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ROLE OF MILLETS IN THE PREVENTION AND MANAGEMENT OF LIFESTYLE DISEASES: NUTRITIONAL, FUNCTIONAL AND THERAPEUTIC PERSPECTIVES – A COMPREHENSIVE REVIEW

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ABSTRACT
Lifestyle diseases, including type 2 diabetes mellitus, obesity, cardiovascular diseases, hypertension, metabolic syndrome, and certain cancers, have emerged as major public health challenges worldwide. These disorders are closely associated with unhealthy dietary patterns, physical inactivity, and rapid urbanization. Consequently, there is growing interest in functional foods that provide health benefits beyond basic nutrition. Millets, a group of small-seeded cereal grains, have gained renewed attention because of their exceptional nutritional composition, climate resilience, and therapeutic potential. Rich in dietary fiber, high-quality protein, essential minerals, vitamins, resistant starch, and diverse bioactive compounds such as phenolic acids, flavonoids, tannins, and phytosterols, millets possess antioxidant, anti-inflammatory, hypoglycemic, hypolipidemic, and cardioprotective properties. Recent evidence suggests that regular millet consumption improves glycemic control, enhances insulin sensitivity, supports weight management, improves gut microbiota, reduces oxidative stress, and lowers the risk of several chronic non-communicable diseases.
This comprehensive review summarizes the current scientific evidence regarding the nutritional composition, functional properties, and therapeutic benefits of major millets, including finger millet, pearl millet, foxtail millet, sorghum, barnyard millet, little millet, kodo millet, and proso millet. Furthermore, the review discusses the mechanisms through which millet consumption contributes to the prevention and management of diabetes, obesity, cardiovascular diseases, hypertension, gastrointestinal disorders, and selected cancers. Current challenges associated with millet utilization, processing technologies, consumer acceptance, and future research priorities are also highlighted. Overall, the available evidence indicates that millets can play an important role in promoting healthy dietary patterns and reducing the burden of lifestyle diseases while contributing to sustainable food systems.

KEYWORDS: Millets, Functional Foods, Lifestyle Diseases, Diabetes Mellitus, Obesity, Cardiovascular Diseases, Bioactive Compounds, Dietary Fiber, Nutraceuticals, Glycemic Index.

1. INTRODUCTION
Lifestyle diseases, commonly referred to as non-communicable diseases (NCDs), represent one of the greatest public health challenges of the twenty-first century. These chronic diseases develop gradually over time and are strongly associated with unhealthy dietary habits, physical inactivity, tobacco use, harmful alcohol consumption, inadequate sleep, and chronic psychological stress. Cardiovascular diseases, type 2 diabetes mellitus (T2DM), obesity, hypertension, metabolic syndrome, chronic kidney disease, and several forms of cancer are among the most prevalent lifestyle diseases worldwide. According to the World Health Organization (WHO), unhealthy dietary patterns are among the leading modifiable risk factors contributing to the global burden of NCDs, emphasizing the importance of adopting healthy dietary practices throughout the life course **(World Health Organization [WHO], 2026).**
Rapid urbanization, economic development, and changing food environments have substantially transformed dietary habits across both developed and developing countries. Traditional diets rich in whole grains, legumes, fruits, and vegetables have increasingly been replaced by ultra-processed foods containing excessive amounts of refined carbohydrates, saturated fats, trans fats, free sugars, and sodium. Such dietary transitions, together with sedentary lifestyles, have accelerated the prevalence of obesity, insulin resistance, dyslipidaemia, hypertension, and type 2 diabetes mellitus. Consequently, nutrition has emerged as a cornerstone in the prevention and management of chronic diseases, leading researchers to explore functional foods capable of providing health benefits beyond basic nutrition **(WHO, 2026).**
Functional foods are defined as foods that, in addition to supplying essential nutrients, exert beneficial physiological effects that may reduce the risk of chronic diseases. Among various functional cereals, millets have received considerable scientific attention because of their exceptional nutritional profile, resilience to harsh climatic conditions, and potential

therapeutic properties. Millets are ancient small-seeded cereal grains cultivated for thousands of years, particularly in Asia and Africa, and include pearl millet (Pennisetum glaucum), finger millet (Eleusine coracana), foxtail millet (Setaria italica), sorghum (Sorghum bicolor), barnyard millet (Echinochloa frumentacea), little millet (Panicum sumatrense), kodo millet (Paspalum scrobiculatum), and proso millet (Panicum miliaceum) **(Jacob et al., 2024).**

Millets possess superior nutritional characteristics compared with many commonly consumed cereals such as polished rice and refined wheat. They are rich sources of complex carbohydrates, dietary fibre, resistant starch, plant protein, essential amino acids, vitamins, and minerals including calcium, iron, magnesium, phosphorus, potassium, and zinc. Furthermore, millets contain numerous bioactive compounds such as phenolic acids, flavonoids, tannins, lignans, phytosterols, and carotenoids that exhibit antioxidant, anti-inflammatory, hypoglycaemic, hypolipidaemic, antimicrobial, and cardioprotective activities. These bioactive constituents play a crucial role in reducing oxidative stress, improving insulin sensitivity, regulating lipid metabolism, and promoting overall metabolic health **(Jacob et al., 2024)**

One of the most important nutritional advantages of millets is their relatively low glycaemic index and high dietary fibre content. These characteristics slow carbohydrate digestion and glucose absorption, thereby reducing postprandial blood glucose excursions and improving glycaemic control. Additionally, the high fibre and resistant starch content enhances satiety, supports healthy gut microbiota, improves bowel function, and contributes to weight management. Consequently, regular millet consumption has been associated with a reduced risk of obesity, type 2 diabetes mellitus, cardiovascular diseases, and other metabolic disorders **(Jacob et al., 2024; Frontiers in Nutrition, 2023).**

The global significance of millets has increased remarkably following the declaration of 2023 as the International Year of Millets by the United Nations, an initiative proposed by India to promote millet cultivation, consumption, and research. This global initiative highlighted the importance of millets in achieving food and nutritional security, climate-resilient agriculture, sustainable food systems, and improved public health. Since then, there has been a substantial increase in scientific investigations evaluating the nutritional composition, functional properties, processing technologies, and therapeutic applications of millet-based foods **(Jacob et al., 2024).**

The renewed scientific interest in millets is closely linked to the increasing demand for nutrient-dense, sustainable, and functional foods capable of addressing the growing burden of lifestyle diseases. Unlike refined cereals, millets undergo minimal processing and retain a substantial proportion of their bran and germ, thereby preserving valuable nutrients and bioactive compounds. Their unique nutritional profile has positioned millets as promising dietary components for improving metabolic health and preventing chronic non-communicable diseases **(Anitha et al., 2022; Taylor et al., 2021).**

One of the most significant nutritional attributes of millets is their high dietary fiber content, which includes both soluble and insoluble fractions. Dietary fiber slows gastric emptying, delays carbohydrate digestion, reduces postprandial glucose excursions, improves satiety, and supports healthy body weight maintenance. Moreover, fiber serves as a substrate for beneficial gut microbiota, leading to the production of short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate, which contribute to improved insulin sensitivity, reduced systemic inflammation, enhanced gut barrier integrity, and better lipid metabolism **(Slavin, 2020; Anitha et al., 2022).** These mechanisms highlight the importance of millet-based diets in promoting gastrointestinal and metabolic health.

In addition to dietary fiber, millets are excellent sources of resistant starch and slowly digestible starch, which contribute to their relatively low glycemic index. Resistant starch escapes digestion in the small intestine and undergoes fermentation in the colon, producing metabolites that improve glucose homeostasis and insulin responsiveness. Consequently, regular millet consumption has been associated with improved glycemic control, lower fasting blood glucose, reduced glycated hemoglobin (HbA1c), and decreased insulin resistance among individuals with prediabetes and type 2 diabetes mellitus (Anitha et al., 2021; Taylor et al., 2021). These findings suggest that replacing refined cereals with millets may represent an effective dietary strategy for diabetes prevention and management.

Millets are also rich in a wide range of bioactive phytochemicals, including phenolic acids, flavonoids, tannins, anthocyanins, lignans, and phytosterols. These compounds possess strong antioxidant properties that neutralize reactive oxygen species (ROS), reduce oxidative stress, inhibit lipid peroxidation, and protect cellular components from oxidative damage. Since oxidative stress and chronic low-grade inflammation are recognized as key mechanisms underlying the development of diabetes, cardiovascular diseases, obesity, and several cancers, the antioxidant potential of millets has attracted considerable scientific attention **(Shahidi & Ambigaipalan, 2018; Saleh et al., 2021).** Furthermore, polyphenols present in millets may inhibit digestive enzymes such as α-amylase and α-glucosidase, thereby slowing carbohydrate digestion and reducing postprandial hyperglycemia.

Several epidemiological studies, randomized controlled trials, and systematic reviews have demonstrated that regular millet consumption is associated with multiple health benefits. These include improved lipid profiles, reduced serum cholesterol and triglyceride concentrations, enhanced insulin sensitivity, better weight management, lower blood pressure, and improved antioxidant status **(Anitha et al., 2021; Kumar et al., 2023).** Additionally, millet-based diets have been shown to improve satiety, decrease energy intake, and positively influence gut microbiota composition, thereby contributing to long-term metabolic health. These findings support the growing recognition of millets as functional foods capable of addressing multiple risk factors associated with lifestyle diseases simultaneously.

Beyond their nutritional advantages, millets offer significant environmental and agricultural benefits. They are climate-resilient crops that require less water, fewer agricultural inputs, and exhibit greater tolerance to drought, heat, and poor soil conditions than major cereals such as rice and wheat. Their cultivation contributes to biodiversity conservation, sustainable agriculture, and food security, particularly in regions vulnerable to climate change **(FAO, 2023).** Recognizing these advantages, the United Nations declared 2023 as the International Year of Millets, aiming to increase awareness of their nutritional value, promote sustainable production systems, and encourage greater consumption worldwide **(FAO,**

2023). This global initiative has renewed scientific, governmental, and industrial interest in millet-based foods and their role in improving public health.

Despite these encouraging findings, millet consumption has declined considerably over the past few decades due to changing food preferences, urbanization, limited consumer awareness, inadequate processing technologies, and the widespread availability of refined cereal products. Traditional perceptions of millets as "poor man's food," along with challenges related to cooking quality, shelf life, and market availability, have further limited their incorporation into modern diets **(Anitha et al., 2022).** Consequently, there is an urgent need to promote millet-based products through scientific evidence, nutritional education, technological innovations, and supportive public health policies.

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2. Global Burden of Lifestyle Diseases

Lifestyle diseases, also known as non-communicable diseases (NCDs), are chronic disorders primarily associated with unhealthy dietary habits, physical inactivity, tobacco use, harmful alcohol consumption, and chronic stress. Major lifestyle diseases include type 2 diabetes mellitus (T2DM), cardiovascular diseases (CVDs), obesity, hypertension, metabolic syndrome, chronic respiratory diseases, and certain cancers. These conditions have become the leading causes of morbidity and mortality worldwide, placing a significant burden on healthcare systems and economies **(WHO, 2023).**

According to the World Health Organization (WHO), NCDs account for approximately 41 million deaths annually, representing nearly 74% of all global deaths. Cardiovascular diseases remain the leading cause, followed by cancers, chronic respiratory diseases, and diabetes. The majority of these deaths occur in low- and middle-income countries, where rapid urbanization and changing dietary patterns have accelerated the prevalence of lifestyle diseases **(WHO, 2023).**
The prevalence of obesity and type 2 diabetes has increased substantially over recent decades due to unhealthy diets, sedentary lifestyles, and population ageing. The International Diabetes Federation (IDF) Diabetes Atlas (2025) estimates that 589 million adults worldwide are living with diabetes, with nearly 90–95% of cases being type 2 diabetes. Likewise, hypertension affects over 1.3 billion adults, significantly increasing the risk of cardiovascular diseases and premature mortality **(IDF, 2025; WHO, 2023).**
The rising burden of lifestyle diseases is closely linked to the global nutrition transition, characterized by increased consumption of refined cereals, ultra-processed foods, sugar-sweetened beverages, and saturated fats, along with reduced intake of whole grains, fruits, vegetables, and dietary fiber **(GBD 2021 Risk Factors Collaborators, 2024).** Consequently, dietary interventions and functional foods have gained considerable attention as sustainable approaches for chronic disease prevention.
Among functional foods, millets have emerged as promising dietary grains because of their high dietary fiber, resistant starch, essential micronutrients, and bioactive phytochemicals. Their low glycemic index, antioxidant, anti-inflammatory, and cardioprotective properties make them valuable in reducing the risk of diabetes, obesity, cardiovascular diseases, and other lifestyle disorders **(Anitha et al., 2022; FAO, 2023).**

2.1 Indian Scenario of Lifestyle Diseases

India is experiencing a rapid rise in lifestyle diseases due to urbanization, changing dietary habits, reduced physical activity, and increasing obesity. The transition from traditional diets rich in whole grains, pulses, and millets to diets dominated by refined cereals, processed foods, sugar-sweetened beverages, and unhealthy fats has significantly contributed to the growing burden of non-communicable diseases (NCDs) **(Anjana et al., 2023; ICMR, 2023).**
According to the International Diabetes Federation (IDF) Diabetes Atlas (2025), India has one of the largest populations of people living with diabetes, with over 89 million adults affected. In addition, the ICMR–INDIAB Study (2023) estimated that approximately 101 million Indians are living with diabetes, while nearly 136 million have prediabetes, indicating a substantial future disease burden. The prevalence of obesity, hypertension, and dyslipidemia has also increased steadily, further elevating the risk of cardiovascular diseases and metabolic syndrome **(Anjana et al., 2023).**
Cardiovascular diseases are the leading cause of mortality in India, accounting for nearly one-fourth of all deaths. Hypertension affects a significant proportion of the adult population, yet many individuals remain undiagnosed or inadequately treated, increasing the risk of heart disease, stroke, and kidney disorders **(WHO, 2023).** These conditions place considerable pressure on healthcare resources and contribute to substantial economic losses due to increased healthcare expenditure and reduced productivity.

Recognizing this growing public health challenge, the Government of India has implemented several initiatives, including the National Programme for Prevention and Control of Non-Communicable Diseases (NP-NCD), the Eat Right India campaign, and the promotion of millets through the International Year of Millets 2023. These initiatives encourage healthier dietary practices and greater consumption of nutrient-rich traditional grains. In this context, millets have re-emerged as valuable functional foods because of their high dietary fiber, low glycemic index, essential micronutrients, and bioactive compounds, making them promising dietary options for the prevention and management of lifestyle diseases.

3. Nutritional Composition of Millets

Millets are highly nutritious cereal grains recognized for their rich content of macronutrients, micronutrients, dietary fiber, and bioactive compounds. Compared with refined cereals such as polished rice and wheat, millets provide superior nutritional quality and are increasingly regarded as functional foods due to their potential role in promoting health and preventing lifestyle diseases (**Anitha et al., 2022).**
Millets are an excellent source of complex carbohydrates, providing sustained energy through their slow digestibility. They also contain 7–13% protein, depending on the millet species, with appreciable amounts of essential amino acids such as methionine and leucine. Although lysine is relatively low, combining millets with pulses improves the overall protein quality of the diet (**Taylor et al., 2021).**
A distinguishing nutritional feature of millets is their high dietary fiber content, which is considerably greater than that of polished rice. Dietary fiber improves satiety, delays gastric emptying, regulates postprandial blood glucose levels, and supports healthy gut microbiota. In addition, millets contain resistant starch, which slows carbohydrate digestion and contributes to a lower glycemic response, making them particularly beneficial for individuals with diabetes and obesity **(Anitha et al., 2021).**
Millets are also rich in essential micronutrients, including calcium, iron, magnesium, phosphorus, potassium, and zinc, as well as B-complex vitamins. Finger millet is especially recognized for its exceptionally high calcium content, while pearl millet is an important source of iron and zinc. Barnyard millet and foxtail millet are valued for their high dietary fiber and low glycemic index, whereas sorghum is abundant in antioxidant polyphenols and phytochemicals that contribute to its health-promoting properties **(Saleh et al., 2021).**
Beyond their nutrient content, millets contain a variety of bioactive compounds, including phenolic acids, flavonoids, tannins, phytosterols, and carotenoids. These compounds exhibit antioxidant, anti-inflammatory, hypoglycemic, and

cardioprotective properties, which help reduce oxidative stress, improve insulin sensitivity, and lower the risk of chronic diseases **(Shahidi & Ambigaipalan, 2018).**

Millet	Major Nutritional Components	Key Bioactive Compounds	Glycemic Index (GI)	Major Health Benefits
Finger millet (Eleusine coracana)	Calcium, dietary fiber, protein, iron	Phenolic acids, flavonoids	Low–Medium	Improves bone health, enhances glycemic control, and provides antioxidant protection
Pearl millet (Pennisetum glaucum)	Protein, iron, zinc, magnesium, dietary fiber	Polyphenols, phytosterols	Low	Supports cardiovascular health, improves iron status, and promotes overall metabolic health
Foxtail millet (Setaria italica)	Dietary fiber, protein, magnesium	Phenolics, flavonoids	Low	Enhances insulin sensitivity, aids weight management, and supports glycemic control
Sorghum (Sorghum bicolor)	Protein, dietary fiber, resistant starch	Tannins, anthocyanins, phenolic acids	Low	Exhibits antioxidant, anti-inflammatory, and anti-diabetic properties
Barnyard millet (Echinochloa frumentacea)	High dietary fiber, iron, calcium	Polyphenols, flavonoids	Very Low	Reduces postprandial blood glucose levels and supports weight management
Little millet (Panicum sumatrense)	Dietary fiber, iron, B-complex vitamins	Phenolic compounds	Low	Improves digestive health and helps regulate blood glucose levels
Kodo millet (Paspalum scrobiculatum)	Dietary fiber, protein, antioxidants	Polyphenols	Low	Reduces oxidative stress and improves metabolic health
Proso millet (Panicum miliaceum)	Protein, phosphorus, magnesium	Phenolic acids	Medium–Low	Supports cardiovascular health and provides sustained energy release

Table 1. Nutritional characteristics and health benefits of major millets.

4. Bioactive Compounds and Functional Properties of Millets

Millets are increasingly recognized as functional foods because they contain a wide range of bioactive compounds that provide health benefits beyond basic nutrition. In addition to carbohydrates, proteins, dietary fiber, vitamins, and minerals, millets are rich sources of phenolic acids, flavonoids, tannins, lignans, phytosterols, carotenoids, and tocopherols. These phytochemicals contribute significantly to the prevention and management of lifestyle-related disorders through their antioxidant, anti-inflammatory, hypoglycemic, hypolipidemic, and cardioprotective activities **(Saleh et al., 2021; Anitha et al., 2022).**

Phenolic compounds represent the predominant class of bioactive constituents in millets. These compounds effectively scavenge reactive oxygen species (ROS), thereby reducing oxidative stress and protecting cellular macromolecules from oxidative damage. Since oxidative stress is a major contributor to the pathogenesis of diabetes mellitus, obesity, cardiovascular diseases (CVDs), metabolic syndrome, and certain cancers, the antioxidant potential of millet-derived phenolics has attracted considerable scientific attention **(Shahidi & Ambigaipalan, 2018).** Flavonoids further enhance these protective effects by inhibiting pro-inflammatory signaling pathways, reducing the production of inflammatory cytokines, and improving endothelial function, thereby supporting vascular health and reducing the risk of chronic diseases.

Another important group of phytochemicals found in millets includes **tannins**, particularly abundant in sorghum and finger millet. Although tannins were once regarded as antinutritional factors due to their ability to reduce mineral bioavailability, current evidence indicates that moderate concentrations exhibit potent antioxidant, antimicrobial, anti-obesity, and anti-diabetic properties. Tannins delay starch digestion by inhibiting digestive enzymes such as α-amylase and α-glucosidase, resulting in slower glucose absorption and improved postprandial glycemic responses. This property makes tannin-rich millets particularly suitable for individuals with type 2 diabetes and insulin resistance **(Taylor et al., 2017).**

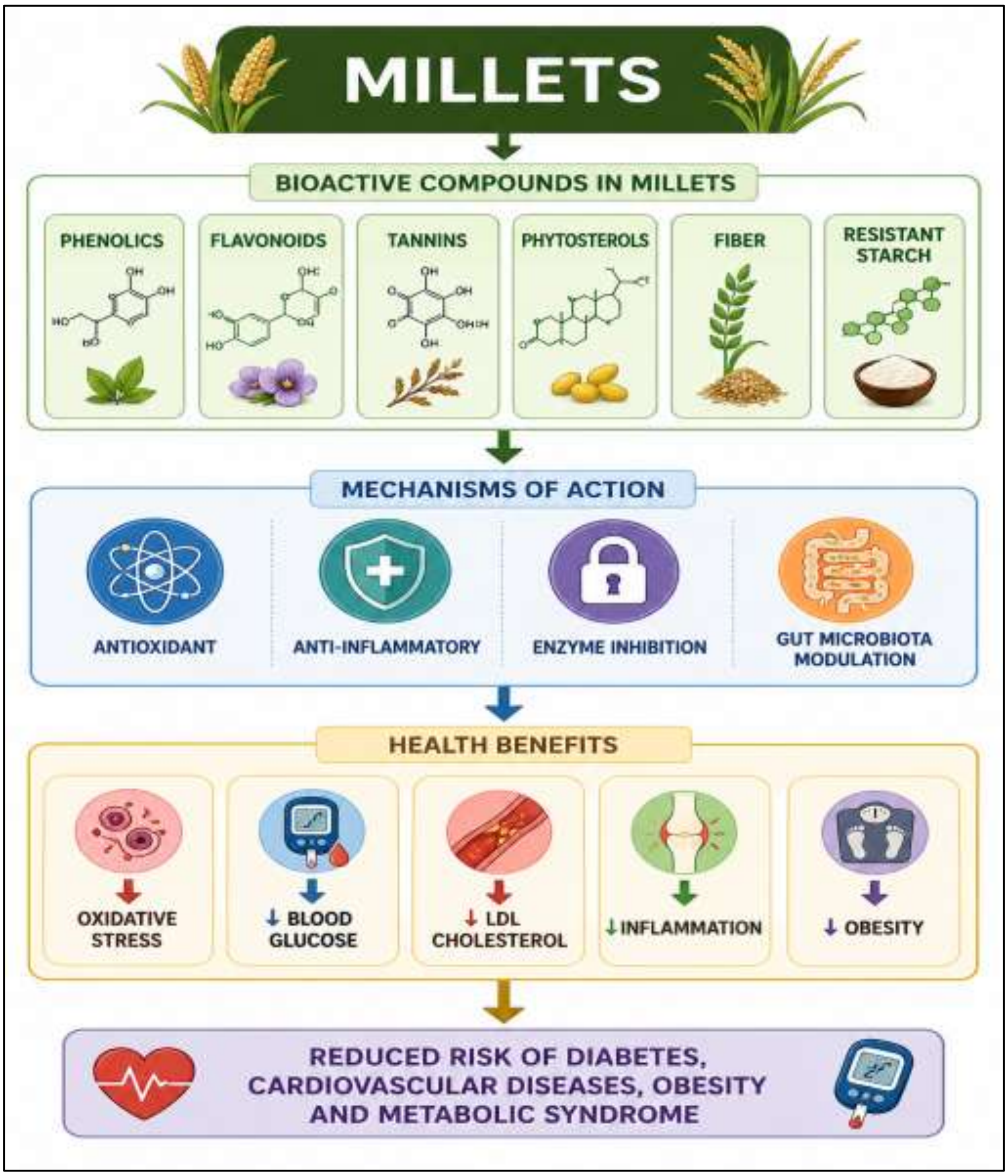
Millets also contain appreciable amounts of **phytosterols**, which structurally resemble cholesterol and competitively inhibit its intestinal absorption. Regular consumption of phytosterol-rich foods has been associated with reductions in serum low-density lipoprotein cholesterol (LDL-C), thereby lowering cardiovascular disease risk. In addition, **tocopherols (vitamin E)** and **carotenoids** contribute to antioxidant defense by protecting membrane lipids from oxidative damage and supporting immune function and visual health. These compounds further enhance the cardioprotective and anti-aging potential of millet-based diets **(Shahidi & Ambigaipalan, 2018).**

The **dietary fiber** and **resistant starch** present in millets also exert significant functional effects. Soluble fiber increases intestinal viscosity, slows gastric emptying, and delays glucose absorption, while insoluble fiber improves bowel motility and gastrointestinal health. Resistant starch escapes digestion in the small intestine and undergoes fermentation by gut microbiota in the colon, producing short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate. These metabolites improve gut barrier integrity, reduce systemic inflammation, enhance insulin sensitivity, and positively modulate the gut microbiome, thereby contributing to metabolic **health (Anitha et al., 2022).**

Recent metabolomic and nutrigenomic studies further suggest that millet bioactive compounds regulate multiple molecular pathways involved in chronic disease prevention. Phenolic compounds activate the **nuclear factor erythroid 2-related factor 2 (Nrf2)** signaling pathway, enhancing endogenous antioxidant enzyme production, while simultaneously suppressing **nuclear factor-kappa B (NF-κB)** activation, thereby reducing chronic inflammation. These mechanisms collectively improve glucose metabolism, lipid homeostasis, endothelial function, and immune responses, highlighting the therapeutic potential of millets in the prevention and management of non-communicable diseases.

Overall, the synergistic interaction between dietary fiber, resistant starch, phenolic compounds, flavonoids, phytosterols, carotenoids, tocopherols, and other phytochemicals makes millets unique among cereal grains. Their combined antioxidant, anti-inflammatory, hypoglycemic, hypolipidemic, and prebiotic properties support their classification as functional foods and justify their growing inclusion in dietary strategies aimed at reducing the burden of diabetes, obesity, cardiovascular diseases, and other chronic metabolic disorders.

Figure 2. Bioactive compounds in millets and their mechanisms of action in preventing non-communicable diseases.



5. Role of Millets in the Prevention and Management of Lifestyle Diseases

5.1 Role of Millets in Type 2 Diabetes Mellitus

Type 2 diabetes mellitus (T2DM) is characterized by insulin resistance and chronic hyperglycemia. Millets have gained considerable attention in diabetes management due to their low glycemic index, high dietary fibre, resistant starch, and rich phytochemical content. These components slow carbohydrate digestion, reduce postprandial blood glucose levels, improve insulin sensitivity, and promote better glycemic control. Additionally, the antioxidants and phenolic compounds present in millets reduce oxidative stress and inflammation associated with diabetes. Studies have reported that regular millet consumption significantly lowers fasting blood glucose, postprandial blood glucose, and glycated hemoglobin

(HbA1c), making millets an effective dietary strategy for diabetes prevention and management **(Anitha et al., 2021; Saleh et al., 2013; Taylor & Emmambux, 2018).**

5.2 Role of Millets in Obesity and Weight Management
Obesity is a major risk factor for several chronic diseases, including diabetes and cardiovascular disorders. Millets support weight management because of their high dietary fibre, resistant starch, and protein content, which increase satiety, delay gastric emptying, and reduce overall energy intake. Their low glycemic index also helps regulate blood glucose and insulin response, thereby limiting fat accumulation. In addition, the polyphenols and antioxidants present in millets improve lipid metabolism and reduce chronic inflammation associated with obesity. Regular consumption of millet-based foods has been associated with modest reductions in body weight, body mass index (BMI), and waist circumference, making millets a valuable component of healthy weight management strategies **(Anitha et al., 2021; Chandrasekara & Shahidi, 2012).**

5.3 Role of Millets in Cardiovascular Diseases
Cardiovascular diseases (CVDs) remain the leading cause of mortality worldwide. Millets contribute to cardiovascular health through their high dietary fibre, magnesium, potassium, and antioxidant content. Dietary fibre helps lower serum cholesterol by enhancing bile acid excretion, while magnesium and potassium support blood pressure regulation and vascular function. Furthermore, the phenolic compounds present in millets reduce oxidative stress and inflammation, thereby lowering the risk of atherosclerosis. Regular millet consumption has been associated with improved lipid profile, better blood pressure control, and reduced cardiovascular risk, highlighting their potential as heart-healthy functional foods **(Anitha et al., 2021; Saleh et al., 2013)**.

5.4 Role of Millets in Cancer Prevention
Cancer is one of the leading causes of death worldwide, and dietary factors play an important role in its prevention. Millets are rich sources of dietary fibre, phenolic compounds, flavonoids, and antioxidants that exhibit anti-carcinogenic properties. These bioactive compounds reduce oxidative stress, inhibit free radical formation, suppress chronic inflammation, and protect DNA from oxidative damage. The high fibre content of millets also promotes gut health and decreases the risk of colorectal cancer. Although more clinical evidence is required, current findings suggest that regular millet consumption may contribute to cancer prevention as part of a healthy dietary pattern **(Chandrasekara & Shahidi, 2012; Saleh et al., 2013).**

5.5 Role of Millets in Hypertension
Hypertension is a major risk factor for cardiovascular diseases and stroke. Millets contain appreciable amounts of magnesium, potassium, dietary fibre, and antioxidants that help regulate blood pressure. Magnesium promotes vascular relaxation, while potassium maintains electrolyte balance and reduces the adverse effects of excess sodium intake. The antioxidant compounds in millets also improve endothelial function and reduce oxidative stress. Therefore, replacing refined cereals with millet-based foods may contribute to improved blood pressure control and overall cardiovascular health **(Taylor & Emmambux, 2018; Anitha et al., 2021).**

5.6 Role of Millets in Dyslipidemia
Dyslipidemia is characterized by elevated cholesterol and triglyceride levels along with reduced HDL cholesterol. Millets improve lipid metabolism because of their high dietary fibre, phytosterols, and polyphenol content. These components reduce cholesterol absorption, enhance bile acid excretion, and improve serum lipid profiles. Studies have shown that regular millet consumption lowers total cholesterol, LDL cholesterol, and triglycerides while increasing HDL cholesterol, thereby reducing the risk of cardiovascular **diseases (Anitha et al., 2021; Saleh et al., 2013).**

5.7 Role of Millets in Gastrointestinal Health
Millets support gastrointestinal health due to their high dietary fibre and resistant starch content. Dietary fibre promotes bowel regularity, improves gut microbiota, and enhances the production of beneficial short-chain fatty acids. Since millets are naturally gluten-free and easily digestible, they are suitable for individuals with gluten intolerance. Regular millet consumption improves digestive function and contributes to overall gut health **(Saleh et al., 2013; Taylor & Emmambux, 2018).**

5.8 Role of Millets in Metabolic Syndrome
Metabolic syndrome comprises obesity, hypertension, insulin resistance, dyslipidemia, and impaired glucose metabolism. Millets help address these risk factors because of their low glycemic index, high dietary fibre, resistant starch, and antioxidant compounds. Regular consumption improves insulin sensitivity, regulates blood glucose, enhances lipid metabolism, and supports weight management. These combined effects make millets promising functional foods for the prevention and management of metabolic syndrome **(Anitha et al., 2021; Chandrasekara & Shahidi, 2012).**

6. Processing Methods Affecting Nutritional Quality of Millets
Millets undergo various processing techniques before consumption to improve their sensory characteristics, digestibility, shelf life, and nutritional quality. Traditional and modern processing methods influence the bioavailability of nutrients as well as the concentration of anti-nutritional factors. Appropriate processing enhances the health-promoting properties of millets and increases consumer acceptability **(Saleh et al., 2013).**

6.1 Dehulling (Decortication)

Dehulling is the removal of the outer husk of millet grains before consumption. This process improves texture, cooking quality, and palatability. However, since the outer layers contain dietary fibre, minerals, and phenolic compounds, excessive dehulling may reduce the nutritional value of millets. Therefore, controlled dehulling is recommended to achieve a balance between sensory quality and nutrient retention **(Taylor & Emmambux, 2018).**

6.2 Soaking

Soaking is a simple traditional processing method that softens millet grains and reduces anti-nutritional factors such as phytates and tannins. It improves mineral bioavailability, shortens cooking time, and enhances protein digestibility. Soaking also activates endogenous enzymes that contribute to better nutrient utilization **(Sharma & Gujral, 2019).**

6.3 Germination (Malting)

Germination is an effective biological process that significantly enhances the nutritional quality of millets. During germination, enzymatic activity increases the availability of amino acids, B-complex vitamins, and bioactive compounds while reducing phytates and tannins. Germinated millets also exhibit improved protein digestibility and antioxidant activity, making them suitable for developing functional foods **(Saleh et al., 2013).**

6.4 Fermentation

Fermentation improves the nutritional and functional properties of millets through the activity of beneficial microorganisms. It enhances protein digestibility, increases B-vitamin content, reduces anti-nutritional factors, and improves mineral absorption. Fermented millet products also contain beneficial probiotics that support gut health and improve overall nutritional quality **(Chandrasekara & Shahidi, 2012).**

6.5 Thermal Processing (Roasting, Popping and Extrusion)

Thermal processing techniques such as roasting, popping, and extrusion improve flavour, texture, and shelf stability of millet products. These methods increase starch digestibility and enhance consumer acceptability. Although prolonged heating may reduce heat-sensitive vitamins, appropriate thermal processing preserves most nutrients while improving the functional and sensory characteristics of millet-based foods **(Taylor & Emmambux, 2018).**

Processing Method	Major Changes in Nutritional Quality	Health Benefits
Dehulling (Decortication)	Removes the outer husk, improving cooking quality but reducing dietary fibre, minerals, and phenolic compounds.	Improves palatability and digestibility.
Soaking	Reduces phytates and tannins, enhances mineral bioavailability, and improves protein digestibility.	Enhances nutrient absorption and reduces cooking time.
Germination (Malting)	Increases protein digestibility, vitamin content, antioxidants, and other bioactive compounds while reducing anti-nutritional factors.	Improves nutritional quality and antioxidant activity.
Fermentation	Enhances B-vitamin content, protein digestibility, and mineral bioavailability while reducing phytates.	Promotes gut health and improves nutrient utilization.
Roasting	Improves flavour and shelf life with minimal nutrient loss when carried out under controlled conditions.	Enhances sensory acceptability and consumer preference.
Popping	Improves starch digestibility and product texture while retaining most nutrients.	Produces nutritious, ready-to-eat millet-based products.
Extrusion	Improves digestibility, texture, and shelf stability; however, slight losses of heat-sensitive vitamins may occur.	Suitable for the development of value-added functional foods.

Source: Adapted from Saleh et al. (2013); Chandrasekara and Shahidi (2012); Sharma and Gujral (2019); Taylor and Emmambux (2018).

7. Challenges and Future Perspectives

Despite their exceptional nutritional composition and health-promoting properties, the utilization of millets remains limited due to several challenges. Low consumer awareness, changing dietary preferences, inadequate processing technologies, limited value-added products, and poor market accessibility have restricted their widespread acceptance. In addition, the presence of anti-nutritional factors such as phytates and tannins may reduce the bioavailability of certain minerals if appropriate processing techniques are not applied. Furthermore, the availability of standardized millet-based functional foods and large-scale clinical studies validating their long-term health benefits is still limited.

Future research should focus on developing innovative millet-based functional foods with improved sensory quality and consumer acceptability. Advanced processing technologies such as germination, fermentation, extrusion, and biofortification can further enhance the nutritional value and bioavailability of millet nutrients. More randomized controlled trials are required to establish the therapeutic potential of millets in the prevention and management of lifestyle diseases. In addition, public awareness campaigns, government initiatives, and supportive policies promoting millet cultivation and consumption can contribute to improved food security, nutritional well-being, and sustainable agriculture. Considering their nutritional richness, climate resilience, and health benefits, millets are expected to play a significant role in future global nutrition and public health strategies (Anitha et al., 2021; Saleh et al., 2013).

8. CONCLUSION

Millets are highly nutritious climate-resilient cereals that provide an excellent source of dietary fibre, quality protein, essential minerals, vitamins, and diverse bioactive compounds. Their low glycemic index, antioxidant potential, and anti-inflammatory properties make them valuable functional foods for the prevention and management of lifestyle diseases, including type 2 diabetes mellitus, obesity, cardiovascular diseases, hypertension, dyslipidemia, and metabolic syndrome. Appropriate processing methods such as soaking, germination, fermentation, and extrusion further improve their nutritional quality and bioavailability.

The growing scientific evidence supports the inclusion of millets as an integral component of healthy dietary patterns. Promoting millet consumption through nutrition education, food product innovation, and supportive public health policies can improve nutritional security while reducing the burden of non-communicable diseases. Continued research and well-designed clinical studies will further strengthen the evidence regarding their therapeutic potential and facilitate their incorporation into sustainable food systems worldwide.

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