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Tuber crops as functional foods for chronic disease prevention and management

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Abstract

The pronounced rise in chronic non-communicable diseases, including diabetes mellitus, cardiovascular disorders, obesity, and cancer, has intensified global interest in dietary strategies for disease prevention. Functional foods derived from plant sources have gained considerable prominence due to their ability to confer health benefits beyond basic nutrition (Granato *et al*., 2020). Tuber crops, traditionally consumed as staple foods in tropical and subtropical regions, are increasingly recognized as phytomedicinal foods owing to their rich content of dietary fiber, resistant starch, vitamins, minerals, and diverse bioactive compounds (Burlingame *et al*., 2019). Major tuber crops such as sweet potato (*Ipomoea batatas*), yam (*Dioscorea* spp.), taro (*Colocasia esculenta*), and cassava (Manihot esculenta) contain specific bioactive constituents, including anthocyanins (cyanidin-3-glucoside and peonidin-3-glucoside), phenolic acids such as chlorogenic acid, carotenoids (β-carotene), steroidal saponins such as diosgenin, and resistant starch fractions (RS2 and RS3). These compounds exhibit well-documented antioxidant, anti-inflammatory, hypoglycaemic, and cardioprotective properties (Wang *et al*., 2022). Emerging experimental and population-level evidence increasingly supports the pivotal role of regular tuber crop consumption in the prevention and management of chronic diseases. This review consolidates current knowledge on the nutritional composition, phytochemical profile, mechanisms of action, and therapeutic potential of tuber crops, highlighting their significance as functional foods and phytomedicinal resources.

1. Introduction

Chronic non-communicable diseases (NCDs), including diabetes mellitus, cardiovascular diseases, obesity and cancer, have emerged as the dominant global health challenge of the twenty-first century. As per World Health Organization, NCDs currently account for nearly 74 per cent of global mortality, with a rapidly increasing burden in low and middle-income countries where dietary patterns are undergoing profound transitions (WHO, 2023). India represents a critical example of this trend, with recent epidemiological evidence detects that more than 101 million adults are living with diabetes and a substantial proportion of the population is affected by hypertension and metabolic syndrome (Anjana *et al*., 2023). These conditions are aligned with dietary shifts characterized by increased consumption of refined carbohydrates, ultra-processed foods and reduced intake of fiber-rich, plant-based diets.

Although, pharmacological interventions serve a key role in disease management, their long-term effectiveness in prevention remains limited, and they are often associated with economic and compliance constraints. Consequently, increasing attention has been directed toward sustainable, diet-based strategies that emphasize the preventive potential of everyday foods. In this context, functional foods defined as foods that confer health benefits beyond basic nutrition have gained significant scientific and public health relevance (Martirosyan and Singh, 2019; Granato *et al*., 2020). Plant-based functional foods are particularly valuable due to their richness in phytochemicals such as polyphenols, flavonoids and carotenoids, which modulate oxidative stress, inflammation, lipid metabolism and glucose homeostasis, all of which are central to the pathophysiology of chronic diseases (Shahidi and Ambigaipalan, 2019). Tuber crops, traditionally consumed as staple foods across tropical and subtropical regions, have long been undervalued in this functional food paradigm due to their perceived high carbohydrate content. However, recent nutritional and clinical research has challenged this perception by demonstrating that tuber crops predominantly contain complex carbohydrates, dietary fiber and resistant starch that contribute to a low glycaemic load and improved metabolic responses (Kaur *et al*., 2021; Burlingame *et al*., 2019). In addition, tuber crops are increasingly recognized as rich sources of bioactive compounds with phytomedicinal properties. Recent intervention and community-based studies provide compelling evidence supporting the functional role of tuber crops in chronic disease management. A dietary intervention study conducted in Bangladesh reported significant reductions in fasting blood glucose and serum lipid levels among individuals with type 2 diabetes following regular consumption of

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sweet potato-based meals over a 12-week period (Alam *et al*., 2021). Similarly, probabilistically this trails assigned in China demonstrated that substitution of refined rice with purple-fleshed sweet potato resulted in significant decreases in oxidative stress markers and inflammatory cytokines among pre-diabetic adults, highlighting the antioxidant and anti-inflammatory potential of anthocyanin-rich tubers (Wang *et al*., 2022).

Large-scale public health programs further underscore the relevance of tuber crops in disease prevention and nutritional security. The promotion of orange-fleshed sweet potato through nutrition-sensitive agricultural interventions in sub-Saharan Africa led to substantial improvements in vitamin A status among women and children, while also demonstrating secondary benefits related to immune competence and metabolic health (Low *et al*., 2019; Ruel *et al*., 2021). These findings emphasize the dual role of tuber crops in addressing micronutrient deficiencies and reducing chronic disease risk. Beyond sweet potato, other tuber crops have also demonstrated significant phytomedicinal potential. Yam species (*Dioscorea* spp.) contain diosgenin, a steroidal saponin that has been shown to exert cholesterol-lowering, anti-inflammatory and cardioprotective effects. Recent experimental studies reported improved lipid profiles and endothelial function following dietary supplementation with yam extracts in hyperlipidaemic models (Price *et al*., 2023). Taro (*C. esculenta*), characterized by its small starch granules and mucilaginous compounds, has been associated with improved digestibility and favourable post-prandial glycaemic responses, particularly among elderly populations, as reported in cohort studies from Japan (Kawai *et al*., 2020). Elephant foot yam (*Amorphophallus paeoniifolius*), widely used in traditional Indian medicine, has recently gained scientific validation for its anti-inflammatory and hepatoprotective properties, with experimental studies demonstrating significant reductions in inflammatory biomarkers and liver enzyme levels following dietary inclusion (Dey *et al*., 2020). Despite this growing body of evidence, tuber crops remains under-represented in functional food and phytomedicine literature compared to cereals, fruits and legumes. Existing studies are often fragmented; focusing on individual crops or isolated compounds, and misconceptions regarding their carbohydrate content continue to limit their inclusion in dietary recommendations for individuals with diabetes and cardiovascular diseases. Given their widespread consumption, cultural acceptability, affordability and resilience under changing climatic conditions, tuber crops represent a strategically important yet underutilized resource for sustainable health promotion. In this context, the present review aims to critically synthesize recent evidence on the nutritional composition, phytochemical profile and mechanistic pathways through which tuber crops contribute to chronic disease prevention and management, thereby highlighting their potential as functional foods and phytomedicinal resources in contemporary diets.

2. Potential of tuber crops in chronic disease management

Tuber crops have gained increasing recognition as functional foods with significant potential in the prophylaxis and control of chronic non-communicable diseases. Traditionally regarded as energy-rich staples, tuber crops are now understood to provide complex carbohydrates, dietary fiber, resistant starch and diverse phytochemicals that collectively influence metabolic health. Recent nutritional and clinical evidence indicates that regular consumption of tuber crops can modulate key physiological processes such as glucose metabolism, lipid regulation, oxidative stress and inflammatory responses, which are central to the expansion and transition of chronic diseases (Kaur *et al*., 2021; Shahidi and Ambigaipalan, 2019).

2.1 Dietary role of tuber crops in glycaemic control and type 2 diabetes mellitus

One of the most extensively documented benefits of tuber crops relates to glycaemic control and diabetes management. Unlike refined cereal-based carbohydrates, tuber crops generally exhibit a low to moderate glycaemic index due to their high fiber content and the presence of resistant starch, which delays gastric emptying and glucose absorption (Zhu *et al*., 2020). Dietary intervention reported sweet potato consumption leads to significant reductions in post-prandial blood glucose levels and enrich insulin sensitivity in including each of them with type 2 diabetes (Alam *et al*., 2021). Polyphenols and anthocyanins present in purple-fleshed sweet potato have further been reported to enhance pancreatic β-cell function and reduce oxidative stress, thereby offering protective effects against diabetes-related complications (Wang *et al*., 2022). In sweet potato, anthocyanins such as cyanidin-3-glucoside and peonidin-3-glucoside, along with chlorogenic acid, have been identified as key contributors to glycaemic regulation. These compounds modulate glucose metabolism by enhancing insulin sensitivity and reducing oxidative stress. Additionally, resistant starch fractions (RS2 and RS3) present in cassava and cooked-and-cooled sweet potato delay carbohydrate digestion and attenuate post-prandial glucose excursions, thereby improving glycaemic control in individuals with type-2 diabetes mellitus. At the molecular level, anthocyanins such as cyanidin-3-glucoside and peonidin-3-glucoside derived from purple-fleshed sweet potato activate AMP-activated protein kinase (AMPK), a central regulator of cellular energy homeostasis. Activation of AMPK enhances glucose uptake in skeletal muscle, suppresses hepatic gluconeogenesis and improves insulin sensitivity. This pathway-mediated action provides a mechanistic explanation for the observed hypoglycaemic effects of anthocyanin-rich tuber crops in experimental and human dietary studies (Khoo *et al*., 2019; Wang *et al*., 2022). In addition to AMPK activation, tuber-derived phenolic compounds, including chlorogenic acid, modulate the phosphatidylinositol 3-kinase (PI3K)/Akt signaling pathway, which plays a critical role in insulin-mediated glucose transport. Enhancement of PI3K/Akt signaling facilitates translocation of glucose transporter-4 (GLUT4) to the cell membrane, thereby improving insulin responsiveness and glycaemic control. These molecular effects support the role of sweet potato and taro as functional foods in the dietary management of type 2 diabetes mellitus (Kaur *et al*., 2021; Wang *et al*., 2022).

In vitro evidence indicates that anthocyanins such as cyanidin-3-glucoside and phenolic acids including chlorogenic acid isolated from sweet potato significantly enhance glucose uptake and suppress oxidative stress in insulin-resistant cell models through activation of AMPK and PI3K/Akt signaling pathways (Khoo *et al*., 2019; Wang *et al*., 2022). *In vivo* (animal) studies further demonstrate that dietary supplementation with anthocyanin-rich sweet potato and diosgenin-containing yam extracts leads to improved insulin sensitivity, reduced fasting blood glucose and attenuation of oxidative stress markers in diabetic rodent models (Price *et al*., 2023). Human dietary and intervention studies provide translational support, with clinical and community-based trials reporting significant reductions in post-prandial blood glucose and improved glycaemic indices following regular consumption of sweet potato-based diets, particularly those rich in resistant starch and anthocyanins (Alam *et al*., 2021; Kaur *et al*., 2021).

Dose response and extract-specific evidence further supports the translational relevance of tuber crops in glycaemic control. In animal studies, aqueous and ethanolic extracts of anthocyanin-rich sweet potato, administered at physiologically relevant doses equivalent to regular dietary intake, have demonstrated significant improvements in fasting blood glucose and insulin sensitivity without adverse effects. Human dietary intervention studies involving daily consumption of boiled or steamed sweet potato for 8-12 weeks have reported measurable reductions in post-prandial glucose levels and glycaemic index, highlighting the effectiveness of whole-food- based interventions rather than pharmacological overdosing (Alam *et al*., 2021; Wang *et al*., 2022). Collectively, the convergence of *in vitro*, in vivo and human dietary evidence strengthens the pharmacological rationale for incorporating tuber crops into chronic disease prevention and management strategies.

2.2 Mechanistic insights into cardiovascular benefits of tuber crops

Cardiovascular health represents a critical domain in which tuber crops exhibit substantial functional potential. Their naturally low fat content, coupled with high levels of potassium and dietary fiber, contributes to effective blood pressure regulation and favorable lipid profiles. Epidemiological evidence consistently links potassium-rich plant-based diets with a reduced risk of hypertension and major cardiovascular events (Mozaffarian, 2020). Experimental studies further demonstrate that flavonoids and phenolic acids present in tuber crops enhance endothelial function, inhibit low-density lipoprotein oxidation, and attenuate systemic inflammation, thereby reducing the risk of atherosclerosis and coronary heart disease (Wang *et al.*, 2022; Price *et al.*, 2023). Chronic inflammation is a central driver of cardiovascular pathology, and tuber-derived phytochemicals exert potent anti-inflammatory effects through suppression of the nuclear factor kappa B(NF-κB) signaling pathway. Anthocyanins from sweet potato and phenolic compounds from elephant foot yam have been shown to inhibit NF-κB activation, resulting in reduced expression of pro-inflammatory cytokines, including tumor necrosis factor-α and interleukin-6. This NF-κB mediated modulation underpins the cardioprotective and anti-inflammatory attributes of tuber crops (Shahidi and Ambigaipalan, 2019; Dey *et al.*, 2020).

Regulation of lipid metabolism by tuber crops is closely linked to activation of peroxisome proliferator-activated receptor gamma (PPAR-γ). Diosgenin, the principal bioactive constituent of yam (*Dioscorea* spp.), functions as a natural PPAR-γ modulator, promoting improved lipid homeostasis, reduced adipocyte inflammation, and enhanced insulin sensitivity. These molecular actions collectively contribute to the cholesterol-lowering and cardioprotective effects associated with yam-based diets (Price *et al.*, 2023). Evidence from *in vitro* and *in vivo* studies indicates that tuber-derived polyphenols inhibit LDL oxidation, enhance endothelial nitric oxide synthase (eNOS) activity, and suppress vascular inflammation, thereby preserving endothelial integrity. Animal studies using diosgenin-rich yam extracts administered over 6-10 weeks at physiologically relevant dietary doses have demonstrated significant lipid-lowering and endothelial-protective effects, underscoring their functional food relevance rather than pharmacological drug action (Price *et al.*, 2023).

Complementing these findings, human observational and dietary studies consistently associate regular consumption of yam and sweet potato with improved lipid profiles, enhanced vascular function, and reduced cardiovascular risk, reinforcing the dose-dependent cardioprotective potential of tuber crops (Mozaffarian, 2020; Price *et al.*, 2023).

2.3 Bioactive mediated anticancer effects of tuber crops

Emerging evidence increasingly supports the role of tuber crops in cancer prevention and management. Bioactive constituents such as anthocyanins, carotenoids, and phenolic acids exhibit potent antioxidant and antiproliferative activities that are critical in mitigating oxidative DNA damage and uncontrolled cellular proliferation. *In vitro* and *in vivo* studies have demonstrated that extracts from purple-fleshed sweet potato and yam suppress the growth of colon, breast, and liver cancer cells through induction of apoptosis and inhibition of inflammatory signaling pathways (Khoo *et al.*, 2019; Price *et al.*, 2023). Although large-scale human clinical trials remain limited, these findings provide a robust mechanistic foundation for the chemopreventive potential of tuber crops. Among the bioactive compounds, anthocyanins particularly cyanidin-3-glucoside from purple-fleshed sweet potato have shown strong antiproliferative and pro-apoptotic effects in experimental cancer models. Similarly, diosgenin from yam exhibits notable chemopreventive activity by inhibiting tumor cell proliferation and suppressing inflammation-related signaling pathways, underscoring the compound-specific anticancer relevance of tuber crops (Khoo *et al.*, 2019; Price *et al.*, 2023).

Although, the majority of anticancer evidence remains preclinical, dose-dependent effects of tuber-derived phytochemicals have been consistently demonstrated. Ethanolic extracts of purple-fleshed sweet potato and yam, enriched in anthocyanins and diosgenin, respectively, exhibit antiproliferative activity at concentrations achievable through concentrated dietary intake rather than pharmacological extremes. This highlights the importance of realistic dose considerations when translating experimental findings into functional food applications (Khoo *et al.*, 2019; Price *et al.*, 2023). Human epidemiological evidence, though limited, indicates that diets rich in phytochemical-dense plant foods, including tuber crops, are associated with a reduced risk of certain cancers, providing population-level support for their chemopreventive potential (Shahidi and Ambigaipalan, 2019).

2.4 Gut microbiota mediated metabolic benefits

Obesity and metabolic syndrome recognized as pivotal antecedents of type 2 diabetes and cardiovascular disorders are increasingly modulated by habitual consumption of tuber crops. The substantial dietary fiber and resistant starch content inherent to tubers promotes prolonged satiety, attenuates overall energy intake, and favorably regulates lipid metabolism. Upon colonic fermentation, resistant starch serves as a substrate for gut microbiota, leading to the generation of short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate, which exert multifaceted physiological effects, including appetite modulation, enhancement of insulin sensitivity, and suppression of low-grade systemic inflammation (Canfora *et al*., 2019). Furthermore, epidemiological and population-based investigations have consistently demonstrated an inverse association between the consumption of fiber-rich root and tuber crops and body mass index, alongside significant improvements in key metabolic biomarkers, underscoring their protective role in metabolic health (Kaur *et al.*, 2021).

2.5 Gastrointestinal health and chronic disease prevention

Beyond their role in metabolic disorders, tuber crops contribute significantly to gastrointestinal health, which is increasingly recognized as a critical determinant of chronic disease risk. Taro and arrowroot, characterized by easily digestible starch granules and mucilaginous compounds, have long been utilized in traditional diets for managing gastrointestinal disorders and during convalescence. Contemporary studies substantiate their prebiotic effects and capacity to enhance gut barrier integrity and microbial diversity, thereby indirectly modulating immune function and metabolic health (Kawai *et al.*, 2020; Montagnac *et al.*, 2021). Collectively, the available evidence highlights the multifaceted role of tuber crops in chronic disease management through integrated nutritional, phytochemical, and microbiota-mediated mechanisms. Their wide availability, cultural acceptance, and affordability further reinforce their potential as sustainable dietary interventions. Consequently, the incorporation of tuber crops into regular diets particularly in regions experiencing rapid nutrition transition offers a practical and cost-effective approach to reducing the burden of chronic diseases and improving population health outcomes.

Table 1: Tuber crops, major bioactive compounds and their role in chronic disease management

Tuber crop	Major bioactive compounds	Target chronic diseases	Mechanisms of action	References
Sweet potato	Cyanidin-3-glucoside, peonidin-3-glucoside, chlorogenic acid, β-carotene, resistant starch	Diabetes, CVDs, cancer, obesity	Antioxidant activity, improved insulin sensitivity, reduced oxidative stress, lipid modulation	Alam *et al.*, 2021; Wang *et al.*, 2022; Khoo *et al.*, 2019
Yam	Diosgenin, flavonoids, saponins	CVDs, cancer, metabolic disorders	Cholesterol lowering, anti-inflammatory effects, endothelial protection	Price *et al.*, 2023; Shahidi and Ambigaipalan, 2019
Taro	Gallic acid, catechin, mucilage, dietary fiber	Diabetes, gastrointestinal disorders	Low glycaemic response, improved gut health, prebiotic effects	Kawai *et al.*, 2020; Temesgen and Retta, 2018
Cassava	Resistant starch (RS2, RS3), polyphenols	Diabetes, obesity, gut health	Improved insulin sensitivity, modulation of gut microbiota	Montagnac *et al.*, 2021; Zhu *et al.*, 2020
Elephant foot yam	Phenolics, flavonoids, bioactive polysaccharides	Inflammatory disorders, liver diseases	Anti-inflammatory, hepatoprotective effects	Dey *et al.*, 2020
Arrow root	Easily digestible starch, dietary fiber	Metabolic disorders, gastro-intestinal health	Improved digestibility, gut soothing and prebiotic effects	Burlingame *et al.*, 2019

3. Tuber crops as functional foods

Tuber crops are increasingly recognized as functional foods owing to their ability to confer physiological benefits beyond basic nutrition. Traditionally consumed as staple foods in tropical and subtropical regions, tuber crops such as sweet potato (*I. batatas*), yam (*Dioscorea* spp.), taro (*C. esculenta*), cassava (*M. esculenta*), elephant foot yam (*A. paeoniifolius*), and arrowroot (*M. arundinacea*) provide a unique combination of complex carbohydrates, dietary fiber, resistant starch, essential micronutrients, and diverse phytochemicals that collectively promote health and reduce disease risk (Burlingame *et al.*, 2019; Granato *et al.*, 2020). The functional attributes of tuber crops are largely mediated by compound-specific bioactive components, including β-carotene in orange-fleshed sweet potato, anthocyanins (cyanidin-3-glucoside and peonidin-3-glucoside) in purple-fleshed varieties, diosgenin in yam, and resistant starch fractions (RS2 and RS3) in cassava, which collectively modulate glycaemic, lipid, and inflammatory pathways. Unlike refined carbohydrate sources, tuber crops predominantly contain slowly digestible starch and resistant starch, which help moderate postprandial glucose responses and improve insulin sensitivity. Recent nutritional studies have demonstrated that diets incorporating tuber-based carbohydrates are associated with lower glycaemic load and improved metabolic outcomes compared with refined cereal-based foods (Kaur *et al.*, 2021; Zhu *et al.*, 2020). This characteristic is particularly relevant in the context of the rising prevalence of diabetes and metabolic syndrome. Beyond their carbohydrate quality, tuber crops are rich in dietary fiber, which plays a pivotal role in regulating gut health, lipid metabolism, and appetite control. Fermentation of dietary fiber and resistant starch by the gut microbiota generates short-chain fatty acids that exert anti-inflammatory effects and enhance glucose and lipid homeostasis, thereby reinforcing the functional food value of tuber crops (Canfora *et al.*, 2019). The phytochemical profile of tuber crops further contributes to their health-promoting properties. Orange and purple-fleshed sweet potato varieties are rich sources of β-carotene and anthocyanins, respectively, with potent antioxidant and anti-inflammatory activities (Khoo *et al.*, 2019; Wang *et al.*, 2022). Yam species contain diosgenin, a steroidal saponin associated with cholesterol-lowering and cardioprotective effects, while taro and elephant foot yam provide phenolic compounds and mucilage that support gastrointestinal and metabolic health (Dey *et al.*, 2020; Price *et al.*, 2023).

3.1 Influence of processing and culinary practices on functional quality

Processing and cooking methods influence the functional quality of tuber crops; however, traditional practices such as boiling, steaming and fermentation generally preserve or enhance bioactive compound availability while reducing antinutritional factors (Montagnac *et al.*, 2021). This makes tuber crops practical functional foods that can be easily incorporated into daily diets without major dietary modifications. Given their affordability, cultural acceptance, nutritional density and phytochemical richness, tuber crops represent sustainable functional foods with significant relevance for public health nutrition. Their integration into regular diets, dietary guidelines and nutrition-sensitive agricultural programs can contribute meaningfully to the prevention and management of chronic diseases, particularly in regions undergoing rapid nutrition transition.

3.2 Phytochemical pharmacological interfaces of tuber crops in chronic disease management

Understanding the health-promoting potential of tuber crops requires moving beyond their general nutritional attributes to a phytochemical-pharmacological interface, wherein specific bioactive compounds are mechanistically linked to molecular targets and disease outcomes. Recent advances in nutritional pharmacology demonstrate that tuber-derived phytochemicals exert therapeutic effects through modulation of key cellular signaling pathways involved in glucose metabolism, lipid regulation, inflammation, oxidative stress, and endothelial function (Zhang *et al.*, 2015; Liu *et al.*, 2021). Anthocyanins present in purple-fleshed sweet potato, particularly cyanidin-3-glucoside and peonidin-3-glucoside, play a pivotal role in metabolic regulation. Experimental evidence indicates that these compounds activate AMP-activated protein kinase (AMPK) and enhance PI3K/Akt signaling, thereby improving insulin sensitivity and glucose uptake in peripheral tissues (Tsuda, 2012; Zhu *et al.*, 2018). Simultaneously, anthocyanins suppress nuclear factor kappa B(NF-κB)-mediated inflammatory responses, reducing chronic low-grade inflammation associated with type 2 diabetes and cardiovascular diseases (Kang *et al.*, 2019). These mechanisms provide a pharmacological basis for the glycaemic and anti-inflammatory benefits observed in anthocyanin-rich sweet potato varieties.

Phenolic acids such as chlorogenic acid, abundantly distributed in sweet potato and taro, contribute to metabolic homeostasis by inhibiting hepatic glucose production and attenuating oxidative stress. Chlorogenic acid modulates glucose-6-phosphatase activity and improves lipid metabolism through regulation of peroxisome proliferator-activated receptor gamma (PPAR-γ) signaling, with particular relevance to metabolic syndrome and dyslipidaemia management (Meng *et al.*, 2013; Tajik *et al.*, 2017). Yam (*Dioscorea* spp.) exhibits distinct pharmacological relevance due to diosgenin, a steroidal saponin with well-documented bioactivity. Diosgenin exerts cholesterol-lowering and cardioprotective effects *via* modulation of PPAR-γ, inhibition of pro-inflammatory cytokines, and enhancement of endothelial nitric oxide synthase (eNOS) activity, leading to improved vascular function (Son *et al.*, 2007; Chen *et al.*, 2015). Additionally, diosgenin demonstrates anti-proliferative effects in cancer models by inducing apoptosis and suppressing tumour-associated inflammatory pathways (Raju and Mehta, 2009).

Taro contains phenolic compounds such as gallic acid and catechin, which exhibit antioxidant and anti-inflammatory activities through scavenging of reactive oxygen species and down regulation of oxidative stress induced signaling cascades. These effects support gastro-intestinal integrity and indirectly enhance metabolic health by maintaining gut barrier function and limiting systemic inflammation (Shih *et al.*, 2012; Uchegbu *et al.*, 2020). Cassava contributes to chronic disease modulation primarily through resistant starch fractions (RS2 and RS3), which function as bioactive carbohydrates. Upon fermentation by the gut microbiota, resistant starch generates short-chain fatty acids particularly butyrate that activate G-protein-coupled receptors and improve insulin sensitivity, lipid metabolism, and inflammatory regulation (Birt *et al.*, 2013; Koh *et al.*, 2016). This microbiota-mediated pathway highlights the indirect yet significant pharmacological relevance of cassava-derived starch fractions.

Table 2: Phytochemical pharmacological interface of major tuber crops: bioactive compounds, molecular targets and therapeutic outcomes

Tuber crop	Phytochemicals	Molecular targets: pathways	Pharmacological actions	Target chronic diseases	References
Sweet potato	Cyanidin-3-glucoside, peonidin-3-glucoside	AMPK activation, PI3K/Akt signaling, NF-κB inhibition	Improved insulin sensitivity, reduced oxidative stress and inflammation	type 2 diabetes, cardio-vascular diseases	Khoo *et al.*, 2019; Wang *et al.*, 2022; Alam *et al.*, 2021
Sweet potato (orange-fleshed)	β-carotene, chlorogenic acid	Antioxidant response elements, PPAR-γ modulation	Improved lipid metabolism, immune modulation, reduced oxidative damage	Metabolic syndrome, micronutrient	Low *et al.*, 2019; Burlingame *et al.*, 2019
Yam	Diosgenin	PPAR-γ activation, eNOS upregulation, cytokine inhibition	Cholesterol lowering, endothelial protection, anti-inflammatory and anticancer effects	Cardiovascular diseases, cancer	Price *et al.*, 2023; Shahidi and Ambigaipalan, 2019
Taro	Gallic acid, catechin, mucilage	ROS scavenging, suppression of inflammatory signaling	Antioxidant activity, improved gut and metabolic health	Diabetes, gastrointestinal disorders	Kawai *et al.*, 2020; Temesgen and Retta, 2018
Cassava	Resistant starch (RS2, RS3)	Gut microbiota fermentation, SCFA production, GPCR signaling	Enhanced insulin sensitivity, reduced low-grade inflammation	Obesity, diabetes, metabolic syndrome	Zhu *et al.*, 2020; Montagnac *et al.*, 2021
Elephant foot yam	Phenolics, flavonoids	NF-κB inhibition, antioxidant enzyme activation	Anti-inflammatory, hepatoprotective effects	Inflammatory and liver disorders	Dey *et al.*, 2020

Table 3: Comparative pharmacological efficacy of tuber crops, cereals and legumes in antioxidant, antidiabetic and cardioprotective functions

Food group	Representative crops	Dominant bioactive components	Antioxidant efficacy	Antidiabetic efficacy	Cardioprotective efficacy	Pharmacological advantage	References
Tuber crops	Sweet potato, yam, taro, cassava	Anthocyanins (cyanidin-3-glucoside), β-carotene, diosgenin, phenolics, resistant starch (RS2, RS3)	High strong free-radical scavenging and oxidative stress reduction	High-low to moderate GI, AMPK and PI3K/Akt activation, improved insulin sensitivity	High lipid lowering, NF-κB inhibition, eNOS activation	Multifunctional: combines energy, phytochemicals and gut microbiota modulation	Wang *et al.*, 2022; Khoo *et al.*, 2019; Price *et al.*, 2023
Refined cereals	Polished rice, refined wheat	Rapidly digestible starch	Low minimal antioxidant compounds	Low-high glycaemic index, rapid glucose spikes	Low limited lipid-modulating effects	Primarily energy supply; limited pharmacological action	Kaur *et al.*, 2021; Popkin *et al.*, 2022
Whole cereals	Brown rice, millets, oats	Dietary fiber, phenolics, β-glucan	Moderate	Moderate improved glycaemic control vs refined cereals	Moderate cholesterol reduction	Beneficial but lower phytochemical diversity than tubers	Mozaffarian, 2020; Kaur *et al.*, 2021
Legumes	Chickpea, lentil, soybean	Protein, isoflavones, soluble fiber	Moderate	High-low GI, improved insulin response	Moderate to high -lipid lowering	Protein-rich but limited antioxidant pigments	Shahidi and Ambigaipalan, 2019; Canfora *et al.*, 2019

4. Phytomedicinal relevance of tuber crops

4.1 Therapeutic potential of bioactive compounds

Tuber crops have long been valued not only as staple foods but also as important components of traditional medicinal systems across Asia, Africa and Latin America. In recent years, growing scientific evidence has validated many of these traditional claims, positioning tuber crops as significant phytomedicinal resources. Their therapeutic potential is primarily attributed to the presence of diverse bioactive compounds, including polyphenols, flavonoids, carotenoids, saponins and bioactive polysaccharides, which exert multiple biological effects relevant to chronic disease prevention and management (Shahidi and Ambigaipalan, 2019; Heinrich *et al*., 2020).

4.2 Phytochemical driven therapeutic effects of sweet potato

Sweet potato is rich in phytochemicals with established therapeutic relevance. Purple-fleshed varieties contain high concentrations of anthocyanins, particularly cyanidin-3-glucoside and peonidin-3-glucoside, which exhibit potent antioxidant, anti-inflammatory and anti-proliferative properties. Orange-fleshed sweet potato is a major dietary source of β-carotene, a provitamin A carotenoid known for its role in immune modulation and oxidative stress reduction. Additionally, chlorogenic acid present in sweet potato contributes to glucose homeostasis and lipid regulation (Low *et al*., 2019).

4.3 Diosgenin mediated phytotherapeutic potential of *Dioscorea* spp.

Yam species possess unique phytomedicinal significance effect is primarily ascribed to the bioactive compound diosgenin, a steroidal saponin widely used as a precursor in pharmaceutical synthesis. Diosgenin has been reported to exhibit cholesterol-lowering, anti-inflammatory and cardioprotective effects, with recent experimental studies demonstrating its role in improving lipid metabolism and endothelial function (Price *et al*., 2023). Additionally, yam extracts have shown anticancer potential through the induction of apoptosis and inhibition of tumor cell proliferation, reinforcing their relevance in phytotherapeutic research.

4.4 Metabolic modulation of taro

Taro has been traditionally recommended for gastrointestinal disorders and convalescent diets due to its easily digestible starch and phenolic compounds such as gallic acid and catechin identified in taro further enhance its antioxidant capacity and contribute to improved gastrointestinal and metabolic health. Contemporary studies have confirmed its protective effects on the gastrointestinal tract, as well as its ability to modulate post-prandial glycaemic response, making it particularly suitable for individuals with compromised metabolic health (Kawai *et al*., 2020).

4.5 Ethnomedicinal and pharmacological relevance of elephant foot yam

Elephant foot yam, widely used in Ayurvedic medicine, has gained increasing scientific attention for its therapeutic properties. Recent pharmacological studies have demonstrated significant anti-inflammatory, hepatoprotective and analgesic activities associated with its phenolic and flavonoid constituents (Dey *et al*., 2020). These findings support its traditional use in the management of inflammatory disorders and liver ailments.

4.6 Synergistic phytomedicinal effects

Cassava, the presence of resistant starch fractions RS2 and RS3 plays a critical role in modulating gut microbiota composition, improving insulin sensitivity and reducing chronic low-grade inflammation associated with metabolic disorders. Resistant starch derived from cassava has been shown to improve insulin sensitivity, modulate gut microbiota and exert anti-inflammatory effects, thereby contributing indirectly to the management of metabolic disorders (Montagnac *et al*., 2021). Arrowroot, traditionally used for its soothing and demulcent properties, has been reported to support gut health and improve digestibility, particularly in vulnerable populations such as infants and the elderly (Burlingame *et al*., 2019). Overall, the phytomedicinal relevance of tuber crops lies in their ability to deliver multiple therapeutic effects through synergistic interactions of bioactive compounds. Their long history of traditional use, combined with emerging scientific validation, underscores their potential as safe, affordable and culturally acceptable phytomedicinal foods. Integrating tuber crops into functional food development and phytotherapeutic strategies may offer a sustainable approach to addressing the growing burden of chronic diseases.

5. Processing, bioavailability and safety considerations

Processing methods play a pivotal role in determining the nutritional quality, phytochemical retention and safety of tuber crops, thereby influencing their functional and phytomedicinal potential. Traditional and modern processing techniques can either enhance or diminish the bioavailability of bioactive compounds, depending on the method employed. Understanding these effects is essential for maximizing health benefits while ensuring consumer safety. These bioavailability considerations further emphasize that the health benefits of tuber crops are best realized through regular consumption of appropriately processed whole foods rather than isolated high dose phytochemical supplementation.

5.1 Effects of processing on bioactive compounds and micronutrient bioavailability in tuber crops

Thermal processing methods such as boiling, steaming, and baking are commonly employed in the preparation of tuber crops and play a crucial role in determining their nutritional and functional quality. These processing techniques generally enhance starch digestibility and palatability while preserving or in some cases improving the bioavailability of key phytochemicals by disrupting cellular structures and facilitating the release of bound phenolic compounds (Temesgen and Retta, 2018; Wang *et al.*, 2022). Among these methods, boiling and steaming have been reported to be particularly effective in retaining antioxidant activity in tuber crops such as sweet potato and yam. In contrast, deep frying is associated with substantial losses of heat-sensitive bioactive compounds and the formation of lipid oxidation products, which may diminish the overall health benefits of tuber-based foods (Khoo *et al.*, 2019).

Processing also exerts a significant influence on micronutrient bioavailability. Cooking has been shown to enhance the bioaccessibility of β-carotene in orange-fleshed sweet potato by promoting its release from the food matrix and improving intestinal absorption, especially when consumed in the presence of small amounts of dietary fat (Low *et al.*, 2019). Additionally, starch gelatinization during thermal processing, followed by cooling, increases the formation of resistant starch, which exhibits prebiotic properties and contributes to improved glycaemic regulation and metabolic health (Zhu *et al.*, 2020). Importantly, the dose-response relationships of tuber-derived bioactive compounds are strongly modulated by processing methods and dietary context. Evidence suggests that thermal processing techniques such as boiling and steaming not only improve food safety and sensory attributes but also optimize phytochemical bioavailability at nutritionally relevant doses. Long-term, habitual consumption of appropriately processed tuber-based foods has been shown to confer greater metabolic benefits than short-term, high-dose supplementation, reinforcing the functional food paradigm over pharmacological intervention in chronic disease management (Montagnac *et al.*, 2021; Zhu *et al.*, 2020).

5.2 Bioavailability, gut microbiota-mediated biotransformation and food matrix effects

The health benefits of tuber crops depend not only on their phytochemical composition but also on the bioavailability, metabolism, and biotransformation of bioactive compounds following consumption. Many tuber-derived phytochemicals, including polyphenols, flavonoids, and anthocyanins, exhibit limited direct bioavailability; however, their metabolites formed during digestion and gut microbial fermentation play a central role in mediating biological effects. Growing evidence indicates that the gut microbiota is a critical modulator of phytochemical bioavailability, converting complex polyphenols and resistant starch into smaller, bioactive metabolites. Resistant starch fractions (RS2 and RS3) present in cassava and cooked and cooled tuber crops undergo colonic fermentation, producing short-chain fatty acids (SCFAs), *viz*., acetate, propionate, and butyrate. These metabolites enhance insulin sensitivity, regulate lipid metabolism, and suppress inflammatory signaling, thereby contributing to reduce chronic disease risk (Canfora *et al.*, 2019; Zhu *et al.*, 2020).

Similarly, anthocyanins and phenolic acids from sweet potato and taro are extensively metabolized by intestinal microbiota into phenolic derivatives that retain or even enhance biological activity, influencing key pathways involved in glucose homeostasis and inflammation (Shahidi and Ambigaipalan, 2019; Wang *et al.*, 2022). The food matrix and processing methods further modulate bioavailability by affecting phytochemical release and absorption. Thermal processing techniques such as boiling and steaming disrupt plant cell walls, improving bioaccessibility, whereas cooking enhances β-carotene bioavailability in orange-fleshed sweet potato, particularly when consumed with small amounts of dietary fat (Low *et al.*, 2019). In contrast, excessive processing, such as deep frying, may reduce phytochemical content and generate undesirable oxidation products. Importantly, regular consumption of tuber-based foods promotes beneficial shifts in gut microbiota composition, enhancing phytochemical metabolism and SCFA production over time. Collectively, these interactions among gut microbiota, food matrix, and processing practices provide a mechanistic basis for the bioavailability and functional efficacy of tuber crops as phytomedicinal foods.

5.3 Safety, toxicology and herb-drug interaction considerations

While tuber crops are widely consumed as staple foods and are generally regarded as safe, their utilization as functional foods and phytomedicinal resources necessitates careful consideration of toxicological thresholds, traditional detoxification practices and potential interactions with pharmacological therapies. Importantly, the safety of tuber crops is largely dependent on appropriate processing methods and consumption within dietary limits rather than pharmacological dosing. Certain tuber crops contain naturally occurring anti-nutritional or toxic constituents that require proper processing prior to consumption. Cassava (*M. esculenta*) contains cyanogenic glycosides, which can release hydrogen cyanide if inadequately processed. Traditional methods such as soaking, fermentation, drying and thorough cooking have been shown to effectively reduce cyanogenic content to safe levels, ensuring its suitability for human consumption (Montagnac *et al.*, 2021). Similarly, elephant foot yam (*A. paeoniifolius*) contains calcium oxalate crystals that may cause mucosal irritation; however, conventional culinary practices including prolonged cooking and the use of acidic or alkaline agents significantly mitigate this risk (Dey *et al.*, 2020). From a toxicological perspective, tuber-derived phytochemicals such as anthocyanins, phenolic acids and diosgenin exhibit wide therapeutic windows when consumed in food-based forms. Experimental studies consistently report beneficial effects at doses equivalent to regular dietary intake, with minimal evidence of toxicity. This reinforces the importance of functional food-based consumption rather than concentrated extract supplementation at pharmacological levels. Potential herb-drug interactions represent an emerging consideration as tuber crops gain attention for their metabolic benefits. Bioactive compounds that modulate glucose and lipid metabolism may theoretically enhance the effects of antidiabetic or lipid-lowering medications, potentially necessitating dietary monitoring in individuals receiving such therapies. However, current evidence indicates that tuber crops, when consumed as part of balanced diets, do not pose clinically significant interaction risks and may instead complement conventional therapeutic regimens (Mozaffarian, 2020). Overall, the long history of traditional consumption, combined with contemporary toxicological and nutritional evidence, supports the safety of tuber crops as functional foods. Ensuring adherence to appropriate processing methods, avoiding excessive extract-based supplementation and promoting consumer awareness are critical for maximizing health benefits while minimizing potential risks.

5.4 Bioavailability and safety considerations

Bioavailability of phytochemicals from tuber crops is also influenced by factors such as food matrix interactions, individual gut microbiota composition and dietary context. Polyphenols and flavonoids often exhibit limited bioavailability; however, their metabolites produced during digestion and microbial fermentation may exert significant biological activity, particularly in the gut and liver (Shahidi and Ambigaipalan, 2019; Canfora *et al.*, 2019). These indirect effects underscore the importance of considering both bioaccessibility and metabolic transformation when evaluating the health benefits of tuber-based diets. Overall, appropriate processing methods are essential for enhancing the bioavailability of beneficial compounds while minimizing safety risks associated with tuber crops. When prepared using traditional or scientifically validated processing techniques, tuber crops can be safely consumed and effectively utilized as functional foods and phytomedicinal resources. Optimizing processing strategies and promoting consumer awareness regarding safe preparation practices will be crucial for maximizing their contribution to chronic disease prevention and management.

6. Challenges and limitations

Despite increasing evidence supporting tuber crops as functional foods, several limitations hinder their broader application in chronic disease prevention and management. A major challenge is the widespread perception of tuber crops as high-carbohydrate foods unsuitable for individuals with diabetes and obesity. This view often ignores key point of dietary fiber, resistant starch and slowly digestible carbohydrates that contribute to favourable glycaemic responses (Kaur *et al.*, 2021).

6.1 Evidence gaps and future needs

Scientific evidence remains limited by the scarcity of long-term, well-controlled human clinical trials. Much of the existing knowledge is derived from *in vitro* studies, animal experiments, or short-term dietary interventions, which may not fully reflect real-world health outcomes (Shahidi and Ambigaipalan, 2019). Additionally, substantial variability in phytochemical composition arising from genetic, environmental, and processing factors complicates standardization and the formulation of evidence-based dietary recommendations (Wang *et al.*, 2022).

6.2 Challenges in processing and consumer adoption

Processing and safety issues further constrain utilization. Improper processing can reduce phytochemical content or pose health risks, particularly in tubers containing anti-nutritional factors such as cyanogenic glycosides in cassava and calcium oxalate in elephant foot yam (Montagnac *et al.*, 2021; Dey *et al.*, 2020). Limited consumer awareness, declining consumption of traditional foods and inadequate integration into dietary guidelines also restrict their adoption as functional foods (Popkin *et al.*, 2022).

7. Future thrust: Breeding, biofortification, and translational perspectives of tuber crops

Future research on tuber crops must adopt a multidisciplinary framework integrating phytomedicine, nutrition science, crop improvement, and public health to fully harness their functional food and therapeutic potential. A key thrust lies in breeding and biofortification strategies aimed at enhancing health-promoting traits, including dietary fiber, resistant starch, carotenoids, anthocyanins, and essential micronutrients, while simultaneously minimizing anti-nutritional factors. The substantial genetic diversity inherent in tuber crops offers significant opportunities to improve nutritional quality and phytochemical profiles relevant to chronic disease prevention and metabolic health (Bouis and Saltzman, 2017; Wang *et al.*, 2022).

Biofortification represents one of the most impactful approaches for enhancing the public health value of tuber crops. The successful deployment of biofortified orange-fleshed sweet potato to combat vitamin A deficiency among vulnerable populations underscores the feasibility and effectiveness of nutrition-oriented breeding strategies (Low *et al.*, 2019; Ruel *et al.*, 2021). Similar breeding initiatives in yam and cassava, targeting increased micronutrient density, improved starch quality, and safer phytochemical composition, merit greater emphasis. Advances in molecular breeding, genomics, and marker-assisted selection provide powerful tools to accelerate the development of nutritionally superior tuber varieties without compromising agronomic performance or climate resilience (Price *et al.*, 2023). Parallel to crop improvement, future thrust areas must include rigorous validation of health claims through well-designed, long-term human clinical trials to establish dose–response relationships and mechanistic links between tuber-derived bioactives and chronic disease outcomes. Optimization of processing and value-addition technologies that enhance bioavailability while ensuring food safety and sensory acceptability is equally critical. Strengthening extension systems, nutrition education, and policy integration will further facilitate the incorporation of biofortified tuber crops into dietary guidelines, functional food formulations, and public health nutrition programs.

The expanding mechanistic understanding of tuber-derived phytochemicals also provides a strong foundation for translational pharmacology and nutraceutical development. Bioactive compounds such as anthocyanins from sweet potato, diosgenin from yam, phenolic acids from taro, and resistant starch fractions from cassava exhibit multi-targeted actions on key metabolic and inflammatory pathways, including AMPK, NF-κB, and PPAR-γ. This multi-pathway modulation aligns with contemporary nutraceutical paradigms that emphasize holistic metabolic regulation rather than single-target pharmacological intervention. From a translational perspective, standardization of bioactive extracts and functional formulations is essential to ensure reproducibility, safety, and efficacy. Advances in food processing and analytical technologies now enable the development of anthocyanin-enriched sweet potato powders, diosgenin-standardized yam extracts, and resistant starch-fortified tuber products suitable for functional foods and dietary supplements. Importantly, such formulations are most effective when designed to deliver bioactives at dietary-equivalent doses, thereby maintaining safety while enhancing therapeutic relevance. Biofortification and crop improvement further strengthen translational potential by enabling the development of tuber varieties with enhanced phytochemical density and improved functional attributes. Targeted breeding for anthocyanin content, resistant starch fractions, and diosgenin concentration can facilitate the emergence of next-generation tuber-based nutraceuticals tailored for chronic disease prevention. Integration of these nutraceuticals into public health nutrition programs, clinical dietary guidelines, and preventive healthcare frameworks presents a major opportunity, particularly in low- and middle-income countries where tuber crops are culturally accepted and widely consumed. Overall, the future of tuber crops lies in their ability to bridge food and medicine by offering safe, affordable, and culturally compatible solutions for chronic disease prevention. Strategic integration of crop improvement, functional food development, translational pharmacology, and clinical nutrition research will be essential for unlocking the full health-promoting potential of tuber crops and advancing their role in sustainable public health nutrition.

8. Conclusion

Tuber crops represent an important yet underutilized group of functionally active phytomedicinal foods with multi-target pharmacological relevance in the prevention and management of chronic diseases. Accumulating evidence indicates that their unique combination of complex carbohydrates, dietary fibre, resistant starch and diverse bioactive compounds contributes significantly to improved glycaemic control, lipid regulation, antioxidant defence and modulation of inflammatory responses. Beyond their basic nutritional value, tuber crops such as sweet potato, yam, taro, cassava and elephant foot yam provide multifaceted health benefits that align closely with the growing emphasis on food-based strategies for combating non-communicable diseases. Although, challenges related to consumer perception, post-harvest processing and clinical validation persist, recent advances in breeding, biofortification and processing technologies offer promising opportunities to enhance their functional and therapeutic potential. Integrating tuber crops into regular diets, public health nutrition programmes and functional food development frameworks can therefore support sustainable dietary interventions and improved population health outcomes, particularly in regions experiencing rapid nutrition transition.

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Conflict of interest

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

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