30
JXGZ	E114.56	N25.49	111	19.8	1319	297	1092	30
GZPZ	E104.28	N25.42	1739	15.2	1390	271	1593	30
GXLZ	E109.24	N24.19	91	19.4	1640	325	1410	30
GXBS	E106.37	N23.54	138	20.5	1115	357	1907	30
GDGZ	E113.15	N23.07	18	21.0	1720	345	1800	30
YNPE	E100.57	N22.49	1302	17.6	1940	315	2088	30
GXPX	E106.45	N22.05	332	20.5	1200	340	1395	30
GDYF	E112.02	N22.55	150	22.4	1900	345	1478	30
HNDZ	E109.57	N19.52	166	23.5	1550	356	1953	30

Note: Meteorological data collected from http://data.cma.cn/ accessed on 20 March 2021.

Due to the low natural germination rate of mature paper mulberry seeds, concentrated sulfuric acid was used to induce germination and then the germinated seeds were moved to a nursery cup for growth and management in a greenhouse. In June 2018, they were transplanted to the afforestation test site for field afforestation. The row spacing of the fixed plants was 0.5 m × 2.0 m. The experiment used a randomized complete block design with 10 blocks containing 5 plants each.

2.2. Experimental Method

The afforestation was uniformly mowed for 1.5 years and continued to grow for 90 days to investigate the growth traits, including plant Height (H in cm), Ground Diameter (GD in cm), and Crown width (C in cm). Then, it was cut again and five plant leaves from each plot were mixed into one sample and there were 10 mixed samples from each provenance. We weighed the fresh weight (leaf biomass, Bio) of each leaf sample, placed the collected leaf samples into an oven at 105 °C for 30 min, and then baked them at 80 °C for 48 h. The samples were mixed evenly by the quartering method and the relevant nutritional indicators were determined by sampling. The Dry Matter (DM), Crude Protein (CP), Ether Extract (EE) and Ash of the samples were detected by the method described by AOAC [24], the contents of Calcium (Ca) and Phosphorus (P) were detected by the method of Tang [25], and the neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were determined by the method described by Van Soest [26].

2.3. Data Analysis

R version 4.0.2 [27] was used for the analysis of the variation in growth and nutritional traits, including coefficient of variation (CV), genetic variation coefficient (GVC), the provenance variance (Vp), the random error variance (Ve), gain (G), and repeatability (R). In order to determine the differences between the phenotypic variables of the provenances, Duncan's multiple range tests were conducted in the agricolae package [28] of R version 4.0.2. Variance analyses were estimated using the sommer package [29] in R version 4.0.2. Cluster analyses were conducted using SPSS 19 software [30]. Based on a General Linear Model:

$$y = X\beta + \varepsilon$$

where y is a vector of trait phenotypes, β is a vector of random effects (provenance), and ε is the residual. X is random effects.

The coefficient of variation (CV) was calculated using the following formula:

$$\text{CV}(\%) = 100 \times \frac{SD}{\overline{X}}$$

where $\overline{X}$ is the trait average phenotypic mean, and SD is the phenotypic standard deviation.

The genetic variation coefficient (GVC) was calculated using the following formula:

$$\text{GVC}(\%) = 100 \times \frac{\sqrt{V_P}}{\overline{X}}$$

To estimate the degree of genetic control for each trait, repeatability (R) for all traits in the provenances overall was calculated using the following formula, based on the variance component estimates from the model analyses:

The realized gain (G) was estimated by:

$$\text{G} = \left(\overline{X}_i - \overline{X}\right)/\overline{X} \times 100\%$$

where $\overline{X}_i$ and $\overline{X}$ are the mean values of the selected superior provenance and the overall trait, respectively.

The repeatability (R) was estimated by:

$$\text{R} = 1 - \frac{1}{F}$$

where F is the mean square ratio between the processing of the statistical method and the random error.

Surfer 13.0 (Golden Software, Golden, CO, USA) software was used for trend surface mapping. The regression equation for the trend surface analysis was as follows:

$$Z_i = \beta_0 + \beta_1 x + \beta_2 y + \beta_3 x^2 + \beta_4 y^2 + \beta_5 xy + \varepsilon_{ij}$$

where β is the regression coefficient, x is the latitude, y is the longitude, and ε_{ij} is the random error.

3. Results

3.1. Variation in Growth Traits of Different Provenances

Among all growth traits (Table 2), the maximum values of GD, H, C, and Bio were 13.87 mm, 107 cm, 134 cm, and 1.64 kg, respectively, and the minimum values of GD, H, C, and Bio were 2.89 mm, 12.50 cm, 5.50 cm, and 0.01 kg, respectively. The variation coefficients of GD, H, C, and Bio were 22.63%, 26.41%, 30.39%, and 62.88%, respectively.

Table 2. Growth trait statistics for *B. papyrifera*.

Trait	Mean	Minimum	Maximum	se	CV (%)
GD (mm)	7.33 ± 1.66	2.89	13.87	0.09	22.63
H (cm)	63.16 ± 16.68	12.50	107.00	0.94	26.41
C (cm)	70.90 ± 21.54	5.50	134.00	1.22	30.39
Bio (kg)	0.47 ± 0.30	0.01	1.64	0.02	62.88

This shows that the genetic differences of growth traits between different provenances. Among all growth traits, GD had the smallest coefficient of variation, while Bio has the largest coefficient of variation. This indicated that the genetic improvement potential of the biomass of the leaves of the arborvitae was the greatest.

3.2. Variation of Nutritional Traits in Different Provenances

Among all nutritional traits (Table 3), the maximum values of CP, NDF, ADF, DM, EE, Ash, Ca, and P were 20.06%, 59.46%, 32.21%, 36.85%, 5.39%, 19.23%, 4.16%, and 5.76%, while the minimum values were 10.60%, 24.02%, 11.00%, 8.92%, 2.23%, 5.71%, 1.00%, and 2.08%, respectively. The coefficients of variation of CP, NDF, ADF, DM, EE, Ash, Ca, and P were 12.77%, 15.75%, 20.88%, 11.39%, 16.61%, 15.32%, 18.64%, and 18.30%, respectively. The coefficient of variation of DM was the smallest and the coefficient of variation of ADF was the largest. The coefficient of variation of all nutritional traits was greater than 10%.

Table 3. Nutritional trait statistics for *B. papyrifera*.

Trait	Mean	Minimum	Maximum	se	CV (%)
CP (%)	14.39 ± 1.84	10.60	20.06	11.46	12.77
NDF (%)	41.53 ± 6.54	24.02	59.46	35.44	15.75
ADF (%)	18.84 ± 3.93	11.00	32.21	21.21	20.88
DM (%)	27.33 ± 3.11	8.92	36.85	27.93	11.39
EE (%)	3.83 ± 0.64	2.23	5.39	3.16	16.61
Ash (%)	12.02 ± 1.84	5.71	19.23	13.52	15.32
Ca (%)	2.70 ± 0.50	1.00	4.16	3.16	18.64
P (‰)	3.49 ± 0.64	2.08	5.76	3.69	18.30

3.3. Analysis of Variance for Different Provenance Traits

Except for the insignificant variance of Ash among different provenances (Table 4), the variances of all the other traits were significant. The provenance variance of GD, H, C, and BIO accounted for 28.67%, 41.75%, 35.76%, and 33.33% of the total variance, respectively. CP, NDF, ADF, DM, EE, Ca, and P accounted for 14.79%, 51.43%, 15.94%, 5.43%, 48.78%, 4.76%, and 17.07% of the total variance, respectively. With the exception of NDF, these values are all lower than the variance component caused by random error, which suggests that the variation in NDF is mainly influenced by genetic effects while the variation in other traits is mainly influenced by random environmental effects. The repeatability of the growth traits (GD, H, C, Bio) was 0.80–0.88, which suggests that these growth traits are under a high degree of genetic control. The repeatability of the nutritional traits (CP, NDF, ADF, DM, P) was 0.48–0.91, which suggests that these traits of paper mulberry are under medium-to-high genetic control. The repeatability of Ash and Ca were 0.25 and 0.33, respectively, and these two traits were under low genetic control. The coefficient of genetic variation (GVC) of growth traits was 12.19–34.27%, and the coefficient of genetic variation (GVC) of nutritional traits was 2.79–11.58%. The GVC of growth traits was greater than that of nutritional traits. The GVC of Bio (34.27%) was much larger than the other traits, showing that the provenance selection potential of Bio is much greater than that of other traits. When comparing growth traits and nutritional traits, the provenance selection potential of growth traits is much greater than that of nutritional traits.

Table 4. Variance components, repeatability, and genetic variation coefficients of the provenances.

Trait	V_P (SE)	Ve (SE)	R	GVC (%)
GD	0.80 ± 0.25	1.99 ± 0.17	0.80	12.19
H	118.80 ± 34.12	165.72 ± 13.98	0.88	17.26
C	169.40 ± 50.48	304.37 ± 25.68	0.85	18.36
Bio	0.03 ± 0.01	0.06 ± 0.01	0.80	34.27
CP	0.50 ± 0.20	2.88 ± 0.24	0.64	4.92
NDF	22.31 ± 6.14	21.07 ± 1.78	0.91	11.37
ADF	2.47 ± 0.97	13.03 ± 1.10	0.65	8.34
DM	0.82 ± 0.45	8.91 ± 0.75	0.48	3.32
EE	0.20 ± 0.05	0.21 ± 0.02	0.90	11.58
Ash	0.11 ± 0.11	3.28 ± 0.28	0.25	2.79
Ca	0.012 ± 0.009	0.24 ± 0.02	0.33	4.07
P	0.07 ± 0.03	0.34 ± 0.03	0.66	7.42

3.4. Typical Correlation Analysis between Growth and Nutritional Traits

The typical correlation analysis results of the growth traits and nutritional traits are shown in Table 5. The correlation coefficient of canonical variable 1 is 0.764 and reaches a significant level, which shows that the relationship between the growth traits and the nutritional traits of paper mulberry provenance is very close. Except for calcium, the typical load coefficient values of all traits exceeded 0.60. From the load symbols of each trait, all growth traits have the same symbols as dry matter and calcium content, which are positively correlated. They are negatively correlated with the sign of crude protein, crude fat, and phosphorus content. It can be seen that with the increase in growth traits among different provenances, the content of dry matter and calcium increases. However, the contents of crude protein, crude fat, and phosphorus tended to decrease. Among canonical variables 1, leaf biomass (−0.915) and crude protein (0.685) had the largest loads, reflecting the effect of total biomass and crude protein on mutual traits. This indicates that the variation in the growth traits and nutritional traits of paper mulberry provenances was most affected by the variation in crude protein and leaf biomass.

Table 5. Canonical correlation analysis of growth and nutritional traits.

		Typical Variable 1	
		Typical Correlation Coefficient n1 = 0.764 *	
		Standardized Typical Factor (u1,v1)	**Typical Load Factor**
Growth traits	GD	0.327	−0.84
	H	−1.631	−0.909
	C	2.156	−0.784
	Bio	−1.776	−0.915
Nutritional traits	CP	0.361	0.685
	DM	−0.649	−0.673
	EE	0.368	0.650
	Ca	0.258	−0.336
	P	0.134	0.636

Note: "*" indicate significant correlation at the levels of 0.05.

3.5. Geographical Variation Analysis of Different Provenances

To better understand the relative trends of each trait and geographic variation, a binary quadratic trend surface analysis was performed (Table 6). The regression equations of GD, H, C, Bio, CP, and EE reached a significant level while the regression equations for NDF, ADF, DM, Ash, Ca, and P did not reach a significant level (subsequent discussions do not consider traits whose geographic variation did not reach a significant level).

It can be seen the relative trends of each trait from the trend surface diagram (Figure 2) that the geographic variation trends of the four growth traits (GD, H, C, and Bio) were similar, with the boundary around 38 °N, and the growth traits generally showed a decreasing trend from west to east in the southern region (influenced by longitude more than latitude). However, the northern area shows a decreasing trend from south to north (mainly affected by latitude, but not much by longitude). CP showed an increasing variation trend from southwest to northeast (more affected by latitude than longitude) and EE showed a trend of increasing first and then decreasing from southwest to northeast (more affected by latitude than longitude).

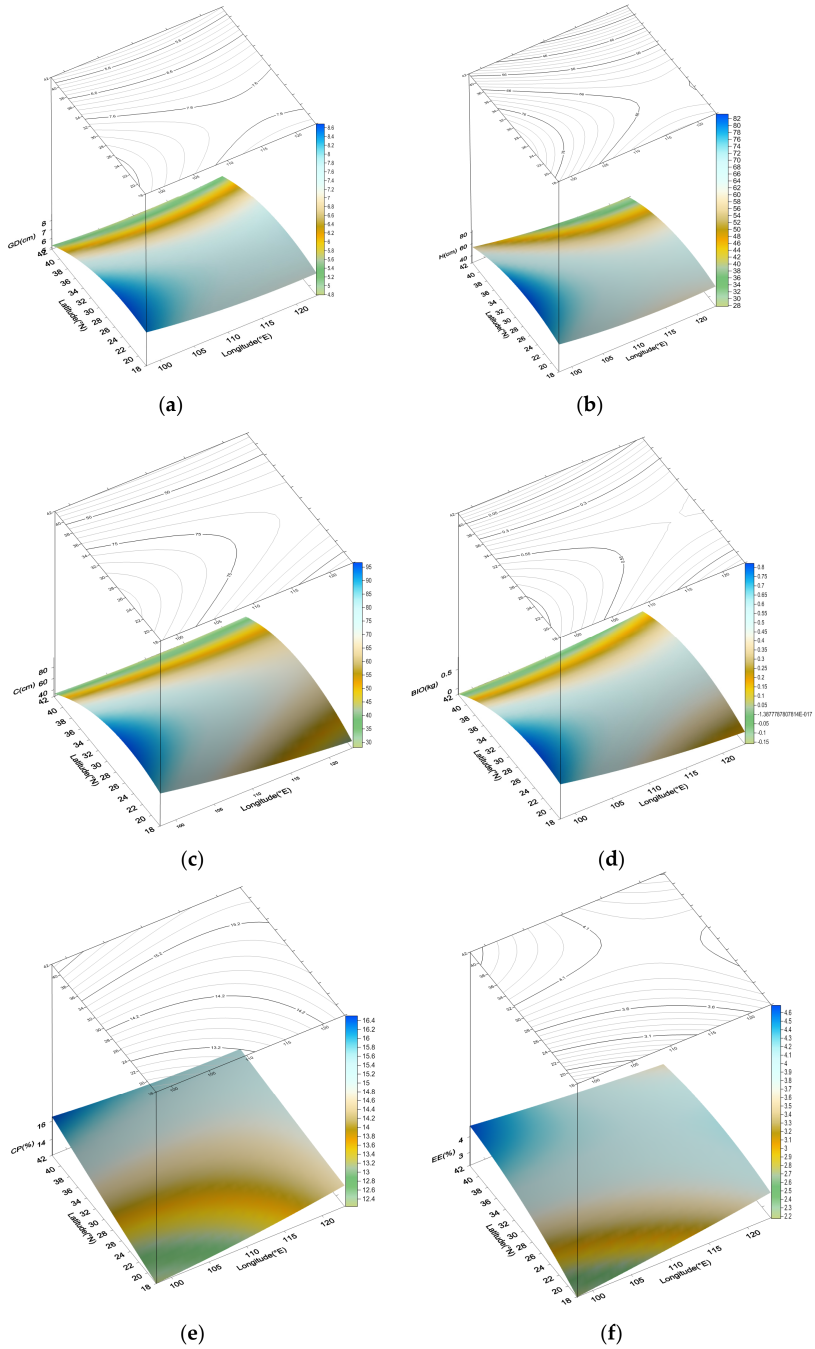

Figure 2. Power contour-trend surfaces for the GD (**a**), H (**b**), C (**c**), Bio (**d**), CP (**e**), and EE (**f**) of *B. papyrifera*. The surface represents the geographic variation and the lines upon the surface represent the contours.

Table 6. Regression equation for each trait.

Trait	Regression Equation of Trend Surface Analysis	Fitting Coefficient	*p*-Value
GD	$Z = 45.633 - 0.698\ x + 0.228\ y + 0.003\ x^2 - 0.009\ y^2 + 0.002\ xy$	0.4866	0.0020
H	$Z = 522.662 - 9.639\ x + 9.127\ y + 0.043\ x^2 - 0.129\ y^2 - 0.024\ xy$	0.5677	2.79×10^{-5}
C	$Z = 592.638 - 9.197\ x + 4.156\ y + 0.027\ x^2 - 0.235\ y^2 + 0.077\ xy$	0.5790	1.99×10^{-5}
Bio	$Z = 10.950 - 0.174\ x - 0.007\ y + 0.001\ x^2 - 0.003\ y^2 + 0.001\ xy$	0.5682	2.75×10^{-5}
CP	$Z = 10.470 - 0.179\ x + 0.708\ y + 0.002\ x^2 + 0.001\ y^2 - 0.006\ xy$	0.4237	0.0011
EE	$Z = -11.34 + 0.045\ x + 0.773\ y + 0.001\ x^2 - 0.003\ y^2 - 0.005\ xy$	0.3435	0.0050

3.6. Provenance Clustering and Provenance Selection

3.6.1. Provenance Clustering

The growth and nutritional traits were used to perform cluster analysis on paper mulberry using the SPSS 19 software, and the results are shown in Figure 3. The threshold was 6, and the 33 paper mulberry provenances were divided into four categories. The first category contains two provenances from southwest China, Mianyang, Sichuan and Kaizhou, Chongqing. This group has the highest leaf biomass and high crude protein. The second category is mainly from the southern and southwestern regions, including Ganzhou in Jiangxi, Yichang in Hubei, Nanchong in Sichuan, Baise in Guangxi, Pu'er in Yunnan, Guangzhou in Guangdong, Dayi in Sichuan, Liuzhou in Guangxi, Yunfu in Guangdong, Panzhou in Guizhou, Huangping in Guizhou, Ping in Guangxi Xiang, and Guizhou Zunyi. This group has low protein content and large leaf biomass. The third group is mainly from the northern and southeastern regions, including Tongbai in Henan, Nanping in Fujian, Shanghai, Xiangxi in Hunan, Tianshui in Gansu, Nanchang in Jiangxi, Huaibei in Anhui, Zhengzhou in Henan, Qingdao in Shandong, Jingdezhen in Jiangxi, Shashi in Hubei, Hangzhou in Zhejiang and Xi'an in Shaanxi Province. The crude protein content of this group was higher and the leaf biomass was lower. The fourth group is mainly from northern provenances, including Wu'an in Hebei, Danzhou in Hainan, Yuncheng in Shanxi, Yangquan in Shanxi, and Beijing. This group has medium crude protein and the smallest leaf biomass.

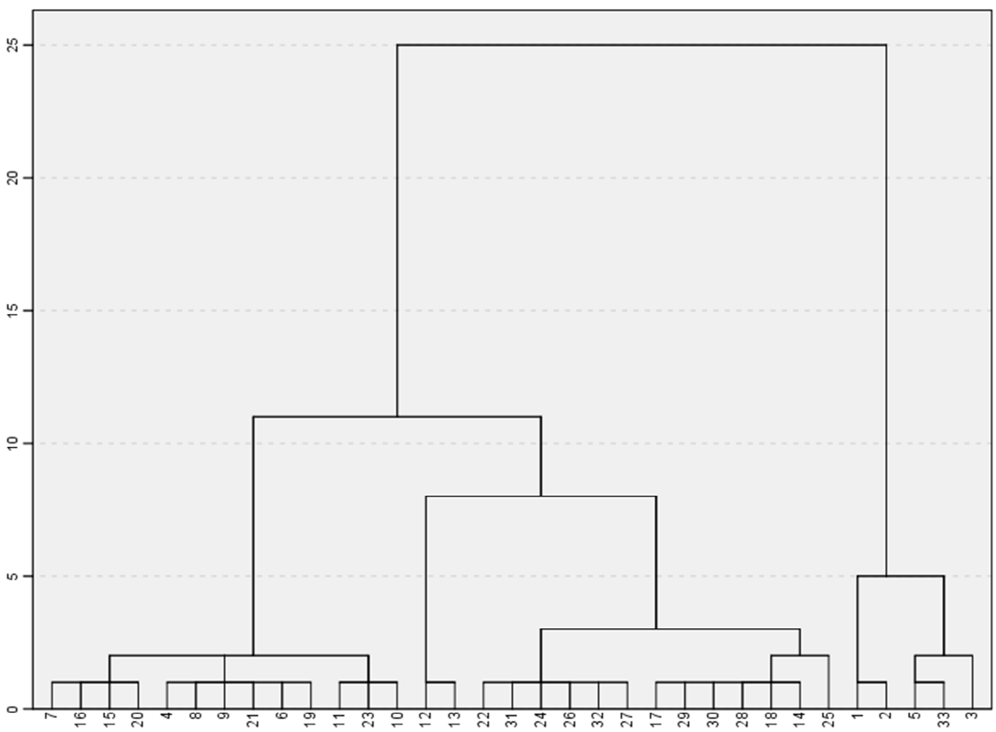

Figure 3. Cluster analysis of paper mulberry from different provenances.

3.6.2. Selection of Superiority Provenance for Feed Type

From the perspective of feed raw material production, the breeding of high-quality varieties is carried out and the main goal of breeding is to select excellent provenances with fast growth, large biomass, and high protein content. In the selection of excellent provenances for high-yield and high-quality feeds, leaf biomass and crude protein content can be considered selection indicators. In this paper, the overall average leaf biomass and crude protein content (0.4662 kg and 14.39%, respectively) were used as the threshold for the selection of superior provenances.

When the leaf samples were used as feed materials, leaf biomass and crude protein content were used as selection indicators. Seventeen provenances has biomass greater than the average (0.4662 g) and 15 provenances had crude protein content greater than the overall average (14.39%). Considering the two indicators, there were only four provenances with both indicators above the threshold (Figure 4), namely Sichuan Mianyang (SCMY), Chongqing Kaizhou (CQKZ), Shanghai (SH), and Fujian Nanping (FJNP). In the cluster analysis, the provenances of Sichuan Mianyang (SCMY) and Chongqing Kaizhou (CQKZ) were clustered into one group and the provenances of Shanghai (SH) and Fujian Nanping (FJNP) were clustered together. These two clusters were closely related. The genetic gains of all traits of the above four provenances are shown in Table 7, where the largest genetic gain is leaf biomass (27.01%), while the genetic gain of neutral detergent fiber is the smallest (−3.06%). The genetic gains were positive for all the growth traits, as well as the crude protein, acid detergent fiber, and crude fat, and negative for the other traits.

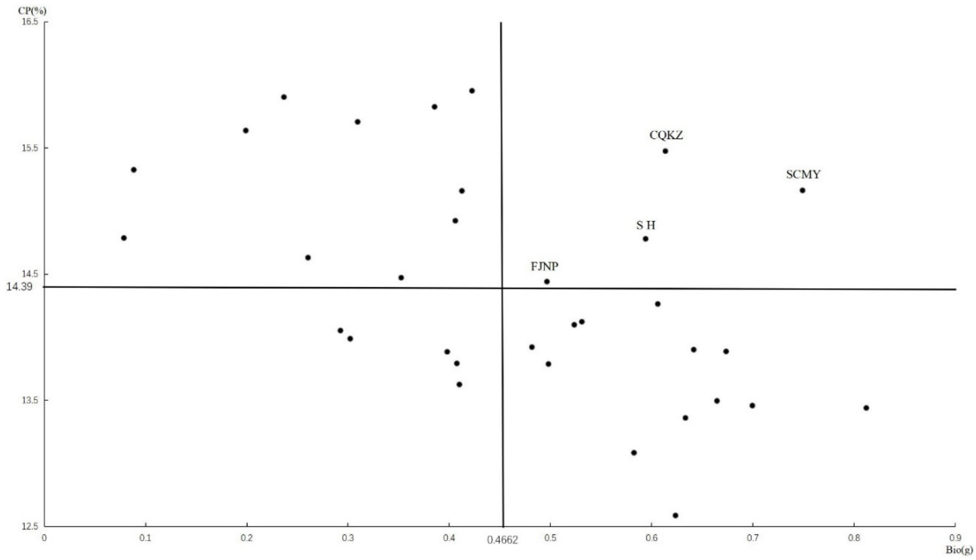

Figure 4. Selection of superiority provenance for feed type.

Table 7. Genetic gain of each characteristic of the selected superior provenances.

Traits	Overall Mean	Mean Value of Superior Provenance	Genetic Gain (%)
GD	7.33 ± 1.66	7.86 ± 1.12	6.74
H	63.16 ± 16.68	66.56 ± 14.60	5.15
C	70.90 ± 21.54	79.57 ± 13.25	11.54
Bio	0.47 ± 0.30	0.62 ± 0.10	27.01
CP	14.39 ± 1.84	14.97 ± 0.45	2.53
NDF	41.53 ± 6.54	40.43 ± 3.36	−3.06
ADF	18.84 ± 3.93	20.32 ± 1.21	5.13
DM	27.33 ± 3.11	26.81 ± 2.15	−0.91
EE	3.83 ± 0.64	4.01 ± 016	3.96
Ash	12.02 ± 1.84	11.53 ± 0.94	−1.03
Ca	2.70 ± 0.50	2.50 ± 0.21	−2.49
P	3.49 ± 0.64	3.42 ± 0.08	−1.32

4. Discussion

4.1. Variation in Growth and Nutritional Traits of Paper Mulberry

In the production and application of woody feed, the speed of growth and the content of nutrients are important indicators. In this study, all traits of the different provenances were significantly different, the coefficient of variation of total leaf biomass was as high as 62%, and the coefficient of variation of the other growth traits was more than 20%, indicating that different provenances of paper mulberry have high genetic diversity, especially as it pertains to the huge potential of leaf biomass selection, which corresponds with the results of Liao [20].

The crude protein content in the leaves is relatively high, and using the leaves as feed materials can increase the growth of cattle and sheep, as it is a feed material with high crude protein content [21]. In this study, the main nutritional properties of the leaf powder were determined, and the crude protein content of the leaves was 10.6–20.6%, which was close to the results of Shi Haina [31] (12.98–19.57%) and slightly lower than those of Chen Tiantian (22.31%) and Zuo Xin (22.49%) [32,33]. It may be that the nutritional value of paper mulberry is affected by the growth period, tenderness, harvesting time, and stubble height of the harvested plants, and the nutritional components are quite different. The contents of crude fat, neutral detergent fiber, acid detergent fiber, crude ash, calcium, and phosphorus are also close to those reported by others [23,34,35]. There are great differences among different provenances for each nutritional trait, and the coefficient of variation is more than 10%, which is consistent with the research of Zuo Xin [33], meaning that the breeding selection potential is huge.

4.2. Correlation of Phenotypic Variation

In this experiment, the correlation between the growth traits was always strong and positive, similar to other plants [36–38]. These results may provide a rationale for indirect selection for growth traits. At the same time, the correlation between growth traits and nutritional traits is weak, which is similar to the findings of Alves [39]. However, the canonical correlation analysis of growth traits and nutritional traits showed that the overall correlation between the two was relatively high. The genes controlling these two types of traits may be related to a certain extent [40–42], but further verification at the molecular level is required.

4.3. Variation Patterns of Geographic Provenance

Geographical changes related to the origin of forest trees are one of the main components of changes at different levels of tree species. Using the influence of this change on growth traits and nutritional value, high-yielding, fast-growing, and high-quality feed-type paper mulberry germplasm resources can be selected [43–45]. In this paper, significant geographic differences were found in GD, H, C, Bio, CP, and EE. All growth traits showed similar patterns of geographic variation, which facilitated the evaluation of the growth potential of different provenances. In general, growth traits are more affected by latitude than longitude and are bounded by about 38° north latitude. Growth traits generally show a decreasing trend from west to east in the southern region. The north area shows a decreasing trend from south to north. This is consistent with the geographic variation of most tree phenotypic traits [46,47]. This pattern is closely related to the climatic conditions of the original tree distribution area [48]. At the paper mulberry seeding sites, the southwest and southern regions have higher annual average temperature, suitable precipitation, and longer plant growth periods. On the whole, CP and EE showed a decreasing trend from north to south, which was consistent with the results of wheat and other crops [49]. These results can play a guiding role in the selection of superior seed sources.

4.4. Source Selection of Forage Paper Mulberry

This study showed that all growth traits tested were significant, so leaf biomass can be used to replace the variation trend of growth traits. When developing fast-growing, high-yield, and forage-quality paper mulberry provenances, growth traits and nutritional traits should be considered comprehensively [50]. In this paper, using growth traits and nutritional traits for cluster analysis, the 33 paper mulberry provenances tested were divided into four categories, some geographically similar provenances were clustered together, and traits closely related to nutritional value were selected: leaf biomass and crude protein content were selected as selection indicators, and the Sichua Mianyang (SCMY), Chongqing Kaizhou (CQKZ), Shanghai (SH), and Fujian Nanping (FJNP) provenances were selected as fast-growing, high-yield, and high-quality paper mulberry provenances. Among the genetic gains of the above four provenance traits, the largest genetic gain was leaf biomass (27.01%), while the genetic gain of neutral detergent fiber was the smallest (−3.06%). Positive genetic gains were observed for all growth traits, including crude protein, crude fat, etc., but the genetic gains of traits such as neutral detergent fiber and ash content, which affect the nutritional value of paper mulberry leaves, were negative, which provides a basis for our selection of high-quality paper mulberry trees for foraging.

5. Conclusions

This study shows that there are significant differences in the growth and nutritional traits of paper mulberry among different provenances, and the potential for genetic improvement is great. Growth traits showed a decreasing trend from south to north, and nutritional traits were just the opposite, but provenances in the southwest and southeast regions showed good growth traits and nutritional traits. Overall, the variations in growth traits and nutritional traits were mainly affected by latitude, showing a relatively obvious south–north variation trend. Sichuan Mianyang (SCMY), Chongqing Kaizhou (CQKZ), Shanghai (SH), and Fujian Nanping (FJNP) were selected as fast-growing, high-yield, and high-quality provenances. If paper mulberry is used as a raw material for development, it is necessary to further improve the evaluation system that refines the quality of paper mulberry and further develop the palatability evaluation of poultry and livestock. This study helps to provide a scientific basis for high-quality paper mulberry breeding, production, and processing.

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