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Blueberry as functional food and dietary supplement: The natural way to ensure holistic health

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Abstract. Blueberry (*Vaccinium* sp.), a fruit crop belonging to family Ericaceae is regarded a repository of functional phytochemicals. Its components, phenolic acids (caffeic, chlorogenic, ferulic, p-coumaric, and cinnamic acids) and flavonoids (anthocyanidins) have been credited to confer manifold healthy properties. The berries have been evidenced to impart relief from obesity, diabetes, retinal injury, heart, liver, stomach and kidney inflammation, tumours, microbial infection, cognitive decline and bone loss. Consumer interest in these berries is reflected in the slew of fortified-foods. The nutraceutical potentials of these nutrient powerhouses warrant deeper investigation for their optimal exploitation. This literature review elucidates the probable modes of biological actions, current status and future scopes of blueberry for prcessed food and dietary supplement development. Relevant information has been mined from PUBMED, SCOPUS and Google scholar database and assembled into an insightful account.

Keywords: Blueberry, anthocyanin, antioxidant, anticancer, neuro-protection, functional food

1. Introduction

Berries have been hailed as excellent reserves of health-restoring phyto-chemicals. The popular berries are *viz*. strawberries, blueberries, blackberries, raspberries, cranberries, red currants, black currants, chokeberries, wolfberries, huckleberries and lingonberries. Dietary enrichment with the berries has emerged as an essential sector of nutritional improvement. Unarguably, blueberry scores the highest in terms of antioxidants and is regarded as a quintessential functional food ingredient. Blueberry (*Vaccinium* sp.) belongs to the family Ericaceae (heath family, to which belong cranberry, azalea and rhododendron). This plant is native to the USA and Southern Canada, growing wild in hilly and woodland regions. The three prominent varieties grown are highbush (*V. corymbosum, V. ashei)*, lowbush (*V. angustifolium*) and evergreen (*V. darrowii*). These plants thrive in acidic soil and require ample sunlight. The shrubs are medium-sized and bear clusters of blue to purple fruits with ashen coatings (Fig. 1). The berries are delicious with sweet, tart, tangy taste. The ripe berries are harvested in summer, ideally from May to October. The USA is the leading producer, Maine, Michigan, Oregon, Washington, New Jersey, Florida, Georgia and North Carolina being the major contributing states. However, the cultivation has now proliferated to Europe, Asia, Africa and Australia. The berries are relished straight off the shrubs or processed into an array of delectable 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. The berries are known to be nutrient storehouse with plentiful fibres, tannins, anthocyanins, proanthocyanidins, vitamin C, ellagic acid,

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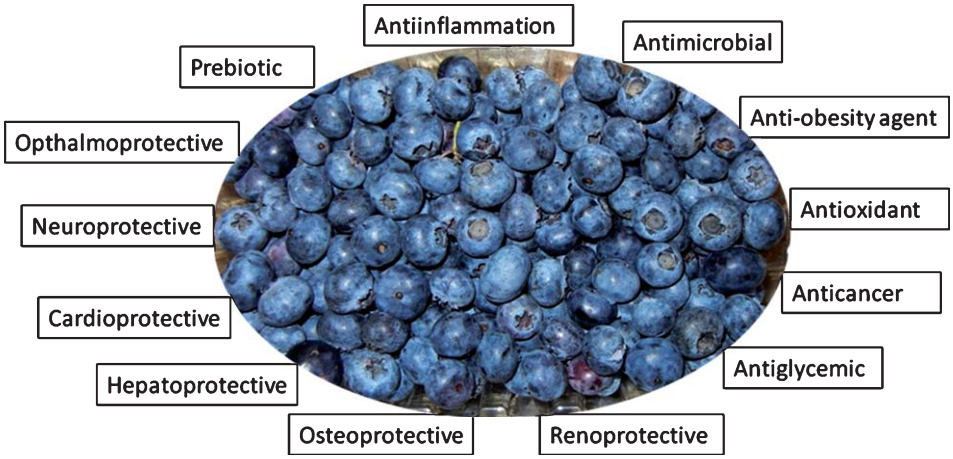

Fig. 1. Validated ameliorative properties of blueberry.

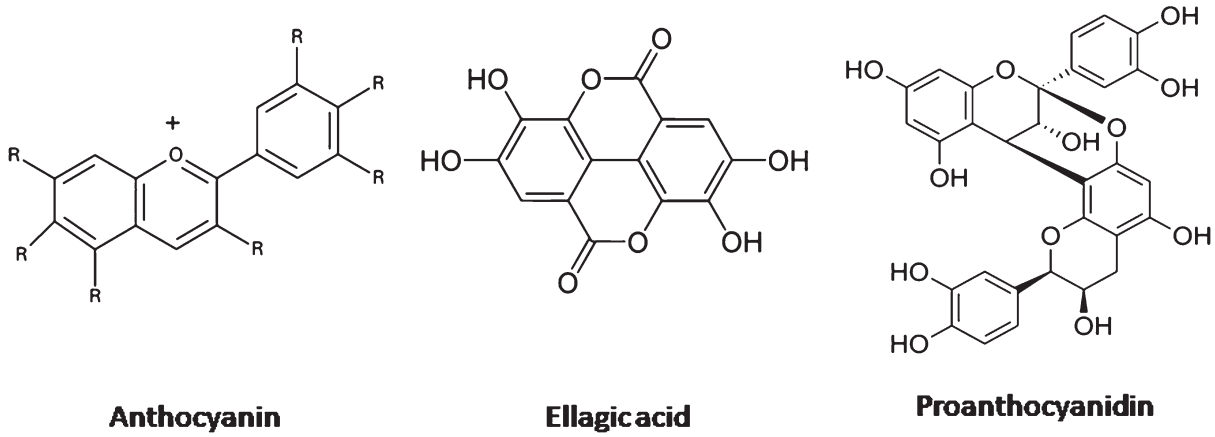

Fig. 2. Structures of major bioactive compounds in blueberry.

omega-3 fatty acids, carotenoids, minerals *etc.* (Fig. 2). A variety of anthocyanins occur in blueberry, the chief types being monoarabinosides, monoglucosides and monogalactosides of cyanidin, petunidin, peonidin, delphinidin and malvidin. United States Department of Agriculture (USDA) human nutrition center recommends its inclusion in diet. The approximate nutrient profile of blueberries is presented in Table 1. An appreciable gamut of health benefits *viz.* antioxidant, anti-inflammation, neuro-protection, anti-metastatic, cardio-protective, antimicrobial, reno-protective, opthalmoprotective, anti-diabetic, hepato-protective, gastro-protective, anti-osteoporotic, anti-aging have been reported. In the USA, it has become an indispensable ingredient of functional food sector. This review presents an updated account of the nutritional advantages of blueberry with special emphasis on functionality.

2. Roles in healthcare

2.1. Antioxidant and anti-inflammation

The total antioxidant capacity and phenolic composition of blueberry was investigated. Both 2, 2′-azino-bis (ABTS) and 2, 2-diphenyl-1-picrylhydrazyl (DPPH) assays revealed its strong total antioxidant capacity. Abundance of

Table 1
Phytochemical profile of blueberry (courtesy: USDA national nutrient database)

Nutrients		per 100 g
Proximate	Energy	57 Kcal
	Protein	0.74 g
	Fat	0.33 g
	Carbohydrate	14.49 g
	Dietary fiber	2.40 g
	Ash	0.24 g
Minerals	Calcium	6.00 mg
	Copper	0.28 mg
	Iron	0.06 mg
	Magnesium	6.00 mg
	Manganese	0.34 mg
	Phosphorus	12.00 mg
	Potassium	77.00 mg
	Selenium	0.10 μg
	Sodium	1.00 mg
	Zinc	0.16 mg
Vitamins	Ascorbic acid	9.70 mg
	Thiamin	0.04 mg
	Riboflavin	0.04 mg
	Niacin	0.42 mg
	Pantothenic caid	0.12 mg
	Pyridixine	0.05 mg
	Folic acid	6.00 μg
	Retinol	54.00 IU
	Tocopherol	0.57 mg ATE

*IU=Intenational Units, *ATE=Alpha tocopherol equivalent.

proanthocyanidins and anthocyanidins were found responsible for enhancing redox status of body [1]. Enzymatic hydrolysis of *V. corymbosum* was carried out using a range of commercial food-grade carbohydrase AMG and protease Alcalase to obtain water soluble compounds. Further, their protective effect was investigated against H_2O_2-induced damage in Chinese hamster lung fibroblast V79-4 cell line. The hydrolysates showed high total phenolic content as well as radical scavenging activities. The cells were also shielded against lipid peroxidation, DNA damage and apoptotic body formation in a dose-dependent manner [2]. Anti-inflammatory effect of blueberry anthocyanins was evaluated on trinitrobenzene sulfonic acid (TNBS)-induced bowel disease model of mice. After administering daily dosage of 40 mg/kg for 6 days, the mice were euthanized. The extract conferred strong protection against colonic damage, and diarrhoea risk could be averted. Reduction in the levels of nitric oxide, myeloperoxidase, interleukin (IL-12), tumor necrosis factor (TNF-α), and interferon gamma (IFN-γ) was reported [3]. It was examined whether consumption of 250 g of blueberries daily for 6 weeks and 375 g given 1 h prior to 2.5 h of running is capable of combating oxidative stress, inflammation and immune changes. Increase in F_2-isoprostanes and 5-hydroxymethyl-2′-deoxyuridine was significantly lower and plasma IL-10 and natural killer (NK) cell counts were significantly greater in the blood of blueberry diet-fed group. Oxidative stress was substantially reduced and anti-inflammatory cytokine level improved following the berry consumption [4]. The mean serum oxygen radical absorbance capacity (ORAC) was significantly higher after the intake of 75 g blueberry. It was inferred that the berry diet might attenuate postprandial stress imposed by high-carbohydrate, low-fat breakfast [5]. It was reported that anthocyanins and proanthocyanidins-rich fractions from fermented blueberry-blackberry wine can reduce lipopolysaccharide (LPS)-induced inflammatory response in mouse macrophages via the nuclear factor kappa B (NF-κB)-mediated pathway [6].

2.2. Diabetes and obesity management

Diabetes begets many incapacitating ailments. Standard drugs though effective in mitigating the disease, result in undesirable health conditions. Metformin is a potent antidiabetic drug but causes multiple side effects *viz.* diarrhoea, nausea, gas, chest pain and allergy. So, complication-free drugs are constantly sought after in diabetes management. It was demonstrated that anthocyanin isolated from *V. angustifolium* berries has the potency to alleviate symptoms of hyperglycaemia in diabetic C57b1/6J mice. Force-feeding with a phenolic-rich extract and an anthocyanin-enriched fraction (500 mg/kg) formulated with an emulsifier lowered the elevated blood glucose levels by 33 and 51%, respectively. The potency compared well with metformin and the efficacy was more pronounced when administered with the delivery system [7]. A supplement of blueberry powder was assessed for its protective effect against adipose tissue inflammation and insulin resistance in high-fat-diet-fed mice. Attenuation in upregulation of inflammatory genes and protection from insulin resistance was conspicuous [8]. A double-blind, randomized study was conducted to assess the impact of the berry diet on insulin sensitivity, inflammatory biomarkers and adiposity. Two varieties of highbush blueberries 'Tifblue' (*V. ashei*) and 'Rubel' (*V. corymbosum*) were freeze-dried and crushed. Consumption of the berry smoothie twice daily for 6 weeks led to improvement of insulin sensitivity in obese, non-diabetic as well as insulin-resistant participants. Diabetes-ameliorating role of blueberries came forth [9]. It was observed that inclusion of 3% blueberry pomace was effective in restoring the fructose-induced metabolic anomalies, including reduction in plasma cholesterol and abdominal fat. These findings lay the foundation for possible battle against obesity [10]. The anti-obesity effect and mechanism of action of blueberry peel extracts was investigated on 3T3-L1 cells and high-fat-diet-induced obese rats. The extracts exerted inhibitory effect on adipogenesis through the down-regulation of C/EBPβ, C/EBPα, and PPARγ and the reduction of the phospho-Akt adipogenic factor in 3T3-L1 cells. Oral administration of the peel extract significantly reduced high-fat-diet-induced body weight gain without affecting food intake. The epididymal or perirenal adipose tissue weights were lower. Total cholesterol and triglyceride levels were modestly reduced, and the HDL-cholesterol level was significantly increased, leading to lowering of body weight [11]. The potential of a wild blueberry-enriched diet to improve blood lipid profile and to modulate the expression of genes related to lipid homeostasis was investigated in obese Zucker rats. Plasma triglyceride and total cholesterol concentrations were significantly lower in the rats after 8% blueberry consumption for 8 weeks. The expression of fatty acid synthase was significantly decreased in both the liver and abdominal adipose tissue. It improved lipid profiles and modulated the expression of key enzymes and transcription factors of lipid metabolism in severely dyslipidaemic rats [12].

2.3. Opthalmo-protective

Potential of blueberries in blocking detrimental effects of light abuse on eyes have been studied. The effect of Chinese blueberries consumption on retinal damage upon light exposure was determined in pigmented rabbits. Feeding the animals with whole blueberries at a dosage of 1.2–4.9 g/kg daily for 4 weeks prior to light exposure effectively reduced the extent of harm to the retinas as assessed by electroretinogram [13]. Further, the protective effect of the berry anthocyanins on retinal pigment epithelium was evaluated against aging and visible or UV light-induced injuries. Delayed aging and apoptosis as well as the down-regulation of vascular endothelial growth factor (VEGF) to normalcy were observed [14]. Blueberry-enriched diet was investigated as a potential protectant against light-induced retinopathy. When given as gavage for 2 to 7 weeks before subjecting to 2 hours of intense light regimen, retinal protection was observed. Placebo-fed rats suffered from damage in the superior hemiretina, which the berry supplemented group escaped [15].

2.4. Cardio-protective and hypotensive

Growing body of evidences suggest that the intake of flavonoid-rich foods exerts cardiovascular benefits. So, amelioration of cardiac disorders by blueberry-fortified diet was assessed. The cardio-protective property of a 3 month berry-enriched diet was assessed in rats. Owing to richness in antioxidant, it protected against reactive oxygen species (ROS) - induced ischemic injuries. Development of post-myocardial infarction and chronic heart failure was notably blunted [16]. The nutritional effect of *V. angustifolium* consumption was assessed on the markers of

oxidative stress, inflammation and endothelial function in 18 male volunteers with risk factors for cardiovascular disease. Intake of the drink for 6 weeks spaced by a 6 week flushing significantly reduced the levels of endogenously oxidized DNA bases and H_2O_2-induced DNA damage [17]. The effect of a 10 week blueberry supplementation on blood pressure and vascular reactivity was investigated in rats fed a high-fat diet. The supplementation with 2% (w/w) blueberry showed significant reductions in systolic blood pressure. The aorta relaxation was significantly greater in response to acetylcholine which confirmed the role of blueberry in improving contractile machinery of endothelial layer [18].

2.5. Hepatoprotective

The possible protective effects of blueberry blended with probiotics *Lactobacillus plantarum* and *Bifidobacterium infantis* was estimated on D-galactosamine and LPS-induced acute liver injury model of rats. After intake, Alanine aminotransferase levels were reported to decrease significantly. Also, bilirubin, liver TNF-α and myeloperoxidase content decreased significantly whereas liver glutathione values increased significantly [19]. It was observed that dietary blueberry improves CCl_4-induced hepatic fibrosis by reducing hepatocyte injury and lipid peroxidation in rat model. The level of liver inflammation marker, hyaluronic acid and alanine aminotransferase were lowered considerably, whereas antioxidant status was promoted [20]. Polyphenol-rich extracts of Chinese blueberries inhibited the triglyceride deposition in the hepatocellular HepG2 cells [13]. Further, the effects of blueberry were evaluated in rats with induced-hepatic fibrosis. After 12 weeks of the administration, the rats were sacrificed. The group administered with blueberry had reduced pathological conditions, manifested in lower collagen build-up and structural anomalies. Stress deduction by amplifying SOD and GSH content and slashing MDA level was reckoned to be the therapeutic mode [21].

2.6. As prebiotics

Probiotics augmentation by blueberries is a comparatively nascent field in nutrition research. In pursuit to determine prebiotic potential of blueberry, both *in vitro* and *in vivo* investigations were carried out. When added to mixed faecal bacteria cultures derived from healthy human volunteers, noticeable growth in *Lactobacillus rhamnosus* and *Bifidobacterium breve* population was observed. The extract when given in gavage to rats for 6 days, probiotics density increased Molan et al. [22]. Also, a 6 week consumption of *V. angustifolium* drink led to the enhancement in *Bifidobacterium spp.* count. High polyphenol and fiber content were credited for inducing the proliferation of probiotics [23]. For promotion of gut health, prebiotic role of blueberries should certainly be studied more intensely [24]. The berry drink resulted in significant increase of *Bifidobacterium longum* subsp. infantis population, as analyzed in the faeces of volunteers. The predominance of *B. longum* subsp. *longum* and *B. adolescentis* was evident [25].

2.7. Antimicrobial

Blueberry has been shown effective against an array of food pathogens, owing to its abundance in phenolic components. The inhibitory effect of blueberry was evaluated on *Giardia duodenalis,* the etiological agent of giardiasis. The berry extract caused inhibition of trophozoites of the protozoa when grown in vitro [26]. *Salmonella* serotype Enteritidis is notorious for causing fever, diarrhoea and abdominal cramps. Blueberry phenolics supplemented in tryptic soy broth showed growth inhibition towards this pathogen [27]. The antimicrobial effects of *V. angustifolium* extracts were studied against *Escherichia coli* O157:H7, *Listeria monocytogenes* and *Salmonella typhimurium* by agar diffusion assay. The flavanol proanthocyanidin demonstrated the lowest minimum inhibitory concentration with strongest inhibitory effect towards *L. monocytogenes* [28].

2.8. Anticancer

Substantial evidences supporting the claims of dysplasia prevention, anti-angiogenesis and anti-metastasis by blueberries have accumulated in recent times. It was reported that blueberries owing to their high content of ellagic acid, foil endogenous oxidative DNA damage leading to diminished cancer risks [29]. The anti-inflammatory role of

blueberry husks in synergy with probiotics in dextran sulphate sodium-induced colorectal tumour models of rat was evaluated. Reduction in the number of colonic ulcers and dysplastic lesions was observed, attributable to the higher level of butyric acid in distal colon [30]. Excess oestrogen level is a risk factor for breast cancer. It was determined whether dietary berries and ellagic acid prevent 17β estradiol (E_2)-induced mammary tumours by altering oestrogen metabolism. At 6 weeks, the E_2-treatment caused 48-fold increase in cytochrome P4501A1 in rat models which was attenuated to 21-fold by the supplement. Mammary tumorigenesis instances were played down by suppressing the levels of E_2-metabolizing enzymes [31]. The antitumor activity of whole blueberry powder was demonstrated against MDA-MB-231 triple negative breast cancer in mice. On ingestion of 5% and 10% blueberry diet, tumour size showed noticeable regression. The caspase 3-activated apoptosis of cancerous cells was greater in the 10% fortified diet. Genes responsible for inflammation, cancer and metastasis were significantly down-regulated [32]. Their role in retarding MDA-MD-231 cell proliferation was further evaluated. The phenolic acids showed potential to target the daughter or progenitor cells in the mammary gland, capable of transformation into malignant cells [33]. Blueberry diet was effective in reducing mammary tissue proliferation in ACI rat mammary tumor model. At 5% dose, tumor appearance was delayed for about 24 days, presumably by downregulation of CYP1A1 expression [34]. Cancer stem cells demonstrate resistance to chemo and radiation therapy, which enables their enrichment. Blueberry phytochemical pterostilbene was evaluated against irradiation-enriched cancer stem cells. The bioactive dose-dependently reduced the enrichment of human hepatocellular carcinoma upon irradiation. Further, it prevented tumour sphere formation, reduced CD133 gene expression, and suppressed invasion and migration abilities as well as increasing apoptosis of the cells. Aggression of liver cancers might be checked by harnessing pterostilbene [35]. The effect of blueberry extracts was evaluated on B16-F10 metastatic melanoma murine cells. The anthocyanin rich-fraction obtained from cultivar Torro possessed the highest antioxidant activity and inhibited the cancer cell proliferation at concentrations higher than 500 μ g/ml. Also, the fraction stimulated apoptosis and increased total lactate dehydrogenase activity in the cancer cells [36].

2.9. Reno-protective

It was reported that a 3% blueberry diet fed for 8 weeks is capable of protecting the kidneys from oxidative damage in spontaneously hypertensive stroke-prone rats. In the berry-administered group, systolic blood pressure was 19% lower at week 4 and 30% lower at week 6 compared to control. Also, reduced markers of renal oxidative stress, such as proteinuria and kidney nitrites were observed [37]. The renoprotective effect of a blueberry-enriched diet was further assessed in rat models of hypertension. The animals fed with the berry diet for 6 or 12 weeks exhibited lower blood pressure, improved glomerular filtration rate and decreased renovascular resistance. Significant fall in total ROS, peroxynitrite and superoxide production rates were observed in kidney tissues. Antioxidant status showed improvement, evident from the renal glutathione and catalase activities. However, only the long-term feeding contributed to the therapeutic value [38].

2.10. Neuroprotective and senescence retardant

Oxidative stress, microglial activation and pro-inflammatory factors lead to aging. Neuro-degeneration predisposes to debilitating Alzheimer's disease. A convincing set of findings have emerged to substantiate the neuroprotective potential of blueberries. The ability of blueberries in preventing aggregation of amyloid-beta (Aβ) into fibrillar amyloid plaques has been evaluated. Microglial proinflammatory activation caused neuronal and synaptic damage, leading to cognitive impairment. The berry extract significantly enhanced the microglial clearance of Aβ, inhibited the aggregation of $A\beta_{1\text{-}42}$ and suppressed microglial activation, all via suppression of the p44/42 MAPK module. Blueberries, by virtue of their anthocyanin content are presumed to improve neuronal signalling, boost memory function and delay the onset of geriatric dementia [39]. The biological effect of daily consumption of *V. angustifolium* juice was investigated in older adults with early stage of memory decline. After 12 weeks of the potion administration, improved ability of paired-associate learning and word list recall was noticed. Also, reduced depressive symptoms were reported. Blueberry supplementation holds promise in promoting neuro-cognitive health [40]. The presence of potent NADPH oxidase inhibitors in Alaskan blueberries was confirmed from the underlying experiment. Incubation of human neuroblastoma SH-SY5Y cells with nonpolar blueberry fractions obstructed the clustering of lipid rafts

into macrodomains, disrupting NADPH oxidase assembly therein and abolishing ROS production. Inflammation and oxidative stress were suppressed, resulting in lowered degeneration of central nervous system [41]. The berry extracts when fed for 6–8 weeks, elevated long-term potentiation in the hippocampus, vital for memory formation. The normalization of long-term potentiation may be due to the blueberry diet preventing a decline in synaptic strength. Phosphorylation of a key tyrosine residue on the NR2B subunit of N-methyl-D-aspartate receptor was enhanced by the diet, which restored cognitive impairment [42]. The importance of a nutraceutical 'NT-020' formulated of blueberry, green tea and carnosine in promoting the proliferation of stem cells was evaluated *in vitro* and *in vivo*. When given as gavage at a dose of 135 mg/kg per day for 4 weeks, a decreased number of OX6 MHC II-positive cells, increased neurogenesis and increased number of proliferating cells were found in rats [43]. The effects of blueberry polyphenols was examined on the lifespan and aging of the nematode *Caenorhabditis elegans.* The complex mixture of blueberry polyphenols was shown to stretch the longevity and impede the aging-related declines. The resistance to acute heat stress was attributed to the proanthocyanidin compounds [44]. Supplementing aged hosts with 2% blueberry in the diet increased central nervous system graft growth and neuronal survival against inflammatory cytokine IL-6 and oxidative stress on intraocular hippocampal grafts. Moderation in immunoreactivity led to decrease in microglial activation and astrogliosis [45]. Blueberry extract was reported to be neuroprotective against amyloid-beta neurotoxicity in all *viz.* embryonic, middle-age or old-age rats. Protection of the primary hippocampal neurons by the berry extract was presumed to be mediated through alteration in stress signalling and shielding from the hazards of ROS. Reversal of the hippocampal Ca^{2+} dysregulation leads to improvement in spatial memory [46]. *Serratia vaccinii*-fermented blueberry juice was recruited to prevent and treat neurodegenerative disorders. When neuronal cell culture was incubated with the juice, significant increment in the activity of antioxidant enzymes *viz.* CAT and SOD was observed. Also, the juice could shield the H_2O_2-induced oxidative stress and resultant cell death in a dose-dependent manner. Activation of p38- and JNK-dependent survival pathways and blockage of MEK1/2- and ERK1/2-mediated cell death was deduced to be the molecular approach [47]. The effect of a blueberry-rich diet was investigated in young rats using a spatial working memory paradigm, the delayed non-match task, using an eight-arm radial maze. A 7-week supplementation with 2% (w/w) blueberry, improvement in the spatial memory performance was observed. The cognitive augmentation was due to the activation of extracellular signal-related kinase (ERK1/2), increased total cAMP-response element-binding protein (CREB) and elevated levels of pro- and mature brain-derived neurotrophic factor (BDNF) in the hippocampus [48].

2.11. Osteoprotective

Bone mass build-up by blueberry-based diet consumption was investigated. Ovariectomy leads to oestrogen deficiency and consequent bone loss. High bone matrix collagen degradation as the result of osteoclast activation is derived to be the cause. The possible role of dietary blueberry in bone density retention was studied. When administered to pre-pubertal rats throughout development or only between postnatal days 20 to 34, ovariectomy-induced bone loss could be prevented in adult life. This protective effect was interpreted to be due to suppression of osteoblastic cell senescence associated with acute loss of myosin expression after the ovary removal [49]. Further, the prevention of ovariectomy-induced bone cell senescence was reconfirmed in adult rats even after only 14 days consumption of blueberry prior to puberty [50]. The effect of blueberry consumption was investigated in weanling rats. When AIN-93G diet supplemented with 10% whole blueberry was administered to 21 day old rats for two weeks, remarkable increase in bone formation was reported. Significantly increased bone mass after feeding 5% BB extracts was also observed in a TEN (total enteral nutrition) rat model in which daily caloric and food intake was precisely controlled. Expression of RANKL (receptor activator of nuclear factor-κB ligand) a protein essential for osteoclast formation was dose-dependently decreased in the femur of BB animals. In addition, expression of PPARγ (peroxisome proliferator-activated receptor γ) which regulates bone marrow adipogenesis was suppressed in BB diet rats compared to non-BB diet controls [51].

3. Tackling post-harvest loss and bioavailability enhancement

Blueberries are delicate and are prone to fungal decay, shrivelling, and mechanical damage. So, maintenance of post-harvest fruit quality during transportation and storage is very challenging. The effect of transport temperature

on the quality of *V. corymbosum* was evaluated. Neither cultivar remained marketable after 6 days or 16 days at room temperature or 10°C. The 'Duke' cultivar had slightly lower weight loss than 'Bluetta,' but difference between the cultivars was not significant after 12 days of storage. Organic acid content declined in both cultivars during storage [52]. Gray mold caused by *Botrytis cinerea* spoils blueberries during transportation, leading to huge economic losses. It was demonstrated that SO_2 fumigation could be an effective method for reducing the risk of fungal damage. The efficacy was tremendous as seen in 'Brigitta' and 'Liberty' cultivars, which contained 97.2% to 97.5% mold in untreated form, which could be minimized to 7.9% to 6.1% in the treated forms [53]. The potentials of plant essential oils and plant oil-derived biofungicides were investigated to check fungi on the berries. When treated under refrigeration for a week, Sporatec volatiles (formulated from rosemary, clove, and thyme oils) significantly reduced fungi, though other oils failed to elicit appreciable antifungal activity. These plant-derived fungicides have limited application possibilities for they negatively affected the sensory attributes of the berries [54].

Processing techniques play important role in maximum retention of bioactive components. Continuous vacuum-belt drying was evaluated as a means to produce high-quality powders from blueberry slurries, with minimal deterioration to anthocyanins. Vacuum-belt drying at 80°C with 0.3 kg maltodextrin/kg dry solids produced non-hygroscopic powders with anthocyanin content similar to freeze-dried powders [55]. The absorption of phenolic and anthocyanin content after consumption of one portion (300 g) of minimally processed blueberry purée was investigated. Phenolic content was higher in blanched compared to non-blanched purée. Blanching enhanced anthocyanin absorption from the gut [56]. Osmotic dehydration has proven to be an ideal method of postharvest shelf-life prolongation. Dehydration at high tempetature (60 and 70°C) led to substantial loss of phenolic compounds and unfavorable changes in the texture of the final product. Pretreatment of the berries with pectinases and lipases, led to increase in dry matter content with a low loss of phenolic compounds. Anthocyanin components (petunidin-3-galactoside and petunidin-3-glucoside) were retained [57].

4. Future directions

The broad spectrum therapeutic possibilities delineate blueberries as nutrient-dense food source. To ensure maximum bioaccessibility of blueberry, the metabolites generated and their fate in the gut should be investigated. Studies have shown that anthocyanins are metabolized by the intestinal microflora to respective phenyl-alkyl acids, which can be further metabolized to benzoic acid. Hippuric acid content in urine indicates that metabolism and excretion of blueberry anthocyanin is based on diet duration [58]. Experiment on a TNO intestinal model (TIM-1) of the human upper gastrointestinal tract showed that polyphenol-rich extract of blueberry generates anthocyanins, which get partially destroyed during transport through upper digestive tract for subsequent colonic delivery release [59]. Metabolism and absorption of other functional components should be probed. New cultivars with improved photochemical profiles should be bred. In this regard, cultivated and wild blueberries were compared for their antioxidant effects. Wild genotypes showed more antioxidants than cultivated counterparts. COMET assay confirmed the stronger action on DNA protection in wild samples [60]. So, wild genotypes must be preserved. Pest management and post-harvest storage are challenging issues that need to be addressed. Blueberries should be introduced to wider market and grown globally. Blueberry-based food innovation should be explored more intensely. Assortment of nutrient-rich botanicals could be combined with blueberries to develop functional foods. The juices of açaí, black cherry, grape, cranberry, pomegranate juice are supposed to boost the goodness of blueberry drinks, in terms of sensory appeal and antioxidant content. A beverage was successfully developed by blending blueberries with apples, cranberries, gingers and supplementing amino acids, vitamins and minerals. The beverage retained sensory appeal while possessing phenolic content, FRAP value and % inhibition of LDL oxidation in amount enough to be a cardio-protective [61]. Efficient protocols for anthocyanin extraction should be emphasized. The berry skins are rich in anthocyanins, cinnamic acid derivatives and flavonol-glycosides. So, recovery of these polyphenolics from the processing wastes must be emphasized. Other ailment management possibilities should be uncovered. Blueberry holds immense promise for prevention of hypertension, promotion of healthy aging and reduction of cancer incidences. Berries are known to control pathogenic microorganisms. More studies on the use of blueberry as a natural antimicrobial in food products are warranted.

5. Conclusions

The review emphasizes the blueberry-based novel nutraceutical development. The plethora of health benefits suggest that research should be directed in understanding the bioactive components of blueberry and precise mechanisms mediating the disease remediation. Its ingestion must be encouraged for valorisation of immunity against nagging health threats. Neo-consumers should be awakened about its multiplicity of goodness. Inclusion of this berry in food platter will certainly be an assured step towards health restoration. Time is ripe for popularization of the berry beyond North America.

Disclosure of interest

There is no conflict of interest in submission of this manuscript.

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