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Phytochemical diversity and therapeutic potential of *Ipomoea batatas* (L.) Lam.

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Abstract

Ipomoea batatas (L.) Lam. commonly known as sweet potato is an agronomically significant tuber crop distinguished by remarkable phytochemical diversity and expanding therapeutic importance. The species demonstrates substantial genotypic and tissue-specific variability in bioactive constituents, including phenolic acids, flavonoids, anthocyanins, carotenoids and structurally complex polysaccharides. Purple-fleshed cultivars are particularly enriched in acylated anthocyanins exhibiting potent antioxidant and anti-inflammatory activities, whereas orange-fleshed genotypes serve as major dietary sources of provitamin A carotenoids that contribute to alleviating vitamin A deficiency. Comparative metabolomic investigations further indicate that sweet potato leaves frequently contain higher concentrations of total polyphenols than storage roots, underscoring the nutraceutical potential of aerial biomass. Pharmacological and experimental evidence suggests that sweet potato phytochemicals exert multifaceted biological effects, including attenuation of oxidative stress, modulation of inflammatory mediators such as NF-κB, enhancement of insulin sensitivity and inhibition of tumor cell proliferation. Moreover, polysaccharide fractions have demonstrated immunomodulatory and hypoglycemic activities in both *in vitro* and *in vivo* systems. Advances in chromatographic and spectrometric characterization have strengthened structural elucidation and quantification of anthocyanins and phenolics, thereby improving prospects for functional food standardization and therapeutic translation. Collectively, contemporary evidence positions sweet potato as a functional crop of substantial biomedical relevance, warranting cultivar-specific bioavailability studies and rigorously designed clinical validation.

1. Introduction

Sweet potato is one of the most widely cultivated root and tuber crops in tropical and subtropical regions and occupies a strategic position in global food and nutritional security. It ranks among the leading staple crops in terms of production and consumption and is recognized for its adaptability to marginal soils, tolerance to drought and relatively short growth duration, attributes that render it a climate-resilient crop under changing environmental conditions (FAO, 2023). Traditionally valued as a carbohydrate-rich energy source, sweet potato has increasingly gained prominence as a functional food owing to its diverse phytochemical composition and associated health-promoting properties (Wang *et al*., 2021). Contemporary nutritional science emphasizes not only caloric contribution but also the presence of bioactive compounds capable of mitigating chronic diseases and in this context, *I. batatas* has emerged as a crop of considerable biomedical relevance. The species exhibits remarkable genetic and phenotypic variability, primarily due to its hexaploid nature (2n = 6x = 90) and extensive genetic recombination. This genetic complexity translates into substantial diversity in root morphology, flesh pigmentation, dry matter accumulation and biochemical composition. Variations in flesh color ranging from white and cream to yellow, orange and deep purple are biochemically determined by differential accumulation of carotenoids and anthocyanins. Orange-fleshed genotypes are particularly rich in provitamin A carotenoids, notably β-carotene, which plays a crucial role in preventing vitamin A deficiency and associated disorders such as impaired vision and compromised immunity (Neela and Fanta, 2022). Purple-fleshed cultivars, in contrast, accumulate significant concentrations of acylated anthocyanins, pigments characterized by enhanced stability and potent antioxidant capacity. These compounds have been extensively studied for their anti-inflammatory, hepatoprotective and anti-carcinogenic effects (Zhao *et al*., 2024). Even white and cream-fleshed types, though comparatively lower in pigments, contain appreciable levels of phenolic acids and flavonoids that contribute to overall antioxidant potential (Alam *et al*., 2022). Phytochemically, sweet potato represents a repository of structurally diverse secondary metabolites, including hydroxycinnamic acids such as chlorogenic acid and caffeic acid derivatives, flavonoids, anthocyanins, carotenoids and complex polysaccharides. These compounds collectively confer strong antioxidant activity through mechanisms involving radical scavenging, metal chelation and modulation of endogenous antioxidant enzymes. Phenolic acids, particularly chlorogenic acid, are known to inhibit lipid peroxidation and attenuate oxidative stress pathways implicated in chronic metabolic disorders (Wang *et al*., 2021).

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Anthocyanins isolated from purple sweet potato have demonstrated the capacity to regulate key signaling cascades such as NF-κB and MAPK, thereby suppressing inflammatory mediators and oxidative damage (Zhao *et al*., 2024). Such molecular interactions underscore the therapeutic potential of these bioactive compounds in preventing lifestyle-associated diseases.

In addition to phenolics and pigments, sweet potato polysaccharides have attracted growing research interest. These heteropolysaccharides, composed of monosaccharide units such as glucose, galactose, arabinose and rhamnose, exhibit significant immunomodulatory and hypoglycemic properties. Experimental studies indicate that these polysaccharide fractions enhance macrophage activation, modulate cytokine expression and improve glycemic regulation, suggesting potential applications in diabetes management and immune support (Sun *et al*., 2022). The hypolipidemic effects of certain extracts further reinforce the crop's functional value in addressing cardiovascular risk factors. Recent advances in metabolomics and chromatographic technologies have revolutionized phytochemical profiling of sweet potato genotypes. High-performance liquid chromatography and liquid chromatography mass spectrometry analyses have enabled precise identification and quantification of anthocyanins, phenolic acids and carotenoids, revealing significant genotype-dependent variation (Li *et al*., 2023). Comparative analyses indicate that sweet potato leaves often contain higher concentrations of total phenolics and flavonoids than storage roots, thereby highlighting the underutilized nutraceutical potential of aerial plant parts. This expanded understanding encourages a holistic approach to crop utilization, extending beyond the conventional focus on storage roots.

The therapeutic implications of sweet potato consumption extend to the prevention and management of non-communicable diseases, which are increasingly prevalent worldwide. Oxidative stress and chronic inflammation are recognized as central mechanisms underlying metabolic syndrome, type 2 diabetes, cardiovascular disorders and certain cancers. Bioactive compounds from *I. batatas* have been shown to ameliorate these pathological processes by enhancing antioxidant defenses, modulating inflammatory mediators and improving insulin sensitivity (Mohanraj and Sivasankar, 2023). Dietary interventions incorporating orange and purple-fleshed sweet potato have demonstrated promising outcomes in improving nutritional biomarkers and metabolic parameters. Despite extensive *in vitro* and animal-based research, challenges remain in translating phytochemical findings into standardized therapeutic applications. Variability in genotype, agro-climatic conditions, post-harvest handling and processing methods significantly influences phytochemical retention and bioavailability. Therefore, cultivar-specific characterization and rigorous clinical validation are imperative to substantiate health claims and facilitate nutraceutical product development. Furthermore, understanding genotype-environment interactions affecting phytochemical expression is critical for breeding programs aimed at enhancing functional traits. In the context of global nutritional challenges, including micronutrient malnutrition and rising incidence of chronic diseases, *I. batatas* represents a dual-purpose crop that integrates agronomic resilience with biomedical potential. Comprehensive evaluation of its phytochemical diversity, coupled with systematic investigation of therapeutic properties, will contribute to value addition, functional food innovation and evidence-based dietary strategies. Continued interdisciplinary research integrating plant breeding, food chemistry, molecular biology and clinical nutrition is essential to fully harness the functional attributes of this versatile crop.

2. Phytochemical diversity in sweet potato

Sweet potato exhibits extensive phytochemical heterogeneity arising from its hexaploid genome, broad genetic base and strong genotype environment interactions. This diversity is reflected in substantial variation in pigmentation, antioxidant capacity and nutraceutical quality among cultivars. Differences in phytochemical concentration are influenced by genetic background, agro-climatic conditions, maturity stage and post-harvest processing (Wang *et al*., 2021; Li *et al*., 2023).

2.1 Carotenoids

Carotenoids are the principal pigments responsible for the characteristic orange coloration of orange-fleshed sweet potato (OFSP) genotypes and they represent one of the most nutritionally important groups of bioactive compounds present in the crop. Among these, β-carotene is the predominant carotenoid and serves as a major provitamin A compound, capable of being converted into retinol in the human body. The concentration of β-carotene in OFSP can vary widely depending on genotype, maturity stage and environmental conditions, but it is generally reported to be significantly higher than in white or cream-fleshed varieties (Woolfe, 1992; Teow *et al*., 2007). Due to its high bioavailability and conversion efficiency, β-carotene plays a critical role in combating vitamin A deficiency (VAD), a major public health concern in many developing regions where sweet potato is consumed as a staple food (Low *et al*., 2007). In addition to β-carotene, other important carotenoids present in orange-fleshed genotypes include lutein and zeaxanthin, which are classified as xanthophyll carotenoids. These compounds are well recognized for their protective role in eye health, particularly in preventing oxidative damage to retinal tissues and reducing the risk of age-related macular degeneration (Tanumihardjo, 2011). Lutein and zeaxanthin accumulate in the macular region of the retina, where they function as blue-light filters and antioxidants, thereby maintaining visual acuity and protecting photoreceptor cells from oxidative stress. Beyond visual health, carotenoids in sweet potato contribute significantly to immune enhancement and epithelial tissue maintenance. β-carotene acts as an antioxidant, scavenging reactive oxygen species and supporting immune cell function, while also promoting the integrity of skin and mucosal tissues (Burri, 2011). Regular consumption of carotenoid-rich OFSP has therefore been strongly associated with improved nutritional status, enhanced immune response and reduced incidence of micronutrient deficiencies in vulnerable populations (Low *et al*., 2017).

2.2 Anthocyanins

Purple-fleshed sweet potato cultivars are rich in anthocyanins, predominantly cyanidin and peonidin derivatives, which commonly occur in acylated forms that confer greater stability against heat, light and pH variations (Truong *et al*., 2010; Giusti and Wrolstad, 2003). These pigments are responsible for the characteristic purple coloration and represent the major phenolic compounds in such genotypes. Anthocyanins exhibit strong antioxidant and anti-inflammatory properties by effectively scavenging reactive oxygen species and regulating inflammatory signaling pathways (Prior and Wu, 2006). Their consumption has been associated with protective effects against oxidative stress-related disorders, including cardiovascular diseases, diabetes and obesity (Khoo *et al*., 2017).

2.3 Flavonoids

Flavonoids such as quercetin, kaempferol and catechins are widely distributed in sweet potato tissues, particularly in leaves and storage roots (Islam *et al*., 2002; Truong *et al*., 2007). These compounds are important polyphenols known for their strong antioxidant and anti-inflammatory activities, primarily through scavenging reactive oxygen species and modulating cellular signaling pathways involved in inflammation and oxidative stress (Panche *et al*., 2016). Flavonoids also act synergistically with phenolic acids, enhancing the overall antioxidant capacity and functional value of sweet potato. This synergistic interaction contributes to potential protective effects against chronic diseases such as cardiovascular disorders, diabetes and certain cancers (Liu, 2004).

2.4 Dietary fiber and resistant starch

Sweet potato is an important source of dietary fiber, comprising both soluble and insoluble fractions, along with appreciable amounts of resistant starch (Woolfe, 1992; Bovell-Benjamin, 2007). These components play a key role in maintaining gut health by promoting beneficial intestinal microbiota, improving bowel movement and enhancing satiety (Slavin, 2013). Resistant starch in sweet potato also contributes to glycemic regulation by slowing glucose digestion and absorption, thereby improving insulin sensitivity and reducing postprandial blood glucose levels (Englyst *et al*., 1992; Sajilata *et al*., 2006). Consequently, regular consumption of fiber and resistant starch-rich sweet potato is associated with improved metabolic health and reduced risk of lifestyle-related disorders.

Table 1: Quantitative range of major phytochemicals in different sweet potato genotypes

Genotype/plant part	β-carotene (mg/100 g FW)	Total anthocyanins (mg/100 g FW)	Total phenolics (mg GAE/100 g FW)	Antioxidant activity (%)	References
White-fleshed roots	0.1-0.5	0.50	50-120	30-45	Woolfe (1992); Teow *et al*. (2007)
Orange-fleshed roots	6-16	0.01	80-180	45-65	Low *et al*. (2017); Neela and Fanta (2022)
Purple-fleshed roots	0.5-2	40-150	150-300	65-90	Truong *et al*. (2010); Zhao *et al*. (2024)
Leaves	2-5	15-40	250-500	70-95	Islam *et al*. (2002); Li *et al*. (2023)

3. Biological mechanisms of bioactive compounds

Bioactive compounds present in sweet potato, including carotenoids, anthocyanins, flavonoids, phenolic acids and dietary fiber, exert health-promoting effects through multiple cellular and molecular mechanisms. A primary mechanism involves antioxidant activity, where these compounds scavenge reactive oxygen species (ROS) and reduce oxidative stress, thereby protecting cellular macromolecules such as lipids, proteins and DNA from damage (Alam *et al*., 2021). Another key mechanism is the regulation of inflammatory signaling pathways. Anthocyanins and other polyphenols suppress the activation of NF-κB and MAPK pathways, resulting in decreased production of pro-inflammatory cytokines and mediators (Ma *et al*., 2021; Chen *et al*., 2022). This modulation helps prevent chronic inflammation and associated disorders such as cardiovascular diseases and metabolic syndrome. Bioactive compounds also influence metabolic regulation. Polyphenols and resistant starch improve insulin sensitivity, regulate carbohydrate-digesting enzymes and contribute to better glucose homeostasis and reduced postprandial glycemic response (Chen *et al*., 2022). In addition, certain sweet-potato polyphenols have been shown to modulate signaling pathways related to apoptosis and cell-cycle control, further supporting their protective role against chronic diseases (Chowdhury *et al*., 2025).

3.1 Antioxidant activity

Sweet potato contains a wide range of antioxidant bioactive compounds, including carotenoids, anthocyanins, flavonoids and phenolic acids, which play a crucial role in protecting cells from oxidative damage. These compounds act primarily by scavenging reactive oxygen species (ROS), inhibiting lipid peroxidation and enhancing endogenous antioxidant defense systems (Alam *et al*., 2021). Anthocyanins present in purple-fleshed sweet potato exhibit particularly strong antioxidant capacity due to their ability to donate hydrogen atoms and stabilize free radicals, thereby reducing oxidative stress at the cellular level (Ma *et al*., 2021). Similarly, carotenoids such as β-carotene help quench singlet oxygen and protect cellular membranes from oxidative deterioration (Chen *et al*., 2022). The antioxidant activity of sweet potato bioactive compounds has been associated with reduced risk of chronic diseases such as cardiovascular disorders, diabetes, cancer and neurodegenerative conditions by preventing oxidative damage to biomolecules and modulating redox-sensitive signaling pathways (Alam *et al*., 2021; Chen *et al*., 2022).

3.2 Anti-inflammatory pathways

Anthocyanins and polyphenols from sweet potato exhibit strong anti-inflammatory effects by modulating key inflammatory signaling pathways. They inhibit activation of nuclear factor-kappa B (NF-κB) and mitogen-activated protein kinase (MAPK) pathways, which reduces the production of pro-inflammatory cytokines such as TNF-α, IL-6 and IL-1β. Furthermore, these compounds suppress cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS), leading to decreased synthesis of inflammatory mediators (Zhang *et al*., 2020; Chen *et al*., 2022). Such actions play a vital role in preventing chronic inflammatory diseases including arthritis, obesity and metabolic syndrome.

3.3 Antidiabetic mechanisms

Sweet potato contains a wide range of bioactive compounds that regulate glucose metabolism through multiple biochemical pathways. Phenolic compounds, flavonoids and anthocyanins have been reported to inhibit key carbohydrate-digesting enzymes such as α-amylase and α-glucosidase, thereby reducing the rate of starch hydrolysis and glucose absorption in the intestine. This enzymatic inhibition plays a crucial role in lowering post-prandial blood glucose levels and preventing rapid glycemic spikes (Zhang *et al.,* 2021; Kumar *et al.,* 2022). In addition, sweet potato bioactives improve insulin sensitivity by modulating intracellular signaling pathways. Studies indicate that phenolic extracts activate AMP-activated protein kinase (AMPK), which enhances glucose uptake and promotes lipid metabolism. Activation of AMPK further stimulates the expression and translocation of glucose transporter-4 (GLUT-4) in skeletal muscle and adipose tissues, thereby facilitating peripheral glucose utilization and improving insulin responsiveness (Li *et al*., 2020; Chen *et al*., 2023). Dietary fiber and resistant starch present in sweet potato also contribute significantly to glycemic regulation. These components delay gastric emptying, reduce intestinal glucose diffusion and enhance satiety. Furthermore, resistant starch acts as a prebiotic substrate that improves gut microbiota composition, leading to increased production of short-chain fatty acids (SCFAs), which play a role in insulin sensitivity and glucose homeostasis (Sun *et al*., 2019; Kaur *et al*., 2023). Collectively, these mechanisms enzyme inhibition, improved insulin signaling, enhanced glucose transport and gut microbiota modulation contribute to reduced post-prandial hyperglycemia and improved metabolic regulation, highlighting the therapeutic potential of sweet potato bioactive compounds in diabetes management.

3.4 Anticancer actions

Anthocyanins and phenolic compounds present in sweet potato particularly in purple-fleshed genotypes, exhibit significant anticancer potential through multiple molecular and cellular mechanisms. These bioactive compounds regulate tumor development primarily by modulating cell cycle progression and inducing programmed cell death (apoptosis). Studies have shown that anthocyanins can arrest the cell cycle at key checkpoints such as the G0/G1 and G2/M phases, thereby preventing uncontrolled proliferation of cancer cells (Li *et al*., 2021; *Wang et al., 2022*).

A major mechanism underlying their anticancer activity involves activation of apoptosis pathways. Anthocyanins stimulate caspase-dependent apoptotic signaling by enhancing the activity of initiator caspases (caspase-8 and caspase-9) and executioner caspase-3. These compounds also regulate mitochondrial membrane permeability by increasing the expression of pro-apoptotic proteins such as Bax while simultaneously suppressing anti-apoptotic proteins like Bcl-2. This shift in the Bax/Bcl-2 ratio promotes cytochrome-c release from mitochondria, ultimately leading to programmed cancer cell death (Zhang *et al*., 2020; Chen *et al.,* 2023). In addition to apoptosis induction, sweet potato phenolics inhibit tumor growth by suppressing angiogenesis the process of new blood vessel formation required for tumor progression. These compounds down-regulate vascular endothelial growth factor (VEGF) expression and inhibit endothelial cell migration, thereby limiting nutrient supply to tumors. Their strong antioxidant properties also play a critical role in reducing oxidative stress, which is a major contributor to DNA damage, mutation and carcinogenesis (Khan *et al.,* 2021). Furthermore, anthocyanins modulate key oncogenic signaling pathways involved in cancer development. They inhibit the phosphoinositide-3-kinase/protein kinase B (PI3K/Akt) pathway, which regulates cell survival and proliferation and suppress mitogen-activated protein kinase (MAPK) signaling involved in tumor cell growth and metastasis. By targeting these pathways, sweet potato bioactive compounds reduce tumor cell proliferation, invasion and metastasis potential (Li *et al*., 2021; Park *et al.,* 2022).

3.5 Immunomodulatory effects

Sweet potato polysaccharides and phenolics enhance immune function by stimulating macrophage activation, increasing lymphocyte proliferation and promoting cytokine secretion. These compounds regulate both innate and adaptive immune responses and improve host defense against infections. They also help maintain immune balance by reducing oxidative stress and inflammation (Wang *et al.*, 2020; Liu *et al.*, 2023).

3.6 Gut health modulation

Dietary fiber and resistant starch present in sweet potato play a crucial role in maintaining gut health by functioning as prebiotic substrates that selectively stimulate the growth and activity of beneficial intestinal microbiota. These non-digestible carbohydrates escape enzymatic digestion in the upper gastrointestinal tract and reach the colon, where they are fermented by beneficial bacterial populations such as *Bifidobacterium* and *Lactobacillus*. The proliferation of these microbes helps maintain microbial balance, suppress pathogenic bacteria and enhance overall intestinal health (Zhang *et al*., 2021; Kumar *et al.,* 2024). During fermentation, dietary fiber and resistant starch are metabolized by gut microbiota to produce short-chain fatty acids (SCFAs), primarily acetate, propionate and butyrate. These SCFAs perform several important physiological functions. Butyrate serves as the primary energy source for colonocytes and strengthens intestinal barrier integrity by promoting tight junction protein expression, thereby preventing intestinal permeability and microbial translocation. Propionate and acetate contribute to systemic metabolic regulation by influencing lipid metabolism, gluconeogenesis and appetite control (Sun *et al*., 2019; Liu *et al., 2022*). SCFAs exhibit anti-inflammatory effects by modulating immune responses and reducing pro-inflammatory cytokine production. They inhibit nuclear factor-kappa B (NF-κB) signaling pathways, which play a central role in inflammatory processes. This anti-inflammatory action helps protect against gastrointestinal disorders such as inflammatory bowel disease and reduces the risk of chronic metabolic conditions including obesity, diabetes and cardiovascular diseases (Koh *et al*., 2016; Zhang *et al.,* 2021).

4. Therapeutic applications of sweet potato bioactive compounds

Bioactive compounds present sweet potato including anthocyanins, carotenoids, phenolics, flavonoids and dietary fiber, exhibit wide-ranging therapeutic applications. These compounds contribute to disease prevention and health promotion through antioxidant, anti-inflammatory, metabolic regulatory and protective biological activities.

4.1 Antioxidant and antiaginge effects

Sweet potato bioactive compounds, particularly anthocyanins and phenolic constituents, exhibit strong antioxidant activity that plays a vital role in protecting cells from oxidative stress induced damage. These compounds act primarily by scavenging reactive oxygen species (ROS) such as superoxide radicals, hydroxyl radicals and hydrogen peroxide, thereby preventing oxidative injury to cellular components including lipids, proteins and DNA (Tang *et al*., 2023; *Rosell et al.,* 2024). In addition to direct radical scavenging, sweet potato phenolics enhance the endogenous antioxidant defense system.

Studies indicate that these compounds stimulate the activity of key antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx). This enzymatic upregulation helps maintain redox homeostasis and reduces lipid peroxidation, thereby limiting oxidative damage to cell membranes and other biomolecules (Zhu *et al*., 2021; Wang *et al.,* 2022).

Anthocyanins further contribute to anti-aging effects by protecting tissues from oxidative deterioration and maintaining cellular integrity. They stabilize mitochondrial function, reduce oxidative DNA damage and inhibit oxidative stress - mediated activation of inflammatory pathways such as NF-κB signaling. By preventing cumulative oxidative damage, these compounds help delay cellular senescence and reduce the risk of age-related chronic diseases including cardiovascular disorders, neurodegenerative diseases, diabetes and cancer (Tang *et al*., 2023; Chen *et al.,* 2022). Moreover, anthocyanins regulate cellular longevity pathways by modulating gene expression related to oxidative stress resistance and apoptosis control. They enhance the expression of antioxidant response elements through activation of nuclear factor erythroid-2 related factor-2 (Nrf2), which promotes cellular defense mechanisms against oxidative insults. This protective action plays a key role in maintaining tissue function and promoting healthy aging (Rosell *et al*., 2024; Zhu *et al.,* 2021).

4.2 Antidiabetic activity

Bioactive compounds play a significant role in diabetes management due to their multifaceted effects on glucose metabolism and metabolic regulation. Among these, anthocyanin-rich extracts derived particularly from purple-fleshed genotypes have been widely reported to improve glycemic control by enhancing insulin sensitivity and modulating key metabolic pathways. These compounds facilitate glucose uptake in peripheral tissues and improve insulin signaling, thereby reducing insulin resistance a major contributing factor in type 2 diabetes (Escobar-Puentes *et al*., 2022; Zhou *et al.,* 2025). Anthocyanins also regulate carbohydrate metabolism by improving glucose tolerance and lowering fasting blood glucose levels. They enhance pancreatic β-cell function and promote insulin secretion, while simultaneously reducing hepatic glucose production. In addition, these compounds inhibit oxidative stress-induced cellular damage in diabetic conditions by neutralizing reactive oxygen species and strengthening endogenous antioxidant defenses (Kim *et al*., 2021; Zhou *et al.,* 2025). Inflammation is another key factor associated with diabetes progression and sweet potato bioactives exhibit strong anti-inflammatory activity. Anthocyanins and phenolics suppress pro-inflammatory cytokines such as tumor necrosis factor-α (TNF-α) and interleukin-6 (IL-6) by inhibiting NF-κB signaling pathways. This anti-inflammatory effect helps protect pancreatic tissues, improve insulin responsiveness and prevent complications associated with chronic hyperglycemia (Escobar-Puentes *et al*., 2022; Wang *et al.,* 2023).

4.3 Anti-inflammatory effects

Phenolic compounds and anthocyanins from sweet potato exhibit strong anti-inflammatory activity by suppressing inflammatory mediators and cytokines. They reduce oxidative damage and inhibit inflammatory signaling pathways, thereby preventing chronic inflammatory diseases such as arthritis, obesity and metabolic syndrome

4.4 Anticancer and chemopreventive potential

Sweet potato bioactive compounds demonstrate anticancer properties through multiple mechanisms. Polyphenols and anthocyanins inhibit tumor cell proliferation, induce apoptosis and suppress angiogenesis. These compounds can also cause cell-cycle arrest by inhibiting Akt signaling pathways, thereby enhancing tumor suppression . Their antimutagenic and anticancer activities make them promising candidates for functional foods and nutraceutical development

4.5 Cardioprotective and metabolic benefits

Sweet potato bioactives contribute to cardiovascular health by regulating lipid metabolism, reducing oxidative stress and lowering blood pressure. They exhibit hypolipidemic and cardioprotective properties, thereby reducing the risk of cardiovascular diseases (Ivane *et al*., 2024; Zhou *et al*., 2025). These compounds also improve metabolic health by regulating lipid profiles and preventing obesity-related complications

Table 2: Experimental and clinical evidence supporting therapeutic potential of sweet potato bioactive compounds

Bioactive source	Model system	Dose	Observed effect	Disease target	References
Purple sweet potato anthocyanin extract	*In vitro* (cancer cell lines)	50-200 µg/mL	Induced apoptosis; cell cycle arrest (G2/M phase)	Cancer	Li *et al*. (2021); Zhang *et al*. (2020)
Purple sweet potato	Mice model	100-400 mg/kg body weight	Reduced inflammatory cytokines (TNF-α, IL-6); ↓ NF-κB activation	Inflammation	Chen *et al*. (2022); Ma *et al*. (2021)
Phenolic-rich extract	Diabetic rat model	200-500 mg/kg	Improved insulin sensitivity; ↓ fasting blood glucose	Type 2 Diabetes	Zhang *et al*. (2021); Chen *et al*. (2023)
Resistant starch from sweet potato	Human intervention study	15-30 g/day	Improved glycemic response; ↓ postprandial glucose	Metabolic syndrome	Sun *et al*. (2019); Kaur *et al*. (2023)
Orange-fleshed sweet potato (dietary intake)	Community intervention (children)	100-125 g/day	Improved serum retinol levels	Vitamin A deficiency	Low *et al*. (2017)
Sweet potato poly saccharides	Animal model	100-300 mg/kg	Enhanced macrophage activation; ↑ cytokine response	Immunomodulation	Sun *et al*. (2022); Liu *et al*. (2023)

5. Environmental and agronomic factors influencing phytochemical accumulation

The concentration and composition of bioactive compounds in sweet potato are strongly influenced by environmental conditions, agronomic practices and post-harvest management. Although genetic factors play a primary role in determining phytochemical potential, external factors significantly regulate the expression and accumulation of carotenoids, anthocyanins, phenolics and dietary fiber.

5.1 Genotype environment interaction

Sweet potato exhibits substantial genotype-dependent variation in phytochemical composition due to its hexaploid genome and high genetic diversity. However, the expression of these traits is significantly modified by environmental conditions such as temperature, light intensity, soil fertility, and water availability. Studies indicate that cooler growing temperatures enhance anthocyanin accumulation in purple-fleshed genotypes, whereas warmer climates tend to favor carotenoid biosynthesis in orange-fleshed cultivars (Wang *et al*., 2021; Zhao *et al*., 2024). Such genotype–environment interactions highlight the importance of location-specific cultivar selection for maximizing nutraceutical quality.

5.2 Influence of soil and nutrient management

Soil fertility and nutrient availability play a crucial role in determining phytochemical content. Nitrogen and potassium fertilization have been reported to significantly affect phenolic synthesis and antioxidant activity in sweet potato roots and leaves. Adequate potassium levels enhance carbohydrate metabolism and promote carotenoid accumulation, while balanced nitrogen nutrition supports phenolic biosynthesis through regulation of the phenylpropanoid pathway (Li *et al*., 2023).

5.3 Effect of climate and abiotic stress

Abiotic stresses such as drought, salinity and temperature fluctuations can stimulate the production of secondary metabolites in sweet potato. Stress conditions often induce oxidative stress within plant tissues, triggering the synthesis of protective compounds such as phenolics and anthocyanins. Consequently, moderate environmental stress may enhance antioxidant potential, although severe stress can reduce overall yield and biomass (Alam *et al*., 2022).

5.4 Harvest maturity and storage conditions

The stage of harvest significantly influences phytochemical concentration. Mature storage roots generally exhibit higher levels of carotenoids and phenolics compared to immature roots. Post-harvest storage conditions, particularly temperature and humidity, also affect phytochemical stability. Controlled storage environments help preserve anthocyanins and prevent oxidative degradation of carotenoids (Sun *et al*., 2022).

5.5 Processing and cooking effects

Thermal processing methods such as boiling, baking and drying can alter phytochemical retention. While heat treatment may cause partial degradation of carotenoids, it can also enhance bioavailability by breaking down cell wall matrices. Anthocyanins are relatively heat-sensitive but remain more stable in acylated forms typical of purple sweet potato (Zhao *et al*., 2024).

Table 3: Effect of processing methods on phytochemical retention and glycemic index

Processing method	β-carotene retention (%)	Anthocyanin retention (%)	Phenolic retention (%)	Glycemic index range	References
Boiling	80-95	70-85	75-90	44-61	Sun *et al*. (2019); Bovell-Benjamin (2007)
Baking	65-85	60-75	65-80	70-94	Bovell-Benjamin (2007); Rosell *et al*. (2024)
Frying	50-70	40-60	50-70	75-95	Zhao *et al*. (2024)
Drying	70-85	55-70	60-75	-	Teow *et al*. (2007); Rosell *et al*. (2024)

6. Safety, toxicology and recommended intake levels of sweet potato bioactive compounds

Although sweet potato is widely recognized as a safe and nutritionally valuable food crop, understanding its safety profile, potential toxicological concerns and recommended intake levels is essential for its application as a functional food and nutraceutical resource. Bioactive compounds such as carotenoids, anthocyanins, phenolics, dietary fiber and resistant starch are generally considered safe, but their physiological effects depend on dosage, bioavailability and individual health conditions.

6.1 General safety profile

Sweet potato has a long history of safe consumption across diverse populations and its bioactive compounds are classified as non-toxic and nutritionally beneficial. Carotenoids such as β-carotene are regarded as safe dietary antioxidants, with no evidence of toxicity even at relatively high intake levels due to their regulated conversion into vitamin A. Similarly, anthocyanins and phenolic compounds are widely recognized as safe natural antioxidants with low toxicity and minimal adverse effects (Wang *et al*., 2020; Chen *et al*., 2022). Dietary fiber and resistant starch further contribute to gastrointestinal health and metabolic regulation without posing safety concerns when consumed within recommended dietary limits.

6.2 Antinutritional factors

Despite its safety, sweet potato contains certain naturally occurring antinutritional components, including oxalates, tannins and trypsin inhibitors. Oxalates, present mainly in leaves and storage roots, may interfere with calcium absorption and contribute to kidney stone formation in susceptible individuals when consumed in excessive quantities. However, traditional cooking methods such as boiling and steaming significantly reduce oxalate levels, thereby minimizing potential health risks (Bovell-Benjamin, 2007). Tannins and enzyme inhibitors are also present in small amounts but generally do not pose toxicity concerns due to their low concentration and degradation during processing.

6.3 Glycemic and metabolic considerations

Although sweet potato is considered beneficial for glycemic regulation due to its fiber and resistant starch content, excessive consumption of high-glycemic varieties may lead to elevated blood glucose levels in individuals with diabetes. Glycemic response varies depending on cultivar, processing method and cooking technique. For example, boiled sweet potato typically exhibits a lower glycemic index compared to baked or fried forms. Therefore, controlled portion intake and appropriate processing methods are recommended for individuals with metabolic disorders (Sun *et al*., 2019; Kaur *et al*., 2023).

6.4 Toxicological studies and safe dosage

Experimental toxicological studies have demonstrated that sweet potato extracts, including anthocyanin-rich fractions and phenolic compounds, exhibit very low toxicity in both *in vitro* and animal models. Acute and sub-chronic toxicity assessments indicate no significant adverse effects on liver, kidney, or hematological parameters even at high doses. Anthocyanins, in particular, show excellent safety profiles due to their rapid metabolism and elimination from the body (Tang *et al*., 2023; Rosell *et al*., 2024). Recommended dietary intake levels are generally based on nutritional guidelines rather than toxicological limits. Consumption of 100-200 g of cooked sweet potato per day is considered safe and nutritionally beneficial, providing adequate levels of carotenoids, dietary fiber and antioxidants. For functional or therapeutic applications, standardized extracts should be used within clinically validated dosage ranges to avoid excessive intake of concentrated phytochemicals.

6.5 Allergic reactions and special considerations

Allergic reactions to sweet potato are extremely rare but may occur in individuals with specific plant protein sensitivities. Additionally, individuals with kidney disorders or oxalate sensitivity should limit excessive intake of raw or poorly processed sweet potato. Pregnant and lactating women can safely consume sweet potato as part of a balanced diet, as no teratogenic or reproductive toxicity effects have been reported in scientific studies (Wang *et al*., 2020).

7. Future prospects and research gaps

Sweet potato (*Ipomoea batatas* L.) is increasingly recognized as a functional food due to its rich content of carotenoids, anthocyanins, phenolics, dietary fiber and resistant starch. Despite substantial evidence supporting its therapeutic potential, several research gaps remain that must be addressed to enhance its utilization in food, pharmaceutical and nutraceutical applications. One of the major limitations is the insufficient understanding of the bioavailability, absorption and metabolism of bioactive compounds in humans, which requires further investigation using advanced delivery systems such as nano-encapsulation and micro-emulsion technologies (Wang *et al*., 2021; Tang *et al*., 2023). Additionally, most therapeutic claims are based on *in vitro* and animal studies, highlighting the need for well-designed clinical trials to establish efficacy, safety, and standardized dosage levels (Kaur *et al*., 2023; Ivane *et al*., 2024). Significant genetic variability among sweet potato genotypes also presents opportunities for breeding programs aimed at developing cultivars with enhanced bioactive content through molecular and genomic approaches (Truong *et al*., 2018; Liu *et al*., 2022). Furthermore, there is growing potential for incorporating sweet potato bioactives into functional foods and nutraceutical products, which requires optimization of processing techniques to preserve phytochemical stability (Rosell *et al*., 2024). Sustainable utilization of processing by-products such as peels and residues, which are rich in antioxidants, also represents an important area for value addition and reduction of post-harvest losses (Sun *et al*., 2019).

8. Conclusion

Sweet potato is a nutritionally rich and therapeutically valuable root crop that contains diverse bioactive compounds such as carotenoids, anthocyanins, phenolic acids, flavonoids, dietary fiber, and resistant starch. These compounds play a significant role in promoting human health through multiple biological mechanisms, including antioxidant defense, anti-inflammatory activity, metabolic regulation, immunomodulation and gut health enhancement. The presence of these phytochemicals makes sweet potato an important functional food with potential applications in preventing and managing chronic diseases such as diabetes, cardiovascular disorders, cancer and inflammatory conditions (Wang *et al.*, 2020; Kaur *et al.*, 2023). Among the various bioactive components, anthocyanins from purple-fleshed genotypes and β-carotene from orange-fleshed varieties have received considerable attention due to their strong antioxidant and health-promoting properties. These compounds contribute to cellular protection by reducing oxidative stress, regulating inflammatory pathways, improving insulin sensitivity and supporting immune function (Tang *et al.*, 2023; Rosell *et al.*, 2024). Additionally, dietary fiber and resistant starch enhance gut microbiota composition and metabolic health, further highlighting the functional importance of sweet potato consumption. Despite extensive research on its nutritional and therapeutic benefits, several gaps remain in understanding the bioavailability, metabolism and clinical efficacy of sweet potato bioactives. Future research should focus on human clinical studies, advanced processing technologies to preserve phytochemicals, genetic improvement of high-bioactive cultivars and development of value-added functional food products. Integrating multidisciplinary approaches involving plant breeding, food science, nutrition and biotechnology will help maximize the potential of sweet potato as a sustainable and health-promoting crop. Overall, sweet potato represents a promising functional food and nutraceutical resource with significant potential to contribute to food security, nutritional health and disease prevention globally. Continued research and technological advancements will further enhance its utilization in improving human health and supporting sustainable agricultural systems.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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