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Relations Among Agronomic Traits of Commercial Blackberry (*Rubus* subg. *Eubatus* Focke) Cultivars Under the Climatic Conditions of the Moscow Region

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Abstract

Blackberry (*Rubus* subg. *Eubatus* Focke) ranks among the four most commercially valuable berry crops globally, alongside raspberry, strawberry, and blueberry, owing to its high antioxidant content—particularly flavonoids, anthocyanins, and polyphenols. Compared to other berry crops, blackberry cultivation requires lower labor and financial inputs, with plantations remaining productive for 12–15 years. In Russia, total blackberry area is limited (~100 ha), and the Moscow Region is particularly suited for trailing and semi-trailing cultivars with early-to-mid-season ripening. This three-year study (2021–2023) conducted at the Tsitsin Main Botanical Garden (RAS) evaluated ten promising blackberry cultivars to (i) assess interrelationships among phenological, morphological, and fruit quality traits; and (ii) identify optimal market niches for each genotype. Cultivars were grouped by ripening time: early ('Karaka Black', 'Loch Tay', 'Natchez') and medium ('Columbia Sunrise', 'Hall's Beauty', 'Caddo', 'Columbia Giant', 'Victoria', 'Brzezina'). Morphologically, 'Columbia Giant', 'Columbia Star', 'Columbia Sunrise', 'Hall's Beauty', and 'Loch Tay' exhibited the most balanced architecture. For fresh-market retail, 'Hall's Beauty' (650.3 gf), 'Loch Tay' (632.0 gf), and 'Victoria' (882.2 gf) stood out for high fruit firmness, whereas 'Columbia Giant' (11.5 g fruit mass, 354.1 gf) is recommended for direct consumer sales due to its large fruit size and acceptable firmness. Key trait associations included flowering duration and drupelet number ($r = -0.83$); fruiting onset and lateral length ($r = 0.75$); central leaflet length and fruiting laterals per shoot ($r = -0.86$); fruit number per lateral and Soluble Solids Content (SSC, $r = 0.83$); and lateral length ($r = 0.84$). These findings indicate the importance of proper variety selection for establishing blackberry plantations in the specific climatic conditions of the Moscow Region.

Keywords: productivity; blackberry varieties; morphological traits; fruit quality; phenology; correlation analysis; cultivar evaluation; fresh market

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1. Introduction

Blackberry (*Rubus* subg. *Eubatus Focke*) ranks among the four globally most economically valuable berry crops, alongside raspberry (*Rubus idaeus* L.), strawberry (*Fragaria* × *ananassa* Duch.), and highbush blueberry (*Vaccinium corymbosum* L.). Mexico is the leading global blackberry producer, accounting for 21.8% of total worldwide production [1].

The nutritional and functional blackberry value stems primarily from its high bioactive compounds content, particularly flavonoids, anthocyanins, and polyphenols. These antioxidants confer significant potential for applications in both the food and pharmaceutical industries. Moreover, the antioxidant constituents present in blackberry play a crucial role in scavenging free radicals and enhancing the body's immune response, thereby contributing to the prevention of oxidative stress–related disorders [2].

Compared to other berry crops, blackberry cultivation entails substantially lower labor and financial inputs, primarily due to the long productive lifespan of plantings, which typically extends over 12–15 years. Throughout this period, blackberry maintains consistently high yields, often significantly exceeding those of raspberry plantings under comparable management conditions [3,4].

In Russia, the total cultivated area dedicated to blackberry production is approximately 100 hectares, with annual domestic output not exceeding 500 metric tons [5]. The majority of commercial blackberry plantations in Russia are located in the southern regions, particularly in the Republic of Adygea [6], where the climatic conditions support the open-field cultivation of varieties with medium and late ripening periods—unlike the Central Region of Russia. On the contrary, the environmental Moscow Region conditions are more favorable for trailing and semi-trailing blackberries exhibiting early-to-medium fruit ripening. In southern Russia, however, early-maturing cultivars are vulnerable to spring frosts during flowering, while berries are prone to sunscald during fruit development due to high solar radiation and elevated temperatures [7,8].

The long-cane production technology for blackberry is gaining increasing popularity in Russia. Currently, container-grown and under tunnel covers blackberry plantations remain limited in scale; however, cultivated areas are expanding annually.

It should be noted that not all cultivars are suitable for long-cane production; furthermore, successful implementation of this technology depends critically on geographic location, climatic conditions, and proximity to regional fruit markets [9].

Global blackberry breeding programs are oriented toward the development of cultivars tailored both for protected cultivation under tunnel systems and for open-field production.

Leading private breeding entities—including Driscoll's (USA), Hortifrut (Chile), NIAB East Malling (UK), and Niwa Breeding (Poland)—have recently introduced updated breeding strategies that explicitly outline objectives and methodologies aimed at developing cultivars optimized for tunnel-based production systems [10].

The blackberry breeding program at the University of Arkansas has played a pivotal role in driving recent advancements in the crop, particularly through the development of first-year cane-fruiting cultivars. This breakthrough led to the release of several notable cultivars in the United States, including the home-garden varieties Prime Jim, Prime Jan, and Prime-Ark® Freedom, as well as the commercial cultivars Prime-Ark® 45 and Prime-Ark® Traveler [11].

The licensing of genetic material from the University of Arkansas to private marketing companies and nurseries has further catalyzed the establishment of first-year cane-fruiting blackberry breeding programs in Australia, the United States, Chile, and the United Kingdom [12]. The Agricultural Research Service (ARS) Horticultural Crops Production and Genetic Improvement Research Unit (HCPGIRU) breeding program in Oregon, sponsored by the U.S. Department of Agriculture (USDA), was the first to establish a dedicated breeding initiative aimed at developing high-yielding first-year cane-fruiting blackberry cultivars with firm, visually appealing fruit [13,14].

Breeding for resistance to Red Drupelet Reversion (RDR) is another priority in contemporary blackberry improvement programs. Empirical observations of RDR indicate that, although the physiological disorder is often triggered by mechanical injury during harvest, both genotypic and abiotic factors significantly influence the incidence and severity of drupelet discoloration [15,16].

In Russia, blackberry breeding is still at an early development stage. However, the introduction of modern foreign cultivars holds considerable potential to transform the current breeding landscape. These accessions exhibit markedly high levels of key agronomic traits, thereby providing breeders with a valuable pool of superior genotypes for use as parental material in targeted crossing programs [17].

The aim of this study was to identify interrelationships among key phenological, morphological, and fruit quality traits in order to facilitate the selection of superior genotypes for the development of blackberry cultivars with enhanced agronomic performance.

Based on phenological and morphological characteristics, as well as key productivity parameters, ten of the most promising blackberry cultivars—suitable for commercial berry production under open-field conditions in the Moscow Region—were selected for this study. In alignment with the requirements of berry producers, a comparative evaluation of the selected cultivars is also essential to determine their market suitability and potential commercial positioning.

2. Materials and Methods

2.1. Study Site

The studies were conducted in 2021, 2022, and 2023 on blackberry plants at the Tsitsin Main Botanical Garden of the Russian Academy of Sciences (55°45′07″ N, 37°36′57″ E; Moscow, Russia), which lies within USDA hardiness zone 5a (USDA Agricultural Research Service, 2014) [18].

2.2. Cultivars

Ten blackberry cultivars—three early-season (‘Natchez’, ‘Karaka Black’, ‘Loch Tay’) and seven mid-season (‘Caddo’, ‘Columbia Sunrise’, ‘Columbia Star’, ‘Columbia Giant’, ‘Hall’s Beauty’, ‘Victoria’, ‘Brzezina’)—were evaluated. ‘Natchez’, which was included in the State Register of Breeding Achievements approved for use in the Russian Federation in 2023, served as the control cultivar.

Production System

Plants were established using two-year-old containerized nursery stock (closed root system) at a spacing of 2.5 × 1.5 m (3000 plants/ha).

Fertilization was applied via drip irrigation (an emitter drip line with a wall thickness of 16 mil (0.41 mm) was used) using water-soluble formulations, as follows:

(1) 1 May—calcium nitrate ($Ca(NO_3)_2$), 10 kg/ha (Russia);
(2) 20 May—NPK fertilizer (18N–18P–18K + 2% MgO), 15 kg/ha (Russia);
(3) 10 June—NPK fertilizer (18N–18P–18K + 2% MgO), 15 kg/ha (Russia);
(4) 1 July—NPK fertilizer (13N–40P–13K + 2% MgO), 20 kg/ha (Russia);
(5) 15 July—NPK fertilizer (13N–40P–13K + 2% MgO), 20 kg/ha (Russia);
(6) 1 August—NPK fertilizer (3N–11P–38K + 2% MgO), 15 kg/ha (Russia);
(7) 15 August—NPK fertilizer (3N–11P–38K + 2% MgO), 20 kg/ha (Russia).

A trellis system was installed on the plantation, consisting of posts 1.5 m above ground level, strung with three parallel wires (2 mm diameter; Lipetsk Trellis Systems, Lipetsk, Russia). For each cultivar, 4–5 canes were retained for fruiting and 4–5 for renewal. To protect plants from winter injury, they were covered with 90 g/m non-woven fabric (Moscow Region, Russia), as winter temperatures in the region can drop to −30 °C, posing a risk of freeze damage. Aisles between rows were mulched with a woven ground cover fabric (100 g/m; Agrojutex, Juta, Czech Republic). Irrigation was provided via a single drip line per row (MasterProf 50M, model MR-U DS.060105, Moscow, Russia), equipped with pressure-compensating emitters delivering 1.6 L/h, spaced at 0.3 m intervals. All measured parameters were collected from a single representative plant per cultivar. Three biological replicates were used for statistical analysis.

The onset of the blackberry growing season was defined as the date when the average daily air temperature stably exceeded 5 °C. This threshold is consistent with regional agroclimatic references [19].

From 2021 to 2023, air temperatures varied considerably. In April, the mean monthly temperature was 7.5 °C in 2021, compared to 5.8 °C in 2022 and 9.7 °C in 2023 (mean yearly air temperature in 2021, 2022, and 2023 was 6.5 °C, 7.0 °C, and 7.3 °C, respectively).

2.3. Phenological and Morphological Observations

Growth and fruiting traits, phenological development stages, and morphological characteristics of blackberry cultivars were evaluated over three years (2021–2023) following the standard methodology for cultivar evaluation of fruit, berry, and nut crops (the studies of I.V. Kazakov, L.A. Gruner, and V.V. Kichiny) [20]. Each cultivar was represented by three replicates with three plants each.

The following phenological phases were observed in blackberry cultivars: budding period, onset of flowering, end of flowering, flowering duration, onset and end of fruit ripening, and fruiting duration.

The following morphological traits of blackberry cultivars were measured: number of first-year canes per plant; shoot length (cm); number of laterals per shoot; number of fruits per lateral; lateral length (cm); length and width of the central leaflet (cm); predominant number of leaflets per compound leaf; petiole length (cm); and flower diameter (mm).

2.4. Evaluation of Blackberry Productivity Parameters

To evaluate productivity-related traits, 30 fully ripe berries per cultivar were randomly sampled in three biological replicates. Harvesting was conducted between 07:00 and 08:00 h during physiological maturity (full ripeness). Individual fruit weight was measured using an Aqua-Lab RF-YA501 electronic balance (Aqua-Lab, Russia; accuracy: ±0.1 g). Fruit length and diameter were measured with an Ada Mechanic 150 digital caliper (Ada, Russia; accuracy: ±0.01 mm). Soluble solids content (SSC, %) was determined at 20 °C using an AQ-REF-BRIX4 digital refractometer (Aqua-Lab—Russia; accuracy: ±1 °Bx) on freshly extracted juice. Fruit firmness was measured using a Megeon 03004 digital penetrometer (Megeon, Russia; unit: gf). Additionally, fruit weight per cultivar was calculated from subsamples of 100 berries per replicate. After six sequential harvests, cumulative yield per plant was computed by summing replicate-specific harvest data and normalizing to a per-plant basis.

2.5. Statistical Data Analysis

Statistical calculations were performed using the SPSS Statistics 25 software. Confidence intervals for the mean values of the features are indicated as the arithmetic mean ± standard deviation (p = 0.05). The division into groups according to significant differences between varieties was obtained based on the Duncan criteria in a two-way analysis of variance (p = 0.05). The correlation coefficients were determined by the Spearman method.

3. Results

3.1. Flowering and Ripening Time of Tested Blackberry Cultivars

It is well established that weather conditions significantly influence agricultural crops, thereby altering biochemical exchange processes in their tissues, as well as the timing and duration of organ development [21]. Therefore, a comprehensive phenological assessment of flowering and fruiting is essential to evaluate blackberry performance in the Moscow Region. This will enable the selection of cultivars for conveyor-style (extended-harvest) berry production.

All studied cultivars are introduced (non-native), and thus their phenological development under local conditions may differ substantially from that observed in their regions of origin, potentially affecting fruiting timing [5]. The onset and progression of blackberry phenophases are influenced by both temperature regimes during the growing season and inherent varietal characteristics.

It should be noted that all tested blackberry cultivars initiate bud formation and flowering relatively late, thereby minimizing the risk of damage from late spring frosts. Among them, 'Caddo' (bud formation: 22–28 May; onset of flowering: 4–6 June) and 'Karaka Black' (bud formation: 24–31 May; onset of flowering: 2–5 June) exhibited the earliest phenological development, whereas 'Victoria' displayed the latest (bud formation: 11–15 June; onset of flowering: 20–25 June). The earliest flowering completion was recorded for the reference cultivar 'Natchez' (24–29 June), while 'Caddo' showed the latest (20–22 July). The shortest flowering duration was observed in 'Loch Tay' and 'Natchez' (18–21 days each), whereas 'Caddo' exhibited the most extended flowering period (46–47 days) (Table 1).

Table 1. Calendar dates of flowering and fruit ripening phenophases of tested blackberry cultivars (2021–2023).

Cultivar	Bud Formation Period, Date	Flowering Onset, Date	Flowering Completion, Date	Flowering Duration, Days	Fruiting Onset, Date	Fruiting Completion, Date	Fruiting Duration, Days
'Brzezina'	01.06–08.06	14.06–20.06	15.07–20.07	30–33	10.08–15.08	15.09–20.09	33–35
'Caddo'	22.05–28.05	04.06–06.06	20.07–22.07	46–47	16.08–20.08	05.09–10.09	18–26
'Columbia Giant'	29.05–02.06	10.06–15.06	08.07–08.07	23–28	27.07–29.07	28.08–02.09	28–37
'Columbia Star'	02.06–02.06	12.06–15.06	10.07–12.07	27–28	19.07–23.07	05.09–09.09	44–51
'Columbia Sunrise'	02.06–02.06	06.06–11.06	01.07–02.07	20–25	21.07–25.07	22.08–28.08	31–35
'Hall's Beauty'	31.05–04.06	11.06–13.06	13.07–15.07	32–34	21.07–26.07	26.08–31.08	31–41
'Karaka Black'	24.05–31.05	02.06–05.06	25.06–27.06	20–25	25.07–28.07	12.08–17.08	15–23
'Loch Tay'	27.05–01.06	08.06–10.06	27.06–30.06	18–21	19.07–22.07	15.08–17.08	24–29
'Natchez' (c)	31.05–04.06	06.06–10.06	24.06–29.06	18–21	23.07–25.07	13.08–21.08	21–28
'Victoria'	11.06–15.06	20.06–25.06	17.07–22.07	22–28	05.08–10.08	28.08–03.09	22–29

Fruiting commenced during the last ten days of July and terminated during the last ten days of September. The earliest onset of fruiting was recorded for 'Loch Tay' (19–22 July) and 'Columbia Star' (19–23 July), whereas 'Caddo' exhibited a significantly delayed onset (16–20 August). Fruiting completion, a critical phenological indicator for full yield realization due to the risk of early autumn frost damage to developing fruit, occurred earliest in 'Karaka Black' (12–17 August), 'Loch Tay' (15–17 August), and 'Natchez' (13–21 August), and latest in 'Brzezina' (15–20 September). In years with early frosts, the prolonged fruiting period of 'Brzezina' may result in incomplete harvest. The shortest fruiting duration was observed in 'Caddo' (18–26 days), which concurrently exhibited the longest flowering duration. In contrast, 'Columbia Star' displayed the most extended fruiting duration (44–51 days).

For continuous (conveyor-style) berry supply to the market, cultivation of multiple cultivars with contrasting fruiting periods on a single plantation is required. Based on fruiting onset and duration, the studied genotypes were categorized as follows:

- Early-ripening: 'Karaka Black', 'Loch Tay', and 'Natchez';
- Medium-ripening: 'Columbia Sunrise', 'Hall's Beauty', 'Caddo', 'Columbia Giant', 'Victoria' and 'Brzezina'.

Notably, 'Columbia Star' exhibited an extended fruiting period, effectively spanning the climatically most favorable window for yield formation in the study region.

3.2. Morphological Traits of Blackberry Cultivars

Reliable cultivar identification and effective yield planning in blackberry production systems depend heavily on stable morphological traits [22,23].

These traits can be divided into two functional groups:

(i) Yield component traits, used to assess cultivar productivity—namely, number of first-year canes per plant, first-year cane length, number of fruiting laterals per first-year cane, number of berries per lateral, and lateral length;

(ii) Discriminatory (diagnostic) traits, employed for cultivar distinction—including length and width of the central leaflet, predominant number of leaflets per compound leaf, petiole length, and flower diameter [24].

Analysis of variance (ANOVA) confirmed significant differences among cultivars for all measured traits (Table 2). Notably, 'Natchez' exhibited the lowest number of first-year canes per plant (2.5) and the shortest first-year cane length (189 cm), yet displayed the highest number of fruiting laterals per first-year cane (18.5). In contrast, its lateral fruit set (6.4 berries per lateral), lateral length (19.3 cm), and diagnostic morphological traits were relatively low: central leaflet length—8.3 cm, width—7.9 cm; petiole length—5.5 cm; flower diameter—3.8 cm.

Table 2. Morphological traits of tested blackberry cultivars (2021–2023; means ± SD, Duncan's grouping, the letters indicate between which specific groups there is a statistically significant difference).

Cultivar	Number of First-Year Canes per Plant, pcs	Cane Length, cm	Number of Laterals per First-Year Cane, pcs	Fruits Number per Lateral, pcs	Lateral Length, cm	Central Leaflet Length, cm	Central Leaflet Width, cm	Petiole Length, cm	Flower Diameter, cm
'Brzezina'	4.8 ± 1.4 c	312 ± 55 c	11.2 ± 3.3 a	10.1 ± 3.1 d	30.5 ± 4.8 c	12.2 ± 1.4 cd	8.8 ± 2.0 b	5.9 ± 1.7 b	3.2 ± 0.6 a
'Caddo'	3.9 ± 1.3 b	202 ± 33 a	12.3 ± 3.2 ab	8.1 ± 2.2 c	26.2 ± 4.1 bc	10.9 ± 3.2 c	7.7 ± 1.5 b	6.1 ± 2.0 b	4.6 ± 1.3 bc
'Columbia Giant'	5.8 ± 1.7 d	301 ± 47 c	15.2 ± 3.7 b	5.8 ± 0.7 a	10.9 ± 3.2 a	18.1 ± 4.5 e	13.4 ± 3.0 c	12.3 ± 3.5 c	4.2 ± 0.8 b
'Columbia Star'	6.7 ± 1.8 e	290 ± 53 c	15.9 ± 4.4 b	6.1 ± 1.5 a	13.1 ± 3.3 a	7.2 ± 1.6 a	5.8 ± 1.6 a	4.6 ± 1.9 a	4.2 ± 1.2 b
'Columbia Sunrise'	7.7 ± 2.1 e	310 ± 89 c	18.5 ± 6.5 d	6.5 ± 1.7 b	15.1 ± 3.2 ab	8.7 ± 2.3 b	6.1 ± 1.9 a	4.3 ± 1.4 a	4.1 ± 1.3 b
'Hall's Beauty'	5.7 ± 1.5 d	302 ± 66 c	15.2 ± 4.9 b	6.6 ± 1.4 b	12.3 ± 2.4 a	12.8 ± 5.9 d	11.1 ± 2.7 c	4.3 ± 1.1 a	5.1 ± 1.3 c
'Karaka Black'	4.7 ± 1.2 c	236 ± 84 b	9.7 ± 1.1 a	6.4 ± 1.8 ab	19.7 ± 2.2 b	11.8 ± 2.8 c	7.2 ± 1.7 b	5.8 ± 1.1 b	3.7 ± 0.9 b
'Loch Tay'	5.4 ± 1.3 c	300 ± 88 c	16.3 ± 3.7 bc	12.5 ± 3.2 d	22.8 ± 5.9 b	9.1 ± 2.6 b	6.2 ± 1.4 a	4.8 ± 1.2 ab	2.7 ± 0.3 a
'Natchez' (c)	2.5 ± 0.8 a	189 ± 26 a	18.5 ± 5.5 d	6.4 ± 1.5 ab	19.3 ± 3.2 b	8.3 ± 2.5 ab	7.9 ± 1.8 b	5.5 ± 1.5 b	3.8 ± 1.0 b
'Victoria'	6.3 ± 2.1 d	344 ± 69 d	18.6 ± 3.4 d	8.5 ± 2.2 c	37.1 ± 9.9 d	7.1 ± 2.0 a	5.3 ± 1.4 a	4.7 ± 1.5 ab	3.3 ± 0.5 ab

'Victoria' demonstrated the highest values for all yield component traits (Figure 1): first-year cane number—6.3 per plant, first-year cane length—344 cm, fruiting laterals per first-year cane—18.6, berries per lateral—8.5, and lateral length—37.1 cm. However, this cultivar showed the smallest values for several diagnostic traits: central leaflet length—7.1 cm, width—5.3 cm; petiole length—4.7 cm; flower diameter—3.3 cm.

Cultivars 'Columbia Giant', 'Columbia Star', 'Columbia Sunrise', 'Hall's Beauty', and 'Loch Tay' exhibited balanced performance across multiple traits, underscoring their agronomic potential for commercial production. In contrast, 'Brzezina', 'Caddo', and 'Karaka Black' showed lower overall productivity compared to the reference cultivar 'Natchez'. Collectively, several newly evaluated cultivars—particularly 'Columbia Sunrise' and 'Victoria'—outperformed 'Natchez' in key productivity parameters.

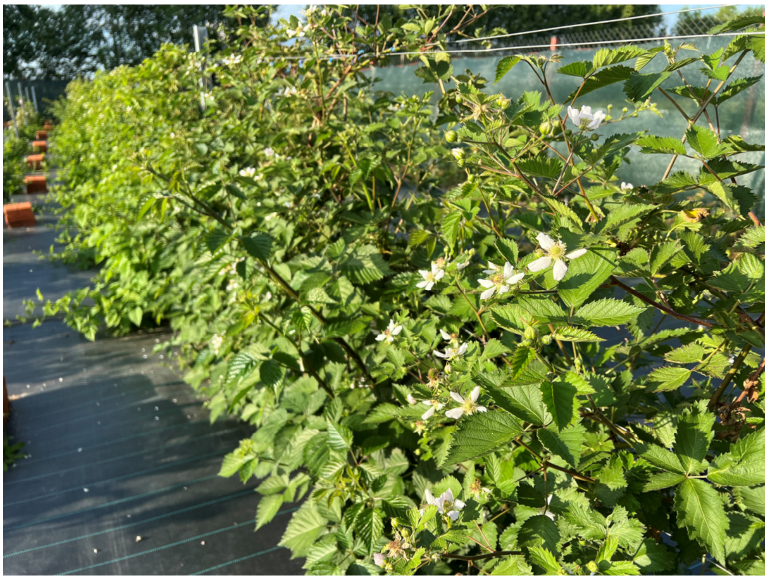

Figure 1. Flowering of 'Victoria' blackberry.

3.3. Evaluation of Blackberry Productivity Parameters

For establishing blackberry plantations, cultivar selection must align with both market demands and end-user (consumer) requirements for fruit quality. Yield-related traits constitute a primary consideration in harvest planning and production forecasting. Retail chains impose specific quality standards for fresh berries, typically stipulated in product specifications—e.g., minimum fruit diameter, soluble solids content (SSC, %), and other physicochemical parameters. In contrast, cultivars intended for direct-to-consumer sales (e.g., pick-your-own, farmers' markets) should prioritize visual appeal and superior sensory attributes, including sweetness, aroma, and texture.

'Hall's Beauty', 'Loch Tay', and 'Victoria' exhibited high fruit firmness—650.3, 632.2, and 882.2 gf, respectively (Figure 2)—indicating enhanced postharvest storability and suitability for retail supply chains. Notably, 'Loch Tay' combined high firmness with elevated yield (3.3 kg per plant), while 'Victoria' displayed the highest soluble solids content (12.3%) (Table 3).

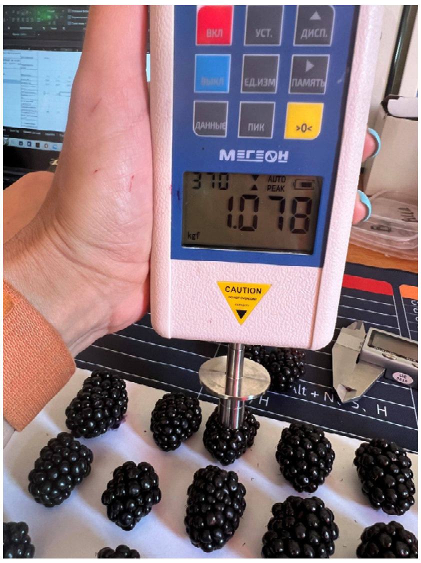

Figure 2. Measurement of fruit firmness in the blackberry cultivar 'Victoria'.

Table 3. Agronomic and fruit quality traits of tested blackberry cultivars (2022–2023; means ± SD, Duncan's grouping, the letters indicate between which specific groups there is a statistically significant difference.).

Cultivar	Yield per Plant, kg	Fruit Mass, g	Length, mm	Diameter, mm	Soluble Solids Content, %	Fruit Firmness, gf	Number of Drupelets per Fruit
'Brzezina'	2.2 ± 0.1 ab	7.2 ± 0.7 c	30.0 ± 2.0 b	22.3 ± 2.0 c	11.3 ± 0.6 bc	416.1 ± 81.2 b	100.4 ± 35.3 a
'Caddo'	2.4 ± 0.2 b	6.5 ± 0.7 b	25.5 ± 4.3 a	17.2 ± 4.3 a	13.0 ± 1.1 c	313.8 ± 80.4 a	100.7 ± 13.8 a
'Columbia Giant'	2.6 ± 0.1 c	11.5 ± 0.9 d	40.3 ± 0.9 c	22.4 ± 4.2 c	10.2 ± 0.8 b	354.1 ± 42.3 ab	219.2 ± 33.1 c
'Columbia Star'	2.0 ± 0.2 a	5.2 ± 0.6 a	29.9 ± 0.6 b	17.5 ± 2.0 a	8.8 ± 0.8 a	286.5 ± 41.7 a	199.5 ± 24.6 bc
'Columbia Sunrise'	2.3 ± 0.2 b	5.9 ± 0.6 a	29.0 ± 2.0 b	18.3 ± 2.0 ab	9.4 ± 0.5 ab	286.4 ± 40.2 a	224.4 ± 23.9 c
'Hall's Beauty'	2.2 ± 0.2 ab	6.2 ± 1.0 b	24.0 ± 2.1 a	17.1 ± 2.1 a	10.0 ± 0.6 b	650.3 ± 60.1 c	86.8 ± 8.0 a
'Karaka Black'	2.0 ± 0.2 a	11.2 ± 1.6 d	41.0 ± 4.1 c	19.2 ± 4.1 b	9.0 ± 0.7 a	566.1 ± 65.2 bc	164.0 ± 18.9 b
'Loch Tay'	3.3 ± 0.2 d	5.4 ± 1.0 a	24.5 ± 2.6 a	21.7 ± 2.6 bc	11.4 ± 1.0 bc	632.2 ± 68.4 c	103.8 ± 11.0 a
'Natchez' (c)	2.3 ± 0.1 b	8.8 ± 1.5 c	31.6 ± 2.7 b	22.1 ± 2.2 c	8.5 ± 0.9 a	422.2 ± 110.2 b	166.5 ± 28.8 b
'Victoria'	2.4 ± 0.2 b	6.2 ± 0.7 b	27.2 ± 2.0 ab	20.9 ± 2.0 b	12.3 ± 0.6 c	882.2 ± 105.2 d	168.4 ± 35.3 b

Cultivars 'Caddo', 'Columbia Star', and 'Columbia Sunrise'—characterized by low fruit firmness (313.8, 286.5, and 286.4 gf, respectively) and small fruit mass (6.5, 5.2, and 5.9 g)—may be better suited for processed berry products rather than the fresh market.

Cultivars 'Brzezina', 'Columbia Giant', 'Karaka Black', and 'Natchez' exhibited intermediate fruit firmness (416.1, 354.1, 566.1, and 422.2 gf, respectively), supporting their suitability for direct-to-consumer markets. 'Columbia Giant' and 'Karaka Black' produced the largest berries (11.5 g and 11.2 g, respectively), indicating their potential as parental sources for large-fruit traits in breeding programs. Likewise, 'Victoria'—with the highest firmness (882.2 gf)—may serve as a donor for enhanced fruit firmness.

Thus, blackberry cultivars of diverse end uses can be successfully cultivated in the Moscow Region.

3.4. Correlations Among Phenological, Morphological, and Agronomically Important Traits in Blackberry Cultivars

To identify patterns of trait variation, a correlation analysis was performed (Table A1), enabling the assessment of the direction and strength of associations among traits. This is particularly valuable in breeding programs, where key agronomic traits can be predicted based on easily measurable proxy characteristics. Our analysis revealed 14 statistically significant correlations ($p \leq 0.05$), including one highly expected association: fruit mass and its length (r = 0.81). Bud formation period showed a moderate negative correlation with flowering completion (r = −0.65). Flowering completion was negatively associated with fruiting duration (r = −0.75), first-year cane quantity per plant (r = −0.63), and first-year cane length (r = −0.66). Flowering duration correlated positively with fruiting onset (r = 0.65) but negatively with the number of fruiting laterals per first-year cane (r = −0.67) and drupelet number per fruit (r = −0.83). Fruiting onset exhibited positive correlations with fruit number per lateral (r = 0.64) and lateral length (r = 0.75). Fruiting duration was negatively correlated with lateral length (r = −0.64). Additionally, a strong negative correlation was found between the number of fruiting laterals per first-year cane and central leaflet length (r = −0.86). Finally, fruit number per lateral showed strong positive correlations with lateral length (r = 0.84) and soluble solids content (SSC, r = 0.83).

Among all significant correlations, the following are of particular agronomic interest:

- A shorter flowering duration is associated with a higher drupelet number per fruit, a trait linked to improved fruit appearance (r = −0.83);

- Later fruiting onset correlates with longer laterals (r = 0.75), a characteristic typically associated with enhanced yield potential;
- Shorter central leaflet length is associated with a greater number of fruiting laterals per first-year cane (r = −0.86);
- Higher fruit number per lateral correlates positively with both soluble solids content (SSC, r = 0.83) and lateral length (r = 0.84).

4. Discussion

Understanding trait interrelationships is essential for integrated management of blackberry production and for advancing breeding programs of this emerging crop in temperate climates.

Strong correlations (r ≥ 0.75) are of particular interest, as they may reflect underlying physiological, developmental, or genetic linkages among traits. Among the significant associations identified in this study, several occur within trait categories (e.g., phenological–phenological or morphological–morphological), while others—more notably—span across categories.

Identifying associations between agronomically important and phenological traits enables early prediction of both yield potential and fruit quality—critical for efficient breeding and orchard management. In our study, a moderate negative association was observed between bud formation period and yield (r = −0.55, $p \leq 0.05$), indicating that earlier-flowering cultivars tend to be more productive. This trend aligns with the positive correlation between bud formation and flowering onset (r = 0.54), confirming phenological synchrony in reproductive development. For instance, 'Caddo' (bud formation: 22 May) and 'Loch Tay' (27 May) yielded 2.4 and 3.3 kg per plant, respectively—among the highest in the trial—whereas 'Karaka Black' (24 May) was an outlier, producing only 2.00 kg per plant.

Notably, phenological earliness could serve as an early indirect selection criterion in seedling progenies: flowering time is assessable in the first reproductive year, whereas reliable yield estimation requires 3–4 years of stable fruiting.

Yield exhibited a moderate positive association with soluble solids content (SSC) (r = 0.62, Table A1), indicating that higher sugar accumulation tends to coincide with greater productivity in blackberry under Moscow-region conditions. SSC formed the core of the most tightly integrated trait network observed: it correlated positively with fruiting onset (r = 0.57), lateral length (r = 0.62), and fruit number per lateral (r = 0.83)—collectively constituting a cluster of traits linked by strong associations (r ≥ 0.57). This suggests coordinated physiological regulation, where early fruit set, extended lateral growth, and high fruit load may collectively enhance sink strength and carbohydrate partitioning toward fruit maturation. The highest-yielding cultivar, 'Loch Tay' (3.3 kg per plant), displayed one of the highest SSC values (11.4%), third only to 'Caddo' (13.0%) and 'Victoria' (12.3%)—cultivars combining high yield (2.4 kg per plant both), early flowering (bud formation: 22 May), and elevated firmness (632.2 gf).

Notably, 'Caddo' also showed the strongest negative correlation between flowering duration and drupelet number (r = −0.83), further reinforcing its role as a source of compact flowering and uniform fruit development. These findings support the hypothesis that SSC serves not merely as a quality trait, but as an integrative indicator of reproductive efficiency and resource allocation—making it a valuable target for indirect selection in breeding programs targeting both yield and fruit quality [25–27].

A strong positive association between fruit number per lateral and soluble solids content (SSC) (r = 0.83, Table A1) aligns with the negative correlations observed between SSC and fruit size traits—namely, fruit length (r = −0.53), diameter (r = 0.01, ns), and mass (r = −0.41). This pattern suggests a potential trade-off between fruit size and sugar concentration; whereby smaller berries tend to accumulate higher SSC—possibly due to more efficient sugar partitioning per unit fruit volume or reduced dilution effects during cell expansion. Consequently, cultivars producing a greater number of smaller berries per lateral may achieve higher overall sweetness and flavor intensity, whereas larger-fruited genotypes may exhibit diluted soluble solids. This is exemplified by 'Caddo' (fruit mass: 6.5 g; SSC: 13.0%) versus 'Karaka Black' (11.2 g; 9.0%), illustrating the contrasting strategies of "smaller but sweeter, with intense flavor" versus "larger but milder". Such variation underscores the importance of defining market-specific quality targets in breeding programs.

A tightly integrated morphometric cluster—fruit length, diameter, and mass—was anchored by strong positive correlations between fruit mass and both fruit length (r = 0.81) and diameter (r = 0.57). Although the associations between fruit mass and fruiting duration (r = −0.13) or fruit number per lateral (r = −0.41) were weak in magnitude, a consistent phenotypic pattern emerged across cultivars: those with earlier fruiting completion (e.g., 'Natchez': 24–29 Jun) and shorter fruiting duration tended to produce larger individual berries (6.5 g), whereas late- and long-fruiting types (e.g., 'Brzezina': 15–20 Sep) yielded smaller fruits (5.2 g). This trend, combined with the observed negative direction of correlations, suggests a resource allocation trade-off—where increased fruit number per lateral may constrain individual fruit size—even if the statistical strength of individual associations remains modest [28–31].

Cultivars producing large berries with relatively few fruits per lateral—such as 'Columbia Giant' (11.5 g, 5.8 berries per lateral) and 'Karaka Black' (11.2 g, 6.4 berries per lateral)—may be particularly suitable for the fresh market under hand-harvest systems, where fruit size and visual uniformity are prioritized over sheer yield. Their moderate yield levels (2.6 and 2.0 kg per plant, respectively) are offset by premium marketability traits, including high fruit mass and acceptable firmness (354–566 gf), aligning with quality standards for direct consumer sales or premium retail segments [32]. In contrast, cultivars with high fruit number per lateral and smaller individual fruit—'Loch Tay' (12.5 berries per lateral, 5.4 g) and 'Columbia Star' (6.1, 5.2 g)—exhibit traits aligned with processing markets: high total yield (3.3 and 2.0 kg per plant respectively), compact fruit size, and efficient fruit set. Notably, 'Loch Tay' combines the highest fruit number per lateral and yield in the trial with exceptional firmness (632 gf), suggesting strong potential for both fresh-pack and frozen processing applications [5,33].

The positive correlation between lateral length and fruit number per lateral (r = 0.84, Table A1) reflects a direct structural relationship: longer laterals provide greater node number and inflorescence capacity, thereby supporting higher fruit set. This pattern is clearly exemplified by the contrasting phenotypes of 'Brzezina' (lateral length: 30.5 cm; 10.1 berries per lateral) and 'Columbia Giant' (10.9 cm; 5.8 berries per lateral)—the extremes in both traits among the cultivars evaluated (Table 2). Such a strong association suggests that lateral length may serve as a reliable morphological predictor of fruiting potential in blackberry breeding and canopy management.

The strong negative correlation between flowering completion and fruiting duration (r = −0.75, Table A1) indicates that, under the temperate climate of Central Russia, delayed floral senescence does not postpone fruiting onset (as evidenced by the non-significant correlation between flowering completion and fruiting onset: r = 0.11), but rather shortens the total fruiting period. Notably, no significant associations were detected between flowering onset and completion (r = −0.36) or between flowering onset and fruiting duration (r = 0.29), suggesting that the timing of floral initiation is largely decoupled from the dynamics of reproductive phase progression in this germplasm. In contrast, the positive correlation between flowering duration and fruiting onset (r = 0.65) points to a developmental linkage: extended flowering may delay the transition to fruit maturation, possibly due to prolonged resource allocation to floral maintenance or staggered pollination events [34].

The strong negative correlation between central leaflet length and number of fruiting laterals per first-year cane (r = −0.86, Table A1) may reflect a developmental trade-off in resource allocation—where genotypes prioritizing vegetative growth (e.g., larger leaf area) exhibit reduced branching intensity, and vice versa. This pattern aligns with the principle of source–sink balance, wherein carbon assimilates are partitioned either toward leaf expansion or lateral meristem activation. Notably, the number of fruiting laterals showed generally weak correlations with most agronomic traits ($|r| \leq 0.48$), with one exception: a moderate positive association with drupelet number per fruit (r = 0.59). This suggests that higher branching intensity may support improved pollination or resource supply to developing carpels, resulting in more completely formed fruits. Nevertheless, the overall pattern indicates high genotypic specificity of lateral branching, as confirmed by ANOVA ($p = 0.05$, Table 2). In contrast, central leaflet length was positively associated with other leaf biometric traits (e.g., width: r = 0.56; petiole length: r = 0.58), suggesting coordinated leaf development governed by shared genetic or physiological regulators [35].

Although a strong negative correlation was detected between drupelet number per fruit and flowering duration (r = −0.83, Table A1), this association lacks a clear phenotypic expression across cultivars. Drupelet number varied widely (86.8–219.2), with the lowest value in 'Hall's Beauty' (86.8) and the highest in 'Columbia Giant' (219.2)—both exhibiting intermediate flowering durations (32–34 and 23–28 days, respectively). In contrast, the cultivars with the shortest ('Loch Tay': 18–21 days) and longest ('Caddo': 46–47 days) flowering durations showed nearly identical drupelet counts (103.8 and 100.7, respectively). This inconsistency indicates that the statistical correlation may not reflect a direct physiological relationship but rather be influenced by genotype-specific genetic architecture, stochastic environmental effects during anthesis (e.g., temperature fluctuations, pollinator availability), or developmental buffering in carpel formation. Consequently, drupelet number appears to be a highly heritable trait, largely decoupled from floral phenology under the studied conditions [36].

Fruit firmness was the only trait for which no statistically significant correlations were detected with other measured characteristics ($|r| \leq 0.48$, all $p = 0.05$). Nevertheless, path coefficient analysis by Vykhadu's method revealed a direct phenotypic association between lateral length and fruit firmness ($r_p = +0.48$, Table A1), suggesting a biologically relevant, though statistically weak, linkage—potentially reflecting coordinated development of fruiting structures and tissue rigidity. Fruit firmness exhibited substantial genotypic variation, ranging from 286.5 gf ('Columbia Star' and 'Columbia Sunrise') to 882.2 gf ('Victoria'), a 2.97-fold difference (Table 2). This pronounced variability, together with significant cultivar effects in ANOVA ($p = 0.05$), confirms high heritability and strong potential for genetic improvement. Notably, Pavlis et al. (2020) demonstrated that fruit firmness in highbush blueberry is highly responsive to mineral nutrition—particularly calcium and potassium fertilization—suggesting that similar agronomic interventions could be evaluated to enhance firmness stability in blackberry under temperate conditions [37–39].

Key breeding objectives in blackberry encompass large fruit size, extended fruiting duration, high yield, elevated soluble solids content (SSC), high fruit number per lateral, and abundant fruiting laterals. Our study identified several favorable positive correlations among these targets, enabling potential multi-trait selection: SSC showed strong associations with fruit number per lateral (r = 0.83) and lateral length (r = 0.62), and a moderate positive correlation with yield (r = 0.62) (Table A1). These linkages suggest that selection for high SSC may concurrently improve fruiting intensity and productivity. However, significant trade-offs were observed: fruit mass showed a moderate negative correlation with fruit number per lateral (r = −0.51), and SSC exhibited a moderate negative association with fruit length (r = −0.53)—a key biometric determinant of fruit mass (fruit mass and length: r = 0.81). In contrast, SSC and fruit diameter were uncorrelated (r = 0.01), indicating that sugar accumulation is more sensitive to longitudinal than radial fruit expansion. These linkages imply that simultaneous selection for large fruit size and high SSC may be constrained, necessitating targeted screening for transgressive genotypes—e.g., high SSC combined with large fruit dimensions. Cultivars such as 'Columbia Giant' (11.5 g, 5.8 berries per lateral) and 'Victoria' (12.3% SSC, 6.2 g, 882.2 gf) represent strategic donors in this context [40,41].

Beyond its established value as a fruit crop, blackberry holds ornamental potential—particularly if thornless, large-flowered genotypes with extended flowering duration, compact growth habit, and high winter hardiness are developed. In our study, flower diameter was assessed as a preliminary ornamental trait, and significant negative correlations were detected with key agronomic characteristics: fruit diameter (r = −0.54), flowering onset (r = −0.61), fruit number per lateral (r = −0.55), and lateral length (r = −0.59) (Table A1). These associations suggest a potential developmental trade-off between floral display and fruiting efficiency—possibly reflecting divergent resource allocation strategies between reproductive structures (petals vs. drupelets) or selection histories favoring either ornamental or fruiting traits. This pattern aligns with findings in Rubus breeding, where ornamental and fruiting types often exhibit contrasting architectures [42–44]. Consequently, large-flower selection may warrant a dedicated ornamental breeding stream, operationally distinct from mainstream fruit-quality and yield improvement programs—enabling parallel development of blackberry for dual-use systems (fruit + landscape).

5. Conclusions

Based on phenological assessments, cultivars were classified as follows: early-ripening—'Karaka Black', 'Loch Tay', and 'Natchez' (c); medium-ripening—'Columbia Sunrise', 'Hall's Beauty', 'Caddo', 'Columbia Giant', 'Victoria', and 'Brzezina'. Notably, 'Columbia Star' exhibited an extended fruiting period, effectively spanning the climatically most favorable window for yield accumulation in the Moscow Region.

Morphological evaluations revealed significant differences among cultivars across all measured traits (number of first-year canes per plant, pcs; cane length, cm; number of laterals per first-year cane, pcs; number of fruits per lateral, pcs; lateral length, cm; central leaflet length, cm; central leaflet width, cm; petiole length, cm; flower diameter, cm). Based on a comprehensive trait profile—including yield components, fruit quality, and phenological adaptability—the cultivars 'Columbia Giant', 'Columbia Star', 'Columbia Sunrise', 'Hall's Beauty', and 'Loch Tay' demonstrated superior overall performance, confirming their high agronomic potential for commercial production in temperate regions.

Yield and fruit quality analyses confirm the feasibility of growing blackberry cultivars with diverse end uses in the Moscow Region. Based on agronomically important traits:

– 'Hall's Beauty' (650.3 gf), 'Loch Tay' (632.2 gf), and 'Victoria' (882.2 gf) exhibited high fruit firmness, supporting their suitability for retail supply chains;
– 'Brzezina' (416.1 gf), 'Columbia Giant' (354.1 gf), 'Karaka Black' (566.1 gf), and 'Natchez' (422.2 gf) showed intermediate firmness, aligning with requirements for direct-to-consumer markets;
– 'Columbia Giant' (11.5 g) and 'Karaka Black' (11.2 g) exhibited the largest fruit mass, identifying them as valuable donors for large-fruit breeding;
– 'Victoria' (882.2 gf) emerged as the premier source of high fruit firmness.

Correlation analysis revealed several key trait associations:

- Shorter flowering duration was linked to higher drupelet number per fruit (r = −0.83), a trait associated with improved fruit appearance;
- Later fruiting onset correlated with longer laterals (r = 0.75), a characteristic generally favorable for yield;
- Shorter central leaflet length was associated with greater numbers of fruiting laterals (r = −0.86);
- Higher fruit number per lateral correlated positively with both soluble solids content (r = 0.83) and lateral length (r = 0.84).

This study provides valuable insights for both blackberry breeding programs and cultivar selection for commercial plantations. Nevertheless, future work should include comprehensive biochemical profiling of the evaluated genotypes to quantify key bioactive compounds (e.g., anthocyanins, flavonoids, and phenolic acids), thereby strengthening the nutritional and functional justification for cultivar recommendations.

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Appendix A

Table A1. Trait correlations.

	Bud Formation Period, Date	Flowering Onset, Date	Flowering Completion, Date	Flowering Duration, Days	Fruiting Onset, Date	Fruiting Completion, Date	Fruiting Duration, Days	Number of First-Year Canes per Plant, pcs	Shoots Length, cm	Number of Fruiting Laterals per Shoot, pcs	Fruit Number per Lateral, pcs	Lateral Length, cm	Central Leaflet Length, cm	Central Leaflet Width, cm	Petiole Length, cm	Flower Diameter, cm	Yield, kg·per Plant	Fruit Mass, g	Fruit Length, mm	Fruit Diameter, mm	Soluble Solids Content,%	Fruit Firmness, gf	Drupelet Number per Fruit
Bud formation period. date	1.00	0.54	−0.65	−0.21	0.07	0.23	0.38	0.52	0.25	0.44	−0.22	−0.03	−0.24	0.31	0.13	−0.25	−0.55	−0.17	−0.06	0.16	−0.08	0.16	0.23
Flowering onset. date		1.00	−0.36	0.07	0.34	0.34	0.29	0.41	0.51	0.07	0.43	0.38	0.04	0.24	0.12	−0.61	−0.05	−0.37	−0.07	0.27	0.47	0.44	−0.14
Flowering completion. date			1.00	0.14	0.11	−0.38	−0.75	−0.63	−0.66	−0.18	0.36	0.46	−0.14	−0.32	−0.50	0.04	0.22	0.10	−0.04	0.06	0.16	0.27	−0.48
Flowering duration. days				1.00	0.65	0.58	0.05	−0.46	0.02	−0.67	0.30	0.22	0.50	0.26	−0.22	0.43	0.08	−0.42	−0.32	−0.25	0.40	0.01	−0.83
Fruiting onset. date					1.00	0.61	−0.21	−0.17	−0.15	−0.46	0.64	0.75	0.20	−0.14	−0.22	−0.18	0.04	−0.42	−0.25	0.08	0.57	0.07	−0.61
Fruiting completion. date						1.00	0.57	0.20	0.12	−0.29	0.13	0.02	0.22	0.01	0.01	0.17	−0.08	−0.53	−0.12	−0.33	0.17	−0.42	−0.17
Fruiting duration. days							1.00	0.49	0.55	0.06	−0.46	−0.64	0.14	0.33	0.26	0.15	−0.29	−0.21	0.19	−0.23	−0.39	−0.42	0.35
Number of first-year canes per plant. pcs								1.00	0.38	0.48	−0.12	−0.18	−0.41	−0.36	−0.06	−0.37	−0.38	−0.35	−0.15	−0.33	−0.16	0.09	0.56
Shoots length. cm									1.00	0.14	0.11	−0.24	0.12	0.39	0.31	−0.28	0.17	−0.32	−0.21	0.04	0.18	0.05	0.12
Number of fruiting laterals per shoot. pcs										1.00	−0.06	−0.16	−0.86	−0.24	−0.13	−0.31	−0.09	−0.24	−0.33	−0.11	−0.13	0.02	0.59
Fruit number per lateral. pcs											1.00	0.84	−0.15	−0.35	−0.27	−0.55	0.50	−0.51	−0.48	0.11	0.83	0.32	−0.46
Lateral length. cm												1.00	−0.14	−0.31	−0.36	−0.59	0.12	−0.26	−0.24	0.35	0.62	0.48	−0.54
Central leaflet length. cm													1.00	0.56	0.58	0.38	0.24	0.43	0.44	0.22	0.15	−0.10	−0.32
Central leaflet width. cm														1.00	0.53	0.22	−0.05	0.32	0.31	0.45	−0.06	0.04	−0.20
Petiole length. cm															1.00	0.06	0.43	0.57	0.50	0.43	0.06	−0.36	0.43
Flower diameter. cm																1.00	−0.01	0.12	−0.05	−0.54	−0.22	−0.36	−0.15
Yield. kg·per plant																	1.00	0.04	−0.13	0.08	0.62	−0.23	0.01
Fruit mass. g																		1.00	0.81	0.57	−0.41	−0.12	0.31
Fruit length. mm																			1.00	0.59	−0.53	−0.25	0.32
Fruit diameter. mm																				1.00	0.01	0.14	0.01
Soluble solids content. %																					1.00	0.35	−0.48
Fruit firmness. gf																						1.00	−0.47
Drupelet number per fruit																							1.00

0.76–1.00	0–−0.25
0.51–0.75	−0.26–−0.50
0.26–0.50	−0.51–−0.75
0–0.25	−0.76–−1.00

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