Selection of Suitable Area and Analysis of Adaptability Difference of *Prunus humilis*

Ze YAO[1,2], Shengxiu JIANG[1,3*], Zizhu YAN[1,3], Qi WANG[1], Dawei WANG[1]

1. Gansu Desert Control Research Institute, Lanzhou 730700, China; 2. Gansu Psammophytes Engineering Technology Research Center, Lanzhou 730700, China; 3. State Key Laboratory of Desertification and Aeolian Sand Disaster Combating, Lanzhou 730700, China

Abstract This paper delves into and assesses the differences in biological traits and fruit nutritional composition of 3 varieties of *Prunus humilis* introduced from 2 different regions. Results showed that (i) the contents of protein, total sugar, and calcium of No. 5 variety were higher those of the other 2 varieties, which was recognized as the most suitable variety for fresh fruit; (ii) the comparison of leaf areas index and fruit shape index of 3 varieties shows that the fruit shape index and individual fruit weight of the introduced varieties were higher than those of the control, the diameter of individual fruit of the introduced varieties higher than that of the control indicated that they had a higher fruit hardness, more dry matter accumulation and better fruit quality, and that the introduction region was more suitable for scale-up of *P. humilis*; (iii) there was a positive correlation with the number of fruiting branches and there was a significant negative correlation with individual fruit weight, while the leaf area had a significant negative correlation with the number of fruiting branches. The introduced varieties can develop normally in the 2 testing areas, notably, No. 5 variety performed better than No. 4 and No. 6. Improving management is the prerequisite for maintaining proper number of fruiting branches and high yield.

Key words *Prunus humilis*, Biological traits, Nutritional components, Introduction and cultivation

1 Introduction

Prunus humilis is a small shrub plant of genus *Prunus* in family Rosaceae, the endemic plant species in China. *P. humilis* was put into artificial cultivation in the 1980s[1]. It has good soil and water conservation effect, and its stems, leaves, fruits and root bark have high economic value[2]. It is an excellent economic tree species that can quickly realize greening barren hills, control soil erosion, prevent wind and fix sand. Its fruit has unique flavor, high nutritional value, high calcium content and it is easy to be directly absorbed by human body, so it is called "Chinese Calcium Fruit". Now it has been widely planted in Northeast China, North China and Northwest China, and has produced good ecological, economic and social benefits, with broad market development and utilization prospects. The State Forestry and Grassland Bureau has designated it as one of the popularized tree species for ecological environment construction in China, and has also been listed as an excellent tree species for ecological forest[3]. According to the different climatic conditions in this area, all localities should scientifically and reasonably select *P. humilis* varieties suitable for local planting. Only by planting according to the physiological needs of varieties and local climatic conditions can we better develop and utilize ecological and climatic resources and rationalize the planting of *P. humilis*. In this study, three varieties, Nongda Calcium Fruit No. 4 (Ca4), Nongda Calcium Fruit No. 5 (Ca5) and Nongda Calcium Fruit No. 6 (Ca6), which were successfully cultivated by Du Junjie's research team of Horticulture College of Shanxi Agricultural University and passed the national certification, were taken as the research objects. Under the conditions of the same planting years and basically the same management level, the biological characteristics, nutritional components and related physical properties of the same varieties in different regions and different varieties in the same region were compared, which provided a basis for the expansion of planting areas, the selection of suitable extension areas and high-yield planting of *P. humilis* in China.

2 Materials and methods

2.1 Overview of the study area The introduction experimental area is located in the experimental base of Minqin Sand Control Comprehensive Experimental Station in Gansu Province on the southern edge of Tengger Desert, and it is a typical temperate continental arid desert climate zone. The geographical location is 102°58′ E, 38°34′ N, and the altitude is 1 378 m. It has a typical temperate continental desert climate, with cold and long winters, hot summers and large temperature difference between day and night. The annual average temperature is 7.80 ℃, the highest average temperature in July is 29.00 ℃, the extreme low temperature is −30.80 ℃, and the extreme high temperature is 40.00 ℃. The annual precipitation is 124.00 mm, the annual evaporation is 2 020.00 mm, the air dryness is 5.10, the light and heat are sufficient, and the active accumulated temperature ≥10.00 ℃ is 3 036.40 ℃. The soil is alkaline sandy soil with deep sand layer and poor fertility, with salt content of 0.146%,

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Ze YAO, senior engineer, master, research fields: ecological forestry.
* Corresponding author. Shengxiu JIANG, associate research fellow, master, research fields: plant physiology and ecology.

organic matter of 0.197%, total nitrogen of 0.008%, total phosphorus of 0.116% and pH of 8.3. The control experimental area is located in the *P. humilis* planting base of the Experimental Station of Horticultural Science and Technology College of Hebei Normal University of Science and Technology (Chengguan, Changli County, Qinhuangdao City, Hebei Province), and the seedlings used in the two bases are all introduced from the calcium fruit cultivation base in Jiangxian County, Shanxi Province.

See Table 1 for the comparison of climatic and environmental conditions in the three regions.

2.2 Test materials The materials used in the experiment are "Nongda Calcium Fruit No. 4" (Ca4), "Nongda Calcium Fruit No. 5" (Ca5) and "Nongda Calcium Fruit No. 6" (Ca6), which have passed the national variety certification.

Table 1 Climate comparison between the origin of *Prunus humilis* and the experimental study area

Experimental area	Latitude and longitude	Light duration h	Average temperature ℃	Highest temperature ℃	Lowest temperature ℃	Precipitation mm	Soil pH	Frost-free period//d	Climate type
Place of origin (Shanxi Agricultural University)	112°28′ E, 37°12′ N	2 527.50	10.40	40.50	−22.70	397.10	7.20	179.00	Warm temperate continental climate
Control experimental area (Chengguan, Changli County, Qinhuang-dao City)	118°65′ E, 39°5′ N	2 809.30	11.00	35.00	−24.00	638.33	Mildly alkaline	186.00	Warm temperate and semi-humid continental climate
Introduction experimental area (Minqin Sand Control Comprehensive Experimental Station)	102°58′ E, 38°34′ N	2 799.40	7.80	40.00	−30.80	124.00	8.30	175.00	Temperate continental arid desert climate

2.3 Determination items and methods Gas exchange and chlorophyll fluorescence parameters were measured by LI-6400XT portable photosynthetic instrument (LI-COR, USA) and its associated fluorescent leaf chamber (LI-6400-40). In the sunny weather from June to September, 2019, 15 plants were selected in sample plots of different varieties by 5-point method, and the net photosynthetic rate (Pn), intercellular carbon dioxide concentration (Ci), stomatal conductance (Gs) and transpiration rate (Tr) of leaves were measured under natural light conditions. The leaves are in the same branch (or different branches), and the 5^{th} to 8^{th} leaves under the top of the tip ensure the consistency of the leaves. Three sample leaves were measured for each plant (each time or test period). The sample leaves were measured once a month for 3 d, from 7:00 to 19:00 every day, and once every 2 h. Five groups of data were recorded repeatedly for each sample leaf, and the average value was taken. Five leaves were selected after determination of photosynthetic value, and brought back to the room with a sealed bag, and the leaf length, width and leaf area were measured by YMJ-C leaf area scanner. After the fruit was fully ripe, 5 kg of fruit was randomly taken, and a company with professional testing qualification was entrusted to carry out determination and testing of nutrients according to relevant national standards.

After the fruit was fully ripe, all the fruit-bearing branches were cut off and brought back to the laboratory for measurement of the number of fruiting branches, the number of fruits per branch and the total fruiting amount per plant. At the same time, the fruit diameter was measured by caliper, and the single fruit was weighed by electronic balance.

2.4 Data processing The data were analyzed by Excel and SPSS 26 software and charts were drawn. Multiple comparisons were made by Duncan test to analyze the significance of the differences.

3 Results and analysis

3.1 Correlation between leaf area and net photosynthetic rate Leaf is the main organ for photosynthesis and transpiration of plants, and it is an important gateway for water and gas exchange between plants and the outside world. Leaf morphology is closely related to physiological and biomechanical needs of plants. Light is an important factor affecting plant photosynthesis, and the change of light intensity in different months has great influence on photosynthetic characteristics of *P. humilis* varieties[10]. It can be seen from Table 2 that the leaf length, leaf width and leaf area of each variety in the control experimental area were larger than those in the introduction experimental area. In the introduction experimental area, the leaf length of Ca5 was significantly greater than that of Ca4 and Ca6 ($P<0.05$), there was no significant difference between Ca4 and Ca6, the leaf width and leaf area of Ca5 were significantly greater than those of Ca6 ($P<0.05$), and the leaf width and leaf area of Ca4 were not significantly different from those of Ca5 and Ca6 ($P<0.05$). In the control experimental area, the leaf length and width of Ca5 were significantly greater than those of Ca6 ($P<0.05$), and the leaf area of Ca4, Ca5 and Ca6 was significantly different ($P<0.05$). The results showed that the leaf area of Ca5 was larger than that of Ca4 and Ca6, and the photosynthesis and dark respiration rate were increased by larger leaf area.

Net photosynthetic rate refers to the organic matter accumulated by plant photosynthesis, and it is an expression of photosynthesis strength[9]. Light provides nutrients for fruit growth and development through photosynthesis of leaves, and indirectly affects fruit quality. The correlation between net photosynthetic rate and other photosynthetic indexes of three *P. humilis* varieties is shown in Table 3. It can be seen from Table 3 that the net photosynthetic rate of Nongda varieties was positively correlated with stomatal conductance, that is, the greater the stomatal opening degree, the higher the net photosynthetic rate. Net photosynthetic rate, stomatal conductance and transpiration rate were also positively correlated. There was a significant negative correlation between net photosynthetic rate and intercellular carbon dioxide concentration, that is, the higher the net photosynthetic rate, the lower the intercellular carbon dioxide concentration.

Table 2 Difference analysis of leaf shape observation values of different Nongda *Prunus humilis* varieties

Variety	Introduction experimental area			Control experimental area		
	Leaf length//mm	Leaf width//mm	Leaf area//mm^2	Leaf length//mm	Leaf width//mm	Leaf area//mm^2
Ca4	4.78 ±1.70 b	24.86 ±0.75 ab	856.52 ±40.76 ab	72.14 ±13.15 a	28.61 ±2.06 ab	1 341.15 ±49.11 b
Ca5	53.06 ±1.72 a	27.98 ±0.49 a	1 066.46 ±32.85 a	76.32 ±12.11 a	32.49 ±2.27 a	1 611.76 ±52.34 a
Ca6	45.61 ±1.67 b	24.61 ±0.54 b	798.69 ±50.65 b	64.40 ±0.05 b	26.37 ±5.09 b	1 111.39 ±33.69 c

NOTE Different lowercase letters in the same column indicate statistical difference, otherwise there is no statistical difference ($P<0.05$).

Table 3 Correlation between net photosynthetic rate and other photosynthetic indexes

	Net photosynthetic rate	Stomatal conductance	Intercellular CO_2 concentration	Transpiration rate	Foliar saturated water vapor pressure difference	Leaf temperature	CO_2 concentration
Pn	1						
Gs	0.821**	1					
Ci	-0.949**	-0.724**	1				
Tr	0.881**	0.977**	-0.769**	1			
Vpdl	0.944**	0.804**	-0.987**	0.822**	1		
Ctleaf	0.986**	0.822**	-0.885**	0.889**	0.879**	1	
CndO2	0.814**	0.995**	-0.695**	0.985**	0.771**	0.827**	1

NOTE ** at 0.01 level (two-tailed), the correlation is significant; * at 0.05 level (two-tailed), the correlation is significant.

3.2 Comparison of fruit shape index and fruit weight Altitude is one of the external environmental factors affecting plant growth and development. With the increase of altitude, leaf thickness and leaf area decreased, and leaf dry matter content increased[12], which affected specific leaf area and stomatal conductance of plant leaves. With the increase of altitude, the total trend of specific leaf area of the same species gradually decreased. The comparison results of this study are shown in Table 4. The test results from the introduction experimental area (see Table 4) showed that the single fruit weight in the introduction experimental area of the same variety was greater than that in the control experimental area. The fruit shape index of the introduction experimental area was larger than that of the control experimental area. The average of the vertical and horizontal diameter of the fruit in the control experimental area was larger than that in the introduction experimental area, while the single fruit weight was smaller than that in the introduction experimental area.

Table 4 Fruit shape index and fruit weight of different Nongda varieties

Variety	Introduction experimental area				Control experimental area			
	Vertical diameter of fruit//mm	Horizontal diameter of fruit//mm	Fruit shape index//%	Single fruit weight//g	Vertical diameter of fruit//mm	Horizontal diameter of fruit//mm	Fruit shape index//%	Single fruit weight//g
Ca4	20.98 ±1.66 a	15.96 ±1.37 b	1.31	7.47 ±0.02 a	23.04 ±2.06 a	22.43 ±3.15 a	1.03	6.80 ±3.15 a
Ca5	22.85 ±0.84 a	19.73 ±0.50 a	1.16	7.65 ±0.05 a	23.60 ±3.15 a	23.15 ±2.09 a	1.02	6.66 ±3.09 a
Ca6	22.86 ±0.98 a	18.91 ±0.34 ab	1.21	6.33 ±0.04 b	23.18 ±1.98 a	22.46 ±1.59 a	1.03	6.54 ±2.52 a

NOTE Different lowercase letters in the same column indicate statistical difference, otherwise there is no statistical difference ($P<0.05$).

3.3 Correlation between fruit yield and biomass of different varieties Plant traits are the result of adapting to different environments in the long-term evolution of species, which can objectively express the adaptability of plants to the external environment, such as plant height, leaf size, *etc.*[9]. According to the correlation analysis of biomass of different varieties in Table 5, there was a very significant negative correlation between leaf area and the number of fruiting branches, and there was a significant positive correlation between the number of fruiting branches and the total amount of fruiting. The more the fruiting branches, the greater the amount of fruiting. There was a negative correlation between the amount of fruiting and the average single fruit weight.

3.4 Comparison of main nutritional components of different varieties Calcium is an important component of cell wall, pectin and calmodulin in plants[13]. As an economic forest plant, *P. humilis* will have a broader development and utilization prospect if it is necessary to realize the demonstration and popularization of excellent varieties, expand the planting range and make people know its nutritional value. See Table 6 for the test results of main nutritional components of different varieties of *P. humilis*s in two experimental study areas. It can be seen from Table 6 that the fruit calcium content of each variety in the introduction experimental area was significantly higher than that in the control experimental area, and the difference was great, while the Vc content in the introduction experimental area was lower than that in the control experimental area. The Vc content was greatly affected by light, and the decomposition of Vc was stronger under the irradiation of strong light. In the same test area, the content of calcium in fruit was Ca6 > Ca5 > Ca4, the content of Vc was Ca4 > Ca6 > Ca5, the content of total sugar was Ca5 > Ca6 > Ca4. The taste of ripe *P. humilis* was slightly sour, but the taste of Ca5 was obviously sweet, which was directly related to the significantly high content of total sugar in fruit.

Table 5 Correlation of biomass of different Nongda varieties

	Average number of fruiting branches	Number of fruits per branch	Total amount of fruiting	Average single fruit weight	Horizontal diameter of fruit	Vertical diameter of fruit	Leaf area
Average number of fruiting branches	1.000						
Number of fruits per branch	0.425*	1.000					
Total amount of fruiting	0.462**	0.918**	1.000				
Average single fruit weight	-0.129	-0.366*	-0.082	1.000			
Horizontal diameter of fruit	-0.056	0.022	-0.050	-0.262	1.000		
Vertical diameter of fruit	-0.024	-0.002	-0.058	-0.294	0.896**	1.000	
Leaf area	-0.672**	-0.297	-0.327	-0.024	0.130	0.140	1

NOTE ** indicates that there is a significant correlation at $P<0.01$ level; * indicates that there is a significant correlation at $P<0.05$ level.

Table 6 Test results of conventional nutrients and trace elements

Nutritiona components	Introduction experimental area			Control experimental area		
	Ca4	Ca5	Ca6	Ca4	Ca5	Ca6
Protein//g/100 g	0.59	0.810	0.610	0.70	0.50	0.60
Vc//mg/100 g	11.60	10.50	10.80	15.00	13.40	13.60
Total sugar//g/kg	56.60	80.25	65.23	43.90	84.50	65.00
Calcium//mg/kg	280.00	340.00	531.00	237.00	240.00	262.00
Energy//KJ/100 g	264.00	300.00	258.00	–	–	–

NOTE The nutrients in the introduction experimental area were determined by Lanzhou Zhongjianke Testing Technology Co., Ltd.

4 Discussion

(i) The calcium content of three *P. humilis* cultivars introduced from two experimental study areas was Ca6 > Ca5 > Ca4, that is, with the progress of artificial cultivation, the calcium content of fruit increased, which may be due to the improvement of Ca content in *P. humilis* through artificial cultivation and optimization, and the formation reasons need to be further studied.

(ii) The indexes of leaf shape such as leaf length, leaf width and leaf area of the same variety in the control study area were larger than those in the introduction study area. This is because the leaf is the basic unit of water and energy exchange in the atmospheric system of plants. The control study area has a warm temperate and semi-humid continental climate, while the introduction study area has a temperate continental arid desert climate. Some studies have shown that the drier the environment, the lower the temperature, the smaller the specific leaf area, the greater the leaf thickness and the smaller the leaf tissue density[9-10, 12], which is consistent with the results of this study.

(iii) Stomatal density controls the water and gas exchange between plants and the environment, which is closely related to photosynthesis, transpiration and respiration of plants. It is mainly affected by temperature and water, and temperature mainly affects stomatal density through water. The higher the water use efficiency of plants, the greater the stomatal density[14]. The results showed that the fruit diameter in the control experimental area was significantly larger than that in the introduction experimental area, while the single fruit weight was just the opposite, that is, the single fruit weight in the introduction experimental area was larger than that in the control experimental area, which was the result of the comprehensive effect of high altitude, strong light, large temperature difference between day and night and other factors.

(iv) Leaf area affected leaf photosynthesis and respiration rate by adjusting photosynthetic area and leaf surface temperature, and had a significant positive correlation with plant relative growth rate[9]. Ca5 was superior to the other two varieties Ca4 and Ca6 in terms of fruit diameter and single fruit weight, which indicated that Nongda Calcium Fruit No. 5 was a variety more suitable for local areas. This may be due to the artificial cultivation and optimization, which further increased the Ca content of *P. humilis*, and made its fruit calcium content higher and higher[13].

(v) The average content of protein and calcium in the introduction experimental area was higher than that in the control experimental area, but the average content of Vc was opposite. The introduction area has an arid desert climate, with strong sunshine and large temperature difference, which is the reason why the Vc in fruit is easy to decompose due to the influence of high temperature. In recent years, *P. humilis* was obtained by artificial breeding of wild varieties in China[17]. A series of studies have been carried out on the resource distribution, biological traits and breeding of *P. humilis*[16-18]. Besides its own genetic factors, the external environmental factors affecting the formation of fruit quality interact and influence each other.

5 Conclusions

In this study, the differences of physiological traits and nutritional components of *P. humilis* introduced and planted in two different climatic regions were analyzed and comprehensively evaluated, and the following conclusions were drawn:

(i) *P. humilis* can grow and develop normally, blossom and bear fruit in the two experimental areas, and can adapt to the local natural environment conditions. The comparison of fruit quality in the two introduction experimental areas showed that *P. humilis* was more suitable for planting in the introduction experimental area (Minqin Sand Control Comprehensive Experimental Station).

(ii) The leaf area in the introduction experimental area was smaller than that in the control experimental area, the single fruit diameter of mature fruit was larger than that in the introduction experimental area, and the fruit shape index and single fruit weight in the introduction experimental area were larger than those in the control experimental area, which showed that the deformation coefficient of the fruit in the introduction experimental area was larger, but the dry matter accumulation of the fruit was higher and the nutrition was richer, so *P. humilis* was more suitable for planting in the introduction experimental area.

(iii) The content of protein and total sugar of Ca5 in the two experimental areas was higher than that of the other two varieties. Nongda Calcium Fruit No. 5 was more suitable for extension and had the best performance of biological traits. The calcium content of fruits in different areas showed the same result of Ca6 > Ca5 > Ca4.

(iv) There was a positive correlation between the fruit yield and the number of fruiting branches, and a significant negative correlation between the fruit yield and the single fruit weight; there was a significant negative correlation between leaf area and the number of fruiting branches. In order to realize the high-yield and high-quality cultivation of *P. humilis*, scientific and reasonable pruning management techniques are needed.

References

[1] WANG YX, HE WP. Cultivation, development and utilization of *Prunus humilis*[M]. Beijing: Jindun Publishing House, 2004: 3 – 8. (in Chinese).

[2] DU JJ, DU JM, CHI JW. Development of *Prunus humilis* series products [J]. Journal of Shanxi Agricultural University, 1999, 19(1): 29 – 30. (in Chinese).

[3] LIU SQ, CHANG H, ZHOU JH, *et al.* Research status of development and application of *Prunus humilis* in China[J]. Food Research and Development, 2009, 30(12): 167 – 170. (in Chinese).

[4] WANG PL. Comparison of biological characteristics and nutritional components of several *Prunus humilis* strains[D]. Hebei: Hebei Normal University of Science and Technology, 2021. (in Chinese).

[5] GAO YJ, REN Q. Extraction, component analysis and antioxidant activity of cultivated plum kernel oil[J]. Food Science, 2015, 36(4): 80 – 85. (in Chinese).

[6] WANG YX, HE WJ, LI XD, *et al.* Germplasm distribution and population taxonomic characteristics of *Prunus humilis*[J]. Shanxi Fruit Tree, 2005,(6): 36 – 38. (in Chinese).

[7] LIU BD, SUN JS, DU J, *et al.* Study on the selection of excellent types of *Prunus humilis*, an endemic wild tree species in western China[J]. Inner Mongolia Forestry Science and Technology, 2008, 34(4): 33 – 48. (in Chinese).

[8] YAO Z, JIANG SX, YAN ZZ, *et al.* Photosynthetic physiological daily course and yield of *Prunus humilis* varieties in arid desert area[J]. Gansu Forestry Science and Technology, 2020, 45(2): 7 – 13. (in Chinese).

[9] LI YH, LU Q, WU BO, *et al.* Relationship between leaf morphological characteristics and plant response and adaptation in arid area[J]. Acta Plant Ecology, 2012, 36(1): 88 – 98. (in Chinese).

[10] WANG Q, JIN ZX, GUO SL, *et al.* Photosynthetic physiological and ecological characteristics of endangered plant *Torreya grandis*[J]. Acta Ecology, 2014, 34(22): 6460 – 6470. (in Chinese).

[11] LIU YL. Analysis of wine grape quality index and its relationship with meteorological conditions[D]. Nanjing: Nanjing University of Information Science and Technology, 2006. (in Chinese).

[12] MENG TT, NI J, WANG GH. Plant functional traits and environmental and ecosystem functions[J]. Acta Plant Ecology, 2007, 31(1): 150 – 165. (in Chinese).

[13] HOU XY. Indicator plants of acidic soil, calcareous soil and saline-alkali soil in China[M]. Beijing: Chinese Academy of Sciences Press, 1954. (in Chinese).

[14] DU LQ, ZENG H, ZOU MH, *et al.* Difference analysis of amino acid content in macadamia nut[J]. Economic Forest Research, 2008, 26(4): 49 – 52. (in Chinese).

[15] LI O. Effects of germplasm and producing area on fruit quality and antioxidant activity of *Prunus humilis*[D]. Beijing: Beijing University of Chinese Medicine, 2013. (in Chinese).

[16] WANG YX, HE WJ, LI XD, *et al.* Study on the distribution of germplasm resources and population classification characteristics of *Prunus humilis*[J]. Shanxi Fruit Tree, 2005, (6): 36 – 38. (in Chinese).

[17] LIU BD, SUN JS, DU J, *et al.* Study on the selection of excellent types of *Prunus humilis*, an endemic wild tree species in western China[J]. Inner Mongolia Forestry Science and Technology, 2008, 34(4): 33 – 48. (in Chinese).

[18] CAO Q, DU JJ, LIU H, *et al.* Nutritional characteristics of wild *Prunus humilis*[J]. Wild Plant Resources of China, 1999, 18(1): 34 – 35. (in Chinese).