

UDC: 634.75:631.52:57.085.23

**COMPREHENSIVE EVALUATION OF GLOBAL STRAWBERRY
(*FRAGARIA* × *ANANASSA* DUCH.) GERMPLASM UNDER GREENHOUSE
CONDITIONS AND IDENTIFICATION OF PROMISING GENOTYPES FOR
BREEDING**

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Abstract. The article presents the results of a comprehensive evaluation of 23 strawberry (*Fragaria* × *ananassa* Duch.) cultivars and breeding lines from the global germplasm collection under greenhouse conditions. Morphobiological traits, yield performance, and breeding value of the genotypes were assessed. The number of leaves, leaf area, number of flower stalks, average fruit weight, total yield, marketable yield, and marketable fruit percentage were evaluated. In addition, the cultivars and breeding lines were classified into groups according to their average fruit weight. The breeding line K-12 ("Yoqut") exhibited the highest performance in morphobiological development, large fruit size, yield, and marketability. The cultivars Albion, Murano, San Andreas, Kingsberry, Florida Beauty, and Sulhyang were also identified as promising breeding materials with high breeding value. The obtained results provide a scientific basis for selecting valuable parental materials and developing high-yielding, large-fruited, and competitive strawberry cultivars adapted to greenhouse conditions in Uzbekistan.

Keywords: strawberry, *Fragaria* × *ananassa*, global germplasm, morphobiological evaluation, yield, marketable yield, large fruit size, breeding value, greenhouse, breeding materials.

Introduction

Strawberry (*Fragaria × ananassa* Duch.) is one of the most widely cultivated berry crops in the world due to its high nutritional value, excellent flavor, and rich content of vitamins, organic acids, sugars, antioxidants, anthocyanins, and other biologically active compounds. It plays an important role in providing consumers with fresh fruit throughout the year and serves as an essential raw material for the food processing industry. Consequently, strawberry production has been steadily increasing worldwide in response to the growing demand for high-quality fresh berries [4–7].

In recent years, increasing consumer demand for fresh, high-quality berries, together with the need for off-season production, has stimulated the rapid expansion of greenhouse strawberry cultivation. Achieving high economic efficiency under protected cultivation largely depends on the development of cultivars that combine high yield, large fruit size, remontant fruiting habit, extended harvesting period, stability under environmental stress, and good adaptation to local soil and climatic conditions [5, 6, 8, 9].

The efficient utilization of global strawberry germplasm has become one of the key components of modern breeding programs. Strawberry cultivars and breeding lines developed in different countries exhibit considerable variation in their morphobiological, physiological, and agronomic characteristics and therefore represent valuable genetic resources for the improvement of economically important traits, including high yield potential, large fruit size, marketability, extended fruiting period, disease resistance, and adaptability to diverse environmental conditions [3, 7, 10–12].

Comprehensive evaluation of strawberry cultivars and breeding lines from the global germplasm collection under local greenhouse conditions provides an effective approach for assessing their adaptive potential and breeding value, identifying highly productive and competitive genotypes, and selecting superior parental materials for cultivar development. In particular, the integrated assessment of morphobiological characteristics, yield performance, and marketable fruit quality provides a reliable scientific basis for increasing breeding efficiency and developing new strawberry cultivars with high commercial value [8, 9, 13–15].

Therefore, the objective of the present study was to comprehensively evaluate the morphobiological characteristics, yield performance, and marketable fruit quality of strawberry (*Fragaria × ananassa* Duch.) cultivars and breeding lines from the global germplasm collection under greenhouse conditions, to identify valuable parental breeding materials, and to select promising genotypes for future strawberry breeding programs.

Materials and Methods

The study was conducted during 2019–2025 in greenhouses located at the Vegetable, Melon and Potato Research Institute and the Tashkent Experimental Station of the Academician M. Mirzaev Research Institute of Horticulture, Viticulture and Winemaking, Uzbekistan. The experimental material consisted of 23 strawberry (*Fragaria* × *ananassa* Duch.) cultivars and breeding lines (20 cultivars and 3 breeding lines) representing the global germplasm collection and originating from Uzbekistan, the Republic of Korea, the United States, Italy, the Netherlands, Spain, and Japan.

The cultivars and breeding lines were comprehensively evaluated for their morphobiological development, yield performance, and economically important traits. Morphological assessment included the determination of the number of leaves per plant, leaf area, number of flower stalks, and average fruit weight. Yield evaluation comprised total yield, marketable yield, and the proportion of marketable fruits. In addition, the cultivars and breeding lines were classified into fruit-size groups according to their average fruit weight, and their breeding value was comparatively assessed.

Field and laboratory observations, biometric measurements, and yield assessments were carried out during the full fruiting period using internationally accepted methodologies for strawberry evaluation. Mean values were calculated for each cultivar and breeding line, and comparative analyses were performed to determine differences among genotypes.

The experimental data were subjected to statistical analysis according to the methods recommended by Dospekhov and Litvinov [1,2]. Morphological traits, yield performance, and marketability were evaluated using internationally recognized strawberry descriptor lists, guidelines for varietal characterization and evaluation, and generally accepted scientific approaches employed in strawberry breeding research [3–15].

Results

According to the data presented in Table 1, the 23 strawberry (*Fragaria* × *ananassa* Duch.) cultivars and breeding lines from the global germplasm collection differed considerably in their morphological and biological characteristics. The number of leaves per plant ranged from 21.5 to 24.8, leaf area from 57.9 to 65.4 cm², the number of flower stalks from 8.0 to 11.3 per plant, and the average fruit weight from 19.8 to 30.6 g.

This considerable variation among the evaluated genotypes indicates a high level of genetic diversity within the global strawberry germplasm, providing valuable opportunities for the identification of promising parental materials for breeding

programs aimed at improving fruit size, yield potential, and adaptation to greenhouse cultivation conditions.

Table 1

Morphological and Biological Characteristics of Strawberry (*Fragaria × ananassa* Duch.) Cultivars and Breeding Lines

Cultivar (Breeding line)	Leaves per plant (No.)	Leaf area (cm²)	Flower stalks per plant (No.)	Average fruit weight (g)
Tong Ifori (Standard)	21.8	58.4	8.2	20.4
Seolhyang	23.6	61.8	9.5	24.8
Maehyang	22.4	60.3	9.1	22.9
Kuemsil	23.0	61.2	9.3	23.6
Aram	24.2	63.7	10.2	27.1
Kingsberry	22.6	62.8	9.0	26.5
Berrystar	23.5	62.4	9.4	25.2
Sulhyang	24.0	63.1	9.8	26.0
Albion	22.8	61.5	10.8	28.7
San Andreas	23.1	62.1	10.5	28.2
Portola	22.9	61.8	10.4	27.8
Monterey	23.2	62.4	10.3	27.5
Cabrillo	22.4	60.9	9.8	26.9
Murano	23.8	63.2	10.7	28.4
Favori	22.7	60.8	9.6	25.7
Elsanta	21.5	57.9	8.0	19.8
Sonata	21.9	58.8	8.4	21.5
Florida Beauty	23.3	62.6	10.4	27.9
Harmony	22.5	60.5	9.2	24.6
Tochiotome	22.1	59.6	8.9	23.8
K-12 ("Yoqut")	24.8	65.4	11.3	30.6
M-11	22.8	61.3	9.5	24.9
K-83	23.0	61.7	9.7	25.5

According to the data presented in Table 2, the 23 strawberry (*Fragaria × ananassa* Duch.) cultivars and breeding lines from the global germplasm collection differed considerably in terms of fruit weight, yield performance, and marketability. The average fruit weight ranged from 24.6 to 39.8 g, total yield from 19.3 to 27.2 t

ha⁻¹, marketable yield from 17.4 to 26.5 t ha⁻¹, and the proportion of marketable fruits from 90.2 to 97.4%. These results indicate substantial genetic variation among the evaluated genotypes with respect to productivity and fruit market quality.

The highest average fruit weight was recorded for the breeding line K-12 ("Yoqut"), reaching 39.8 g. Relatively large fruits were also produced by Kingsberry (36.8 g), Albion (35.4 g), Murano (35.0 g), San Andreas (34.2 g), Florida Beauty (34.0 g), Portola (33.8 g), Monterey (33.5 g), and Cabrillo (32.8 g). In contrast, the lowest average fruit weight was observed in Elsanta (24.6 g), followed by Sonata (25.4 g) and the standard cultivar Tong Ifori (26.8 g).

Analysis of total yield revealed that the breeding line K-12 ("Yoqut") produced the highest yield (27.2 t ha⁻¹), corresponding to 132.7% of the standard cultivar Tong Ifori. High total yields were also recorded for Albion (26.6 t ha⁻¹; 129.8%), Murano (26.3 t ha⁻¹; 128.3%), San Andreas (25.8 t ha⁻¹; 125.9%), Florida Beauty (25.6 t ha⁻¹; 124.9%), Portola (25.4 t ha⁻¹; 123.9%), Kingsberry (25.2 t ha⁻¹; 122.9%), and Monterey (25.0 t ha⁻¹; 122.0%). The lowest total yield was recorded for Elsanta (19.3 t ha⁻¹), which was lower than that of the standard cultivar.

Marketable yield exhibited a similar trend. The highest marketable yield was obtained from K-12 ("Yoqut") (26.5 t ha⁻¹), followed by Albion (25.6 t ha⁻¹), Murano (25.3 t ha⁻¹), San Andreas (24.7 t ha⁻¹), Florida Beauty (24.5 t ha⁻¹), Portola (24.3 t ha⁻¹), Kingsberry (24.1 t ha⁻¹), and Monterey (23.8 t ha⁻¹). The lowest marketable yields were recorded for Elsanta (17.4 t ha⁻¹), Sonata (18.0 t ha⁻¹), and the standard cultivar Tong Ifori (18.7 t ha⁻¹).

The proportion of marketable fruits ranged from 90.2% to 97.4%. The highest value was recorded for K-12 ("Yoqut") (97.4%), followed by Albion and Murano (96.2%), San Andreas, Portola, and Florida Beauty (95.7%), Kingsberry (95.6%), and Monterey (95.2%). Cabrillo and M-11 each produced 95.0% marketable fruits. The lowest proportions were observed in Elsanta (90.2%), Sonata (90.9%), and the standard cultivar Tong Ifori (91.2%).

Statistical analysis confirmed significant differences among the evaluated genotypes. The least significant difference (LSD_{0.05}) was 0.85 t ha⁻¹ for total yield and 0.78 t ha⁻¹ for marketable yield, while the experimental error (S_x) was 2.5% and 2.4%, respectively. These values indicate a high level of experimental precision and reliability of the obtained results.

Overall, the comparative evaluation demonstrated that the breeding line K-12 ("Yoqut") exhibited superior performance for average fruit weight, total yield, marketable yield, and marketability. In addition, Albion, Murano, San Andreas, Kingsberry, Florida Beauty, and Portola also showed excellent agronomic

performance. These genotypes can therefore be considered valuable parental materials for strawberry breeding aimed at developing high-yielding, large-fruited, and commercially competitive cultivars adapted to greenhouse production conditions in Uzbekistan.

Table 2.

Yield and Marketability of Strawberry (*Fragaria × ananassa* Duch.) Cultivars and Breeding Lines

Cultivar (Breeding line)	Average fruit weight (g)	Total yield (t ha⁻¹)	Relative to the standard (%)	Marketable yield (t ha⁻¹)	Marketable fruits (%)
Tong Ifori (Standard)	26.8	20.5	100.0	18.7	91.2
Seolhyang	31.2	22.9	111.7	21.6	94.3
Maehyang	29.8	22.2	108.3	20.8	93.7
Kuemsil	30.5	22.6	110.2	21.3	94.2
Aram	31.0	23.0	112.2	21.7	94.3
Kingsberry	36.8	25.2	122.9	24.1	95.6
Berrystar	30.2	22.5	109.8	21.2	94.2
Sulhyang	31.5	23.3	113.7	22.1	94.8
Albion	35.4	26.6	129.8	25.6	96.2
San Andreas	34.2	25.8	125.9	24.7	95.7
Portola	33.8	25.4	123.9	24.3	95.7
Monterey	33.5	25.0	122.0	23.8	95.2
Cabrillo	32.8	23.8	116.1	22.6	95.0
Murano	35.0	26.3	128.3	25.3	96.2
Favori	31.6	23.1	112.7	21.8	94.4
Elsanta	24.6	19.3	94.1	17.4	90.2
Sonata	25.4	19.8	96.6	18.0	90.9
Florida Beauty	34.0	25.6	124.9	24.5	95.7
Harmony	30.8	22.8	111.2	21.5	94.3
Tochiotome	29.4	22.0	107.3	20.7	94.1
K-12 ("Yoqut")	39.8	27.2	132.7	26.5	97.4
M-11	32.4	21.8	106.3	20.7	95.0

K-83	31.8	22.4	109.3	21.2	94.6
LSD_{0.05}	—	0.85	—	0.78	—
Sx (%)	—	2.5	—	2.4	—

Marketable yield also differed considerably among the evaluated genotypes. The highest marketable yield was obtained from the breeding line K-12 ("Yoqut"), reaching 26.5 t ha⁻¹. This was followed by Albion (25.6 t ha⁻¹), Murano (25.3 t ha⁻¹), San Andreas (24.7 t ha⁻¹), Florida Beauty (24.5 t ha⁻¹), Portola (24.3 t ha⁻¹), and Kingsberry (24.1 t ha⁻¹). In these cultivars, marketable yield accounted for 95.6–97.4% of the total yield, indicating their excellent commercial quality and suitability for greenhouse production.

Considerable variation was also observed in the proportion of marketable fruits. The highest value was recorded for the breeding line K-12 ("Yoqut") (97.4%). Similarly, high percentages of marketable fruits were observed in Albion and Murano (96.2%), San Andreas, Portola, and Florida Beauty (95.7%), as well as Kingsberry (95.6%). In contrast, relatively lower values were recorded for Elsanta (90.2%), Sonata (90.9%), and the standard cultivar Tong Ifori (91.2%).

Statistical analysis confirmed significant differences among the evaluated genotypes for both total and marketable yield. The least significant difference (LSD_{0.05}) was 0.85 t ha⁻¹ for total yield and 0.78 t ha⁻¹ for marketable yield. The relative experimental error (Sx) was 2.5% and 2.4%, respectively, demonstrating the high precision and reliability of the experimental data.

Overall, the comprehensive evaluation of yield performance and marketability revealed substantial breeding differences among the strawberry cultivars and breeding lines. In particular, the breeding line K-12 ("Yoqut") exhibited superior performance in average fruit weight, total yield, marketable yield, and the proportion of marketable fruits. Furthermore, Albion, Murano, San Andreas, Kingsberry, Florida Beauty, and Portola also demonstrated outstanding agronomic performance, combining high productivity, large fruit size, and excellent marketability. These genotypes can therefore be recommended as valuable parental materials for breeding new high-yielding and commercially competitive strawberry cultivars adapted to greenhouse cultivation conditions in Uzbekistan.

According to the data presented in Table 3, the 23 strawberry (*Fragaria* × *ananassa* Duch.) cultivars and breeding lines from the global germplasm collection were classified into four fruit-size groups based on average fruit weight. The

classification demonstrated a close relationship between fruit size, yield performance, and marketability.

The small-fruited group (24.0–28.0 g) included the standard cultivar Tong Ifori, Elsanta, and Sonata, comprising three cultivars (13.0%) of the entire collection. This group produced an average total yield of 19.9 t ha⁻¹, a marketable yield of 18.0 t ha⁻¹, and 90.8% marketable fruits. These values were lower than those of the other groups, indicating their relatively limited yield potential.

The medium-fruited group (28.1–33.0 g) represented the largest proportion of the collection and included Seolhyang, Maehyang, Kuemsil, Aram, Berrystar, Sulhyang, Cabrillo, Favori, Harmony, Tochiotome, K-83, and M-11. This group consisted of 12 cultivars and breeding lines (52.2%) and achieved an average total yield of 22.6 t ha⁻¹, a marketable yield of 21.3 t ha⁻¹, and 94.4% marketable fruits, clearly outperforming the small-fruited group.

The large-fruited group (33.1–37.0 g) included Kingsberry, Albion, Murano, San Andreas, Portola, Monterey, and Florida Beauty, accounting for seven cultivars (30.4%) of the collection. This group produced an average total yield of 25.5 t ha⁻¹, a marketable yield of 24.6 t ha⁻¹, and 95.9% marketable fruits, demonstrating the superior productivity and commercial quality associated with large-fruited strawberry cultivars.

Table 3.

Classification of Strawberry (*Fragaria* × *ananassa* Duch.) Cultivars and Breeding Lines According to Fruit Weight and Yield Performance

N o.	Group	Average fruit weight (g)	Cultivars and breeding lines	Number of genotypes	Proportion (%)	Average total yield (t ha ⁻¹)	Average marketable yield (t ha ⁻¹)	Marketable fruits (%)
1	Small-fruited	24.0–28.0	Tong Ifori (Standard), Elsanta, Sonata	3	13.0	19.9	18.0	90.8

2	Medium-fruited	28.1–33.0	Seolhyan g, Maehyan g, Kuemsil, Aram, Berrystar , Sulhyang , Cabrillo, Favori, Harmony , Tochioto me, K-83, M-11	12	52.2	22.6	21.3	94.4
3	Large-fruited	33.1–37.0	Kingsberry, Albion, Murano, San Andreas, Portola, Monterey, Florida Beauty	7	30.4	25.5	24.6	95.9
4	Very large-fruited	≥37.1	K-12 ("Yoqut")	1	4.4	27.2	26.5	97.4
	Total	24.0–39.8	20 cultivars and 3 breeding lines	23	100.0	23.1	21.9	94.6

The very large-fruited group (≥ 37.1 g) consisted exclusively of the breeding line K-12 ("Yoqut"). Although this genotype represented only 4.4% of the evaluated collection, it demonstrated the highest performance for all assessed traits. Specifically, it produced an average fruit weight of 39.8 g, a total yield of 27.2 t ha⁻¹, a marketable yield of 26.5 t ha⁻¹, and a marketable fruit proportion of 97.4%.

Overall, the classification of strawberry cultivars and breeding lines according to fruit weight revealed a clear positive relationship between fruit size, total yield, marketable yield, and the proportion of marketable fruits. As fruit size increased, both yield performance and fruit marketability improved consistently. In particular, the large- and very large-fruited genotypes, including Kingsberry, Albion, Murano, San Andreas, Portola, Monterey, Florida Beauty, and the breeding line K-12 ("Yoqut"), exhibited superior agronomic performance under greenhouse conditions. These genotypes combined large fruit size, high productivity, and excellent marketability, making them valuable parental materials for breeding new high-yielding and commercially competitive strawberry cultivars adapted to greenhouse production in Uzbekistan.

This study demonstrates that fruit-size classification is an effective approach for identifying superior breeding materials and can be successfully applied in strawberry breeding programs aimed at improving yield potential and fruit quality under protected cultivation systems.

Conclusions

1. The evaluation of 23 strawberry (*Fragaria* × *ananassa* Duch.) cultivars and breeding lines from the global germplasm collection revealed a high level of genetic diversity in morphological, biological, and agronomically important traits. This diversity provides a valuable genetic basis for the development of improved strawberry cultivars.
2. According to the morphobiological assessment, the breeding line K-12 ("Yoqut") exhibited the best performance, recording the highest number of leaves (24.8 per plant), largest leaf area (65.4 cm²), greatest number of flower stalks (11.3 per plant), and highest average fruit weight (39.8 g). These characteristics identify it as one of the most valuable genotypes for future breeding programs.
3. Yield evaluation demonstrated that K-12 ("Yoqut") achieved the highest total yield (27.2 t ha⁻¹), marketable yield (26.5 t ha⁻¹), and proportion of marketable fruits (97.4%). In addition, Albion, Murano, San Andreas, Kingsberry, Florida Beauty, and Portola also exhibited excellent yield performance and marketability, indicating their high breeding value.

4. Classification of cultivars according to average fruit weight demonstrated a clear positive relationship between fruit size and yield performance. Large- and very large-fruited genotypes consistently produced higher total yield, marketable yield, and marketable fruit percentage than small-fruited cultivars under greenhouse conditions.
5. Based on the comprehensive evaluation, the breeding line K-12 ("Yoqut"), together with the cultivars Albion, Murano, San Andreas, Kingsberry, Florida Beauty, and Portola, are recommended as promising parental materials for breeding new high-yielding, large-fruited, and commercially competitive strawberry cultivars adapted to greenhouse production conditions in Uzbekistan.

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