Analysis of Outdoor Cultivation of Pepino (*Solanum muricatum*) in Qinghai Province

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Abstract [**Objectives**] This study was conducted to explore the feasibility of planting pepino (*Solanum muricatum* Ait.) in Qinghai Province, and to understand the cultivation quality and yield in various areas of Qinghai. [**Methods**] With small fruit type of pepino as the material, four areas in eastern Qinghai were selected to determine the agronomic traits, yield and quality indexes of pepino. [**Results**] Under the same cultivation conditions, there were some differences in the cultivation status of pepino, but overall, pepino fruit had higher quality. Various physiological indexes were correlated with quality and yield. [**Conclusions**] This study clarified the specific cultivation situation of pepino in Qinghai Province, and evaluated the quality and yield of pepino, providing strong data support for the promotion and planting of pepino in various regions in the future.

Key words Pepino; Eastern agricultural area of Qinghai Province; Yield; Quality

Pepino (*Solanum muricatum* Ait.), also known as Renshenguo and Changshouguo, is native to the northern foot of Andes in South America. It is an annual or perennial crop in the Solanaceae family. The fruit is usually circular, elliptical, or slender, and has a yellow skin covered with purple stripes when ripe. It is usually eaten as fresh fruit, with rich nutrients and high trace element contents[1]. In China, pepino is mainly distributed in Gansu, Qinghai, Yunnan and other areas. It is mostly cultivated in greenhouses in Gansu and Qinghai Provinces, while in Yunnan, which is located in the Yunnan - Guizhou Plateau of China, with a high altitude, pepino is cultivated in the open air, with high quality and wide planting area. However, the quality and yield of fruit are not only influenced by environmental factors, but also by the agronomic traits of plants[2-3], which have been studied in different types of crops. The determination of crop quality and yield based on different agronomic traits can also be applied in new variety breeding[4]. In some studies, it has also been demonstrated that there is a significant correlation between the changes in plant yield and the changes in traits[5]. The traits that need to be measured for pepino have been determined based on the main agronomic traits of different Solanaceae plants[6-7]. The differences between different areas will be reflected in the growth status and fruit quality of plants[8-9], so it is crucial to understand the differences between areas. After investigation and analysis on the climate resource status and characteristics in eastern Qinghai, the utilization rate can be increased[10]. Qinghai Province is located on the Qinghai Tibet Plateau, with long sunshine time, strong radiation, large temperature difference between day and night, and it is suitable for growth of few fruit crops. Therefore, exploring whether high altitude areas are suitable for outdoor cultivation of pepino can improve land use and promote economic development in Qinghai Province. Based on the unique climatic conditions and geographical distribution of Qinghai Province, four areas were selected for outdoor cultivation of pepino, with the aim of understanding the cultivation characteristics of pepino in different areas, evaluating whether each area is suitable for pepino, and making the quality of pepino fruit clear. This study provides a theoretical basis for expanding the outdoor cultivation range of pepino and enriching the varieties of fruit with high nutritional value in Qinghai Province.

Materials and Methods

General situation of experimental fields

The four test areas are located in the eastern part of Qinghai Province, Guide County of Hainan Tibetan Autonomous Prefecture (hereinafter referred to as GD), Minhe County of Haidong City (hereinafter referred to as MH), Xunhua County (hereinafter referred to as XH), and Chengbei District of Xining City (hereinafter referred to as XN). All of them are located in the agricultural region in the eastern part of Qinghai Province, and have a plateau continental climate. The altitude ranges from 1 700 to 2 300 m. The annual rainfall is 260 - 380 mm. The annual daily sunshine hours in Guide County are 1 900 - 3 000 h.

Experimental materials

The experimental material was the cutting plantlets of pepino cultivated by asexual reproduction in the Horticultural Innovation Base of Qinghai Academy of Agricultural and Forestry Sciences. In early May, the cutting plantlets were planted in the four experimental areas. When measuring physiological indexes, pepino plants, which were healthy, averagely growing, free of diseases and pests, were selected, and the measurement began from the second month after planting.

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Determination of agronomic traits

Measurement of morphological indexes Plant height (cm): the height from the base of the plant stem to the growth point of the stem tip; stem diameter (mm): the diameter of the plant stem base, measured with a vernier caliper; stem spacing (cm): the 4th segment below the growth point of the stem tip, measured with a ruler; leaf width, leaf length, and petiole length (cm): corresponding to the width of widest part of the leaf, the length from the tip of the leaf to the base of the leaf, and the length from the base of the petiole to the base of the leaf, respectively, measured with a ruler; petiole thickness (mm): the longitudinal height of the transverse section of the petiole, measured with a vernier caliper; flower diameter and petiole length (mm): the diameter of a fully developed flower, and the length from the base of the calyx to the base of the flower stalk, measured with a vernier caliper; fruit length, fruit width, fruit stalk length, and fruit stalk thickness (mm): corresponding to the longest and widest parts of a normally developing fruit, the length from the bottom of the fruit to the base of the fruit stalk, and the thickness of the fruit stalk base, respectively, measured with a vernier caliper.

Yield measurement The weight of each fruit and the yield of each plant were measured using a balance in gram.

Determination of physiological indexes

(1) Organic acids: Determined by high-performance liquid chromatography (HPLC)[11].

(2) Soluble carbohydrates: Sucrose, glucose, fructose, determined by high-performance liquid chromatography (HPLC)[12].

(3) Flavonoids (spectrophotometer method): Pepino fruit samples were oven-dried and crushed, and sieved through a 40-mesh sieve. Next, 0.5 g was weighed, added with 5 ml of extracting solution, and extracted by the ultrasonic extraction method. Specifically, under an ultrasonic power of 300 W, the extraction system was extracted for 30 min by crushing for 5 s with an interval of 8 s at 60 ℃. Next, centrifugation was performed at 12 000 rpm and 25 ℃ for 10 min, and the supernatant was diluted with the extracting solution to 5 ml for testing. A visible spectrophotometer was preheated for more than 30 min, and adjusted to a wavelength of 470 nm, and zero setting was performed with distilled water. After mixing, the test solution was heated in a 37 ℃ water bath for 45 min and centrifuged at 10 000 r for 10 min, and the reference tube was adjusted to zero. The absorbance value was measured using a 1 ml glass cuvette.

(4) Total phenols (spectrophotometer method): Pepino fruit samples were oven-dried and crushed, and sieved through a 40-mesh sieve. Next, 0.2 g was weighed, added with 5 ml of extracting solution, and extracted by the ultrasonic extraction method. Specifically, under an ultrasonic power of 300 W, the extraction system was extracted for 30 min by crushed for 5 s with an interval of 8 s at 60 ℃. Next, centrifugation was performed at 12 000 rpm and 25 ℃ for 10 min, and the supernatant was diluted with the extracting solution to 5 ml for testing. A visible spectrophotometer was preheated for more than 30 min, and adjusted to a wavelength of 760 nm. After mixing, the test solution was stood for 10 min at room temperature. The absorbance value was measured using a 1 ml glass cuvette.

Statistical analysis methods

Correlation analysis was performed using coreplot. The significance of differences was analyzed in IBM SPSS statistical 26.

Results and Analysis

Correlation analysis of agronomic traits, yield and quality of pepino in different areas

Correlation analysis of agronomic traits, yield and quality of pepino in GD area In this study, four areas were selected for outdoor cultivation experiments of pepino to analyze the correlation between agronomic traits, yield and quality in different areas for future research. The correlation between agronomic traits, quality and yield in GD area is shown in Fig. 1. The yield per plant in GD area was positively correlated with stem diameter and leaf width ($r=0.87$; $r=0.89$), but significantly negatively correlated with fruit stalk length and fruit stalk width ($r=-0.84$; $r=-0.96$). Analyzing the correlation between the quality of pepino and its agronomic traits, it could be concluded that there was a significant positive correlation between citric acid content, and stem diameter and leaf width ($r=0.96$; $r=0.97$). Glucose had a significant positive correlation with petiole length ($r=0.89$), and a significant negative correlation with stem spacing ($r=-0.98$). Sucrose had a significant negative correlation with fructose and fruit stalk width ($r=-0.99$). There was a significant positive correlation between ascorbic acid, and inflorescence and flower number ($r=0.99$). Therefore, it could be seen that the yield of pepino was mainly affected by stem diameter, leaf shape, and fruit stalk shape, which might be due to that the accumulation of nutrients in the leaves affected the development of the fruit, while the stem diameter affected the transportation of nutrients, and the shape of fruit stalks affected fruit setting rate, which in turn affected yield. The quality of fruit was closely related to the morphological indexes of plants, of which the shapes of fruit stalks and leaves were the main influencing factors.

Correlation analysis of agronomic traits, yield and quality of pepino in XH area The correlation analysis between agronomic traits, yield, and quality of pepino in XH area is shown in Fig. 2. There was a significant positive correlation between single fruit weight, and fruit stalk length and fruit length ($r=0.99$; $r=0.96$). Moreover, there was a significant correlation between flavonoids and the shape of leaves, so leaf shape was an important factor affecting flavonoid content. Citric acid had a significant positive correlation with fruit length and fruit stalk length ($r=0.94$), and a significant negative correlation with leaf width and petiole length ($r=-0.91$; $r=-0.90$). Total phenols showed an absolute positive correlation with the number of inflorescences and the length of flower stalks, but a significant negative correlation with the number of flowers ($r=-0.90$). There was an absolute positive correlation between ascorbic acid and leaf width. There was also a

significant correlation between the quality of fruit and the quantity and morphology of flowers. A significant positive correlation was found between the number of inflorescences and the number of flowers, and the quality and quantity of inflorescences were also important factors affecting fruit quality. The shape of flowers might have a significant impact on fruit setting rate in the later stage, thereby affecting fruit quality.

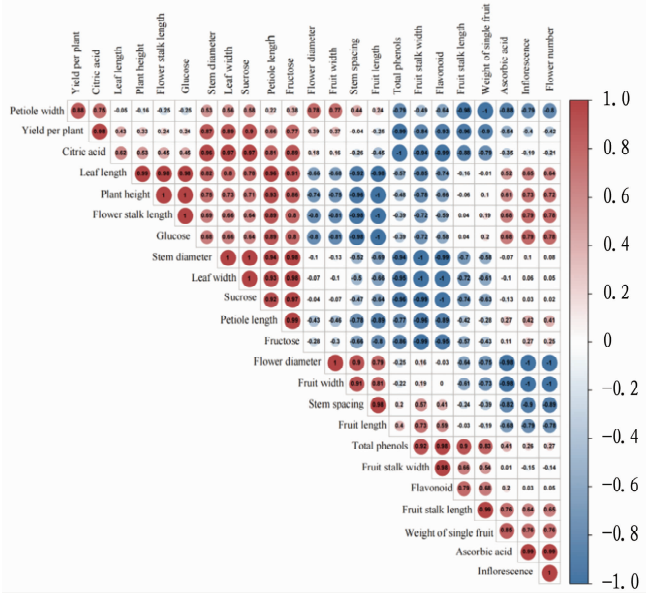

Fig. 1 Correlation analysis of agronomic traits, yield and quality in GD area

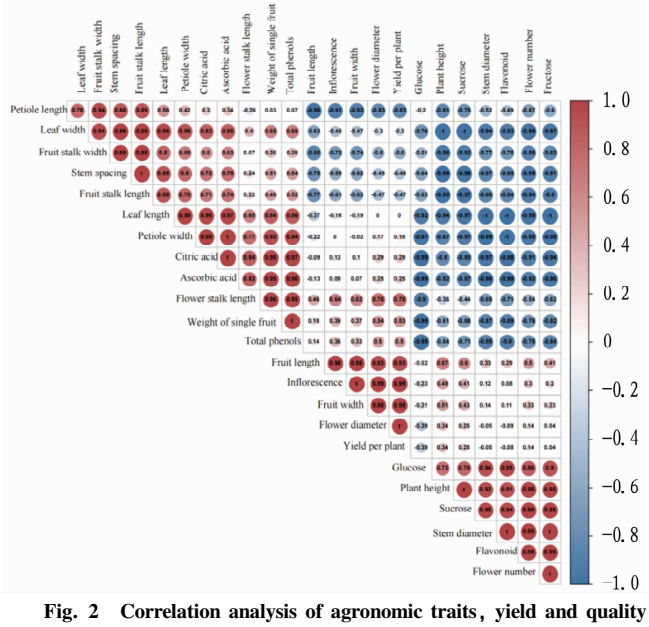

Fig. 2 Correlation analysis of agronomic traits, yield and quality in XH area

Correlation analysis of agronomic traits, yield and quality of pepino in MH area The correlation analysis between agronomic traits, yield and quality of pepino in MH area is shown in Fig. 3. Ascorbic acid and citric acid had a significant negative correlation with stem diameter and flower number, with a correlation coefficient greater than 0.9. Glucose and sucrose were significantly positively correlated with stem diameter ($r=0.94$; $r=0.95$). There was a significant positive correlation between flavonoids and the number of flowers ($r=0.98$). The main difference between MH area and other three areas was that the fruit quality in this area was affected by plant morphology, but the yield was not significantly affected.

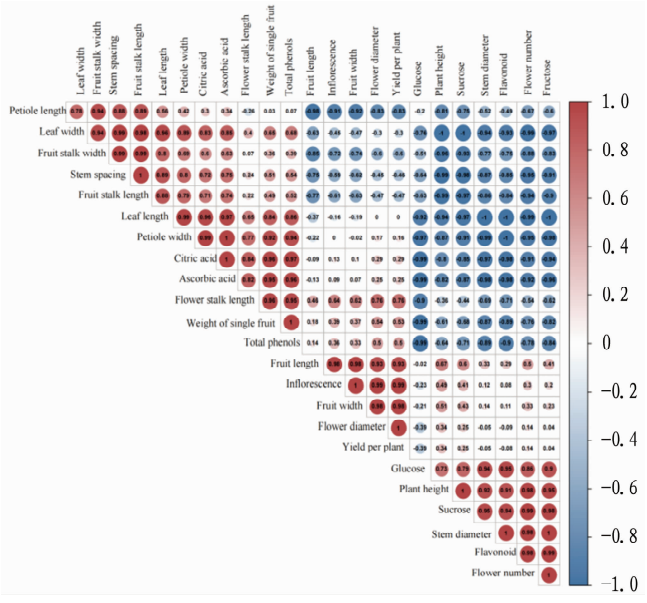

Fig. 3 Correlation analysis of agronomic traits, yield and quality in MH area

Correlation analysis of agronomic traits, yield and quality of pepino in XN area The correlation analysis between agronomic traits, yield and quality of pepino in XN area is shown in Fig. 4. Flavonoids were significantly positively correlated with fruit width and length ($r=0.98$). Sucrose was absolutely positively correlated

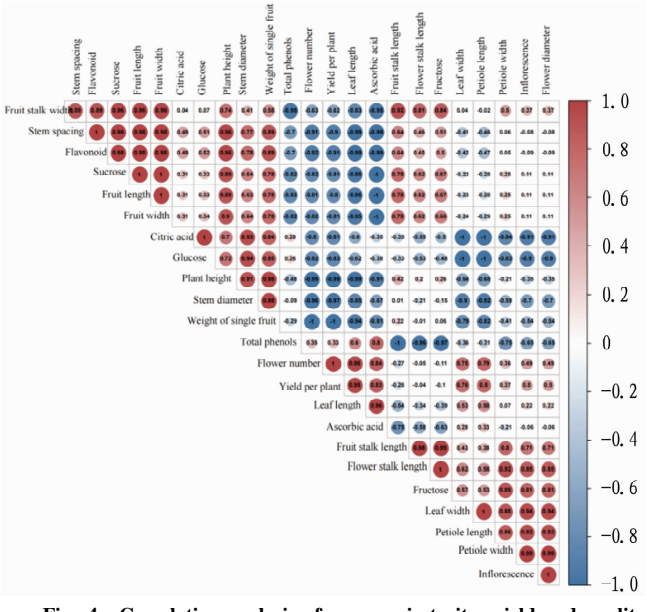

Fig. 4 Correlation analysis of agronomic traits, yield and quality in XN area

with fruit width and length. Citric acid had a significant positive correlation with glucose and stem diameter ($r=0.93$; $r=0.94$), and an absolute negative correlation with leaf width and petiole length. Citric acid also showed a significant negative correlation with inflorescence and flower diameter ($r=-0.91$), and glucose had a significant negative correlation with inflorescence and flower diameter ($r=-0.90$). There was an absolute negative correlation between single fruit weight and flower number. The yield per plant had a significant positive correlation with leaf length ($r=0.95$). The quality and yield of the above areas were significantly correlated with plant morphology. Based on above results, it could be inferred that changes in plant morphology were important factors contributing to differences in plant quality and yield.

Comparison of agronomic traits of pepino in different areas

The comparison of plant height, stem diameter and stem spacing of pepino in different areas is shown in Table 1. There were no significant differences in stem diameter and stem spacing among the four areas. The plant height in MH area was significantly higher than those in XH, XN and other areas ($P<0.05$) (Table 1).

Table 1 Comparison of plant height, stem diameter and stem spacing of pepino in different areas

Area	Plant height//cm	Stem spacing//cm	Stem thickness//mm
GD	66.29±2.17 ab	3.29±0.43 a	12.31±2.58 a
XH	65.01±2.73 b	3.36±0.57 a	11.09±1.09 a
MH	70.78±2.41 a	3.79±0.62 a	10.51±1.49 a
XN	64.17±1.11 b	2.88±0.45 a	11.51±1.17 a

Lowercase letters in the table indicate significant differences at the level of $P<5\%$. The same below.

The comparison results of leaf indexes are shown in Table 2. The petiole widths in XH and GD areas showed no significant differences from that in MH area. The petiole width in MH area was significantly higher than that in XN area ($P<0.05$).

Table 2 Comparison of pepino leaf indexes in different areas cm

Area	Leaf length	Leaf width	Petiole length	Petiole width
GD	11.52±0.35 a	4.53±0.29 a	5.87±0.91 a	3.81±0.34 ab
XH	13.39±3.51 a	3.92±0.11 a	5.23±0.24 a	3.70±0.27 ab
MH	14.79±4.36 a	7.20±4.25 a	6.81±0.83 a	4.43±0.35 a
XN	12.90±3.24 a	3.90±0.62 a	5.60±0.53 a	2.91±0.76 b

There were no significant differences in fruit morphology among different areas, and the fruit morphology of pepino was within a fixed range under regional environmental conditions ($P>0.05$) (Table 3).

Table 3 Comparison of fruit morphology of pepino in different areas mm

Area	Fruit length	Fruit width	Stalk length	Stalk width
GD	59.90±11.99 a	61.70±9.07 a	18.43±0.75 a	3.29±0.32 a
XH	55.56±12.57 a	59.86±16.81 a	15.50±1.88 a	2.96±1.08 a
MH	67.37±4.53 a	63.99±15.74 a	14.89±0.42 a	2.37±0.48 a
XN	51.32±9.82 a	56.05±16.21 a	14.73±2.12 a	2.62±1.30 a

Comparison of pepino yield in different areas

The analysis of yield differences among different areas is shown in Table 4. The yield per plant in XN area was significantly lower than that in other three areas, and there were no significant differences among other regions ($P<0.05$).

Comparison of cultivation quality of pepino in different areas

The quality of pepino in various areas is shown in Table 5. MH and GD were significantly higher than XH and XN ($P<0.05$). The sucrose content in GD area was significantly lower than those in XH, XN and MH ($P<0.05$). The fructose content in GD area was significantly higher than that in XN ($P<0.05$), and there were significant differences between XN, XH and MH ($P<0.05$).

Table 4 Comparison of pepino yield in different areas

Area	Yield per plant//kg	Weight of single fruit//g
GD	2 433.33±225.46 a	155.07±19.75 a
XH	2 563.33±210.79 a	168.65±19.17 a
MH	2 856.33±64.66 a	168.13±26.02 a
XN	1 830.00±135.28 b	140.97±16.55 a

Table 5 Comparison of pepino in different areas

Area	Citric acid//μg/g	Ascorbic acid//μg/g	Sucrose//mg/g	Glucose//mg/g	Fructose//mg/g	Flavonoids//mg/g	Total phenols//mg/g
GD	443.69±33.56 a	162.15±45.11 a	10.27±0.42 b	4.55±0.42 a	8.07±0.40 a	19.55±5.95 a	14.08±2.54 a
XH	345.81±35.98 b	172.25±18.04 a	16.59±0.77 a	4.21±2.04 a	4.51±0.41 c	17.00±8.32 a	11.63±0.75 a
MH	483.17±22.35 a	149.23±22.6 a	18.27±1.88 a	4.49±1.20 a	4.94±0.13 c	21.70±4.31 a	12.19±1.54 a
XN	326.25±43.34 b	158.59±31.75 a	18.88±1.12 a	5.76±0.40 a	5.97±0.22 b	16.96±3.85 a	14.15±1.28 a

Discussion and Conclusions

The eastern agricultural area of Qinghai Province is suitable for the growth of most crops with a relatively mild climate and belongs to high-altitude areas. In this study, with the eastern

agricultural area of Qinghai Province as the range of experimental area, four areas were selected for cultivation experiments. The selected pepino variety in this study was the small fruit type of pepino, which is mostly used for outdoor cultivation. The fruit is small and round in shape, and has rich juice and sweet flesh, and it is mostly used for fruit consumption, while the large fruit type of pepino is mostly used for greenhouse cultivation. In the process of experimental statistics, it was found that there was a greater correlation between the yield and agronomic traits of pepino, and a greater correlation was shown between yield and leaf shape, which was reflected in all four areas. Leaves are an important site for photosynthesis in plants, and they are also important parts for plants to absorb water and CO_2 to generate energy. They are also factories for plant synthesis of amino acids, antioxidants, and various nutrients. In agriculture, crop yield is often measured by measuring the size of leaf area, and leaf number is also an important factor affecting crop yield[13]. In the research on tomatoes, it has been shown that the traits of leaves on the secondary branches of plants play a key role in the yield per plant[14]. The length and width of leaves are the main factors affecting leaf area and thus also affect crop yield. During the statistical process, it was found that there was no significant difference in the shape of pepino fruit. All pieces of pepino fruit were fully mature, and the growth cycle of pepino was not significantly prolonged. The growth and development cycle was normal. It could be seen that cultivating pepino in the open air in Qinghai Province is feasible. There are many studies on the correlation analysis between plant agronomic traits and yield and quality, such as sorghum[15], soybean[16], flax, and medicinal plant *Dendrobium nobile*[17-18]. The important correlation between agronomic traits and quality and yield has been demonstrated in various studies, providing a good foundation for further research in the later stage.

Pepino is a perennial plant in foreign countries, and it has a planting history of about 30 years in China. The fruit is low in sugar and fat, high in protein, rich in various vitamins, and high in nutrition[19-20]. After being introduced into China, it is an annual plant and is mostly consumed as a fruit. Pepino is not tolerant to cold or drought, but has good quality and high nutritional content when planted in Qinghai Province. In the analysis of significant differences among different areas, the plant height in MH area was significantly higher than those in other areas, but had no significant difference compared with GD area. The petiole width in MH area was significantly higher than that in XN area with the lowest yield per plant. The highest fructose content was found in GD area. Differences in altitude, annual average temperature, precipitation, and precipitation cycle among different regions may result in slight differences in the quality and growth status of pepino. This study demonstrated through cultivation experiments in various areas that pepino is suitable for cultivation in Qinghai Province, and the planting situation is good. This study determined that Qinghai Province is suitable for planting pepino by analyzing the correlation between the quality and yield, and agronomic traits of pepino. When comparing the differences among these areas, due to geographical location factors, there were significant differences in the traits and quality among various areas. The agronomic traits had a significant correlation with yield and quality in various areas. In this study, we analyzed the relationship of growth status with fruit quality and yield, and determined the feasibility of planting pepino in the eastern area of Qinghai Province. This study provides data support for large-scale planting of pepino in the later stage, while enriching the types of fruit with high nutritional value in Qinghai Province and promoting the development of horticultural industry economy in Qinghai Province. The cultivation situation and fruit quality of pepino in Qinghai Province were clarified, providing a theoretical basis for large-scale promotion and cultivation of small fruit type of pepino in Qinghai Province in the later stage.

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were both higher than the CK (10.96%), while other varieties were lower than the CK. Varieties Beinong Tianjiao 2, Beinong Tianjiao, Hongfushi and Jingxin 2 had medium to little fiber, and their texture was loose and crisp or crisp, so they had good taste.

Table 3 Comparison of fruit quality among tested watermelon varieties

Variety	Skin color	Peel thickness//cm	Peel hardness kg/cm^2	central sugar content//%	Flesh color	Fiber	Texture	Taste
Beinong Tianjiao 2	Dark green	0.95	35.64	11.75	Bright red	Less	Loose and crisp	Good
Beinong Tianjiao	Dark green	1.02	42.35	10.88	Red	Moderate	Crisp	Good
Hongfushi	Green	0.96	22.32	11.33	Pink	Less	Loose and crisp	Good
Yongfeng 1	Dark green	1.35	58.63	9.8	Red	Much	Hard	Poor
Beinong Futian	Dark green	1.21	52.34	10.59	Red	Much	Hard	Poor
Beinong Shijia	Dark green	1.13	20.62	9.93	Red	Much	Hard	Ordinary
Beinong Jinxiu	Dark green	1.02	43.25	10.19	Bright red	Moderate	Hard	Ordinary
Jingxin 2 (CK)	Green	0.98	28.32	10.96	Red	Less	Loose and crisp	Good

Conclusions and Discussion

Beijing has a temperate semi-humid and semi-arid monsoon climate, with low temperatures in early spring. It has high requirements for the low temperature and weak light tolerance of watermelon varieties, and it is generally advisable to choose early- or medium-maturing varieties. Beijing area has high requirements for the quality of watermelons, and prefers watermelon varieties with thin peel, fine fiber, crisp or loose and crisp texture, high sugar content, and good taste. Among all the tested varieties, Beinong Tianjiao 2 had an earlier maturation stage, and a fruit development period of 38 d and a total growth period of 118 d, both of which were less than the CK. It showed stable growth, with a single fruit weight of 7.56 kg, a fruit setting rate of 0.99 per plant, and a yield of 83 076.9 kg/hm^2, which ranked, respectively, second, first, and second among all tested varieties, and were significantly superior to the CK.

Furthermore, this variety had thin and tough peel, a bright red flesh color, high central sugar content, loose and crisp flesh, and a good taste. It is preliminarily believed that it is suitable for early spring watermelon production in Beijing area.

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