# THE SUSTAINABLE UTILISATION OF SOME FOOD PRODUCTION METHODS: A NON-WASTE APPROACH TO MITIGATING ENVIRONMENTAL RISKS

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**Abstract**

*Increased consumer demand for healthy and functional food products has led to greater interest in the food industry in developing products using polyphenol-rich raw materials. Vaccinium fruits are particularly noteworthy among these materials. Current juice extraction technologies leave a substantial proportion of biologically active compounds in the resulting by-products, such as skins, seeds, and residual juice. The effective utilization of these by-products could significantly enhance the nutritional and economic value of Vaccinium fruits. This study aims to investigate the physicochemical properties and phytochemical composition of wild bilberries (Vaccinium myrtillus L.) and whortleberries (Vaccinium arctostaphylos L.) in the mountainous region of Adjara. The study also seeks to evaluate the physicochemical and phytochemical composition of blueberry sauce produced using a zero-waste processing method involving the use of homogenized whole fruit, including seeds. A comparative analysis of the results obtained will also be provided. To achieve these objectives, high-purity chemical reagents were employed, alongside classical and advanced analytical techniques, to analyze the components quantitatively. The study aimed to quantify the dry matter content, active acidity (pH), organic acids, carbohydrates, total phenolic compounds, flavonoids, anthocyanins, vitamin E, chlorogenic acid, and mineral elements in the fruit and sauce. The study also aimed to evaluate the antioxidant activity of these compounds. The findings revealed that the homogenized fruit product containing seeds had significantly higher levels of phytonutrients than the raw fruit. Incorporating this sauce as a multifunctional bioactive supplement into the human diet could support health maintenance and overall well-being. This study also emphasizes the importance of sustainably processing natural resources in order to reduce agro-industrial waste. Using whole fruits, including by-products, provides a sustainable model for food production that minimizes ecological risk by reducing the accumulation of organic waste.*

**Keywords:** environmental risk, risk mitigation, *Vaccinium myrtillus* L., *Vaccinium arctostaphylos* L., fruit, biologically active compounds, functional product

# I.Introduction

More than 200 species of Vaccinium are distributed worldwide [1]. According to available data [2], four species are found in Georgia: bilberry (*Vaccinium myrtillus L.*), highbush blueberry (*Vaccinium corymbosum*), lingonberry (*Vaccinium vitis-idaea*), and Caucasian whortleberry (*Vaccinium arctostaphylos* L.). In the mountainous region of Adjara, located in western Georgia, Vaccinium arctostaphylos L. and Vaccinium myrtillus L. are the most prevalent species. These plants typically grow at elevations ranging from 300 to 1200 meters above sea level.

Research conducted by Lasekan and Paedres-Lopez [3,4] has established that dietary composition plays a critical role in maintaining human health. According to Jung [5], sufficient consumption of berries, vegetables, and fruits may significantly reduce the risk of breast cancer. Berries, often classified as "superfruits" by researchers, are abundant in natural antioxidants and contribute positively to human health [6]. Findings from Rasmussen [7] indicate that the flavonoid profile of berries comprises anthocyanins, flavonols, and flavanols, along with stilbenes, tannins, phenolic acids, and lignins. In addition to their nutritional value, Vaccinium species offer an opportunity to address environmental concerns. Traditional fruit processing methods often generate waste, contributing to bio-waste management issues. The use of non-waste processing methods presents a path toward sustainable and environmentally responsible food systems.

An experiment conducted by Mikulic-Petkovsek and Seeram [8,9] on the polyphenol content of 25 wild berry species revealed that wild berries contain two to three times more polyphenols than their cultivated counterparts. Studies by Nile et al. [10], supported by experimental evidence, have demonstrated that unregulated oxidative processes in the human body contribute to the development of various pathological conditions, including chronic inflammatory diseases, metabolic disorders, and cancer. The incorporation of polyphenol-rich berries into the human diet has been shown to exert significant protective effects against these health issues.

Moreover, research by Slatnar and Wu [11,12] has highlighted blueberries as particularly exceptional among berry species due to their diverse polyphenolic profile, high anthocyanin concentration, and potent antioxidant activity.

Scientific studies conducted by Diaconeasa, Gordillo and Moze [13-15] have identified petunidin, delphinidin, cyanidin, and malvidin as the predominant anthocyanins in blueberries, while chlorogenic acid has been recognized as the primary phenolic acid, with concentrations ranging from 23.1 to 70.0 mg per 100 g of fresh weight.

The anti-inflammatory, antioxidant, anticancer, cardioprotective, and neuroprotective properties of blueberries have been extensively documented in the research of Kalt et al. [16].

Experimental studies conducted by Casedas et al. [17] demonstrated that blueberry extracts and their bioactive derivatives protect pancreatic β-cells from glucose-induced oxidative stress, enhance insulin secretion, exhibit hypoglycemic effects, restore glutathione levels, and improve insulin sensitivity.

According to the literature, blueberry fruit is a promising raw material rich in phytonutrients, making it suitable for the development of multifunctional blueberry sauce. This study aimed to:

1. Evaluate the physicochemical properties of wild-growing blueberry species (*Vaccinium myrtillus* L. and *Vaccinium arctostaphylos* L.) from the high-mountainous region of Adjara.
2. Assess the physicochemical characteristics and antioxidant activity of homogenized blueberry sauce (including seeds) and perform a comparative analysis between the raw fruit and the resulting sauce.

To determine the physicochemical composition of the samples, experimental analyses were conducted to quantify organic acids, carbohydrates, total phenolics, flavonoids, anthocyanins, chlorogenic acid, vitamin E, and mineral compounds, along with an assessment of antioxidant activity.

## II. Materials and Methods

**Research Object**

This study focused on the fruit of wild-growing blueberry species (*Vaccinium myrtillus L.* and *Vaccinium arctostaphylos L.*) from the high-mountainous region of Adjara. Additionally, the study examined the homogenized blueberry sauce derived from whole berries, including crushed seeds. The investigation aimed to evaluate the physicochemical properties and bioactive compound composition of both the raw fruit and the processed sauce. This methodology not only ensures full utilization of biological material but also significantly reduces environmental impact from agro-industrial waste. Such approaches contribute to risk mitigation in food system sustainability and support broader ecological goals.

**Research Methods**

To ensure accuracy and reliability, high-purity reagents required for the study were sourced from Sigma-Aldrich (Merck, Germany). A range of physicochemical analytical methods was employed to assess various parameters. The determination of dry matter content, active acidity (pH), and titratable acidity was conducted according to the AOAC Official Method. Carbohydrate quantification was performed using high-performance liquid chromatography (HPLC) to ensure precise measurement of sugar composition.

Phytochemical analysis was carried out using spectrophotometric methods (Shimadzu, Japan) to quantify bioactive compounds, while thin-layer chromatography (TLC) was utilized for qualitative compound identification. Additionally, elemental composition analysis was performed using an inductively coupled plasma atomic emission spectrometer (ICPE-9820, Shimadzu Corporation) to determine the mineral content in the samples.

**Method for Determining Total Carbohydrate Content**

The total carbohydrate content was analyzed using high-performance liquid chromatography (HPLC). The analysis was conducted on a Waters HPLC system equipped with a refractive index (RI) detector and a Binary HPLC Pump 1525. Chromatographic separation was performed using an Amide 120 column (250 mm × 4.5 mm), specifically designed for carbohydrate analysis. The column temperature was maintained at 40°C, and 80% acetonitrile (Merck; Sigma-Aldrich) was used as the mobile phase. Detection was carried out using an RI detector, ensuring accurate quantification of carbohydrate content.

Sample Preparation: to precipitate pectin, the juice was mixed with 96% ethanol in a 1:1 ratio. After centrifugation, the supernatant was combined with the mobile phase (80% acetonitrile) in a 1:1 ratio. Before injection into the HPLC system, the sample was filtered through a 0.45 μm membrane filter to remove particulates and enhance analytical precision.

**Method for Determining Total Phenolic Content**

The total phenolic content was analyzed using a Shimadzu spectrophotometer (Shimadzu, Japan). The method was based on the interaction of phenolic compounds with protein substances, leading to their precipitation as metal salts. This reaction was followed by oxidation, resulting in the formation of a colored complex. The analysis was conducted following the protocol described by Cheng et al. [18]. The quantification of total phenolic compounds was performed using a calibration curve and expressed as mg of gallic acid per 100 g of fruit (mg GA/100 g).

**Method for Determining Total Flavonoid Content**

The total flavonoid content was determined using a spectrophotometric method, as described by Cheng et al. [18], with modifications for plant-derived fruit samples. The quantification was carried out using a calibration curve, and the results were expressed as mg of catechin per 100 g of fruit (mg C/100 g).

**Method for Determining Total Anthocyanin Content**

The total anthocyanin content in fruit extracts was quantified using a spectrophotometric method. The analysis was performed in a buffer solution at pH 1.0 and pH 4.5, following the protocol described by Cheng et al. [18]. The anthocyanin concentration was calculated using the equation provided by Cheng et al. and expressed as mg of cyanidin-3-glucoside per 100 g of fruit (mg CG/100 g).

**Method for Determining Vitamin E Content**

The thin-layer chromatography (TLC) method described by Whitte et al. [19] was utilized to quantify vitamin E content, employing Emmerie-Engel reagent for detection. The concentration of tocopherol was determined as a percentage, calibrated against a standard curve, and converted to $\alpha$-tocopherol equivalents based on sample weight, expressed as mg per 100 g (mg/100 g).

**Method for Determining Chlorogenic Acid Content**

The chlorogenic acid content was quantified using the method outlined by Trineeva et al. [20], employing direct spectrophotometric analysis (Shimadzu, Japan). Chlorogenic acid from the "Fiuka" brand (Germany) served as the standard substance. The concentration of chlorogenic acid was calculated as a percentage by applying the chlorogenic acid coefficient of 507 and using the appropriate formula for dry mass.

**Method for Determining Antiradical Activity (DPPH Method)**

The DPPH method, based on the reaction between the stable synthetic radical DPPH (2,2-diphenyl-1-picrylhydrazyl) and antioxidants dissolved in ethanol, was used to assess antiradical activity [18]. The antioxidant activity was quantified using the EC30 parameter, which represents the extract concentration required to inhibit 30% of the oxidation reaction. A lower EC30 value indicates greater antioxidant activity, as the rate of oxidative degradation inhibition increases.

**Method for Determining Qualitative and Quantitative Mineral Content**

Multi-elemental analysis of the samples was performed using an inductively coupled plasma atomic emission spectrometer (ICPE-9820, Shimadzu Corporation). This method relies on measuring the intensity of light emitted by atoms of various elements, which are excited by an inductively coupled argon plasma at different wavelengths [21]. Qualitative analysis is conducted by determining the specific wavelengths, while quantitative analysis is based on the intensity of the emitted light at those wavelengths. The correlation coefficient was ≥ 0.99.

The experiments were conducted in triplicate, and statistical analysis of the results was performed using Stewart's t-test, with a significance level of $p < 0.05$.

## III. Results and Discussion

Research by Uleberg et al. [22] demonstrates that both low temperatures and genetic factors significantly influence the flavor profile of blueberry fruit. The organoleptic properties of the fruit are determined by factors such as dry matter content, active acidity (pH), and titratable acidity. Blueberry fruit is known to contain several organic acids, including malic, citric, gallic, chlorogenic, ascorbic, and quinic acids. Studies have shown that malic acid is the dominant acid in wild blueberries, while citric acid is the primary acid in cultivated garden varieties.

The results of the physicochemical analysis of wild blueberries (*Vaccinium arctostaphylos* and *Vaccinium myrtillus* L.), as well as homogenized blueberry sauce containing seeds, are presented in Table 1.

The dry matter content in the fruit of the Caucasian blueberry (*Vaccinium arctostaphylos L.*) was found to be low, measuring 9.4 ± 0.18%, while the common blueberry (*Vaccinium myrtillus L.*) fruit contained a higher dry matter content of 10.5 ± 0.12%. The active acidity (pH) of the common blueberry sauce was 3.6 ± 0.06, while the pH of the Caucasian blueberry sauce was slightly higher at 3.9 ± 0.07. The acidity was also higher in the Caucasian blueberry sauce, with a value of 1.09 ± 0.08%, compared to the common blueberry sauce, which showed a lower acidity of 0.93 ± 0.08%.

**Table 1:** *Physicochemical Properties of Vaccinium arctostaphylos L. and Vaccinium myrtillus L. Fruits and Blueberry sauce*

| Sample Name | Dry Matter (%) | Active Acidity, pH | Titratable Acidity (% as Malic Acid) |
|---|---|---|---|
| Friut of Vaccinium Arctostaphylos L | 9,4 ± 0,18 | 4,0 ± 0,08 | 1,20 ± 0,08 |
| Friut of Vaccinium Myrtilus L | 10,5 ± 0,12 | 3,8 ± 0,06 | 1,01 ± 0,08 |
| Sauce of Vaccinium ArctostaphylosL | 11,1 ± 0,10 | 3,9 ± 0,07 | 1,09 ± 0,08 |
| Sauce of Vaccinium Myrtilus L | 11,7 ± 0,12 | 3,6± 0,06 | 0,93 ± 0,08 |

According to studies by Uleberg [22], the free sugars present in blueberry fruit include fructose and glucose, with sucrose detected in trace amounts. Our research findings on sugar content are consistent with those of Uleberg [22]. The results of the study are presented in Table 2.

**Table 2:** *Carbohydrate Content in Vaccinium arctostaphylos L. and Vaccinium myrtillus L. Fruits, Seeds, and Homogenized Sauce*

| Sample Name | Fructose % | Glucose % | Total Sugars % |
|---|---|---|---|
| Fruit of Vaccinium Arctostaphylos L. | 5,3 ± 0,8 | 3,4 ± 0,8 | 8,7 ± 0,8 |
| Friut of Vaccinium Myrtilus L | 5.5 ± 0,6 | 4,1 ± 0,8 | 9,6 ± 0,6 |
| Sauce of Vaccinium ArctostaphylosL | 5,4 ± 0.8 | 4.0 ± 0,8 | 9.4 ± 0,6 |
| Sauce of Vaccinium Myrtilus | 5,4 ± 0,6 | 4,5 ± 0,8 | 9,9 ± 0,6 |

The analysis of carbohydrate content revealed that neither blueberry fruit nor sauce contains sucrose. The fructose content in both the fruit and sauce ranged from 5.3% to 5.5%, contributing to the pleasant taste of the sauce.

**Phenolic compounds** are among the most prevalent chemical constituents in plants. Medical research has demonstrated their high biological activity and significant prophylactic effects against various diseases [23]. Consequently, determining the quantitative levels of phenolic compounds is essential for evaluating the antioxidant activity of the studied samples, as numerous studies have established a direct correlation between these two parameters. The total phenolic content of the samples analyzed in this study is presented in Table 3. High concentrations of phenolic compounds were observed in the Vaccinium myrtillus fruit and sauce, with 1677 mg GC/100 g in the fruit and 2585 mg GC/100 g in the sauce. In contrast, lower levels were found in the Vaccinium arctostaphylos fruit (1554 mg GC/100 g) and sauce (2477 mg GC/100 g).

**Flavonoids** are bioactive compounds known for their high biological activity, with several being successfully utilized in pharmacology to treat cardiovascular diseases [23]. The quantitative concentration of flavonoids plays a crucial role in determining the antioxidant activity of a sample. In wild-growing blueberries, flavonoid content is 2-3 times higher compared to cultivated varieties. The results of the flavonoid content analysis for the samples studied are presented in Table 3. Lower concentrations of flavonoids were found in the Caucasian blueberry fruit and sauce, with 522 ± 10.3 mg catechin/100 g in the fruit and 940.7 ± 14.3 mg K/100 g in the sauce. In contrast, the common blueberry fruit and sauce contained 757 ± 10.3 mg catechin/100 g and 1190 ± 14.3 mg K/100 g, respectively.

**Table 3:** *Content of Biologically Active Compounds in the Fruit and Sauce of Caucasian (Vaccinium arctostaphylos) and Common (Vaccinium myrtillus) Bilberries*

| Chemical components | Fruit of Vaccinium Arctostaphylos | Fruit of Vaccinium Murtilus | Sauce of Vaccinium Arctostaphylos | Sauce of Vaccinium Murtilus |
|---|---|---|---|---|
| Phenolic Compounds (mg%) | 1554 ± 14,3 | 1677 ± 10,3 | 2477 ± 14,3 | 2585 ± 14,3 |
| Flavonoids (mg%) | 522 ± 10,3 | 757 ± 10,3 | 940,7 ± 14,3 | 1190 ± 14,3 |
| Anthocyanins (mg%) | 280 ± 12,3 | 540 ± 15,3 | 500,7 ± 10,3 | 1041 ± 14,3 |
| Vitamin E (mg%) | - | - | 0,58 ± 14,3 | 0,60 ± 14,3 |
| Chlorogenic Acid (%) | 1,5 ± 12,3 | 1,7 ± 13,3 | 5,8 ± 14,3 | 6,8 ± 14,3 |
| Antioxidant Activity (mg/mL) | 1,1 ± 0,03 | 1,3 ± 0,03 | 2,0 ± 0, 03 | 2,3 ± 14,3 |

**Anthocyanins** are a class of polyphenolic compounds that are exclusively synthesized in plants. The concentration of anthocyanins is a key factor in determining their antioxidant properties. These compounds are highly sensitive to factors such as temperature and light. Blueberries are notably rich in anthocyanins [24]. The results of the analysis of anthocyanin content in the samples are presented in Table 3. High anthocyanin concentrations were found in both the common blueberry fruit and sauce, with 757 ± 10.3 mg cyanidin-3-glucoside/100 g in the fruit and 1190 ± 14.3 mg CG/100 g in the sauce.

**Free radicals** in the body can lead to the degradation or mutation of living cells [23]. Antioxidants are capable of neutralizing free radicals. The DPPH method, which measures the interaction between free radicals and 2,2-diphenyl-1-picrylhydrazyl, is commonly employed to evaluate antioxidant activity. The results of the DPPH-based antiradical activity analysis for the samples are presented in Table 3. According to these findings, the blueberry sauce demonstrated antioxidant activity that was twice as high as that of the corresponding fruits. The fruits exhibited values of 1.1 ± 0.03 mg/mL and 1.3 ± 0.03 mg/mL, while the sauce showed values of 2.0 ± 0.03 mg/mL and 2.3 ± 14.3 mg/mL.

**Chlorogenic acid,** an ester of caffeic acid and quinic acid, is a key polyphenol in blueberry fruit. It is renowned for its potent antioxidant, antiviral, antibacterial, antifungal, anti-inflammatory, and antidiabetic properties. Additionally, it demonstrates hypoglycemic, hypocholesterolemic, hepatoprotective, and anticancer effects. The results of the study on the quantitative content of chlorogenic acid in blueberry fruit samples are presented in Table 3. The findings indicate that relatively lower concentrations of chlorogenic acid were detected in the Caucasian blueberry fruit and sauce (1.5 ± 12.3% and 5.8 ± 14.3%, respectively), while higher concentrations were observed in the common blueberry fruit and sauce (1.7 ± 13.3% and 6.8%, respectively).

**Vitamin E** is a powerful natural antioxidant that plays a crucial role in maintaining normal blood coagulation and promoting wound healing, thereby reducing the risk of scar formation. It also supports nutrient absorption, enhances metabolic functions, and strengthens capillary walls. Blueberry sauce contains $\alpha$-tocopherol, the most bioactive and valuable form of Vitamin E.

A study examining the $\alpha$-tocopherol content [16] in both blueberries and blueberry sauce demonstrated that the fruit contains $\alpha$-tocopherol in trace amounts. The sauce derived from Caucasian blueberries has a concentration of 0.58 ± 14.3 mg%, while the sauce from common blueberries contains 0.60 ± 14.3 mg%.

Sauce It is important to note that, when consumed, the skin and seeds of blueberries are typically not processed. However, homogenized blueberry sauce, which includes both the seeds and the skin, is further enriched with the biologically active compounds mentioned above, including Vitamin E, which is present in the fatty oils of the seeds.

**Mineral Elements:** The objective of this study was to analyze the chemical element content in the fruit of wild blueberries and homogenized blueberry sauce with seeds from the high-mountainous region of Adjara. The qualitative and quantitative analysis of mineral elements was conducted using an inductively coupled plasma atomic emission spectrometer (ICPE-9820). A total of 28 elements were analyzed, including 7 macronutrients (Ca, K, P, Mg, Na, Si, Fe) and 21 microelements and ultramicroelements (Al, Zn, Mn, B, Cu, Ba, Se, Cr, Ni, Mo, Co, V, Cd, Pb, Be, Li, Ti, As, Hg, Sb, Tl). The mineral content of the blueberry fruit and sauce is presented in Table 4.

**Table 4:** *Mineral Element Content (mg/L on a dry weight basis)*

| № | Element Name | Fruits of Vaccinium Arctostaphylos | Fruits of Vaccinium Murtilus | Sauce of Vaccinium Arctostaphylos | Sauce of Vaccinium Murtilus |
|---|---|---|---|---|---|
| | | **Macroelements (mg/L)** | | | |
| 1 | Calcium (Ca) | 790 | 911 | 2209 | 2948 |
| 2 | Potassium (K) | 1232 | 1510 | 2528 | 3001 |
| 3 | Phosphorus (P) | 940 | 1132 | 1500 | 2395 |
| 4 | Magnesium (Mg) | 160 | 201 | 20 | 280 |
| 5 | Sodium (Na) | 50 | 65 | 80,6 | 73,6 |
| 6 | Silicon (Si) | 62 | 53,9 | 75,9 | 89,7 |
| 7 | Iron (Fe) | 11,8 | 18,2 | 28,9 | 35,2 |
| | | **Microelements (mg/L)** | | | |
| 8 | Aluminum (Al) | 21,6 | 25 | 28,7 | 26,2 |
| 9 | Zinc (Zn) | 13,6 | 16,1 | 20,6 | 20,8 |
| 10 | Copper (Cu) | 5,7 | 8,7 | 12,7 | 9,8 |
| 11 | Manganese (Mn) | 9,2 | 18,6 | 30,5 | 27,9 |
| 12 | Molybdenum (Mo) | 0,004 | 3,7 | 10,8 | 7,7 |
| 13 | Boron (B) | 12,5 | 10,6 | 25,4 | 22,6 |
| 14 | Cadmium (Cd) | <0,00049 | < 0,004 | < 0,001 | |
| | | **Ultramicro Elements (µg/L)** | | | |
| 15 | Beryllium (Be) | <0,0001 | <0,0004 | <0,0053 | <0,001 |
| 16 | Lithium (Li) | BDL | BDL | BDL | BDL |
| 17 | Lead (Pb) | 0,0007 | 0,0021 | <0,001 | <0,0008 |
| 18 | Titanium (Ti) | <0,012 | <0,075 | <0,01 | <0,01 |
| 19 | Vanadium (V) | 0,008 | 0,006 | 0,004 | 0,002 |
| 20 | Barium (Ba) | 0,06 | 0,06 | 0,4 | 0,4 |
| 21 | Arsenic (As) | BDL | <0,003 | <0,080 | <0,003 |
| 22 | Chromium (Cr) | 2,6 | 1,79 | 1,8 | 2,1 |
| 23 | Nickel (Ni) | 0,15 | 0,37 | 0,07 | 0,04 |
| 24 | Selenium (Se) | 0,8 | 1,71 | 7,2 | 8,5 |
| 25 | Cobalt (Co) | 1,116 | 1,0453 | 0,31 | 0,7 |
| 26 | Mercury (Hg) | BDL | BDL | BDL | BDL |
| 27 | Antimony (Sb) | <0,0014 | <0,0011 | <0,0034 | <0,002 |
| 28 | Thallium (Tl) | BDL | BDL | BDL | BDL |

**BDL** – Below the detection limit

The research has demonstrated that both blueberry fruit and sauce contain essential elements for nutrition, making these findings valuable for assessing the ecological status of the region.

Among the macronutrients, the samples analyzed are particularly rich in K, P, and Ca. Additionally, significant amounts of Mg and Si were detected. The concentrations of Na, Fe, Zn, Cu, Mn, Mo, B, V, and Ba are following food safety standards. Levels of toxic elements, such as Pb, Ti, As, Cd, Be, Li, V, Ba, Ni, Sb, and Tl, were found to be below detection limits. The study supports an environmentally responsible processing strategy that limits waste output and maximizes resource use. Such non-waste approaches can play a role in reducing the environmental footprint of food production chains, contributing to risk-informed sustainable development in agricultural infrastructure.

It is well-established that there is a correlation between mineral elements and biologically active compounds. The presence of Cr, Cu, and Mo promotes the accumulation of flavonoids in plant materials and enhances the P-vitamin activity and anti-inflammatory properties of blueberry fruit. The elements Mo, Zn, B, Cu, and Si facilitate the accumulation of polyphenolic compounds, thereby contributing to the raw material's choleretic, diuretic, antidiarrheal, and anti-inflammatory effects. Furthermore, Mg, P, Mn, Ca, and Ni help regulate blood sugar levels and may support the treatment of mild forms of diabetes. Fe, Mn, Cu, and Co are components of the blood-forming complex, and their concentrations are crucial for the medicinal properties of blueberry fruit.

## IV. Conclusion

The study reinforces the need for risk-oriented design in food production processes, particularly by reducing organic waste through whole-fruit utilization. This aligns with sustainability paradigms aimed at preserving ecological balance and reducing environmental hazards associated with fruit processing. The research has shown that homogenized blueberry sauce, including seeds, contains significantly higher levels of phytonutrients than the whole fruit, particularly in terms of biologically active compounds. This is primarily due to the elevated concentrations of polyphenols, anthocyanins, and flavonoids. The multifunctional properties of blueberry sauce make it a valuable bioactive food supplement, not only for promoting health and preventing diseases but also for potential applications in the pharmaceutical industry.

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**CONFLICT OF INTEREST**.
The authors declare that they have no conflict of interest.

## References

[1] Nagulsamy P., Ponnusamy R., Thangaraj P. Evaluation of antioxi dant, anti-inflammatory, and antiulcer properties of Vaccinium leschenaultii Wight: A therapeutic supplement. // J Food Drug Anal 2015; 23: 376-86.

[2] Khintibidze L. Georgian Soviet Encyclopedia, vol. 7, Tbilisi, 1984.

[3] Lasekan O. Exotic berries as a functional food. Curr. Opin. Clin.nutr. Metab. Carte. v.17. № 6. p. 589 – 595. 2014. doi: 10.1097/MCO.0000000000000109.

[4] Paedres-Lopez O. Berries improving human health and healthy aging, and promoting quality life. // Plant Foods Hum. Nutr. v. 65. № 3. p. 299-308. 2010.

[5] Jung S. Fruit and vegetable intake and risk of breast cancer by hormone receptor status. v. 105. p. 219-236. 2013.

[6] Manganaris G.A. Berry antioxidants: small fruits providing large benefits. // J. sci Food agric. v. 94, №40, 2014.

[7] Rasmussen S.E. Dietary proantocyanidins: occurrence, dietary intake, bioavailability, and protection against cardiovascular disease. // Mol. nutr. Res., v. 49. p. 159 – 174. 2005.

[8] Mikulic-Petkovsek M. Composition of sugars, organic acids, and total phenolics in 25 wild or cultivated berry species. // J. Food sci. v. 77, № 10, p.1064-1070, 2012. doi/10.1111/j.1750-3841.2012.02896.

[9] Seeram N.P. Berry fruits: compositional elements, biochemical activities, and the impact of their intake on human health, performance, and disease. // J. Agric Food Chem. v.56, №3, p.627-629. 2008. doi: 10.1021/jf071988k

[10] Nile S.H., Park S.W. Edible berries: bioactive components and their effect on human health. // Nutrition. v. 30, № 2, p.134-144, 2014. doi: 10.1016/j.nut.2013.04.007

[11] Slatnar A. The effect of bioactive compounds on in vitro and in vivo antioxidant activity of different berry juices. // PLos One v. 7, №10. 2012. doi 10.1371

[12] Wu X. Concentrations of anthocyanins in common foods in the United States and estimation of normal consumption. // J. agric Food Chem. v.54, p.4069 – 4075, 2006.

[13] Diaconeasa Z. Antiproliferative and antioxidant properties of antocyanidin rich extract from, blueberry and blackcurrant juice. // Int. J. Mol. sci. v.16, p.2352 – 2365. 2015 doi: 10.3390/ijms16022352

[14] Gordillo G. Oral administration of blue berry inhibits angiogenic timor growth and enhances survival of mice with endothelial cell neoplasm. antioxid. // Redox signal. v.11, p. 47–58, 2009.

[15] Moze S. Phenolics in slovenian bilberries (Vaccinum myrtillus L.) and blueberries (Vaccinum corymbosum L.). // J. Agric Food Chem. v.59, №13, p. 6998 – 7004. 2011, doi: 10.1021/jf200765n.

[16] Kalt, W., Cassidy, A., Howard, L.R., Krikorian, R., Stull, A.J., Tremblay, F., Zamora-Ros, R. Recent research on the health benefits of blueberries and their anthocyanins. Adv. Nutr. 2020.

[17] Casedas, G., Les, F., Gomez-Serranillos, M.P., Smith, C., López, V. Anthocyanin profile, antioxidant activity, and enzyme inhibitory properties of blueberry and cranberry juices: a comparative study. // Food Funct. 8, 4187–4193, 2017.

[18] Cheng, A., Chen, X., Wang, W., Gong, Z. et al. 2013. Contents of extractable and non-extractable polyphenols in the leaves of blueberry. // Czech Journal of Food Sciences, 31(3), pp. 275–282. DOI: https://doi.org/10.17221/272/2012-cjfs

[19] Whittle K. J. and Pennock J. F. The examination of tocopherols by two-dimensional thin-layer chromatography and subsequent colorimetric determination. https://pubs.rsc.org/en/content/articlelanding/1967/an/an9679200423/unauth 1967

[20] Trineeva, O. V., Slivkin, A. I., Safonova, E. F. Determination of hydroxycinnamic acids, carotenoids and chlorophyll in stinging nettle leaves (URTICA DIOICA L.). // Chemistry of plant materials. No. 3. p.105-110. 2015DOI: 10.14258/jcprm.201503522, http://journal.asu.ru/cw/article/view/522/672

[21] Papunidze S., Seidishvili N., Mikeladze Z., Chkhartishvili I., Papunidze G., Kutaladze N. Content of Mineral Elements in Wild-Growing Blueberry Leaf Teas. // Bulletin of the Georgian National Academy of Sciences, 17(4), 2023, 118-123, http://science.org.ge/bnas/vol-17-4.html.

[22] Uleberg E., Rohloff J., Jaakola L., et al. Effects of temperature and photoperiod on yield and chemical composition of northern and southern clones of bilberry (Vaccinium myrtillus L.). // J Agric Food Chem 60: 10406-14. 2012.

[23] Li, A.-N., Li, S., Zhang, Y.-J., Xu, X.-R. et al. 2014. Resources and biological activities of natural polyphenols. // Nutrients, 6(12), pp. 6020-6047. DOI: https://doi.org/10.3390/nu6126020 .

[24] Chang, S. K., Alasalvar, C., Shahidi, F. 2019. Superfruits: Phytochemicals, antioxidant efficacies, and health effects – A comprehensive review. // Critical Reviews in Food Science and Nutrition, 59(10), pp. 1580–1604. DOI: https://doi.org/10.1080/10408398.2017.1422111.