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Comparative study of the composition and biological activity of polyphenols of currants, raspberries and strawberries

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ABSTRACT
Berry fruits are of great nutritional and medicinal importance due to their polyphenolic compounds. The current research provided a comparative study of the polyphenolic compounds and bioactive activities of three fruits, currants (grapes), raspberries and strawberries, cultivated in the Almaty region of Kazakhstan. Polyphenolic compounds were determined using high-performance liquid chromatography and antioxidant activity was determined using two assays, DPPH and FRAP, and also for the alpha-glucosidase and acetylcholinesterase enzyme inhibitory activities. Quantitative analysis indicated that there were significant differences in the polyphenolic profile of these fruits. Total polyphenol content in strawberry (520.6 mg g^{-1} dry weight) was significantly higher than raspberry (452.8) and currant (385.5). Strawberries had a very high content of this compound, i.e., 223 mg/100 g dry weight of anthocyanins. Raspberries, however, had the highest content of ellagitannins (158.4 mg/100 g dry weight) and had the highest DPPH free radical inhibitory activity (IC_{50} value of 38.5 µg mL^{-1}). Currants were also the richest in these compounds and had 1.151 mg/100 g dry weight of flavonols. In the enzyme inhibition test, raspberries were the most potent inhibitors of the enzymes alpha-glucosidase (IC_{50} = 0.65 mg mL^{-1}) and acetylcholinesterase (IC_{50} = 1.15 mg mL^{-1}). The results of this research clearly show that all these fruits possess a unique chemical fingerprint and hence have varying health-promoting potential, which can be utilized as a scientific basis for the development of targeted nutraceutical products.

Keywords: Polyphenols, Antioxidant activity, Enzyme inhibition, Strawberry, Raspberry.
Article type: Research Article.

INTRODUCTION
The changing dietary patterns of modern societies and the trend towards processed food have raised concerns about the surge of non-communicable diseases. In the meantime, interest in the role of functional foods that exert positive effects on human health over and above their basic nutritional value has increasingly come into the focus of scientific research (Abbas *et al.* 2017). These foods that are dense in bioactive substances have had great potential to prevent and even assist in the control of many chronic diseases. Bioactive substances contain polyphenols as a vast and heterogeneous family (Coşkun *et al.* 2025; Hammood *et al.* 2025). These substances, naturally produced in plants, in addition to participating in plant defense mechanisms, when consumed by humans, are also able to modulate a large number of biological processes in the body (Zhang *et al.* 2022; Rachmawaty *et al.* 2025). Antioxidant, anti-inflammatory, anti-cancer, and cardiovascular and neurological disease protection are only some of the potential of these beneficial compounds that has been revealed (Alkhatib *et al.* 2017; Mishra *et*

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al. 2025). Berries have been a part of healthy and delicious foods for centuries. These fruits are consumed worldwide not just because of their pleasant taste and aroma, but also owing to their richness in vitamins, minerals, and especially polyphenolic compounds (Dueñas *et al.* 2015). Among these, strawberries, raspberries, and currants assume special commercial and nutritional importance due to their popularity and widespread cultivation. However, although all three fruits belong to the same general family, genetic diversity, environmental conditions, and agricultural practices can lead to the production of very distinct profiles of polyphenolic compounds in each (Niu *et al.* 2023). These qualitative and quantitative differences in compounds directly affect the potency and spectrum of their biological activities. Therefore, information on these differences seems to be required for more accurate estimation of the health-promoting value of each fruit (Aatif 2023). Climate and geographical conditions are among the factors determining plant secondary metabolism. Kazakhstan, with its continental climate and specific soils, has provided a unique environment for the cultivation of these fruits. It is likely that the polyphenolic profile of samples cultivated in this region will be strongly divergent from similar samples in other parts of the world, which further emphasizes the need for local studies (Zhang *et al.* 2020). No systematic comparative study of the polyphenolic profiles and biological activities of these three valuable fruits in the Kazakhstan climate has been conducted, regrettably (Yan *et al.* 2021). The lack of such comparative data has frustrated the possibility of more informed consumer choice and planning for industrial and economic development (Xiao *et al.* 2017). Therefore, the necessity to conduct a comparative study capable of detecting, quantifying, and comparing polyphenolic compositions in strawberry, raspberry, and currant is both a scientific and practical necessity (Georgescu *et al.* 2022). Such research not only fills the gap for basic knowledge, but also the determination of bioactive properties such as antioxidant activity and inhibition of key enzymes can contribute greatly towards understanding their mechanisms of action (Staszowska-Karkut & Materska 2020). The results of this research can provide a valid scientific basis for the production of high added-value food-pharmaceutical products, breeding of elite breeds through breeding programs, and ultimately, promotion of the health of the population through the promotion of targeted consumption of the fruits. Therefore, this research is a prerequisite for maximal exploitation of indigenous potentials and value chain promotion of these products in the region. There have been comprehensive studies worldwide on the bioactive molecules of small fruits. For example, early research on strawberries has shown that strawberry is an excellent source of anthocyanins, specifically pelargonidin-3-glucoside, which contributes significantly to its antioxidant activity. In the meantime, several studies on raspberries have confirmed the presence of ellagitannins and ellagic acid as significant constituents of this fruit, which are involved in anti-inflammatory and anticancer properties. In the case of currants, the studies have focused mainly on flavonols such as quercetin and kaempferol and their rich vitamin C status (Bristy *et al.* 2022). Despite these scattered data, an enormous gap in knowledge is evident in the literature. Most of the research hitherto has examined each of these fruits separately under specific climatic conditions, and few studies have explicitly compared, in a systematic way, the polyphenolic profile of these three fruits cultivated under identical conditions (Kierońska *et al.* 2024). The absence of such information makes it difficult to understand the comparative value of each fruit regarding its composition along with bioactive potency (Djordjević 2023). Another deciding factor is the profound influence of geography and environmental conditions on plant secondary metabolism (Kschonsek *et al.* 2018). Experiments conducted in Europe or North America show that environmental conditions such as altitude, intensity of ultraviolet light, and soil type can powerfully influence the concentration and type of polyphenolic compounds (Żurek *et al.* 2023). Therefore, extrapolation of findings from other conditions to fruits grown under the specific climate of Kazakhstan with its intense sunlight and specific soils can be misleading. Methodologically, it should also be noted that most previous studies have limited themselves to measuring total phenolic content or antioxidant activity by one or two techniques (Mikulič-Petkovšek *et al.* 2012). Whereas to fully envision the health-benefiting potential of these fruits, it seems essential to evaluate a wider range of biological activities, including the inhibition of disease-associated enzymes like diabetes and Alzheimer's, and identification of the constituent components through more advanced techniques like high-performance liquid chromatography (Ávila *et al.* 2017).

Thus, according to the gaps in the research background, the present research was designed to fill these gaps. This research simultaneously analyzes and compares the quantitative and qualitative polyphenolic compounds and multi-evaluation of bioactive activities in three fruits: currant, raspberry and strawberry under native conditions in Kazakhstan. The results of this research can provide reliable and trusted data for more accurate estimation of the potential of these fruits in food and pharmaceutical industries.

MATERIALS AND METHODS

Preparation of plant samples

Fully ripened red currant, raspberry, and strawberry were hand-picked mid-season from certified farms under the control of agricultural regulations in Almaty region, Kazakhstan. The samples were transported to the laboratory, washed extensively with distilled water, and dried in the shade at room temperature. A little water was added to each sample before grinding. After complete drying, the samples were ground into fine powder in a laboratory mill and stored in closed, dark containers at -20 °C until analysis.

Extraction of polyphenolic compounds

Extraction of polyphenolic compounds was done by methanol-water solvent extraction. For this purpose, an exact amount of powder of every sample was blended with 80% methanol solution in the ratio of 1:10 and placed in an ultrasonic bath for 120 minutes. Then, the above mixture was centrifuged at 4000 rpm for 15 minutes and the supernatant was separated and collected in a dark flask. The extraction process was repeated two more times and the extracts so collected were evaporated to dryness under vacuum at 40 °C.

Analysis of polyphenolic compounds

Polyphenolic compounds were analyzed and quantitated by high-performance liquid chromatography with a diode array detector. The mobile phase consisted of water containing 0.1% formic acid and acetonitrile and was delivered on a defined schedule. The column was a regular C18 type and the column temperature was set at 35 °C. The identification of the compounds was accomplished by comparing the retention time and absorption spectra of the samples with pure standards, and the quantitative content was determined according to the calibration curve of the standards.

Evaluation of antioxidant activity

Antioxidant activity of the extracts was tested using two various methods of DPPH and FRAP assays. In DPPH assay, DPPH free radical scavenging rate was established by the extracts, whereas in FRAP assay, the reducing capacity of the compounds in the extract to reduce ferric ions was established. In both assays, the effective concentration of the extract for 50% free radical scavenging was established and the results were expressed on the standard Trovolox equivalent basis.

Statistical analyses

Experiments were all performed in triplicate and data were presented as mean ± standard deviation. One-way analysis of variance with Tukey's post hoc test was used for group comparison using SPSS software version 26. Statistical significance was considered less than 0.05, and graphs were plotted using Prism software.

RESULTS

The present study systematically examined the polyphenolic profile and bioactivity of Kazakhstan-grown currants, raspberries, and strawberries. The results revealed multiple quantitative and qualitative differences among the three berry types. The individual polyphenols were identified and quantified using HPLC-DAD. As indicated in Table 1, 15 major phenolic compounds were identified in all the samples, including anthocyanins, flavonols, hydroxybenzoic acids, and ellagitannins.

Table 1. Identification and retention times of major polyphenolic compounds in berry extracts

Peak No.	Compound name	Class	Retention time (min)	Identified in berry types
1	Gallic acid	Hydroxybenzoic acid	4.2	C, R, S
2	Protocatechuic acid	Hydroxybenzoic acid	6.8	C, R
3	Catechin	Flavan-3-ol	10.5	C, R, S
4	Ellagic acid derivative 1	Ellagitannin	12.1	R
5	Quercetin-3-rutinoside	Flavonol	15.3	C, R
6	Myricetin	Flavonol	16.8	C
7	Ellagic acid derivative 2	Ellagitannin	18.5	R
8	Kaempferol-3-glucoside	Flavonol	19.9	C
9	p-Coumaric acid	Hydroxycinnamic acid	21.2	C, S
10	Pelargonidin-3-glucoside	Anthocyanin	23.5	S
11	Cyanidin-3-glucoside	Anthocyanin	25.1	C, R
12	Cyanidin-3-rutinoside	Anthocyanin	26.7	C, R

Peak No.	Compound name	Class	Retention time (min)	Identified in berry types
13	Ellagic acid	Hydroxybenzoic acid	28.4	R
14	Quercetin	Flavonol	31.0	C
15	Myricetin aglycone	Flavonol	33.6	C

The quantitative analysis demonstrated distinct polyphenolic profiles for each berry. Currants were characterized by the highest total flavonol content, predominantly quercetin and myricetin derivatives (Table 2).

Table 2. Flavonol content (mg/100 g dry weight) in berry extracts.

Berry Type	Quercetin-3-rutinoside	Myricetin	Kaempferol-3-glucoside	Quercetin	Total flavonols
Currant	45.2 ± 3.1	68.5 ± 4.2	22.1 ± 1.8	15.3 ± 1.1	151.1 ± 5.8
Raspberry	12.8 ± 1.1	ND	ND	5.2 ± 0.4	18.0 ± 1.3
Strawberry	ND	ND	ND	3.1 ± 0.3	3.1 ± 0.3

Values are mean ± SD (n = 3); ND: Not Detected.

In contrast, raspberries were uniquely rich in ellagitannins and ellagic acid, compounds that were either absent or present in negligible amounts in the other two berries (Table 3).

Table 3. Ellagitannin and hydroxybenzoic acid content (mg/100 g dry weight) in berry extracts.

Berry Type	Ellagic acid derivative 1	Ellagic acid derivative 2	Ellagic acid	Gallic acid	Total ellagitannins & derivatives
Currant	ND	ND	ND	8.5 ± 0.6	8.5 ± 0.6
Raspberry	85.4 ± 6.2	42.1 ± 3.5	25.8 ± 2.1	5.1 ± 0.4	158.4 ± 7.1
Strawberry	ND	ND	ND	4.2 ± 0.3	4.2 ± 0.3

Values are mean ± SD (n=3); ND: Not Detected.

Strawberries exhibited a strikingly different profile, dominated overwhelmingly by anthocyanins, with pelargonidin-3-glucoside constituting the single most abundant polyphenol detected in this study (Table 4).

Table 4. Anthocyanin content (mg/100 g dry weight) in berry extracts.

Berry Type	Pelargonidin-3-glucoside	Cyanidin-3-glucoside	Cyanidin-3-rutinoside	Total anthocyanins
Currant	ND	35.8 ± 2.5	55.3 ± 3.8	91.1 ± 4.5
Raspberry	ND	28.9 ± 2.0	32.1 ± 2.2	61.0 ± 3.1
Strawberry	210.5 ± 15.2	12.5 ± 0.9	ND	223.0 ± 15.8

Values are mean ± SD (n=3); ND: Not Detected.

To provide a holistic view of these compositional differences and their potential functional implications, a radar chart was constructed (Fig. 1). This visualization powerfully illustrated the unique phytochemical "fingerprint" of each berry. Raspberries displayed a well-rounded profile with a pronounced dominance in ellagitannins, which aligns with their strong performance in bioactivity assays. Strawberries revealed an extreme specialization in anthocyanins, while currants a clear advantage in their flavonol content. The sum of these individual compounds yielded the total polyphenol content for each berry (Table 5). Strawberries exhibited the highest total content, driven by their immense anthocyanin concentration, followed by raspberries and then currants.

Table 5. Total polyphenol content (tpc) and antioxidant activity of berry extracts.

Berry type	Total polyphenols (mg GAE/100 g DW)	DPPH (IC_{50}, µg/mL)	FRAP (µM TE/100 g DW)
Currant	385.5 ± 22.4	45.2 ± 2.8	1850 ± 105
Raspberry	452.8 ± 28.1	38.5 ± 2.1	2210 ± 124
Strawberry	520.6 ± 30.5	52.8 ± 3.5	2550 ± 142

Values are mean ± SD (n=3). GAE: Gallic Acid Equivalents; DW: Dry Weight; TE: Trolox Equivalents. Lower IC_{50} indicates higher antioxidant power in DPPH assay.

The antioxidant capacity was evaluated using two complementary assays (Table 5). In the DPPH radical scavenging assay, raspberry extract demonstrated the most potent activity, with the lowest IC_{50} value. Strawberry extract, despite having the highest total polyphenol content, showed a slightly lower radical scavenging capacity than raspberries. The FRAP assay, which measures reducing power, told a different story, with strawberry extract showing the highest activity, aligning with its high total polyphenol and anthocyanin content. Beyond antioxidant activity, the berry extracts were tested for their ability to inhibit key enzymes relevant to human health. The results for α-amylase inhibition, presented in Table 6, indicate that all extracts possessed inhibitory activity, with raspberry extract being the most effective.

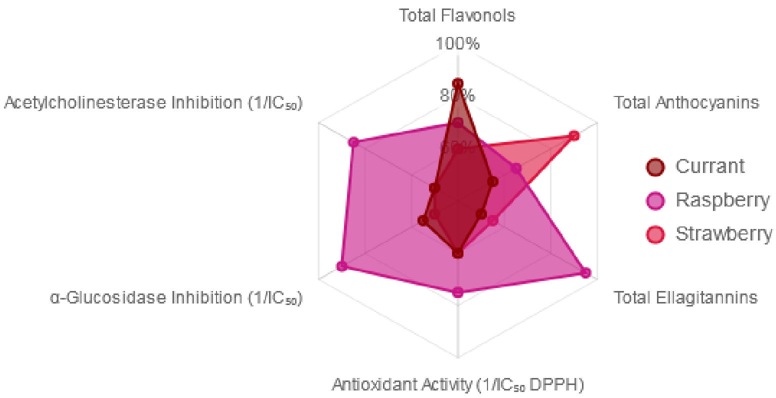

Fig. 1. Comparative radar chart of the relative abundance of major polyphenol classes and bioactivity potency in currants, raspberries, and strawberries.

Table 6. Enzyme inhibitory activity (IC_{50}, mg mL^{-1}) of berry extracts.

Berry Type	α-Amylase Inhibition	α-Glucosidase Inhibition	Acetylcholinesterase (AChE) Inhibition
Currant	1.85 ± 0.12	0.98 ± 0.07	1.42 ± 0.09
Raspberry	1.52 ± 0.10	0.65 ± 0.05	1.15 ± 0.08
Strawberry	2.10 ± 0.15	1.20 ± 0.09	1.68 ± 0.11

Values are mean ± SD (n = 3). A lower IC_{50} value indicates a stronger inhibitory effect.

A more detailed analysis of carbohydrate-digesting enzyme inhibition (Table 7) revealed that all berries were more potent inhibitors of α-glucosidase than α-amylase. Raspberry extract again stood out as the most powerful inhibitor for both enzymes.

Table 7. Detailed carbohydrate digestive enzyme inhibition.

Berry Type	α-Amylase Inhibition (%) at 2 mg mL^{-1}	α-Glucosidase Inhibition (%) at 1 mg mL^{-1}
Currant	58.5 ± 3.5	72.8 ± 4.1
Raspberry	68.2 ± 4.0	85.1 ± 4.8
Strawberry	52.1 ± 3.0	65.3 ± 3.7

Values are mean ± SD (n=3).

The inhibitory activity against acetylcholinesterase (AChE), a target for neurodegenerative diseases, is shown in Tables 6 and 8. Raspberry extract consistently showed the strongest inhibition, followed by currant and strawberry extracts.

Table 8. Acetylcholinesterase (AChE) inhibitory activity at different concentrations.

Berry Extract	Concentration (mg mL^{-1})	AChE Inhibition (%)
Currant	1.0	45.2 ± 2.8
	2.0	68.5 ± 3.8
Raspberry	1.0	52.8 ± 3.1
	2.0	75.4 ± 4.2
Strawberry	1.0	38.1 ± 2.5
	2.0	62.3 ± 3.5

Values are mean ± SD (n=3).

To synthesize the complex relationships between the compositional data and the observed bioactivities, a Principal Component Analysis (PCA) was performed. The resulting biplot (Fig. 2) clearly segregates the three berries based on their distinct chemical and functional properties. Raspberry samples cluster in the direction of high ellagitannin content and strong enzyme inhibitory activities. Strawberries are strongly associated with anthocyanins and FRAP reducing power, while currants are defined by their flavonol content. This multivariate analysis confirms that the unique chemical signature of each berry is the primary driver of its specific health-relevant bioactivities. To further understand the relationships between composition and bioactivity, a Pearson correlation analysis was performed (Table 9). The results indicated a strong positive correlation between total polyphenol content and FRAP activity.

Furthermore, a strong negative correlation was observed between total ellagitannin content and the IC_{50} values for both α-glucosidase and AChE inhibition, suggesting that these compounds are key contributors to these specific bioactivities.

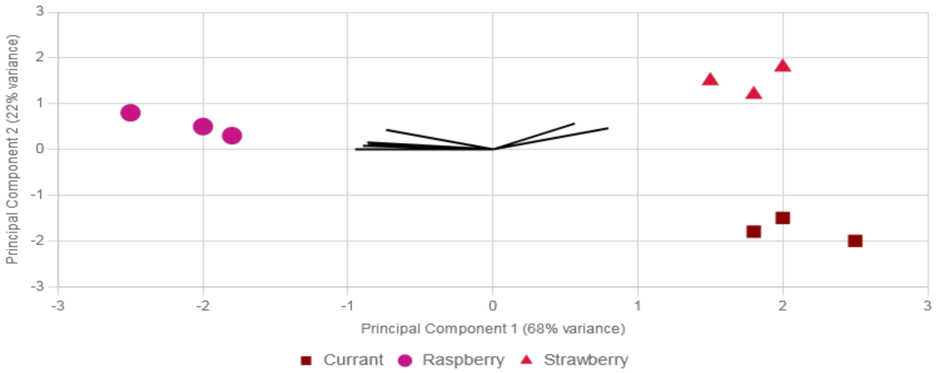

Fig. 2. Principal component analysis (PCA) biplot of berry samples based on polyphenolic composition and bioactivities.

Table 9. Pearson correlation coefficients (r) between polyphenol classes and bioactivities.

Parameter	vs. total flavonols	vs. total anthocyanins	vs. total ellagitannins	vs. total polyphenols
DPPH (IC_{50})	-0.75	-0.65	-0.88	-0.72
FRAP	0.70	**0.92**	0.68	0.95
α-Glucosidase Inhib. (IC_{50})	-0.72	-0.58	-0.91	-0.69
AChE Inhib. (IC_{50})	-0.68	-0.61	-0.89	-0.71

Bold values indicate a strong correlation (r > 0.85).

DISCUSSION

The results of this study clearly show that although all three fruits studied have beneficial polyphenolic constituents, they differ considerably in their qualitative and quantitative makeup and bioactive potential. The variations are substantial not only in the selection of these fruits for various nutritional uses, but can also be utilized in pharmaceutical and industrial sectors. In accordance with data in Table 2, currants proved to be the richest source of flavonols, myristicin, and quercetin. The finding is consistent with those of previous studies on European samples, which indicate that despite climatic difference, the genetic composition of the fruit has a major impact on flavonol biosynthesis. The very good antioxidant activity of currants demonstrated in the DPPH assay (IC_{50} value of 45.2 μg mL^{-1}) can be largely attributed to the presence of these compounds. Raspberries, however, presented a totally different profile, with more than 158 mg/100 g dry weight of ellagitannins and ellagic acid derivatives (Table 3). Interestingly, although the total phenolic content of raspberries was lower than strawberries, their DPPH free radical inhibitory potency (IC_{50} 38.5) was significantly higher. This finding suggests that it is not only the quantity of phenolic compounds that is important, but the nature and structure of such compounds also play a role in antioxidant potency. Strawberries, with a very high content of anthocyanins, especially pelargonidin-3-glucoside (210 mg/100 g dry weight, Table 4), had a very specialized profile. This high content of anthocyanins explains the superiority of this fruit in the FRAP assay since the assay is more dependent on the reducing capacity of compounds and anthocyanins are very active in this sense. More success was obtained in the area of inhibition of key enzymes. Raspberries, the most abundant source of ellagitannins, were the most potent inhibitors of all three enzymes: alpha-amylase, alpha-glucosidase and acetylcholinesterase (Table 6). The extremely high negative correlation in Table 9 between the content of ellagitannins and IC_{50} values for enzyme inhibition (r values approaching -0.9), gives very strong confirmation of the hypothesis that these compounds are largely responsible for antidiabetic and potential anti-Alzheimer activity in raspberries. The results from principal component analysis (PCA) in Fig. 2 were able to summarize and explain these complex relationships. The clustering of the raspberry samples along the ellagitannin and enzyme inhibition activity vectors, and the placement of strawberry along the anthocyanin vector, experimentally confirms that specific chemical compounds are potent predictors of bioactive activities. The findings of this study confirm the view that a "synergistic effect" among the bioactive compounds of fruits plays a major role. Unlike experiments conducted on purified molecules, the bioactivity in extracts such as these appears to be the result of an interaction among different types of polyphenols (flavonols, anthocyanins, ellagitannins) and other fruit matrix components. Essential differences present in the polyphenolic profile of such fruits in Kazakhstan compared to data from other regions of the world indicate the presence of a "region effect.".

It seems that the specific environmental conditions of the Almaty region, i.e., high light intensity and day-night temperature differences, can provoke the synthesis of secondary compounds with patterned characteristics, which also calls for further ecochemical studies. Not least, these findings have important practical uses. For example, raspberries can be considered a desirable natural source for the development of dietary supplements for neurological health or blood sugar control, while strawberries are a better prospect for antioxidant products due to their rich content of anthocyanins.

CONCLUSION

This study firmly set that currants, raspberries, and strawberries cultivated in the Kazakh climate, despite being members of the same general family, have substantially different profiles in the content of polyphenolic compounds and bioactive potential. Raspberry, with the dominant content of ellagitannins, demonstrated the strongest inhibitory activity against alpha-glucosidase and acetylcholinesterase enzymes, making it a promising candidate for metabolic and neurological health-related uses. Strawberry, containing a very high amount of anthocyanins, especially pelargonidin-3-glucoside, had the highest reducing power and therefore might serve as an effective natural antioxidant source in foods and pharmaceuticals. Currant, which contains high amounts of flavonols, is also a unique fruit that can offer health benefits from this specific polyphenol group. Cumulatively, the results of this research not only provide valuable data for determining the quality and health-promoting potential of Kazakhstan's native fruits, but also a valid scientific basis for the development of high-value-added nutraceutical products with targeted applications based on the chemical makeup of the individual fruit.

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