Research article

https://doi.org/10.31279/2949-4796-2026-16-1-82-90

Morphological and biochemical responses of blackberry (*Rubus* spp.) cultivars under agro-climatic conditions of the Samarkand region

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FOR CITATION:
Jumakulova N.Sh., Kabulova F.D., Ismoilov K.T.
Morphological and biochemical responses of blackberry (*Rubus* spp.) cultivars under agro-climatic conditions of the Samarkand region. *Agrarian Bulletin of the North Caucasus*. 2026;16(1):82-90. https://doi.org/10.31279/2949-4796-2026-16-1-82-90

RECEIVED: 20.11.2025
REVISED: 19.03.2026
ACCEPTED: 20.03.2026

DECLARATION OF COMPETING INTEREST:
none declared.

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ABSTRACT

INTRODUCTION. Blackberry (*Rubus* spp.) is an important berry crop valued for its nutritional and medicinal properties. However, there is limited information on the morphological and biochemical responses of different blackberry cultivars under the semi-arid agro-climatic conditions of the Samarkand region. Research on cultivar performance under local conditions is essential for improving cultivation strategies and functional food development.

AIM. To evaluate the morphological characteristics and biochemical composition of thornless and thorny blackberry cultivars grown under the agro-climatic conditions of the Samarkand region.

MATERIALS AND METHODS. Seven cultivars—Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna, and the thorny Brazos—of composite origin belonging to *Rubus* spp. were studied during 2022–2024. Physiological and biochemical parameters were analyzed at key phenological stages, including leaf water content, fruit composition, vitamin C, flavonoids, amino acids, and carbohydrate levels.

RESULTS. Leaf water content showed clear diurnal variations. Karaka Black exhibited the highest water retention and better adaptation to arid conditions, while Thornfree and Jumbo were more sensitive to heat and water stress. Significant differences were observed in fruit biochemical composition among the cultivars, including vitamin C, flavonoids, amino acids, and carbohydrates. The thorny Brazos cultivar demonstrated intermediate responses in water retention and biochemical composition. The study identified cultivars with superior adaptation to semi-arid conditions of the Samarkand region.

CONCLUSION. Karaka Black, Brzezina, Chester, and Brazos cultivars are promising for cultivation in the semi-arid regions of Samarkand and for the development of functional food products. The findings provide a scientific basis for selecting blackberry cultivars adapted to local environmental conditions.

KEYWORDS: blackberry *Rubus* spp., thornless and thorny cultivars, morphology, biochemical composition, Samarkand, semi-arid conditions

Исследовательская статья

https://doi.org/10.31279/2949-4796-2025-15-4-10-23

Морфологические и биохимические ответные реакции сортов ежевики (*Rubus* spp.) в агроклиматических условиях Самаркандского региона

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Жумакулова Н.Ш., Кабулова Ф.Д., Исмоилов К.Т.
Морфологические и биохимические ответные реакции сортов ежевики (*Rubus* spp.) в агроклиматических условиях Самаркандского региона. *Аграрный вестник Северного Кавказа*. 2026;16(1):82-90. https://doi.org/10.31279/2949-4796-2026-16-1-82-90 EDN ATUHKA

ПОСТУПИЛА: 20.11.2025
ДОРАБОТАНА: 19.03.2026
ПРИНЯТА: 20.03.2026

КОНФЛИКТ ИНТЕРЕСОВ:
авторы сообщают об отсутствии конфликта интересов.

АННОТАЦИЯ

ВВЕДЕНИЕ. Ежевика (*Rubus* spp.) является важной ягодной культурой, ценимой за питательные и лечебные свойства. В то же время существует ограниченная информация о морфологических и биохимических реакциях различных сортов ежевики в условиях полузасушливого климата Самаркандской области. Исследования продуктивности сортов в местных условиях необходимы для улучшения методов культивирования и разработки функциональных продуктов питания.

ЦЕЛЬ. Оценить морфологические характеристики и биохимический состав бесшипых и колючих сортов ежевики, выращиваемых в агроклиматических условиях Самаркандской области.

МАТЕРИАЛЫ И МЕТОДЫ. В течение 2022–2024 гг. изучались семь сортов: Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna и колючий сорт Brazos, которые относятся к *Rubus* spp. и имеют смешанное происхождение. Физиологические и биохимические параметры анализировались на ключевых фенологических стадиях, включая содержание воды в листьях, состав плодов, витамин C, флавоноиды, аминокислоты и углеводы.

РЕЗУЛЬТАТЫ. Содержание воды в листьях демонстрировало явные суточные колебания. Сорт Karaka Black показал наибольшую способность удерживать воду и лучшую адаптацию к засушливым условиям, тогда как Thornfree и Jumbo оказались более чувствительными к тепловому и водному стрессу. Были отмечены значительные различия в биохимическом составе плодов среди сортов, включая витамин C, флавоноиды, аминокислоты и углеводы. Колючий сорт Brazos продемонстрировал промежуточные показатели удержания воды и биохимического состава. Исследование выявило сорта, наиболее приспособленные к полузасушливым условиям Самаркандской области.

ЗАКЛЮЧЕНИЕ. Сорта Karaka Black, Brzezina, Chester и Brazos показали наибольший потенциал для выращивания в полузасушливых районах Самарканда и для разработки функциональных пищевых продуктов. Результаты исследования предоставляют научную основу для выбора сортов ежевики, адаптированных к местным условиям.

КЛЮЧЕВЫЕ СЛОВА: ежевика *Rubus* spp., бесшипые и колючие сорта, морфология, биохимический состав, Самарканд, полузасушливые условия

INTRODUCTION

Blackberries are among the most valuable berry crops worldwide due to their rich nutritional profile, diverse bioactive compounds, and multifunctional applications in both the food and pharmaceutical industries. The fruits are a significant source of essential vitamins, including vitamin C, A, E and B-complex, alongside phenolic compounds, flavonoids, amino acids, and carbohydrates, which collectively confer antioxidant, anti-inflammatory, and antimicrobial properties. With increasing global awareness of health and functional nutrition, blackberries have attracted considerable attention as natural sources of bioactive compounds that promote human health and wellbeing [1–5].

The successful cultivation of blackberries is strongly influenced by environmental factors, particularly in arid and semi-arid regions where high temperatures, limited water availability, and soil heterogeneity pose significant challenges to plant growth, fruit development, and the accumulation of bioactive substances. Leaf water status is a key determinant of physiological stability, as it regulates turgor pressure, supports photosynthesis, facilitates nutrient transport, and modulates transpiration. Monitoring leaf water content provides crucial insights into plant stress tolerance, adaptation mechanisms, and overall productivity [6–10].

In recent decades, thornless blackberry cultivars have gained prominence due to their ease of management, improved fruit accessibility, and greater suitability for cultivation under adverse environmental conditions. Despite their growing popularity, there remains limited information on cultivar-specific morphological and biochemical responses, particularly under the semi-arid agro-climatic conditions of regions such as Samarkand, Uzbekistan. Understanding these responses is essential for optimizing cultivar selection, improving fruit quality, and enhancing the nutritional and functional potential of berries [2; 4; 11].

Previous studies have demonstrated that blackberry cultivars differ significantly in their physiological, morphological, and biochemical traits, including leaf water relations, fruit composition, and adaptive responses to drought and heat stress. However, comprehensive evaluations that integrate leaf water dynamics, phenological variations, and biochemical profiling under local environmental conditions are scarce. Such research is critical for advancing sustainable cultivation practices, maximizing yield, and ensuring the production of berries with high functional food value [2; 4; 8].

The present study aims to investigate the morphological traits, leaf water content dynamics, and biochemical composition—including vitamin C, flavonoids, amino acids, and carbohydrates—of six thornless blackberry cultivars: Jumbo, Thornfree, Karaka Black, Brzezina, Chester, and Cacanska Bestrna. The research evaluates these cultivars across key phenological stages (budding, flowering, fruiting, and the end of vegetation) over three consecutive years (2022–2024). By elucidating cultivar-specific adaptive mechanisms and stress tolerance, this study seeks to provide valuable insights for sustainable berry production, cultivar improvement, and the development of functional food applications in arid and semi-arid environments.

MATERIALS AND METHODS

Plant Material and Experimental Site

Seven blackberry cultivars—Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna, and the thorny Brazos—of composite origin belonging to *Rubus* spp. were grown at the experimental plots of Samarkand State Medical University from 2022 to 2024. Plants were managed under standard agronomic practices suitable for semi-arid conditions.

Experimental Design and Phenological Observations

A randomized complete block design with three replicates per cultivar was employed. Each plot consisted of 10 plants, and all cultivars were maintained under the same agronomic conditions. Observations and measurements were performed at four key phenological stages: budding (spring), flowering, fruiting, and the end of vegetation (late summer). Phenological stages were determined according to the BBCH-scale adapted for berry crops.

Leaf Water Content Measurement

Leaf water content (LWC) was evaluated to assess the physiological status and drought tolerance of the cultivars. Fully expanded leaves from the middle part of shoots were sampled at six time points during the day (08:00, 10:00, 12:00, 14:00, 16:00 and 18:00). Fresh weights were recorded immediately, and leaves were subsequently oven-dried at 70°C until constant weight to determine dry matter content.

Fruit Morphological and Biochemical Analysis

Fruits were harvested at full maturity for each cultivar. Morphological parameters, including fruit weight, size, and shape, were recorded.

Vitamin C content was determined in fully ripe blackberry fruits using the titrimetric method described by AOAC (2016) [12; 13]. Approximately 5 g of homogenized fruit sample was extracted with 100 mL of 3% metaphosphoric acid solution. The extract was titrated with 2,6-dichlorophenolindophenol solution until a persistent pink endpoint appeared. Results were expressed as mg of ascorbic acid per 100 g fresh weight (FW). All measurements were performed in triplicate.

Flavonoid content was measured using the aluminum chloride colorimetric assay [14]. One gram of dried fruit sample was extracted with 10 mL of 80% ethanol for 24 h at room temperature. The extract was reacted with 10% aluminum chloride solution, and absorbance was measured at 415 nm using a spectrophotometer. Flavonoid content was expressed as mg quercetin equivalents per 100 g dry weight (DW). Experiments were conducted in triplicate.

Amino acid composition was analyzed using the ninhydrin reaction [15]. Fruit samples (0.5 g) were hydrolyzed in 6N HCl at 110°C for 24 h, neutralized, and reacted with ninhydrin. Absorbance was read at 570 nm, and amino acid content was expressed as mg/g protein. All analyses were performed in triplicate.

Carbohydrate content was determined by the phenol–sulfuric acid method [16]. One gram of fruit sample was extracted with 10 mL distilled water, reacted with 5% phenol and concentrated sulfuric acid. Absorbance was measured at 490 nm, and carbohydrate content was expressed as mg glucose equivalents per 100 g FW. Measurements were performed in triplicate.

All analyses were conducted in triplicate to ensure accuracy and reproducibility.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using SPSS software. Differences between cultivars, phenological stages, and diurnal measurements were assessed using Tukey's multiple comparison test at a significance level of $p < 0.05$. Graphical representation of leaf water content dynamics and fruit biochemical parameters was performed using OriginPro 2021.

RESULTS

Leaf Water Content Dynamics

Leaf water content (LWC) was assessed in seven blackberry cultivars (Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna, and Brazos) across four phenological stages: budding, flowering, fruiting, and the end of vegetation. Measurements were conducted at six daily time points (08:00, 10:00, 12:00, 14:00, 16:00, 18:00) over three consecutive years (2022–2024) to capture diurnal fluctuations and annual trends.

All cultivars exhibited pronounced diurnal patterns, with maximum LWC recorded at 08:00 and gradual decreases throughout the day due to transpiration, followed by partial recovery in the evening (18:00). During the budding stage, the greatest daily fluctuations were observed in Thornfree (5.25%) and Jumbo (4.45%), indicating lower leaf water retention capacity. In contrast, Karaka Black (1.8%), Brzezina (1.75%), and Brazos (2.35%) maintained more stable LWC, demonstrating superior hydrostability (Figure 1).

Boxplots represent minimum, maximum, and median leaf water content values for seven cultivars (Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna, and Brazos) measured at four phenological stages: budding, flowering, fruiting, and end of vegetation. Data were averaged over three consecutive years (2022–2024). Narrow ranges in Karaka Black, Brzezina, and Brazos indicate efficient water conservation and high hydrostability, whereas broader ranges in Thornfree, Jumbo, and Chester reflect greater sensitivity to transpiration and environmental stress.

During flowering, similar trends persisted. Thornfree (8.15%) and Jumbo (7.56%) exhibited the highest LWC reduction, reflecting elevated transpiration and energy expenditure associated with reproductive development. Karaka Black (1.85%), Brzezina (1.45%), and Cacanska Bestrna (2.15%) retained minimal daily variation, confirming effective physiological water-conservation mechanisms.

The fruiting phase marked the highest physiological load on the plants. Jumbo (4.15%) and Thornfree (4.25%) experienced significant water loss due to transpiration, whereas Karaka Black (2.05%), Brzezina (1.7%), and Cacanska Bestrna (1.95%) maintained high leaf water stability. By the end of vegetation, overall LWC declined in all cultivars due to leaf senescence and reduced transpiration. Nonetheless, Karaka Black (2.1%), Brzezina (1.8%), and Cacanska Bestrna (1.85%) maintained relatively stable LWC, whereas Thornfree (3.05%), Jumbo (3.5%), and Chester (3%) were more susceptible to water stress (Figures 1 and 2).

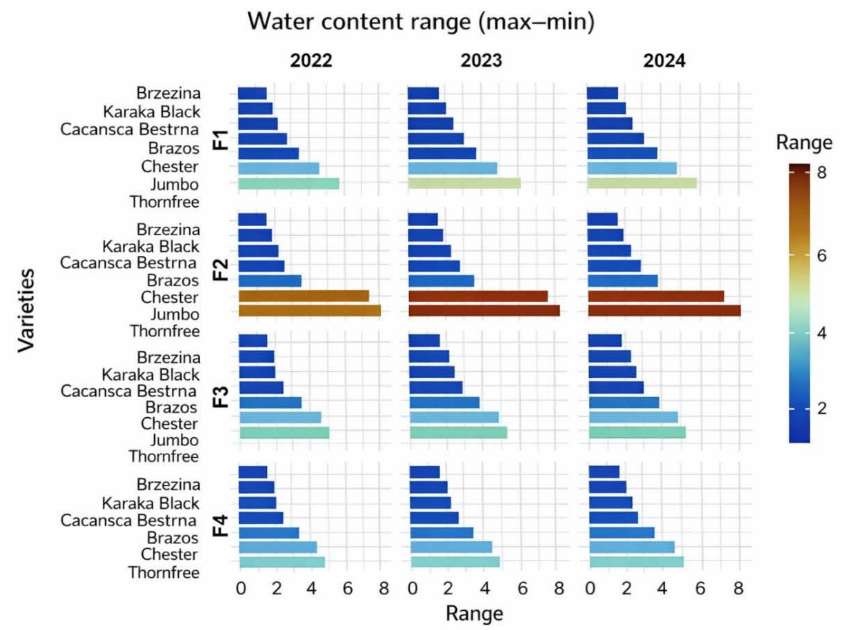

Figure 1
Range of leaf water content (%) across phenological stages in blackberry cultivars during 2022–2024

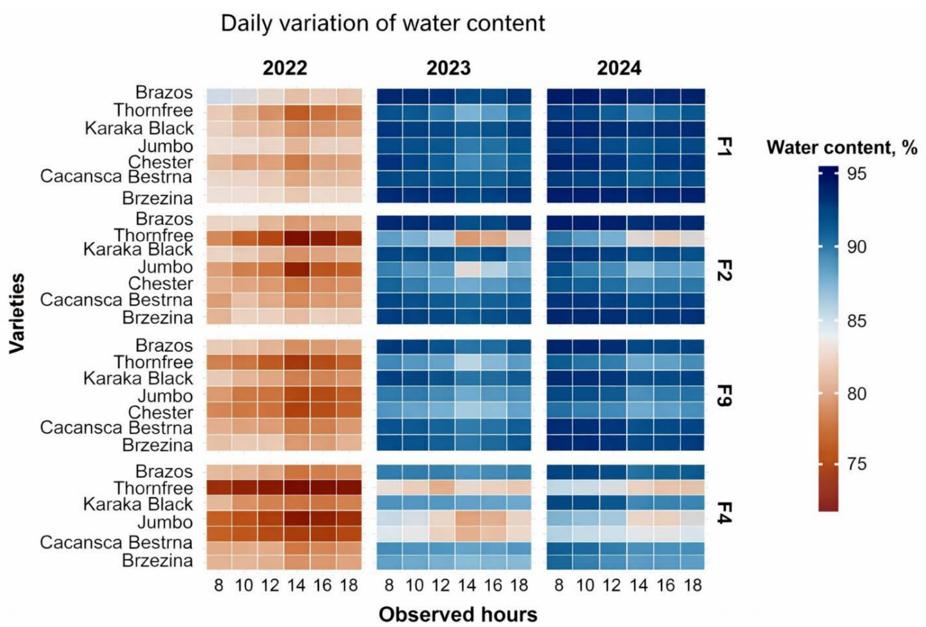

Figure 2
Annual changes in leaf water content (%) of blackberry cultivars during 2022–2024

Yearly and Phenological Influence on Leaf Water Content

Across all cultivars, LWC progressively declined from budding to the end of vegetation, reflecting the combined effects of increased physiological demands and environmental stress. Annual data (2022–2024) demonstrated a gradual increase in average LWC, suggesting improved plant adaptation or favorable climatic conditions over time (Figure 2).

The figure illustrates leaf water content measured at six daily time points (08:00, 10:00, 12:00, 14:00, 16:00, and 18:00) for seven cultivars (Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna, and Brazos) across three consecutive years. Data show a gradual increase in average leaf water content over the years, indicating improved adaptation or favorable environmental conditions. Diurnal dynamics highlight maximum water content in the morning and progressive decline during midday due to transpiration, followed by partial recovery in the evening.

Evaluation of the LWC range across phenological stages revealed cultivar-specific differences in water balance stability. Minimal daily fluctuations were observed in Karaka Black, Brzezina, and Brazos, indicating highly efficient water conservation strategies. Conversely, Thornfree, Jumbo, and Chester exhibited larger ranges, reflecting greater sensitivity to transpiration and drought stress.

Fruit Morphology

Morphological analyses highlighted significant inter-cultivar differences in fruit weight, size, and shape (Table 1).

Karaka Black and Brzezina produced larger, heavier fruits, whereas Chester and Thornfree yielded smaller fruits. The observed morphological differences correlated with leaf water retention capacities and overall stress tolerance.

Fruit Biochemical Composition

Biochemical characterization demonstrated pronounced cultivar-specific variation in vitamin C, total flavonoids, amino acids, and carbohydrates (Table 2).

Karaka Black exhibited the highest vitamin C (211.32 mg/100 g) and flavonoid content (84.12 mg/100 g), confirming its potent antioxidant capacity. Chester contained the highest total amino acids (22.55 mg/g), suggesting enhanced protein nutritional value, whereas Cacanska Bestrna showed the highest carbohydrate concentration (9.01 mg/g), favoring both fresh consumption and processing. Brazos exhibited intermediate biochemical profiles, consistent with its moderate hydrostability and fruit morphology.

Integration of Morphological, Physiological, and Biochemical Traits

Integration of LWC dynamics, fruit morphology, and biochemical composition highlights a strong relationship between water management and fruit quality. Cultivars exhibiting higher leaf hydrostability, including Karaka Black, Brzezina, Cacanska Bestrna, and Brazos, maintained superior fruit biochemical profiles under arid conditions. In contrast, cultivars more susceptible to water loss (Thornfree, Jumbo, Chester) showed reduced biochemical accumulation and less stable fruit development.

Table 1
Morphological characteristics of blackberry cultivars
Data represent mean ± SD (n = 10 fruits per cultivar). Measurements include fruit weight, length, diameter, and shape across seven cultivars cultivated in Samarkand region.

Cultivar	Average fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Fruit shape
Jumbo	5.8 ± 0.35	22.3 ± 1.2	18.5 ± 1.1	Oval
Thornfree	5.2 ± 0.28	21.1 ± 1.1	17.9 ± 0.9	Oval
Karaka Black	6.4 ± 0.30	24.0 ± 1.0	19.2 ± 1.0	Oblong
Brzezina	6.2 ± 0.32	23.5 ± 1.1	18.8 ± 1.2	Oblong
Chester	4.9 ± 0.25	20.5 ± 0.9	17.2 ± 0.8	Round
Cacanska Bestrna	5.7 ± 0.27	22.7 ± 1.0	18.1 ± 0.9	Oval
Brazos	6.0 ± 0.33	23.0 ± 1.1	18.5 ± 1.0	Oblong

Table 2
Biochemical composition of blackberry fruits

Cultivar	Vitamin C (mg/100 g)	Total flavonoids (mg/100 g)	Total amino acids (mg/g)	Total carbohydrates (mg/g)
Jumbo	189.45 ± 4.12	72.30 ± 3.25	18.25 ± 1.10	8.75 ± 0.45
Thornfree	182.60 ± 3.95	70.12 ± 3.00	17.90 ± 1.05	8.55 ± 0.42
Karaka Black	211.32 ± 4.25	84.12 ± 3.40	20.50 ± 1.15	8.90 ± 0.48
Brzezina	205.10 ± 3.90	80.25 ± 3.20	19.85 ± 1.12	8.85 ± 0.46
Chester	175.85 ± 3.70	68.45 ± 3.10	22.55 ± 1.20	8.40 ± 0.44
Cacanska Bestrna	198.20 ± 4.05	75.60 ± 3.30	19.10 ± 1.08	9.01 ± 0.50
Brazos	200.45 ± 3.95	77.80 ± 3.25	20.05 ± 1.10	8.88 ± 0.47

These findings underscore the pivotal role of physiological adaptation in determining both productivity and nutritional quality of blackberries in semi-arid agro-ecosystems.

DISCUSSION

The present study investigated morphological, biochemical, and physiological traits of seven *Rubus* spp. cultivars (Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna, and Brazos) under the agro-climatic conditions of the Samarkand region. Significant cultivar-specific differences were observed in leaf water content dynamics, fruit composition, and adaptive responses to environmental stress, highlighting their potential for sustainable cultivation in arid and semi-arid areas [2; 4].

Leaf water content is a critical physiological indicator, affecting cell turgor, photosynthetic efficiency, and overall plant growth. In our study, Karaka Black, Brzezina, and Brazos maintained the highest leaf hydrostability, showing minimal diurnal and phenological fluctuations. This suggests that these cultivars possess efficient water-use mechanisms and are better adapted to water-limited conditions. Conversely, Thornfree, Jumbo, and Chester exhibited greater diurnal variation and reduced water retention, indicating higher sensitivity to transpiration and environmental stress. For instance, during the flowering and fruiting stages, Thornfree and Jumbo lost up to 8.15% and 7.56% of leaf water content, respectively, reflecting their lower capacity to maintain hydro-balance under high transpiration rates [17; 18].

Diurnal patterns consistently showed maximum leaf water content in the early morning (08:00) and a gradual decline towards midday due to transpiration, followed by partial recovery in the evening (18:00). These dynamics demonstrate the interplay between environmental factors, such as temperature and solar radiation, and cultivar-specific physiological responses. The cultivars with stable water content, particularly Karaka Black, effectively regulated stomatal aperture and maintained turgor, thereby supporting photosynthetic activity and nutrient transport even under high evaporative demand [7; 10; 18].

Biochemical analyses revealed that Karaka Black contained the highest vitamin C (211.32 mg/100 g) and total flavonoids (84.12 mg/100 g), while Chester exhibited the highest amino acid content (22.55 mg/g) and Cacanska Bestrna showed the greatest carbohydrate level (9.01 mg/g). These findings suggest a correlation between water stability and accumulation of bioactive compounds. Cultivars capable of maintaining leaf turgor and hydrostability during peak stress periods tend to preserve higher levels of antioxidants and essential metabolites, which is consistent with reports on berry crops under water-limited environments [2; 4; 16; 18; 19].

The morphological traits, including fruit size and shape, also contributed to the observed physiological differences. Larger, oblong fruits of Karaka Black and Brzezina may provide greater surface area for transpiration regulation and metabolite accumulation. In contrast, smaller fruits of Chester and Jumbo, while potentially favorable for certain processing purposes, were associated with higher sensitivity to daily water loss [2; 4].

Overall, these results underscore the importance of integrating morphological, physiological, and biochemical assessments when selecting cultivars for arid and semi-arid regions. Karaka Black and Brzezina, in particular, demonstrate a combination of high adaptive potential, hydrostability, and nutritional value, making them suitable candidates for functional food production and sustainable horticulture [19–22]. Conversely, Thornfree, Jumbo, and Chester may require tailored irrigation and management strategies to mitigate water stress and optimize fruit quality.

These findings provide a scientific basis for cultivar selection, irrigation planning, and breeding programs aimed at enhancing stress tolerance, improving fruit quality, and promoting the use of *Rubus* spp. as a valuable functional food resource in regions with limited water availability.

CONCLUSION

The present study provides a comprehensive assessment of morphological, physiological, and biochemical traits of seven blackberry cultivars (Jumbo, Thornfree, Karaka Black, Brzezina, Chester, Cacanska Bestrna and Brazos) under the agro-climatic conditions of the Samarkand region. The results demonstrated significant cultivar-specific differences in leaf water content dynamics, fruit composition, and stress adaptation.

Contributions

N. S. Jumakulova: data curation, formal analysis, investigation, writing-original draft, writing-review & editing.

F. D. Kabulova: conceptualization, methodology, project administration, supervision, writing-review & editing.

K. T. Ismoilov: investigation, resources, data curation.

Вклад авторов

Н. Ш. Жумакулова: отбор данных, формальный анализ, исследование, написание-черновик, написание – рецензирование и редактирование.

Ф. Д. Кабулова: концептуализация, методология, администрирование проекта, руководство, написание-рецензирование и редактирование.

К. Т. Исмоилов: исследование, ресурсы, отбор данных.

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