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# Blueberry-Derived Anthocyanin's as Natural Colorants and Bioactive Agents: A Compressive Review

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Futuristic Publications



**Abstract** Natural colorants derived from plant sources have gained substantial attention as a result of rising consumer demand for safe, health-promoting, and environmentally sustainable alternatives to synthetic food dyes. Blueberries and bilberries (Vaccinium spp.) are abundant anthocyanin sources, a class of water-soluble polyphenolic pigments responsible for their characteristic blue-to-purple coloration. This review comprehensively summarizes the botanical classification, cultivation history, production systems, and physicochemical characteristics of blueberries, with a focus on anthocyanin composition, stability, and analytical profiling. Factors influencing color expression, including cultivar variation, pH, metal complexation, and processing conditions, are discussed. The extraction, identification, and characterization of blueberry anthocyanin's using spectrophotometric, chromatographic, and mass spectrometric techniques are evaluated critically. Furthermore, the technological applicability of blueberry-derived pigments as natural food colorants and functional ingredients is examined. Beyond their coloring properties, blueberry anthocyanin's exhibit strong antioxidant, anti-inflammatory, antimicrobial, cardio protective, neuroprotective, antidiabetic, anti-obesity, and anticancer activities, contributing to their expanding function in foods and dietary supplements. Evidence Studies carried out in vivo, on humans, and in vitro demonstrate the possible health advantages of regular blueberries. Consumption. Overall, blueberries represent a promising natural source of colorants with added therapeutic value, supporting their application in food, pharmaceutical, and nutraceutical industries.

**Keywords**: Vaccinium, bilberry, acetylation, antioxidant, cluster analysis, anthocyanin, pyruvic acid, liposome, portisin, anticancer, neuro-protection, functional food.

## INTRODUCTION

Botanical Classification Blueberries belong to the genus *Vaccinium* in the heath family *Ericaceae.* Several sections are agriculturally important, including *Cyan coccus* (true blueberries), *Ox coccus* (cranberries), and Myrtillus (bilberries and whortleberries). Wild representatives of *Ox coccus* and *Myrtillus* are found in both Europe and North America, while *Cyan coccus* is solely North American. [1]Cultivated species North American Cultivated Species in North America, four taxa of *Cyan coccus* are grown: Highbush, or *Vaccinium corymb sum L. Myrtilloides V. Michx. V. angustifolium* Ait (lowbush) *V. Ashei Reade* (rabbit eye) Mixed stands of *V.angustifolium* and *V. myrtilloides* make up the majority of lowbush fields.(2) Soil and Habitat Requirements All blueberry species thrive in soils that contain a lot of organic matter and develop on acidic soils (pH 3.5–5.5). But in lowbush blueberry production, fire trimming has significantly reduced organic matter.)In deep loamy-sand or sandy-loam shallow water table soils (30 to 50 cm), highbush and rabbit eye blueberries are typically grown. Highbush blueberries are typically found on shallow, hardpan soils in North Carolina and New Jersey, while rabbit eye blueberries can be found on extremely dry locations.(3)

The most obvious difference is physical characteristics between these varieties of blueberries is their stature, however their physiologies also vary. Lowbush plants often attain heights of 0.30 to 0.60 meters in the wild. The height of highbush the range of blueberries is 1.8 to 4.0 meters. Rabbit eye blueberries have a maximum height of six meters. Cultivated highbush blueberries are maintained between 1.8 and 2.5 m by pruning, and cultivated rabbit eye below 3 m. (4)

**History of Cultivation Introduction**

| Aspect | Details |
|---|---|
| Historical Evidence | *Vaccinium spp*. fruit has been collected from the wild for as long as blueberries and animals have coexisted. |
| Cultivation Method | Aboriginal North Americans burned heaths to increase production. |
| First Type Cultivated | Lowbush plants were probably the first blueberries to be grown. |

**Highbush Blueberry Culture**

**Fig 1:** Highbush Blueberry Culture

**History and Regional Differences in Blueberry Cultivation**

| Person 1 | Person 2 | Event | Year | Location | Region |
|---|---|---|---|---|---|
| F.V. Coville | Elizabeth C. White | Establish highbush blueberry cultivation | Early 1900s | The Jersey | Eastern, Midwestern, Mid-Atlantic, Northern states |

**Rabbit eye Blueberries**

Compared to highbush types, rabbit eye blueberries have been grown for a longer period of time. When M.A. Sapp moved native seedlings to his property in Crestview, Florida, in 1893, rabbit eye blueberries were first grown commercially. In the states of the South, these enhanced cultivars are now commonly planted. (7)

**Production Statistics (North America)**

The majority of the U.S. blueberry crop is made in nine states: Florida, Georgia, North Carolina, Oregon, Arkansas, Maine, Michigan, New Jersey, and Washington. Substantial blueberry production is also present in the British provinces of Canada Nova Scotia, New Brunswick, and Quebec. The average production in North America was 81,400 Many per year over the period 1983-1987. Michigan's production averaged 21,000 tons annually, with Maine coming in second with 15,300 tons and 12,800 tons from New Jersey. (8)

**Table 1:** North America's Estimated Blueberry Area

| Location | Area (ha) |
|---|---|
| Mid-Atlantic | |
| New Jersey | 3700 |
| North Carolina | 1600 |

| | |
|---|---|
| Central | |
| Arkansas | 400 |
| Others | 400 |
| Northeast | |
| Maine | 20000 |
| Maritime Provinces | 20000 |
| Others | 2000 |
| Midwest | |
| Michigan | 7500 |
| Others | 500 |
| Northwest | |
| Oregon | 400 |
| Washington | 400 |
| British Columbia | 2000 |
| Southeast | |
| Georgia | 1600 |
| Florida | 800 |
| Others | 400 |

**Comprehensive Crop**

North American Blueberry Production Trends, 1992–2003, & Growth Projections the lowbush blueberry (Vaccinium angustifolium) region A rose 33% and highbush 24%. Between From 1992 to 2003, the area planted to highbush, which comprises rabbit eye (*V. ashei*) and northern (*V.corymbosum*) and southern highbush (*Vaccinium sp*.) blueberries, 15% more from 48,790 acres (19,745 ha) to 55,898 acres (22,622 ha).[9]

**Fig 2:** All-Inclusive Crop

**Production Regions**

Although blueberries are likely cultivated to some extent (e.g., home gardens or small test evaluation trials) in most regions of North America, commercial cultivation was not present or was considered very minor in 2003 in Alberta, Manitoba, Northwest Territories, Nunavut, Saskatchewan, the Yukon, Alaska, Arizona, Colorado, Hawaii, Montane, Nebraska, New Mexico, North Dakota, Rhode Island, South Dakota, Utah, and Wyoming. Because highbush and lowbush blueberries have quite different production systems, each of which is enclosed in turn in the following sections for ease of presenting. [10]

**Cultivars**

HIGH BUSH. Between 1992 and 2003, the area planted to northern highbush and rabbit eye blueberries in North America grew by 15% and 9%, respectively. [11]

**Production Systems**

In addition, changes such as higher density plantings, particularly in pine bark beds in southern highbush (Florida, Georgia), raised beds with irrigation in rabbit eyes (Georgia*)*, machine pruning postharvest in southern highbush (Georgia, Carolina, North), annual pruning of rabbit eyes (Mississippi), more machine harvest (Mississippi), and better post-harvest fruit handling to improve fruit quality (Florida, North Carolina, Georgia, and Mississippi). [12]

**Issues with the Production Culture**

The difficulties of culture connected to the manufacturing of highbush blueberries in North America in (2003) included: spring frost injury (Mississippi, Georgia and Florida),winter cold damage (Minnesota, Quebec), issues with the soil, including drainage or unfavorable pH (Arkansas, California, Georgia, Minnesota, North Carolina, New York, Mexico), pollination concerns (Georgia), significant rain at harvest, declining quality of fruit (Georgia), challenging irrigation management (North Carolina, Oregon), short plant life (Florida), inadequate planting setup (Mexico), aging fi elds of low yielding 'Jersey' (Michigan), maintaining adequate, fresh fruit quality in machine-harvested fruit (Michigan), erratic yields due to moist springs in blossom (Washington),and ignorance about fertility needs other than nitrogen (Oregon).[13]

**Difficulties**

Although many of these diseases were discovered in all production regions, of particular importance is blueberry scorch virus, a relatively new virus to the western half of Canada. Blueberry scorch is an aphid-transmitted virus that was originally found in New Jersey in the late 1970s. The East Coast strain, formerly known as the Sheep Pen Hill strain, exhibits symptoms on all cultivars except 'Jersey'. This virus is spreading in British Columbia and may have implications on production potential in the near future. [14]

***Insects***

Elevated bush importance of insect pests in highbush blueberry production varies tremendously by region lowbush. Blueberry maggot Most of important insect problem in lowbush blueberry production. The other problems mentioned were weeds and birds (in highbush and lowbush fi elds) and deer (New Jersey, British Columbia, Quebec) and voles Microtus creatures or other rodent pests, mostly Among the Highbush fields Arkansas, California, Oregon, and British Columbia.[15]

**The Blueberry Industry in North America**

North American culture's use of blueberries is quite new. Since native North Americans are believed to have burned wild stands to increase production and European settlers started tending wild stands in the lowbush species *Vaccinium angustifolium Ait. V* as well. *myrtilloides Michx*. are believed to have been the first blueberries to be managed. These days, in North America, blueberries represent a significant fruit crop. I carried out a survey in 1992 to describe the quickly evolving nature of the blueberry sector in North America as well as to record its current state. [16]

**Production Characteristics**

| Type | Location | Hectares |
|---|---|---|
| Highbush | Michigan | 6890 |
| Highbush | New Jersey | 3320 |
| Highbush | North Carolina | 1375 |
| Highbush | Oregon | 670 |
| Highbush | Arkansas | 520 |
| Highbush | Washington | 490 |
| Highbush | New York | 490 |
| Lowbush | Maine | 24300 |
| Lowbush | Quebec | 12230 |
| Lowbush | Nova Scotia | 11410 |
| Lowbush | New Brunswick | 3240 |
| Lowbush | Newfoundland | N/A |
| Lowbush | New Hampshire | N/A |
| Lowbush | Massachusetts | N/A |
| Southern Highbush | Florida | N/A |

**"Projections Of Production Area During The Year 2000 Indicate Continued Growth Of The Blueberry Industry."**

North America's blueberry planting area has grown by 19% during the last ten years, from 62,260 to 74,380 hectares. The percentage increase was greater in wild species (14%) than in cultivated types (47%). It is projected that the overall area of all kinds will expand by 14% to 84,490 hectares, with cultivated types increasing by 28% and wild lowbush by 8%. Southern highbush will see the most percentage growth (372%), although its planted will continue to be the smallest of all the types. States with highbush cultivars typically have lower per-hectare yields than those with rabbit eye cultivars. Highbush yields averaged 5.7 that–1, rabbit eye 7.2 that–1, and lowbush 1.9 that–1 across all locations. [18]

**Market Outlet**

Pick-your-own (PYO and local marketplaces are usually utilized by states with limited blueberry plantings, whereas states with substantial production ship or process fresh fruit. In North America, only 4% of fruit is PYO, 15% is sold fresh, and 81% is processed. The grown blueberries are split nearly evenly between processed (43%) and fresh (45%), with 12% being sold PYO. [19]

**Method of Harvest**

Interestingly, the percentages of produced and wild blueberries are similar. The percentage of cultivated land that is harvested by machines is closely related to the size of each state's industry. Almost all respondents in the states with greater output levels predicted an increase in machine harvesting when questioned about whether they anticipated a change in harvesting procedures in the future. [20]

**Highbush Blueberry Cultivars' Color and Composition**

Highbush blueberry color is a crucial quality feature that affects fresh-market value and the berries' suitability for processing, is a very complicated characteristic influenced by the amount and composition of surface anthocyanin (7, 19).wax (2), pH, and perhaps the distribution of individual anthocyanins (6) and the creation of anthocyanin metal complexes. Our particular goal was to evaluate the relative significance of the elements listed above determine the color of blueberries above. Food colorants serve a key function in food production, hiding disagreeable attributes or boosting the food products' natural characteristics.[21] Natural food colorants are gradually becoming more popular due to changing consumer lifestyles and growing concerns about potential negative health repercussions and damage done to the environment by synthetic colorants, even though the food ingredient industry is more committed to developing synthetic colorants because of their stability, attractive color, and low cost.[22

**Fig 3:** Highbush Blueberry Cultivars' Color and composition

**Supplies and Procedures**

Blueberry cultivar colorimetry and sampling. Eleven highbush blueberry varieties, including "Berkeley," "Bluetta," "Blue crop," "Blue ray," "Burlington," "Collins," "Colville," "Earl blue," "Elliott," "Jersey," and "Weymouth," were sampled from the flora at the USDA, Rutgers University Blueberry and Cranberry Research Center in Chatsworth, New Jersey. Twice in 1982 (one to two weeks apart), once in 1983, and once in 1981, samples were gathered for analysis. In addition to mature berries, small samples of berries without a waxy bloom that ranged in color from dark blue to green or black were taken out for microscopic examination. [23] Blueberry composition and spectrophotometry. About log of berries were homogenized at a high speed for two minutes in a semimicro stainless steel blending container with a 250 ml capacity on a Waring base. Using a wooden plunger to push the blueberries against the blender blades makes the blending process easier. [24]

**Natural Food Colorants' Technological Characteristics in Food Systems**

Many food colorants have been extracted from different sources for application in food systems. [25]

**Fig 4:** Natural Food Colorants in Blueberry

**Blueberry Species' Anthocyanin Concentration and Profile**

Blueberry species' anthocyanin concentration and profile. 79: 617–623. Can. J. Comparison of Plant Science of the anthocyanins in the ripe fruit of four Vaccinium species and the genotypes within these species showed notable differences both within and between these commercial and non-commercial blueberries. The highest total content of anthocyanins is found in the bilberry (*V. myrtillus L.)*.[26] Three economically important blueberry species in North America are Lowbush blueberry (*V. angustifolium Aiton*), highbush blueberry (*V. corymb sum L.), and rabbit eye (V. ashei Reade*). [27] The basis of Europe's indigenous commercial blueberry business is the bilberry, also known as *V. myrtillus L.,* the

European blueberry. Commercial lowbush blueberries, a very diverse group Velvet leaf blueberries are less common in wild genotypes of *V. angustifolium*.(28) Anthocyanins are antioxidants, according to Wang et al. (1997), and dietary antioxidants may help reduce the risk of several degenerative diseases in humans. This study examined the range of anthocyanins present in Vaccinium species blueberries, both nonprofit and commercial. (29)

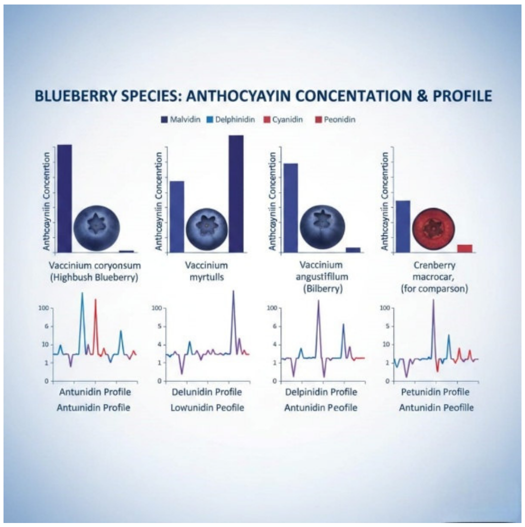


**Fig 5:** Blueberry Species' Anthocyanin Concentration and Profile

### Materials and Techniques

### Samples

Ripe lowbush samples blueberry fruit obtained from three distinct there were at least 20 clones in different parts of Nova Scotia. Blue crop, Colville, and Jersey highbush blueberries were harvested from three distinct plants at Blueberry Acres in Sheffield Mills, Nova Scotia. Three velvet leaf blueberry clones were collected from the wild, and three subsamples were utilized for analysis. Fruit was kept at -70°C until it was examined. (30)

### Preparing Samples

Creating Samples Frozen fruits were shredded in a food processor without being thawed. Ten grams or so of the mixture were homogenized for six minutes using 10 mL of MeOH/formic acid/water extraction solvent (70/2/28, M/F/W) and 2.5 g of Celite filter aid were added to a Vertis Homogenizer (Gardiner, NY). Before being added to the HPLC, the homogenate was crushed and coarsely filtered for 60 minutes using a 0.45-µM Duropore filter (Millipore, Canada).(31)

### HPLC Examination

An Beckman System Gold HPLC (Palo Alto, California) with a Model 126 binary pump system and a Model 167 Scanning UV Detector was used to separate a 50-µL filtrate injection on an SB-C18 column (5 µm, 250 mm × 4.6 mm; 4 × 10 Zorbax, mm guard column, Hewlett-Packard Canada, Mississauga, ON).Gestate was used to evaluate spectrophotometric and HPLC data. (32)

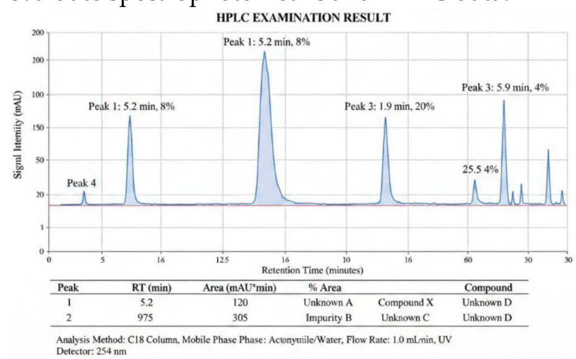


**Fig 8:** Hplc Examination

### Hierarchical Cluster Analysis

For every genotype, sample means of the normalized. Each chromatogram's peak areas were calculated. Every one of the sixteen genotypes had 25 peaks in total. (33)

### Prepared Antioxidant Blueberry (*Vaccinium Myrtillus*) Extracts Characteristics

Blueberries are one of the fruits most well-known for their potential health benefits. Many of the health advantages of blueberries are believed to be caused by two bioactive compounds called proanthocyanidins and anthocyanins. Anthocyanins, one of the most important groups of plant pigments, are rich in blueberries. These natural pigments have been thoroughly researched for technical uses, particularly in the food industry. (34) The stability of anthocyanins (or other derived pigments) in relationship to pH and temperature fluctuations is one of the primary barriers to their application in food matrixes. Many methods have been developed to test the antioxidant activity of plasma as a measure of the antioxidant status in vivo, as well as to evaluate the efficacy of dietary antioxidants in food extracts or as pure molecules. (35)

### Blueberry Extracts' Antioxidant Qualities

Chelation of metal ions or lipid peroxidation (6, 7). Consequently, methods that assess the scavenging of stable radical species via antioxidants include those that use 2,2-diphenyl-1-picrylhydrazyl (DPPH) (8) or N,N-dimethyl-p-phenylenediamine (DMPD).[36] However, because these systems enable the study of the protection of a substrate by an antioxidant within a model biological membrane model like a lipoprotein, the use of LDL or liposomes seems to be a more practical method for assessing antioxidant properties relevant to human nutrition.[38]The latter extract (C), It is highly intriguing for potential applications in the food industry and shows a bluish hue even in acidic environments. The creation of conjugated diene hydroperoxide and oxygen consumption were noted following membrane lipid oxidation was extended. [37]


**Fig 6**: Antioxidant Properties of Blueberry Extracts

## Materials and Methods

### Reagents

Chemicals. Tosoh (Tokyo, Japan) supplied Toy pearl Gel; Sigma-Aldrich (Madrid, Spain) supplied AAPH, DPPH, $FeCl_3$, DMSO, pyruvic acid, quercetin, $AlCl_3$, NaOH, $NaNO_2$, $Na_2CO_3$, Trolox, catching, Hopes, NaCl, and soybean L-R-phosphatidylcholine; Fluke (Madrid, Spain) supplied 2,4,6-tripyridyl-s-triazine (TPTZ); and Reagent Folin-Ciocalteu was provided by Merck (Darmstadt, Germany).[38]

### Extract Preparation

Fifty milliliters of 50% aqueous ethanol (pH 1.5) were used to extract 200 grams of field-picked blueberries (Vaccinium myrtillus) for 30 minutes at room temperature. Following the previously outlined protocol, the blueberry anthocyanin extract (A) was refined using Toyopearl gel column chromatography. [39] And filtered over a 50 µm nylon membrane. Anthocyanin-pyruvic acid adducts (extract B) were created by reacting the real anthocyanin extract with pyruvic acid in water (pH 2.6, 35 °C) for five days at a about 50:1 molar ratio of pyruvic acid to anthocyanin. Toy pearl gel column chromatography was used to purify the resultant extract, and the anthocyanin-pyruvic acid adducts fraction was eluted using 20% (v/v) water/ethanol. [40]

### Conditions for HPLC

All of the extracts were analyzed on a 250 × 4.6 mm I using HPLC (Knavery K-1001).d. reversed-phase C18 column (Merck); detection at 511, 528, and 570 nm was done using a Knauer K-2800 diode array detector. The solvents were (A) $H_2O/HCOOH$ (9:1) and (B) $H_2O/CH_3CN/HCOOH$ (6:3:1). The gradient was 20–85% B at a flow rate of 1.0 mL/min for 70 minutes. [41]

### LC-MS Conditions

A liquid chromatograph (Hewlett-Packard 1100 series) was equipped with a water (Phenomenex, Torrance, CA) reversed phase column (5 µm, 150 × 4.6 mm, C18) thermostatic at 35°C. As previously mentioned, the gradient was made using (A) aqueous 0.1% trifluoroacetic acid and (B) acetonitrile. A photodiode spectrophotometer and mass spectrometry were used for double-online detection. The capillary temperature was 190 °C and the capillary voltage was 3 V. Positive ion mode spectra were captured between m/z 120 and 1500. [42]

### Overall Phenol

A microscale variant of the Folin-Ciocalteu method was used to determine the extracts' total polyphenol content. 50 µl of Folin-Ciocalteu reagent, 10 µl of sample dissolved in methanol, and 790 µl of distilled water were added to an Eppendorf tube. After a minute, 150 µl of aqueous 20% $Na_2CO_3$ was added. The mixture was then combined and left to stand for 120 minutes at room temperature in the dark. [43]

### Flavonoids in Combination

A colorimetric technique with specific modifications was used to determine the extracts' total flavonoid content. Aliquots of suitably diluted methanol solutions were added to an Eppendorf tube that held 75 µl of 5% NaNO2 and 1 mL of distilled water. Five minutes later, 75 µl of a 10% AlCl3 solution was added. 0.5 mL of 1 M NaOH was added to the mixture after it had rested for an additional five minutes. The reaction solution was mixed and then allowed to sit for fifteen minutes. (44)

**Total Pigments**

The anthocyanin-pyruvic acid adduct extract (B) and blueberry extract (A) samples were subjected to HPLC analysis under the previously mentioned conditions. Calibration curves were used to determine the concentrations of anthocyanin and anthocyanin-derived pigment in the extracts. The results were expressed as milligrams per liter of malvidin 3-glucoside, milligrams per liter of malvidin-pyruvic acid adduct, and milligrams per liter of vinylpyranomalvidin-catechin for extracts A, B, and C, respectively. (45)

**An Overview of the Metabolism of Blueberry Anthocyanin's in Promoting Health**

A part from being essential for preventing illness, eating also has a big impact on health and, consequently, disease treatment. Therefore, identifying the dietary components involved in illness prevention is one of the primary goals of genuine science. Polyphenolic substances, like ACNs, have strong antioxidant properties that protect pancreatic b-cells from glucose-induced oxidative stress. (46)

**Chemistry of Blueberries**

Scientists have examined the phenolic chemical profile and composition of BB, especially *Vaccinium angustifolium* (lowbush BB) and *Vaccinium corymb sum* (highbush BB). (47)

**Bio kinetics of anthocyanin's**

It is essential to consider the absorption, metabolism, tissue distribution, excretion, biochemical actions, and interactions with other nutrients of phenolic compounds, especially ACNs, in order to assess their bioavailability and possible health implications. (48)

**Bioavailability and Absorption**

Because concurrent consumption of other substances may affect the absorption of certain nutrients, xenobiotics, and medications, it is crucial to consider the amount of the food source or extract offered when evaluating the absorption of ACNs. (49)

**Biotransformation**

Bacterial breakdown of the glycosidic linkage of ACNs by the gastrointestinal tract may cause the glycosidic forms of ACNs to undergo metabolic changes prior to absorption. (50)

**Metabolic Disorder**

Impaired glucose tolerance, insulin resistance (IR), abdominal obesity, dyslipidemia, and high blood pressure are all components of the metabolic syndrome, which raises the risk of diabetes and cardiovascular disease. By either inhibiting the liver's synthesis of glucose or encouraging its absorption and utilization, insulin helps maintain blood glucose levels within normal ranges. (51)

**Wild Blueberry Fruits' Bioactive Characteristics**

The entire phytochemical richness of wild blueberries has not been fully defined, despite the fact that much is known about the small to medium molecular weight components. One of the most noticeable and prevalent flavonoids in blueberries is anthocyanin's. (52)

**Source Materials**

The challenges of using frozen fruits, liquid extracts, and freeze-dried powdered fruit as starting material were evident during both the extraction processes and the initial bioassays. Despite the fact that the extracts from the majority of sources were active, they formed intractable residues that were challenging to remove from sample containers due to their very hygroscopic and gum-like nature. (53)In this case, these snippets appear to be the result of high concentrations of saccharides and poly-saccharides, especially pectin's. This is being studied in our lab to evaluate additional potential bioactive components that are exclusive to whole blueberry fruit components and may not be found in powders that have been spray-dried. (54)

**Extract Fractionation**

The techniques employed to extract and preserve blueberries may have a significant impact on their phytochemical content and consequent biological activity. Fruits that have been frozen Fruits stored at 20 °C or below appear to have a pretty full supply of the phenolic and flavonoid components sat until they are frozen.(55) Most of the time, once fractions or combination fractions were bio assayed before additional chromatographic separation, only fractions with the desired activity were pursued. Thin-layer chromatography (TLC) and high-performance liquid chromatography (HPLC) analysis of extracts and fractions produced enough information to identify the kind of compound—that is, whether it was an anthocyanin, flavone, phenolic acid, or proanthocyanidin. Not every component has been fully identified and measured yet. (56)

### Antioxidant Activity

Antioxidant activity was measured at 5, 50, and 500 g/mL for The material extracted from blueberry powder using 70% aqueous acetone and fractions from that extract produced by vacuum chromatography.(57)

### Chemoprevention Activity against Cancer Onset

QR activity was clearly and significantly increased by the unrefined 70% acetone extract from wild blueberries. (58) Neither crude extracts nor flavonoid-rich components of wild blueberries were shown to cause QR activity in a previous study. (59)

### Blueberry Supplementation Enhances Neuronal Activation in Mild Cognitive Impairment

### Blueberry Supplementation and Techniques for Neuronal Activation

### Techniques

Using functional magnetic resonance imaging before and after the interference during a working memory task in a randomized, double-blind, placebo-controlled trial, we assessed the effect of blueberry supplementation on the blood oxygen level-dependent (BOLD) signal in older adults with mild cognitive impairment, a risk condition for dementia.(60)

### Participants

Participants 68 years of age and older from the Cincinnati, Ohio, USA, area were recruited via print notices inquiring about age-related memory decline. The age range of the sample was 68 to 92.Diabetes, liver disease, kidney disease, dementia or other neurological diseases, claustrophobia, substance misuse, severe psychiatric issues, and implanted ferromagnetic devices were all excluded. Men and women who satisfied the clinical requirements for MCI were included in our sample. (61)

### Clinical Assessment

An informant, such as a spouse or adult child, conducted a systematic assessment of the participant's cognitive ability as part of the mCDR classification. With an emphasis on memory capacity, the informant provided information on how they functioned in six areas of everyday activity. (62)

### Blueberry Powder and Placebo

The US Highbush Blueberry Council (Folsom, CA, USA) supplied a placebo powder and powder made from entire freeze-dried blueberries (*Vaccinium*). The blueberry fruit powder was created from an equal mixture of the blueberry cultivars *V. ashei Reade* "Tubule" and *V. corymb sum L.* "Rubel". The flavor, color, and sugar content of the placebo powder were all processed to the same extent. Because it was unclear how fiber would affect the participants in the control group's health and neurocognitive abilities, it was left out of the placebo. (63)


**Fig 7:** Neuronal Activation with Blueberry

### Functional Neuroimaging

While participants completed a sequential letter n-back working memory task that was created and delivered Using E-Prime, functional magnetic resonance imaging (fMRI) data were collected. In compliance with the task instructions, the participants indicated "yes" or "no" by pressing one of two buttons. (64)

### Statistical Research

Demographic, clinical, and cognitive data, including behavioral performance during the n-back task, they analyzed using SPSS version 21 (Statistical Package for the Social Sciences, Chicago, IL, USA).For a corrected significance level of $p < 0.01$ for all clusters, cluster thresholds were set at 86 contiguous (faces touching) voxels, and voxel significance thresholds were established at $p < 0.01$.[65]

**Functional Food and Dietary Supplement**

*Les babies courante's comprennent les fraises, myrtles, mûres, farmhouses, canneberges, cassis rouges, cassis noirs, babies de sureau, babies de goji, airless ET lingonberries. L'enrichissement alimentary avec les babies s'est impose comme un domain* crucial for improving nutrition. Unquestionably, the myrtle is the most antioxidant-rich food and is regarded as an exceptional functional ingredient. *La myrtle (Vaccinium sp.)* is un member of la faille *des Ericaceous* (famille *des bruyères, qui comp rend la canneberge, l'azalée et le rhododendron*). [66] The berries are savored right off the plants or cooked into a diversity of scrumptious recipes. The fruits are generally processed into jam, syrup, pie, soup, tart, cobbler, smoothie, pancake, muffin, cupcake, salsa, salad, lemonade, waffles, ready-to eat breakfast cereals, yoghurts and beverages.[67]

**1. Roles in Healthcare**

**1.1. Antioxidant and Anti-Inflammation**

The phenolic content and total antioxidant capacity of blueberries were examined. Using a variety of commercial food-grade carbohydrase AMG and protease *Alcalase, V. corymb sum* was hydrolyzed enzymatically to yield water-soluble chemicals. The anti-inflammatory qualities of blueberry anthocyanins were examined in a mouse model of intestinal illness brought on by trinitrobenzene sulfonic acid (TNBS). Before being put to death, the mice received a daily dose of 40 mg/kg for six days. The mean blood oxygen radical absorbance capacity (ORAC) increased significantly after eating 75 g of blueberries.[68]

**1.2. Diabetes and Obesity Management**

Metformin is a strong anti-diabetic medication but has many adverse effects viz. diarrhea, nausea, gas, chest pain and allergies. Therefore, complication-free drugs are constantly monitored in order to treat diabetes. In diabetic C57b1/6J mice, anthocyanin derived from *V. angustifolium* berries was shown to be able to lessen hyperglycemia symptoms. The elevated blood glucose levels were decreased by 33 and 51%, respectively, by force-feeding with a phenolic-rich extract and an anthocyanin-enriched fraction (500 mg/kg) prepared with an emulsifier. [69]

**1.3. Ophthalmic-Protective**

The potential of blueberries to protect the eyes from the harmful effects of light abuse has been studied. In pigmented rabbits, the impact of Chinese blueberries on light-induced retinal damage was assessed. Feeding the rats whole blueberries at a dose of 1.2–4.9 g/kg daily for four weeks before light exposure significantly decreased the degree of retinal damage, according to an electroretinogram. The capacity of the berry anthocyanins to protect the retinal pigment epithelium from UV or visible light damage and aging was also evaluated. Vascular endothelial growth factor (VEGF) was down-regulated to normalcy, and apoptosis and delayed aging were noted. [70]

**1.4 .Cardio-Protective and Hypotensive**

Eating foods rich in flavonoids has been shown to provide heart-healthy benefits. Thus, a blueberry-fortified diet's potential to lower heart disease was assessed. The cardio-protective properties of a three-month berry-enriched diet were assessed in rats. Because of its high antioxidant content, it offered protection against ischemic damage brought on by reactive oxygen species (ROS).The blueberry's ability to improve the contractile mechanism of the endothelial layer was confirmed by the aorta's significantly greater relaxation in response to acetylcholine.[71]

**1.5. Antimicrobial**

Blueberries have been shown to be effective against a range of food pathogens due to their high phenolic content. At the lowest minimum inhibitory concentration, the flavanol proanthocyanidin had the strongest inhibitory effect on *L. monocytogenes.* [72]

**1.6. Anticancer**

An increasing amount of research indicates that blueberries have anti-angiogenesis and anti-metastasis qualities in addition to preventing dysplasia. There were fewer colonic ulcers and dysplastic lesions because the distal colon contained more butyric acid. Whole blueberry powder was demonstrated to have anticancer properties in mice with MDA-MB-231 triple negative breast cancer. Tumor size significantly decreased after consuming a 5% and 10% blueberry diet. In the 10% enriched diet, malignant cells underwent more caspase 3-activated apoptosis. There was a marked down-regulation of genes linked to metastasis, cancer, and inflammation. [73]

### Functional Blueberry Ingredients' Molecular Mechanism and Health Impact on Chronic Illness in Humans

### 1. Functional Ingredients in Blueberry

Anthocyanin's, polyphenols, and antioxidant qualities are among the bioactive elements in blueberries. Pectin from blueberry powder contained anthocyanidins and cyanidin-3-glucoside ($C_{21}H_{21}O_{11}Cl$). However, two main mechanisms of anthocyanin stacking and ionic interaction for pectin and anthocyanin binding may be represented by anthocyanidins like cyanidin (color change with pH, red < 3, violet 7–8, blue > 11), pelargonidin ($C_{15}H_{11}O_5{}^+$, orange), malvidin (blue), petunidin (dark-red, purple), and delphinidin (blue, blue-red).[78]Wild blueberry polyphenols are broken down by colonic fermentation into syringic ($C_9H_{10}O_5$), cinnamic ($C_9H_8O_2$), caffeic ($C_9H_8O_4$), and protocatechuic ($C_7H_6O_4$) acids.[74] Antioxidant activity (+31%), total phenolic content (+43%), and anthocyanin content (+60%) were all considerably higher in the juice from blueberries that had been prepared with a pulsed electric field.[75]

### 2. Preventive Chronic Disease of Blueberry

### Blueberries' Anticancer and Functional Components

By preventing the growth of cancer cells, blueberry anthocyanins and their synthesis with pyruvic acid ($C_3H_4O_3$) can decrease the progression of cancer. [76] For fresh weight, the anthocyanin content of blueberries varied from 1.02 to 1.95 g/kg of malvidin-3-glucoside. This substance is employed as chemo preventive metastasis and has antipro-liferative and apoptotic properties in cancer cells [76]. However, its anticancer efficacy in HepG-2 cells is connected with anthocyanin content.[77] Probiotic-rich foods made from blueberry husks can postpone colon cancer. In addition to acting as a methylation suppressor for human DNA methyl transferase 1 and methylenetrahydrofolate reductase, blueberry juice displays anti-premutagenic properties comparable to those of vitamin C. Blueberry anthocyanin and anthocyanin extracts can stop B16-F10 cells from proliferating and cause them to undergo apoptosis. [78]

### 3. Anti-Obesity and Functional Ingredients of Blueberry

Freeze-dried blueberry powder can treat and prevent obesity-related chronic diseases, but anthocyanin's from blueberry dealcohol fermented beverages can inhibit insulin signaling in adipocytes, which induced insulin glucose uptake and reduced glycerol release in adipocytes [84]. Increased consumption of wild blueberries significantly reduced the expression of fatty acid synthase in the adipose tissue of the liver and abdomen. [79]

### Prevent Degenerative Diseases and Functional Ingredients of Blueberry

The ant proliferative and antioxidant qualities of blueberry juices are associated with anthocyanins; frequent consumption of blueberries can prevent a number of degenerative disorders. Because of their high anthocyanin and polyphenol content, four varieties of *Suwon blueberries—Elliott*, *Rubel*, *Rancocas*, and Friendship—have strong antioxidant activity. Lowbush blueberries contain 0.44 mg/g of chlorogenic acid. The phenolic acid combination reduces inflammation by controlling nuclear factor-κB activation and producing high levels of inflammatory cytokines. [80]

### Anti-Inflammatory and Functional Ingredients of Blueberry

Antibacterial and anti-inflammatory phenolic acids (6.6%), flavonoids (12.9%), and procyanidins (2.7%) are included in the blueberry extract. When consumed acutely, blueberries with a high anthocyanin content can lower oxidative stress and boost anti-inflammatory cytokines. Blueberry proanthocyanidins' antibacterial and anti-inflammatory qualities shield the oral keratinocyte barrier and counteract their leukotoxin characteristics, making them potential new therapeutic agents. [81]

### Protective Vision and Functional Ingredients of Blueberry

After photo bleaching, eating blueberries with anthocyanins accelerated the recovery of visual acuity. The retina can be shielded from light-induced damage by blueberry polyphenols. [82]

## DISCUSSION

The significance of blueberries and bilberries (*Vaccinium spp.)* as abundant natural sources of anthocyanin pigments that function well as substitutes for artificial food coloring is highlighted in this review. The need for plant-based colorants with additional functional value has been strengthened by growing health concerns and regulatory restrictions related to artificial dyes. Depending on pH, cultivar type, and processing circumstances, blueberry anthocyanins can provide a broad spectrum of red to blue hues. Color intensity, stability, and industrial applicability are all greatly impacted by differences in anthocyanin makeup between species, genotypes, and growing conditions. Blueberry anthocyanins have significant biological activity in addition to their capacity to color. Their antioxidant, anti-inflammatory, antimicrobial, cardioprotective, neuroprotective, antidiabetic, anti-obesity, and anticancer activities have been shown in numerous in vitro, in vivo, and clinical investigations. Anthocyanins' capacity to scavenge free radicals, control inflammatory mediators, safeguard brain function, enhance metabolic balance, and prevent the growth of cancer cells is largely responsible for these health-promoting benefits. Such multifunctional properties support the growing use of blueberry extracts as functional food ingredients and dietary supplements.

The practical use of anthocyanins obtained from blueberries is hampered by issues with pigment stability, bioavailability, and deterioration during processing and storage, despite their encouraging promise. Variations in pH, temperature, light, and oxygen exposure can all lower color quality and efficacy. Stability and functional performance may be improved by new techniques such encapsulation, pigmentation, anthocyanin-polysaccharide interactions, and the creation of anthocyanin-derived pigments. The use of blueberries as sustainable natural colorants with therapeutic value will be strengthened by additional research concentrating on formulation improvement and clinical validation.

## CONCLUSION

The anthocyanin's found in blueberries and bilberries (*Vaccinium spp.)* are valuable natural sources of anthocyanin-based pigments that are effective substitutes for synthetic colorants. These pigments have a wide range of biological activities, such as antioxidant, anti-inflammatory, cardioprotective, neuroprotective, antidiabetic, anti-obesity, and anticancer effects. The cultivar type, environmental conditions, and processing techniques have improved the pigment stability and bioavailability. As a result, blueberry-derived anthocyanins have significant potential as multipurities in the food, nutraceutical, and pharmaceutical industries.

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