HortScience 59(7):925–933. 2024. https://doi.org/10.21273/HORTSCI17832-24

Phenotypic Trait Analysis for Registered Cultivars of *Camellia sasanqua*

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Keywords. International Camellia Register, phenotypic trait, registered cultivar, Sasanqua

Abstract. **Based on the International Camellia Register (ICR), an analysis of 1616 cultivars of Sasanqua that were registered in 2022 and earlier was conducted. This analysis focused on the resource and biological characteristics of the cultivars. Additionally, a trait diversity analysis, principal component analysis, and cluster analysis of 118 cultivars that had complete morphological records were performed. The findings revealed a rich diversity of Sasanqua cultivars, with Japan, the United States, and Australia being the main sources. The primary flower color was red, followed by multiple colors, white, and rare colors. The predominant flower forms were single-petal and semi-double-petal, with a limited number of formal double-petal forms. Elliptical leaf shapes were the most common, and the predominant leaf colors were green and deep green. The flowering period mainly corresponded to early flowering cultivars. The phenotypic diversity index (*H*) of the 118 cultivars ranged from 0.31 to 1.84. The flower diameter exhibited the highest *H* value (1.84), whereas leaf shape had the lowest *H* value (0.31). The coefficient of variation (*CV*) ranged from 21.67% to 71.81%, with the flower diameter having the smallest *CV* (21.67%) and petal number having the largest *CV* (71.81%). The first three principal components, which accounted for a cumulative contribution rate of 62.49%, effectively represented most of the information regarding the seven trait indicators of the different cultivars. Furthermore, a cluster analysis was conducted based on the flower form, diameter, petal numbers, and other characteristics of the various cultivars. The 118 cultivars were divided into three groups. The first group could be used for breeding single-petal flower cultivars, whereas the third group exhibited a larger number of petals and could be used for breeding double-petal flower cultivars.**

Received for publication 27 Mar 2024. Accepted for publication 12 Apr 2024.
Published online 30 May 2024.
N.Z. and G.W. contributed equally.
This research was supported by Yunnan Province Agricultural Joint Special General Project (no. 202101BD070001-95), Yunnan Provincial Department of Education Science Research Fund Project (no. 2022J0520), Natural Science Foundation of China Regional Project (no. 32260416), and Yunnan Province "Xingdian Talent Support Plan" Youth Talent Special Project (no. 990123083).
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Sasanqua, a member of the genus *Camellia* in Theaceae, is a renowned ornamental flower and the sister flower of Camellia, which is one of the top 10 famous flowers in the world. It remains evergreen throughout the year, boasting an elegant tree shape, colorful flowers, a long flowering period, and high ornamental value. Sasanqua primarily blooms in autumn and winter, and many cultivars emit a pleasant fragrance, making them beloved by many. With the increasing strength of international cultural exchange, Sasanqua has spread widely across the globe (Xu 2007).

According to its evolution degree, the flowering period, flower and leaf characteristics, and ecological differences, Sasanqua can be divided into the following three groups: the *Sasanqua* group; the *Hiemalis* group (also known as Hanshan Sasanqua in Japan); and the *Vernalis* group.

The *Sasanqua* group comprises a group of cultivars with ecology and morphology similar to wild species. Flowering occurs during October to December.

The *Hiemalis* group comprises 'Little Rose' (Hanchun or Shizitou in Japan) as the basic variety and includes its seedling progeny. Because this group can be hybridized with the cultivars of the other two groups to produce offspring, there is no strict definition of this group. The flowering period is late and occurs from November to March.

The *Vernalis* group can be considered as the interspecific hybridization between *C. sasanqua* and *C. japonica* and its offspring. The flowering period is later, from December to April (Xu 1991; Zhu et al. 2022).

The current registration of new Sasanqua cultivars shows that most originate from the selection of natural hybrid seedlings and sports. Japan has a long history of Sasanqua cultivation and places great emphasis on its development. Consequently, most of the registered cultivars have been documented by Japanese horticulturists. Although the introduction of Sasanqua to the United States occurred relatively recently, the diligent breeding work has resulted in the cultivation of numerous new cultivars. In China, the currently cultivated Sasanqua cultivars are mainly from Japan, except for the well-established Haihong (commonly referred to as Xiaomeigui or Little Rose in recent Chinese terminology) and Huanghainan Baozhu. Some camellia enthusiasts, such as Mr. Huang Delin, a renowned horticulturist in China, have also conducted breeding work. From 1987 to 1988, Mr. Huang Delin conducted more than 50 combinations of Sasanqua and other camellia cultivars (Xu 2007). Because of its beautiful tree shape, long flowering period, lush flowers and leaves, considerable flowers and leaves, easy cultivation, fast molding, strong resistance, fewer pests and diseases, and strong antipollution ability, Sasanqua has broad uses for landscaping. Whether it is park or green space, road greening, residential area, courtyard greening or indoor display, almost all have the figure of Sasanqua. (Li et al. 2014).

Phenotypic traits are the result of the combined effects of genotype and environmental factors, which represent the most visible manifestation of plant growth. They play a vital role in evaluating the genetic diversity of plant germplasm resources (Geng et al. 2022; Wang et al. 2014). Phenotypic trait diversity is expressed through diversity indices derived from information theory, reflecting the classification and distribution of qualitative traits, including the richness and evenness of diversity. Diversity indices based on qualitative and quantitative traits directly indicate the diversity of these two types of traits and offer accuracy, scientific validity, and ease of operation. Exploring the diversity of phenotypes helps researchers comprehend the evolutionary potential and genetic stability of species and provides scientific references for screening and using excellent germplasm resources

and conducting genetic research (Zhang et al. 2021).

This study is based on the records of Sasanqua cultivars (including the *Sasanqua* group, *Hiemalis* group, and *Vernalis* group) registered in the International Camellia Register (ICR) (http://camellia.iflora.cn) and provides a review of relevant camellia cultivars from the literature, as well as the collection and organization of registered Sasanqua cultivars. A total of 1616 Sasanqua cultivars were used to classify resources and analyze phenotypic traits. This study provides a theoretical foundation for effectively preserving Sasanqua germplasm resources in the future and the targeted cultivation of exceptional cultivars.

Materials and Methods

Materials and trait selection

This study was conducted between 2022 and 2023 using the ICR to search for *C. sasanqua*, *C. hiemalis*, and *C. vernalis* cultivars. A total of 1616 cultivars were obtained (as of Dec 2022), with three cultivars lacking clear registration dates. Therefore, for this study, we only considered 1613 cultivars as the basic data; relevant data are stored in the permanent database.

From this dataset, a subset of 118 cultivars with complete phenotypic trait records (Table 1) were selected for the correlation analysis. The qualitative traits of Sasanqua were assigned to the following six categories: flower color, flower form, flowering period, leaf color, leaf shape, and flower fragrance. According to Xu (2007), they are defined as follows.

Flower color. The flower color is divided into level I and level II, which include the red series (pink, rose red, bright red, deep red, and purple red), white series (pure white, milky white, pink white, yellow white, and green white), multicolor series (a combination of red and white in different states, mainly including edges, various stripes, and patches), and rare color schemes (light yellow, blue purple). Level I is shown in Fig. 1 (images are from the ICR). Because only a few registered cultivars contain Royal Horticultural Society information, only typical color photos are labeled as Royal Horticultural Society.

Flower form. The flower form is divided into the following six groups: single-petal form, semi-double-petal form, anemone form, peony form, rose form, and formal double form. A typical example of the flower form is shown in Fig. 2 (images are from the ICR).

Flowering period. The cultivars were divided into three groups based on the following flowering periods: early flowering (blooming before the end of November), middle flowering (blooming from early December to the end of January), and late flowering (blooming after the beginning of February).

Leaf color. The leaf colors can be divided into the following five grades: light green, yellow green, green, deep green, and variegated (leaves with spots).

Table 1. List of the 118 cultivars of Sasanqua.

No.	Name	No.	Name
1	Akashigata (sasanqua)	60	Shuchūka
2	Alison Spragg	61	Snowflake
3	Asahi-zuru	62	Sunset Clouds
4	Baiying	63	Taishō-nishiki
5	Beatrice Emily	64	Takara-awase
6	Bettie Patricia	65	Takasago (Hakoda)
7	Boiro	66	Winter's Charm
8	Brooksie Anderson	67	Xiangfei
9	Cherie	68	Xiangfen
10	Chiyozuru	69	Xiangjinhua
11	Chōjiguruma	70	Xiangyong
12	Chō-no-asobi	71	Xiangyun
13	Cotton Candy	72	Xiangzi
14	Fengcheng Zhiguang	73	Xiangziyi
15	Fengcheng Zhimeng	74	Xingyuan Feidie
16	Fengcheng Zhirong	75	Xingyuan Zhixing
17	Fengcheng Zhixia	76	Xingyuan Zidai
18	Fengyun Xiaoxiang	77	Yidianxiang
19	Fenmeigu	78	Yokihi
20	Frosted Star	79	Yoshihime
21	Fuji-no-mine	80	Zihongmei
22	Gingetsu	81	Azumabotan
23	Gwen Pike	82	Bettye J
24	Hanajiman	83	Bonanza
25	Higo-irihi-no-umi	84	Chigo-zakura
26	Higo-zakura	85	Chōshun (hiemalis)
27	Hinode-no-umi	86	Elfin Rose
28	Hi-no-hakama	87	Fanghua
29	Hi-no-tsukasa	88	Feitianyu
30	Ikegamikou	89	Fuji-no-yuki
31	Jennifer Susan	90	Hanxiu
32	Jewellery in the Yellow Sea	91	Haresugata
33	Kin-no-zai	92	Hatsuhikari (hiemalis)
34	Kōgyoku	93	Hi-inkō
35	Mangetsu (sasanqua)	94	Hi-otome-sazanka
36	Mikunikō	95	Interlude
37	Miss Ed	96	Kanjirō
38	Narumigata	97	Kira-shiro-kantsubaki
39	Nodami-ushiro	98	Nara-no-miyako
40	Old Faithful	99	Shikishima
41	Omigoromo	100	Shin-otome
42	Omiyage	101	Haihong
43	Ō-nishiki (Yamazaki)	102	Showa Supreme
44	Otome-sazanka	103	Shōwa-no-sakae
45	Ō-zora	104	Sparkling Burgundy
46	Paradise Gillian	105	Xiangyue
47	Paradise Hilda	106	Asahi (vernalis)
48	Paradise Jennifer	107	Benisuzume (vernalis)
49	Paradise Pearl	108	Egao
50	Pink Snow	109	Ginryū
51	Radiant Beauty	110	Hiryū
52	Red White	111	Kamakura-shibori
53	Rowena Gordon	112	Kokinran (vernalis)
54	Sakura-goromo	113	Koshi-no-kaori
55	Sakura-zukuyo	114	Mennai-chidori
56	Sessan (Minagawa)	115	Ōmigoromo (vernalis)
57	Setsugekka	116	Ryūkō
58	Shinonome	117	Takarazuka
59	Shi-undai	118	Umegaka

Leaf shape. The leaf shape of Sasanqua cultivars is primarily elliptical but includes several variations, such as oval, lanceolate oval, wide ellipse, oval shape, and obovate.

Flower fragrance. The flower fragrance is divided into the following three groups: unscented, light fragrance, strong fragrance.

Flower diameter. The flower diameter (D) of different Sasanqua cultivars was divided into the following five levels: extremely large flowers ($D > 10$ cm), large flowers ($8 < D \leq 10$ cm), medium flowers ($6 < D \leq 8$ cm), small flowers ($5 < D \leq 6$ cm), and extremely small flowers ($D \leq 5$ cm).

Data processing and analysis

The geographical and temporal distributions of the collected 1616 cultivars were analyzed using Excel 2019 (Microsoft, Redmond, WA, USA). The phenotypic characteristics of flower color, flower form, flowering period, flower diameter, leaf shape, and leaf color were also analyzed. The raw data for quantitative traits were organized, and the mean (X),

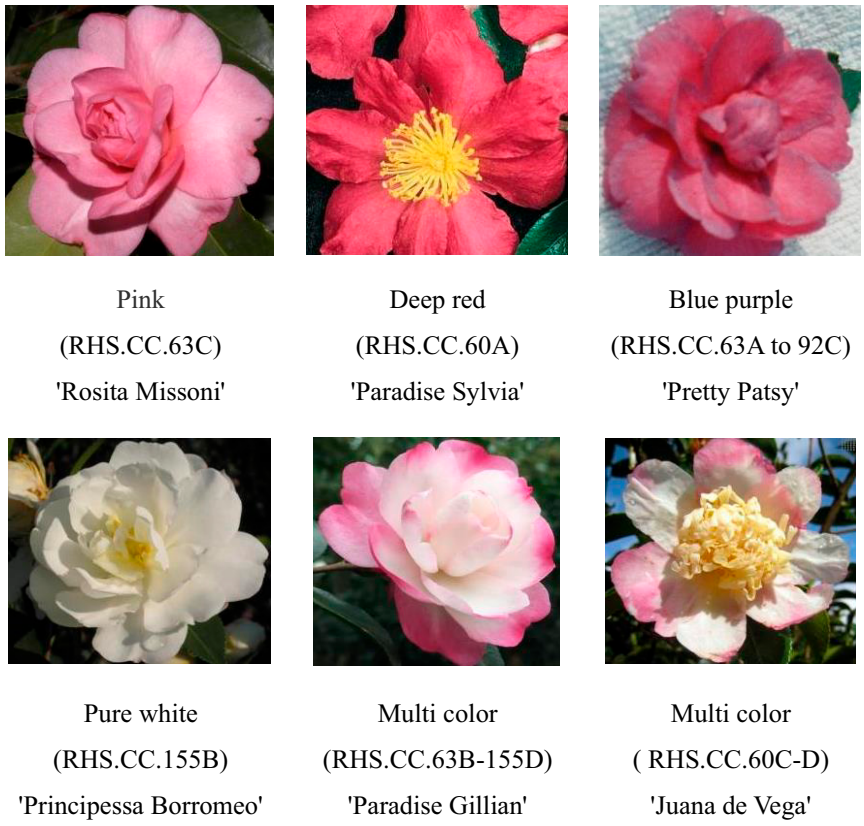


Fig. 1. Typical examples of flower color.

SD, and coefficient of variation (*CV*) were calculated using the following formula: $CV = SD/X$. When calculating the frequency distribution, each quantitative trait was classified into 10 levels with a difference of 0.5 *SD* between adjacent levels. The levels are defined as follows:

Level 1: $< X - 2SD$
Level 2: $X - 2SD \leq$ level 2 $< X - 1.5SD$
Level 3: $X - 1.5SD \leq$ level 3 $< X - SD$
Level 4: $X - SD \leq$ level 4 $< X - 0.5SD$
Level 5: $X - 0.5SD \leq$ level 5 $< X$
Level 6: $X \leq$ level 6 $< X + 0.5SD$
Level 7: $X + 0.5SD \leq$ level 7 $< X + SD$
Level 8: $X + SD \leq$ level 8 $< X + 1.5\ SD$
Level 9: $X + 1.5SD \leq$ level 9 $< X + 2SD$
Level 10: $X + 2SD \leq$ level 10

The frequency of each interval was calculated based on the distribution of the germplasm quantity. The diversity index *H* was further calculated using the Shannon-Weaver information index calculation formula, $H = -\Sigma Pi\ lnPi$, where Pi represents the probability of the i^{th} level occurrence of a certain trait (Wu et al. 2020).

The frequency distribution and genetic diversity index (*H*) for both qualitative and quantitative traits were calculated. Additionally, the average (X), maximum (max), minimum (min), *SD*, range, and *CV* for quantitative traits were studied.

A correlation analysis and principal component analysis were conducted using SPSS 13.0 software (SPSS, Chicago, IL, USA) and Origin 2021 (Origin, Northampton, MA, USA) for drawing. During the clustering analysis process, values were first standardized and converted to facilitate quantification and statistical analyses. The Euclidean distance and clustering situation were obtained using the sum of squares of deviations in SPSS 13.0 (SPSS). Finally, the clustering diagram was drawn and enhanced (https://cloud.keyandaydayup.com/).

Results and Discussion

Overview of registered cultivars of Sasanqua

Geographical and temporal distribution of registered cultivars. Based on the data from the ICR, as of Dec 2022, a total of 1613 cultivars of Sasanqua have been registered in various countries and at different times. The detailed distribution of registered cultivars is shown in Table 3.

The registration time of Sasanqua cultivars in the ICR was divided into 12 stages (Table 3). The overall number of registered cultivars has been increasing over time. Before 1912, several cultivars were registered worldwide, and they mainly originated from Japan. From 1943 to 2012, the number of registered cultivars in various countries showed a general upward trend; however, the number of cultivars registered in Japan decreased significantly between 1943 and 1952. Between 1983 and 2002, the number of registrations in Japan decreased further, whereas registrations in other countries increased relatively. Between 1913 and 1932, other countries, except for Japan, Portugal, England, and Italy, did not register a single cultivar for 20 years. After 1942, the number of registered cultivars began to increase, especially in Japan, where 140 cultivars were registered between 1983 and 1992, setting a record high.

Analysis of biological characteristics of Sasanqua cultivars. **Flower color analysis of different cultivars**. According to the database of the ICR, there are 1483 cultivars with complete records of Sasanqua flower color. Based on the color system characteristics of Sasanqua and the work of Xu (2007), the flower colors of these 1483 cultivars are divided into level I and level II. The specific analysis results are shown in Table 4.

The analysis showed that the main flower color of Sasanqua is red, followed by multicolor and white. Red cultivars account for the majority, with pink being the most common color. White cultivars, especially pure white, are also relatively abundant. However, colors such as yellow, blue, and green are rare among Sasanqua cultivars.

Compared with other cultivars and species of camellia flowers, such as *C. japonica*, *C. reticulata*, and *C. chrysantha*, Sasanqua exhibits relatively diverse flower colors that are magnificent and elegant. However, the variety of flower colors of Sasanqua is still limited, particularly in terms of rare colors.

Flower diameter analysis of different cultivars. According to the database of the ICR, there are 596 cultivars with complete records of the flower diameter for Sasanqua cultivars. The results are shown in Fig. 3. The majority of Sasanqua cultivars have large and extremely large flowers, with 371 cultivars (62.25% of the total) comprising these categories. Medium flowers are relatively common, whereas small and extremely small flowers are less common, accounting for only 11.58% of the total. Overall, Sasanqua cultivars are known for their large and extremely large flowers, thus providing a visually impressive display.

Flower form analysis of different cultivars. According to the database of the ICR, there are 1179 cultivars with complete records of flower patterns for Sasanqua cultivars (Fig. 4). The majority of Sasanqua cultivars have single-petal or semi-double-petal forms, accounting for 77.16% of the total. The anemone, peony, rose, and formal double forms are relatively less common, demonstrating that Sasanqua cultivars predominantly exhibit single or semi-double flower patterns, with rare occurrences of formal double forms.

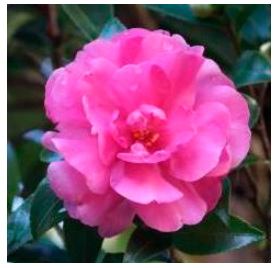
Leaf shape analysis of different cultivars. According to the analysis of registered Sasanqua cultivars, there are 406 cultivars with complete records of leaf shape characteristics. The majority of Sasanqua cultivars have an oval leaf shape, accounting for 59.89% of the total. The lanceolate oval, wide ellipse, oval shape, and obovate leaf shapes are relatively less common, indicating that the leaf shape of Sasanqua cultivars has undergone minimal evolution, with the oval shape being the most prevalent. The distribution of leaf shapes can be

Single petal form ('Hi-no-hakama')

Semi double petal form ('Boiro')

Anemone form ('Chōjiguruma')

Peony form ('Shōwa-no-sakae')



Rose form ('Hi-otome-sazanka')

Formal double form ('Omiyage')

Fig. 2. Typical examples of the flower form of cultivars.

observed in Fig. 5, which provides a graphical representation of the different leaf shapes of Sasanqua cultivars.

Leaf color analysis of different cultivars. According to the analysis of 406 Sasanqua cultivars with complete leaf color records in the ICR database, the majority of Sasanqua cultivars have dark green or green leaves, with a total of 351 cultivars, accounting for 86.45% of the total. The remaining 13.55% of cultivars exhibit light green, variegated, or yellow green leaf colors. The distribution of leaf colors can be observed in Fig. 6, which provides a graphical representation of the different leaf colors of Sasanqua cultivars.

Distribution pattern of the flowering period of different cultivars. An analysis of 552 Sasanqua cultivars with complete flowering period records in the ICR database was performed (Fig. 7). The majority of Sasanqua cultivars exhibit early flowering and middle flowering patterns, accounting for 86.78% of the total. Late-flowering cultivars comprise a smaller proportion.

It is worth noting that Sasanqua is divided into the *Sasanqua* group, *Hiemalis* group, and *Vernalis* group. The flowering period is typically categorized into three seasons, autumn, winter, and spring, which correspond to early flowering, middle flowering, and late flowering, respectively. However, there may be variations in the flowering period of individual cultivars. For example, some cultivars that belong to the *Hiemalis* group, such as Asakura and Hatsuhikari (hiemalis), may start flowering as early as late September or October. In general, the flowering period is not used as a primary indicator of the cultivar group classification. However, in some cases, early-flowering double-petal cultivars have been included in the *Sasanqua* group in catalog compilations by the International Camellia Association (Xu 2007).

Phenotypic trait diversity analysis of sasanqua cultivars

Analysis of trait diversity of Sasanqua cultivars. The analysis of 118 Sasanqua cultivars in the database revealed the diversity of six qualitative traits (flower color, flower form, flowering period, leaf color, leaf shape, and flower fragrance) and two quantitative traits (flower diameter and petal number). The Shannon-Wiener index is used to represent the genetic diversity, indicating the degree and distribution of phenotypic traits, as well

Table 2. Evaluation of qualitative traits of Sasanqua cultivars.

Qualitative traits	Description of grading					
Flower color	1: White	2: Red	3: Multicolor	4: Rare color		
Flower form	1: Single	2: Semi-double	3: Anemone	4: Peony	5: Rose	6: Formal double
Flowering period	1: Early flowering	2: Middle flowering	3: Late flowering			
Leaf color	1: Yellow green	2: Light green	3: Green	4: Deep green		
Leaf shape	1: Ellipsoidal	2: Lanceolate	3: Oval			
Flower fragrance	1: Unscented	2: Light fragrance	3: Strong fragrance			

Table 3. Origin and registration time of Sasanqua.

Registration time	China	America	Australia	New Zealand	Japan	Portugal	England	France	Spain	Germany	Italy	South Africa	Total	Percentage (%)
–1912	2	6	1	0	349	0	0	2	0	0	1	0	361	22.38
1913–1922	0	0	0	0	2	2	1	0	0	0	0	0	5	0.31
1923–1932	0	0	0	0	14	0	0	0	0	0	1	0	15	0.93
1933–1942	0	43	3	0	64	0	4	0	0	0	0	0	114	7.06
1943–1952	0	46	6	0	12	0	0	0	0	0	0	0	64	3.97
1953–1962	0	74	10	1	137	0	1	0	0	0	0	0	223	13.83
1963–1972	8	46	18	4	54	0	5	1	0	0	0	0	136	8.43
1973–1982	0	20	39	2	36	0	1	1	0	0	0	0	99	6.14
1983–1992	13	23	22	7	140	0	2	0	0	0	2	0	209	12.96
1993–2002	2	38	57	8	27	0	1	10	0	0	4	0	147	9.12
2003–2012	14	36	65	4	25	0	0	8	0	2	3	3	160	9.91
2013–2022	24	26	20	0	1	2	0	2	2	1	2	0	80	4.96
Total	63	358	241	26	861	4	15	24	2	3	13	3	1613	100
Percentage (%)	3.91	22.19	14.94	1.61	53.38	0.25	0.93	1.49	0.12	0.19	0.81	0.19	100	

Data are from the International Camellia Register (organized by Office 2019; Microsoft).

Table 4. Flower color classification of Sasanqua cultivars.

Level I	Level II	Cultivar number	Percentage (%)
Red	Bright red	133	8.97
	Pink	616	41.54
	Rose red	22	1.48
	Purple red	37	2.49
	Deep red	76	5.12
White	Pure white	209	14.09
	Milk white	6	0.40
	Pink white	28	1.89
	Yellow white	3	0.20
	Green white	2	0.13
Rare color	light yellow	2	0.13
	Blue purple	1	0.07
Multicolor	Red and white in different states of the composite, mainly edge, stripes, and plaques	348	23.47

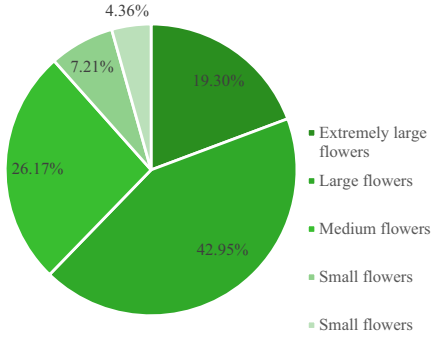


Fig. 3. Distribution of the flower diameters of different Sasanqua cultivars.

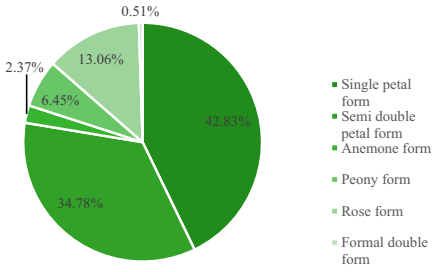


Fig. 4. Distribution of the flower form of different Sasanqua cultivars.

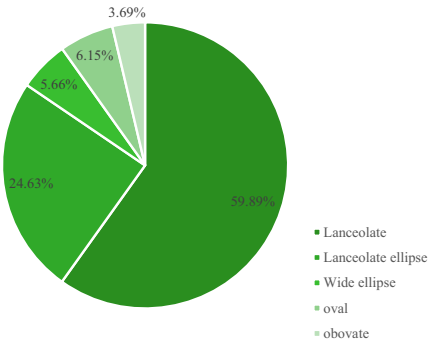


Fig. 5. Distribution of the leaf shape of different Sasanqua cultivars.

as the richness and evenness of diversity (Wang et al. 2022; Wei et al. 1999).

The assigned values and variation forms of the six qualitative phenotypic traits are presented in Table 2, resulting in a total of

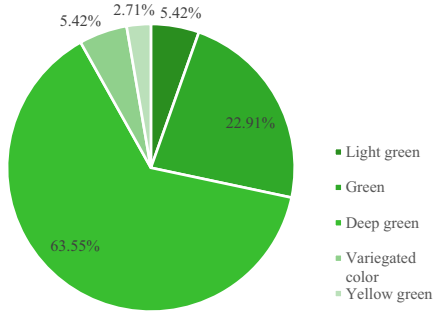


Fig. 6. Distribution of the leaf color of different Sasanqua cultivars.

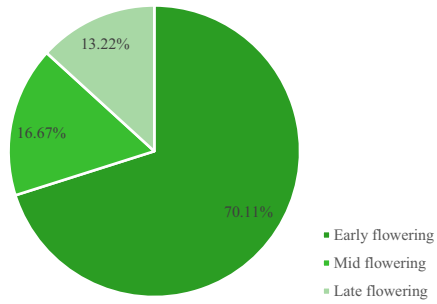


Fig. 7. Distribution of the flowering period pattern of different cultivars.

23 variation forms. The flower form and color exhibit relatively large variation ranges. The main flower colors of Sasanqua include the white series, red series, multicolor series, and rare color series, with the red series accounting for 66.10%, followed by the multicolor series (16.10%), white series (16.10%), and rare color series (1.60%). Regarding flowering periods, Sasanqua cultivars are mainly categorized as early flowering (66.70%), followed by middle flowering (22.10%) and late flowering (11.00%). The variation in flower forms of Sasanqua cultivars includes single-petal, semi-double-petal, anemone, peony, rose double petal, and formal double forms. The main flower forms are single-petal and semi-double forms, accounting for 66.95%, followed by peony and rose forms with a higher proportion of 26.27%. Leaf color can be divided into the following four categories: yellow green, light green, green, and deep green, with deep green (73.72%) being the dominant color. The majority of Sasanqua cultivars have an elliptical leaf shape, accounting for 92.30%. Among the different cultivars, 37.2% exhibit a floral fragrance, which aligns with the overall phenotypic traits of 1616 cultivars in the database.

According to Table 5, the diversity index (H) range for the qualitative traits of Sasanqua cultivars is 0.31 to 1.48, with an average value of 0.87. Traits with high diversity indices ($H > 0.87$) include flower color and flower form, indicating a relatively balanced distribution of these traits among different cultivars of Sasanqua (Wang et al. 2022). The lowest diversity index ($H = 0.31$) is observed for leaf shape, whereas the highest diversity index ($H = 1.48$) is for the flower form. The diversity indices of flower color, flowering period, leaf color, and flower fragrance are 0.93, 0.84, 0.77, and 0.86, respectively. This suggests that the genetic diversity of Sasanqua leaf shape is relatively limited, whereas the genetic diversity of flower form is more abundant.

The *CV* is used to measure the degree of dispersion of phenotypic traits (Fu et al. 2021). According to Table 6, the average *CV* for different Sasanqua cultivars is 44.47%, with a range of 21.67% to 71.81%, indicating that there are relatively rich genetic variations in the traits among different cultivars of Sasanqua. The smallest *CV* is observed for flower diameter (21.67%), whereas the largest *CV* is observed for petal number (71.81%).

Among the qualitative traits of flowers, the *CV* for flower form is the highest, at 63.56%, followed by flower color at 31.03%. The *CV* for the flowering period is 48.25%, and the *CV* for flower fragrance is 54.22%. In terms of quantitative traits of flowers, the average flower diameter is 8.49 cm, and the average petal number is 19. There is a significant difference in the *CV* between these two traits. The cultivar with the highest petal number is Miss Ed, with up to 80 petals, whereas the cultivars with the smallest petal number are Kin-no-zai, Sunset Clouds, and Koshi-no-kaori, with all having only five petals. The cultivar with the smallest flower diameter is Baiying, at 3.6 cm, whereas the cultivar with the largest flower diameter is Ō-zora, at 13 cm.

The diversity index (H) of Sasanqua traits ranges from 0.31 to 1.84, with the highest diversity index observed for flower diameter (1.84), followed by petal number (1.81) and flower form (1.48). This indicates that the genetic diversity of flower diameter, petal number, and flower form among different cultivars of Sasanqua is relatively rich.

Correlation analysis of phenotypic traits of Sasanqua cultivars. A Pearson correlation analysis of the quantitative traits of 118 Sasanqua cultivars (Table 7, Fig. 8) was performed and found the following correlations.

Flower form and petal number. Flower form and petal number had a highly significant positive correlation and a correlation coefficient of 0.763, suggesting a close relationship between flower form and the number of petals.

Flower diameter and fragrance. Flower diameter and fragrance had a significant positive correlation ($P < 0.05$), indicating that as the flower diameter increases, the likelihood of having a fragrance also increases.

Table 5. Diversity analysis of qualitative traits of 118 cultivars of Sasanqua.

	Frequency of classification (%)						
Qualitative traits	1	2	3	4	5	6	*H*
Flower color	16.1	66.1	16.1	1.7			0.93
Flower form	36.4	30.5	4.2	10.2	16.1	2.5	1.48
Flowering period	67.8	21.2	11				0.84
Leaf color	5.9	1.7	18.6	73.7			0.77
Leaf shape	92.4	1.7	5.9				0.31
Flower fragrance	62.7	8.5	28.8				0.86

H = diversity index.

Table 6. Diversity analysis of quantitative traits of 118 cultivars of Sasanqua.

Quantitative traits	Min	Max	Range	X	*SD*	*CV* (%)	*H*
Flower color	1	4	3	2.03	0.63	31.03%	0.93
Flower form	1	6	5	2.47	1.57	63.56%	1.48
Flowering period	1	3	2	1.43	0.69	48.25%	0.84
Leaf color	1	4	3	3.6	0.80	22.22%	0.77
Leaf shape	1	3	2	1.14	0.49	42.98%	0.31
Flower fragrance	1	3	2	1.66	0.90	54.22%	0.86
Corolla diameter	3.6	13	9.4	8.49	1.84	21.67%	1.84
Petal number	5	80	75	18.94	13.60	71.81%	1.81

CV = coefficient of variation; *H* = diversity index; Max = maximum; Min = minimum; X = mean.

Table 7. Correlation analysis of quantitative traits of 118 cultivars of Sasanqua.

Traits	Flower form	Corolla diameter	Petal number	Flowering period	Leaf color	Leaf shape	Flower fragrance
Flower color	−0.207*	0.022	−0.123	0.005	0.062	0.125	0.036
Flower form		−0.335**	0.763**	0.026	−0.062	−0.061	−0.244**
Corolla diameter			−0.213*	−0.059	0.035	−0.035	0.199*
Petal number				0.107	−0.038	−0.116	−0.168
Flowering period					−0.026	−0.023	−0.107
Leaf color						−0.190*	0.001
Leaf shape							0.106

**$P < 0.01$, *$P < 0.05$.

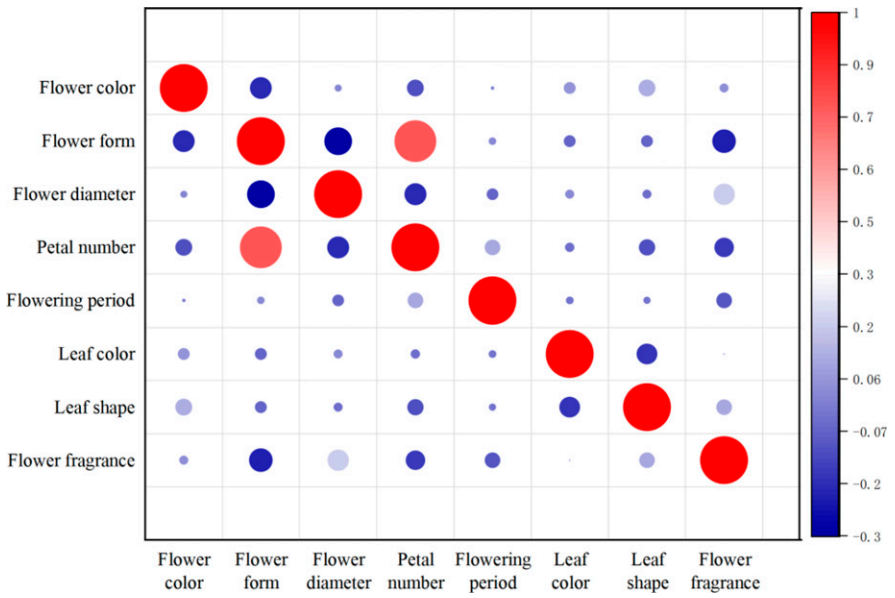


Fig. 8. Correlation analysis of quantitative traits of 118 cultivars of Sasanqua. The circle size represents the degree of correlation among traits. Red represents positive correlation. Blue represents negative correlation.

Flower form, flower diameter, and fragrance. Flower form was significantly negatively correlated ($P < 0.01$) with both flower diameter and fragrance, indicating that cultivars with a particular flower form are likely to have smaller flower diameters and may not possess a fragrance.

Flower color and flower form. There was a significant negative correlation ($P < 0.05$) between flower color and flower form, implying that different flower forms are associated with distinct flower colors.

Flower diameter and petal number. There was a significant negative correlation ($P < 0.05$) between flower diameter and number of petals. As the flower diameter increases, the number of petals tends to decrease.

Leaf color and leaf shape. There was a significant negative correlation ($P < 0.05$) between leaf color and leaf shape, suggesting that certain leaf colors are associated with specific leaf shapes.

Flowering period, leaf color, and other traits. No correlation was observed among flowering period, leaf color, and other traits based on the provided information.

Observations. These correlation analyses provided insights into the relationships between different quantitative traits of Sasanqua cultivars, indicating the interdependencies and associations among these traits.

Principal component analysis of sasanqua cultivars

A principal component analysis of the seven trait indicators of Sasanqua cultivars (flower color, flower form, flower diameter, petal number, leaf color, leaf shape, and flower fragrance) was performed (Table 8). The first three principal components (PC1, PC2, and PC3) had feature values greater than 1.00, indicating their significance in explaining variations in the data. The contribution rates of these components were 30.18%, 17.37%, and 14.94%, respectively. The cumulative contribution rate of the first three components reached 62.49%, indicating that they captured a significant portion of the overall information from the seven indicators.

PC1 had a characteristic value of 2.11, and the indicators with higher absolute values were flower form, flower diameter, and petal number, suggesting that PC1 primarily reflected flower-related indicators. This indicated that variations in flower form, diameter, and petal number contributed significantly to the overall variation observed in Sasanqua cultivars.

PC2 had a characteristic value of 1.22, and the indicators with higher absolute values were leaf color and leaf shape, indicating that PC2 mainly reflected leaf-related indicators. This implied that variations in leaf color and

Table 8. Principal component (PC) analysis of quantitative traits of 118 cultivars of Sasanqua.

	PC eigenvector									
PC	Flower color	Flower form	Flower diam	Petal number	Leaf color	Leaf shape	Flower fragrance	Eigen value	Contributive percentage (%)	Total percentage (%)
PC1	−0.31	0.90	−0.51	0.84	−0.08	−0.18	−0.44	2.11	30.18	30.18
PC2	0.18	0.07	−0.24	0.00	−0.70	0.79	0.11	1.22	17.37	47.55
PC3	0.74	−0.06	−0.42	−0.08	0.38	0.10	−0.41	1.05	14.94	62.49

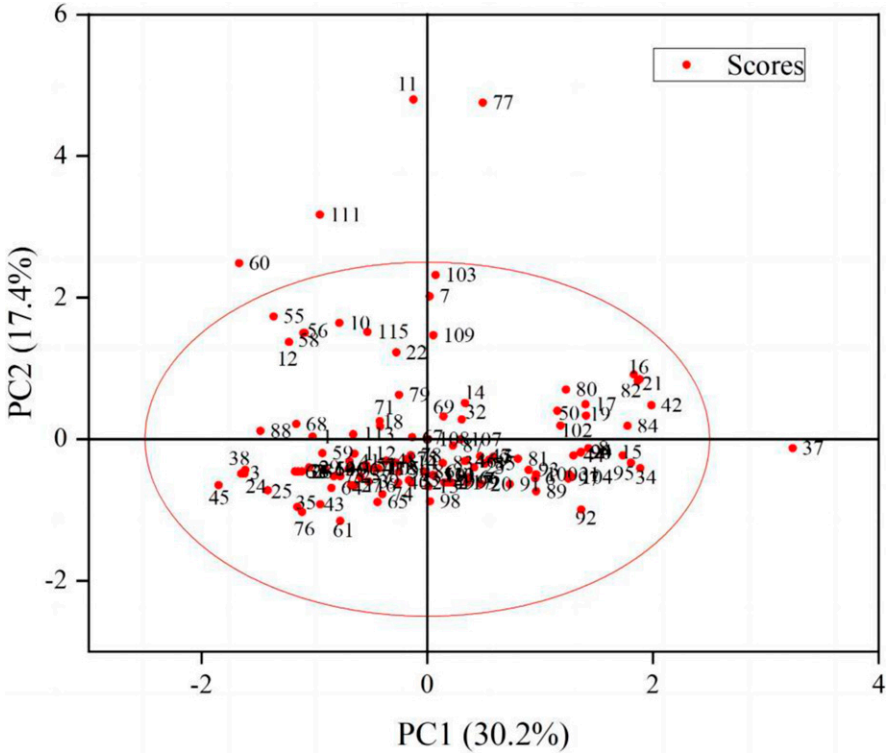


Fig. 9. The score plot of the principal component analysis of quantitative traits of 118 cultivars of Sasanqua.

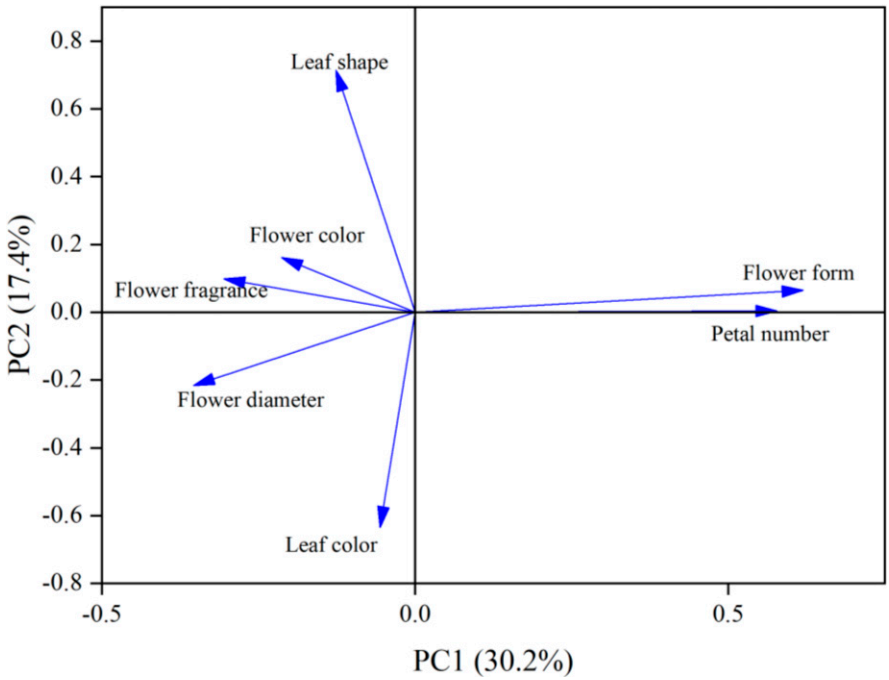


Fig. 10. The loading plot of the principal component analysis of quantitative traits.

shape contributed significantly to the overall variation observed in Sasanqua cultivars.

PC3 had a characteristic value of 1.05, and the indicator with a higher absolute value was flower color, suggesting that PC3 is primarily determined by flower color. This indicated that variations in flower color contributed significantly to the overall variation observed in Sasanqua cultivars.

The principal component analysis score plot (Fig. 9) and loading plot (Fig. 10) of 118 cultivars of Sasanqua were drawn. In Fig. 9, 118 cultivars of Sasanqua are mainly distributed below the origin, reflecting the characteristics of leaf shape and leaf color of PC2. The distribution of 118 cultivars of Sasanqua was relatively balanced on the left and right sides of the origin, mainly reflecting the characteristics of flower form and petal number of PC1.

Figure 10 reveals the relationship between different quantitative traits. The flower form and petal number are basically the same in the PC1 principal component value. The leaf color and leaf shape are basically the same in the PC2 principal component value. The flower color, flower diameter, and flower fragrance are basically the same in the PC3 principal component value. These results are consistent with the results of the correlation analysis, indicating a correlation between traits (Lin et al. 2020).

In summary, the principal component analysis revealed that the first three components effectively captured the variations in the seven trait indicators of Sasanqua cultivars. PC1 mainly reflected flower-related traits. PC2 primarily reflected leaf-related traits. PC3 was primarily determined by flower color. These findings provide insights into the key factors that contribute to the phenotypic diversity observed in Sasanqua cultivars.

Cluster analysis of different cultivars of sasanqua resources

Based on the Ward clustering analysis of the traits of Sasanqua cultivars, 118 cultivars were divided into three groups at a genetic distance of 12.5. The clustering results are shown in Fig. 11.

The first group consists of 60 cultivars, including Asahi-zuru, Chōjiguruma, Taishō-nishiki, Kanjirō, Hanajiman, and Narumigata. These cultivars are characterized by a single-petal flower pattern with fewer petals (average of eight petals) and have the largest average flower diameter of the three groups (9.0 cm).

The second group consists of 46 cultivars, including Bonanza, Hi-otome-sazanka,

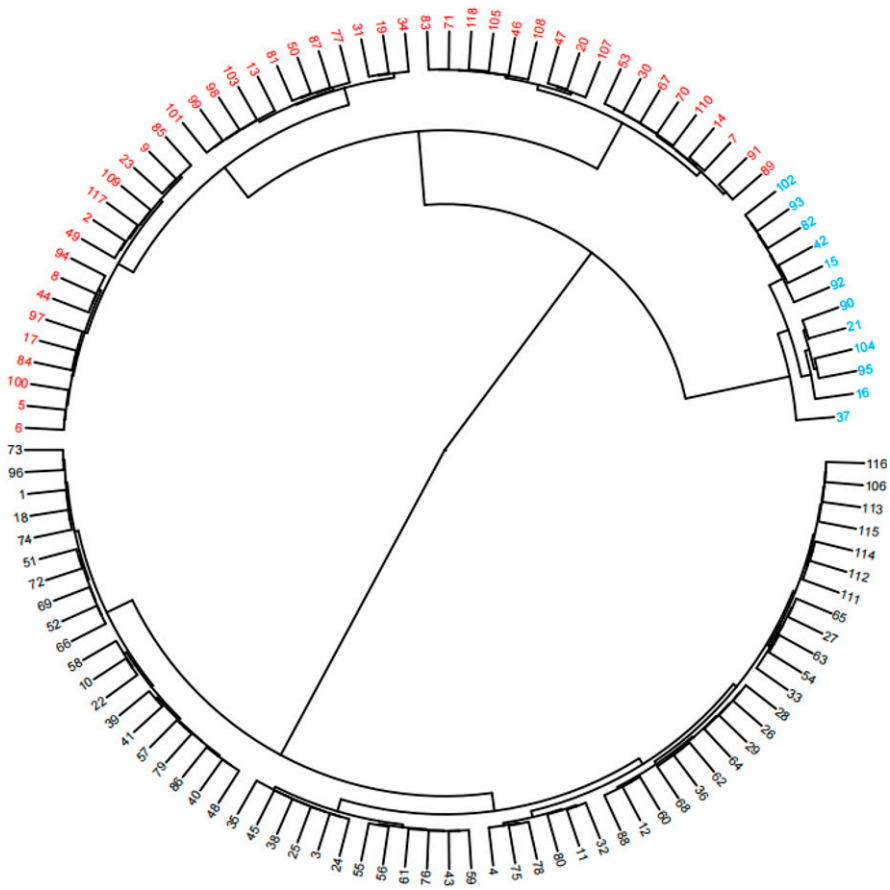


Fig. 11. Cluster analysis of quantitative traits of 118 cultivars. Black represents group I. Red represents group II. Blue represents group III.

Shishigashira, Shōwa-no-sakae, Cotton Candy, and Fengcheng Zhiguang. The characteristics of this group are intermediate between the first and third groups. The flower form is mainly semi-double-petal, with an average flower diameter of 8.9 cm and 24 petals.

The third group consists of 12 cultivars, including Fuji-no-mine, Bettye Jo, Hi-inkō, and Showa Supreme. The main feature of this group is the predominance of the double-petal flower form, with more petals than those of the other two groups. The average number of petals in this group is 48, and the average flower diameter is 7.9 cm.

The clustering analysis based on Ward's method provided insights into the grouping patterns and characteristics of Sasanqua cultivars and helped to identify distinct groups based on flower form, petal number, and flower diameter, which contribute to the understanding of the genetic diversity and classification of Sasanqua cultivars.

Discussion

The analysis and research of Sasanqua phenotypic characteristics play crucial roles in evaluating and breeding Sasanqua cultivars. The findings of this study are summarized here.

Richness of Sasanqua cultivar resources. As of Dec 2022, there are 1616 registered cultivars of Sasanqua, indicating a relatively rich resource base. The number of registered cultivars has shown significant growth since 1942, with more than 1600 new cultivars introduced. Japan has the highest number of registered cultivars, followed by the United States, Australia, China, and other countries, in alignment with previous distribution studies.

Biological characteristics analysis. The majority of Sasanqua cultivars exhibit flower colors in the red series, followed by the multicolor series, accounting for ~83.08% of the cultivars. Large and extremely large flowers are prevalent in terms of flower diameter, whereas the flower forms are primarily single-petal and semi-double-petal; formal double forms are rare. Early flowering is the most common, followed by middle flowering. The predominant leaf shape is oval, and the primary leaf colors are deep green and green.

Genetic diversity analysis. The genetic variation in Sasanqua cultivars is reflected in the *CV* and diversity index. The *CV* ranged from 21.67% to 71.81% for different phenotypic traits, indicating considerable variation. Flower diameter exhibited the smallest *CV* (21.67%), whereas petal number had the largest *CV* (71.81%). The diversity index revealed that flower form had the highest index for quality traits, whereas flower diameter had the highest index for quantitative traits. Genetic diversity is important for species and ecosystem diversity. The higher the diversity index, the stronger the adaptability of resources to the environment (Ma et al. 2021; Ning et al. 2014).

Correlation analysis. Significant positive correlations were found between flower form and petal number and flower diameter and fragrance. Significant negative correlations were found between flower form and flower diameter, flower color and flower form, flower diameter and petal number, and leaf color and leaf shape. These correlations indicate the interactions between different phenotypic traits (Huang et al. 2022).

Principal component analysis. The first three principal components captured the majority of information from the seven traits analyzed, with a cumulative contribution rate of 62.49%. Flower form exhibited the highest contribution to the phenotypic traits of Sasanqua.

Cluster analysis. The Sasanqua cultivars were divided into three groups based on their phenotypic traits. Group I mainly comprised cultivars with a single-petal form, average of eight petals, and flower diameter of 9.0 cm. Group II consisted of cultivars with a semi-double-petal form, average flower diameter of 8.9 cm, and 24 petals. Group III mainly comprised cultivars with a double-petal form, average of 48 petals, and flower diameter of 7.9 cm. These groups can guide breeding efforts for specific flower forms.

Conclusion

Phenotypic traits are the result of the interaction of internal genetic materials and the external living environment of plants. They can represent the genetic diversity of individual plants at the morphological level, and their phenotypic characteristics can be directly measured by visual observation or measurement instruments (Sun et al. 2022; Xie et al. 2019). This method is simple, convenient, and fast, and it is the easiest method of studying plant genetic diversity (Cai et al. 2019). The analysis of phenotypic traits in Sasanqua cultivars provided important insights into their genetic diversity and a basis for future breeding and identification. Based on existing information, it is necessary to continuously enrich the cultivars of Sasanqua, cultivate new and excellent Sasanqua cultivars using the successfully introduced and collected Sasanqua resources, strengthen research of the cultivation conditions of Sasanqua in different environments, promote communication and cooperation, and gradually expand the planting areas of Sasanqua. Further analyses using molecular techniques can enhance the understanding of genetic diversity, facilitate germplasm resource protection, and promote efficient creation of new Sasanqua germplasm.

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