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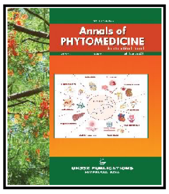

Review Article : Open Access

A comprehensive review on the significance of millet consumption in type 2 diabetes: Exploring the benefits and the realities

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Abstract

Type 2 diabetes is a metabolic disease characterized by impaired glucose and lipid homeostasis in humans. Millet-based food products have recently gained popularity due to their antidiabetic, antihyperlipidaemic, anticarcinogenic, anti-inflammatory, antiallergic for gluten-sensitive persons, antiageing, and nephroprotective properties. Relevant reviews were conducted to collate available evidence of the impact of millet consumption on type 2 diabetes. Two studies on male Wistar rats revealed a significant decrease (33%-41%) in glycated hemoglobin levels in the diabetic experimental group compared to the diabetic control group, indicating the beneficial effect of the finger millet-based diet. A single investigation on normoglycemic healthy human subjects found a significant decrease of 18.82% and 7.65% in fasting blood sugar and glycated hemoglobin levels by consuming a millet-based diet. In contrast, another study in Sri Lanka encountered a non-significant decrease of 4.59% in fasting blood sugar levels. Moreover, millets have a constructive impact on diabetes by reducing postprandial, fasting blood glucose, and glycated hemoglobin levels, as well as offering low glycemic index meals.

1. Introduction

1.1 Understanding type 2 diabetes: A lifelong health issue

Among chronic diseases, diabetes is a prevalent one (Raj and Singh, 2022). Following estimates, there will be more people with diabetes worldwide than in 2021 (537 million), rising to 643 million by 2030 and 783 million by 2045 (IDF, 2022). Among adults with diabetes, three out of four reside in low- and middle-income nations. Across all 15 Indian states, the overall prevalence of diabetes was 7·3%. The percentage of people with diabetes ranged from 4.3% in Bihar to 10.0% in Punjab (Anjana *et al.,* 2017). Over 90% of cases of diabetes are type 2 diabetes (T_2D). T_2D is a metabolic disease characterized by impaired glucose and lipid homeostasis in humans. Ecological factors, lifestyle, physical inactivity, and abrupt modification in food patterns are all strongly linked to an elevation of the prevalence of T_2D (Ramachandran, 2012). Consumption of high-energy processed foods is linked to an increase in glucose intolerance, obesity, and gestational diabetes. At the same time, whole grain products have been shown to improve metabolic homeostasis, resulting in lower insulin and triglyceride levels among individuals with metabolic syndrome (Giacco *et al.,* 2014). Relative to processed grains, whole grains possess an average to low glycemic index (GI), which minimizes sharp spikes in blood sugar (Banu *et al*., 2024). Incorporation of millets with elementary crops might assist with ameliorating non-communicable diseases (NCD) (Chuwa and Dhiman, 2022; Choudhury and Chaudhary, 2023). Moreover, nutrient-dense grains and nutricereals can be integrated to offer balanced nutrients, lessening the risk of metabolic disorders, malnutrition, and NCD (Mounika and Hymavathi, 2021). Because of how carbohydrate diet affects insulin resistance progression, insulin secretion pattern, and lipid homeostasis, the glycemic index and glycemic load have gained prominence in recent decades (Asif, 2014). In the prevention and control of T_2D, dietary components or food groupings and nutritional techniques are essential. Research suggests that patients with metabolic syndrome may benefit from diets high in protein and fiber since they may also have improved lipid profiles, insulin sensitivity, and reduced hyperglycemia (Post *et al.,* 2012; Silva *et al.,* 2013). For effective prevention of diabetes and cardiovascular disease, the United Nations FAO/WHO advises choosing foods with low GI (foxtail millet, 50-60; little millet, kodo millet, proso millet, barnyard millet, 50-65; finger millet, 70-80; pearl millet, sorghum, 70-85) and high dietary fiber composition (finger millet, 15 g/100 g; kodo millet, 9 g/100 g; foxtail millet, pearl millet, 8 g/100 g; little millet, 7 g/100 g; barnyard millet, 6 g/100 g; proso millet, 3 g/100 g) when developing a dietary plan (Agrawal *et al.,* 2023; Jacob *et al.,* 2024)

1.2 Millets: Superfood of India

India, as the "precious continent of agriculture", is home to hardworking farmers who produce a wide variety of nutrient-rich crops. Millets stand out among these, mostly grown for their tiny, delectable seeds. Millets mainly grow in semi-arid regions due to their short growing period and higher productivity even under extreme environmental conditions. They are considered as the 6th cereal crops

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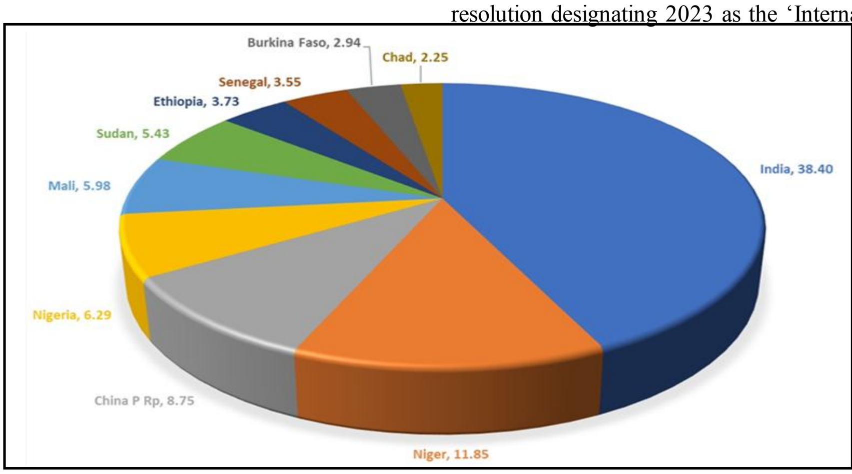
in reference to the worlds' agricultural production and are very important from a food security point at the regional and farm level. Therefore, more than one-third of the world's population uses millet in their diet (Ambati and Sucharitha, 2019). FAO Stat, 2021 estimated that India produced about 173 lakh tonnes of millet, accounting for about 80% of Asia's production and 20% of the world's total production. Figure 1 and Table 1 indicated both country-wise and state-wise production of millets, respectively. Over 79.6% of the total millet is produced in six states such as Rajasthan, Uttar Pradesh, Karnataka, Maharashtra, Madhya Pradesh, and Haryana. 31.3 per cent of India's total millet production comes from Rajasthan. The two varieties of millets that together make for the majority of India's overall production are pearl millet (Bajra) and sorghum (Jowar). Apart from this, India is one of the top 5 millet exporters in the world, and over the last five years, ending in 2020, its exports have increased steadily at a rate of about 3% compound annual growth rate (CAGR). In India, the production of millets and the area under cultivation witnessed negative CAGR of -0.94% and -3%, respectively, from 2010-11 to 2019-20. Despite decreased area and output, overall yield growth has been favourable, with a CAGR of 2.12% (Directorate of Economics and Statistics, Ministry of Agriculture; Report on Promoting Best Practices on Millet, Niti Aayog). With a gazette notice dated 10.04.2018, the Indian government designated millets as "Nutri Cereals" due to their high nutritional content, and in 2018, they celebrated the 'National Year of Millets'. Along with it, India presented the 'International Year of Millets' to the United Nations General Assembly (UNGA) with the support of almost 70 nations. As a result, the UNGA adopted a resolution designating 2023 as the 'International Year of Millets'.



Source: Indian Millets (apeda.gov.in)

Figure 1: Country-wise production of millets-2022.

Table 1: State-wise production of millets: Total millets (2023-24)

States	Area (lakh ha)	Production (lakh tonnnes)	Yield (kg/ha)
Rajasthan	47.75	48.09	1007
Uttar Pradesh	13.47	26.98	2003
Karnataka	14.25	17.49	1227
Maharashtra	20.82	17.15	824
Madhya Pradesh	6.40	12.68	1982
Haryana	5.90	11.94	2024
Tamil Nadu	4.69	6.23	1327
Gujarat	2.64	4.51	1707
Andhra Pradesh	1.46	3.90	2672
Uttarakhand	1.09	1.61	1481
Telangana	0.62	1.15	1851
Odisha	1.04	0.72	694
Jharkhand	0.32	0.30	922
Chhattisgarh	0.53	0.20	387
Bihar	0.08	0.08	1001
West Bengal	0.05	0.06	1103
Assam	0.05	0.04	705
Himachal Pradesh	0.03	0.02	718
Kerala	0.02	0.01	367
Punjab	0.01	0.00	654
All India	121.88	153.79	1262

Source: Department of Agriculture and Farmers Welfare, Indian Millets (apeda.gov.in).

1.3 Management of type 2 diabetes with millets

It has been observed that millet-based food products have become increasingly popular recently, partly because the United Nations declared 2023 to be the 'International Year of Millets'. Through this effort, millets were to be cultivated and consumed globally, to increase knowledge of their health benefits and environmental sustainability. Furthermore, the millet family (Poaceae) consists of major millets such as *Sorghum vulgare* (Jowar), *Pennisetum typhoideum* (Bajra), *Eleusine coracana* (Ragi); minor millets, *i.e.,* foxtail millet (Kangani/ Kakun), proso millet (Cheena), kodo millet (Kodo), barnyard millet (Sawa/Sanwa/ Jhangora), little millet (Kutki), brown top millet and two pseudo millets (Buck-wheat and Amaranth) (FSSAI, 2020). Although, millets were once considered "coarse cereals," their nutrient content has led to their current classification as "nutri cereals" (Saini *et al*., 2021). These non-glutinous millets are rich in nutrients and are known as "non-acid-forming foods" (Sarita and Singh, 2016). Millets are stuffed with fibers and contain complex carbohydrates, protein, smaller fat, carotenoids, and flavonoids (Saleh *et al.,* 2013), and a relatively low glycemic index (Ugare *et al.,* 2014). Table 2 displays the starch and specific sugar profiles of a few important grains and millets. Millets have notable nutraceutical and therapeutical properties like antidiabetic, antihyperlipidaemic, anticarcinogenic, antiinflammatory, antiallergic for gluten-sensitive persons, antiageing, nephroprotective, *etc*. Additionally, it promotes hemoglobin levels, strengthens the neurological system, and is helpful in wound healing (Chauhan and Sarita, 2018). Furthermore, they are filled with micronutrients like calcium, iron, magnesium, zinc, *etc*., and have an array of biochemical properties such as disaccharidase activity (Kim *et al.,* 2011; Shobana *et al.,* 2009), antioxidant properties (Chandrasekara *et al.,* 2012), and thus may have the power to lower insulin resistance and oxidative stress, which are key players in the pathogenesis of T_2D (Cakar *et al.,* 2018).

Table 2: Starch and individual sugar profiles of key cereals and millets

Millets and cereals	Total available CHO (g)	Total starch (g)	Fructose (g)	Glucose (g)	Sucrose (g)	Total freesugars
Sorghum	60.96	59.70	0.57	0.10	0.60	1.27
Bajra	56.02	55.21	0.21	0.60	NA	0.81
Ragi	62.47	62.13	NA	0.25	0.12	0.34
Little millet	56.43	56.07	NA	0.24	0.13	0.37
Kodo millet	66.25	64.96	NA	0.89	0.40	1.29
Wheat						
Whole	58.60	56.82	0.72	0.78	0.30	1.80
Refined flour	71.82	70.03	0.64	0.75	0.40	1.79
Atta	58.62	56.82	0.72	0.78	0.30	1.80
Semolina	59.85	58.20	0.60	0.55	0.50	1.65
Rice						
Raw brown	72.00	71.31	NA	0.55	0.14	0.69
Raw milled	76.39	75.70	NA	0.54	0.15	0.69
Parboiled	76.80	76.14	NA	0.51	0.16	0.67
Amaranth seed, black	56.71	55.83	0.10	0.22	0.46	0.88
Amaranth seed, pale brown	60.13	59.33	0.10	0.22	0.48	0.80
Quinoa	49.825	48.41	NA	NA	NA	NA
Maize, dry	61.01	59.35	0.16	0.80	0.70	1.66

*NA: Not Applicable

Source: Indian Food Composition Tables, NIN - 2017 and Dayakar *et al.,* 2017

2. Materials and Methods

2.1 Search strategy

By integrating every possible sequence of all the keyword categories, a systematic search was carried out. This was carried out in three online databases, *i.e*., Google Scholar, Scopus, and PubMed for studies describing the impact of millet-based diets and/or millets in T_2D in peer-reviewed journals. Boolean logic operators such as AND, NOT, OR, double quote, *etc.,* were used to produce more relevant results along with advanced filters like year, subject, and type (review only, review, research only). The following search terms included: human/ animal studies on millets and diabetes, the significance of millet consumption in diabetes mellitus, the impact of supplementation of millet-based diets on type 2 diabetes, positive and or and negative and impact and of and millets and on and diabetes; studies on finger millet/foxtail millet/mixture of millets to prevent T_2D, millets OR T_2D, millets AND T_2D, millets AND diabetes mellitus AND NOT other non-communicable diseases, "diabetes mellitus", "millets", "finger millet/foxtail millet/barnyard millet/proso millet/the mixture of millets" (Type 2 diabetes), (Finger millet/Foxtail millet/Barnyard millet/Proso millet) with the limits 'Publication Date from 01/01/ 2002 to 01/04/2024, Humans, Animals, English'. A comprehensive search criterion was applied to obtain the greatest number of pertinent articles. A simultaneous evaluation of the retrieved papers' references was conducted to find additional applicable research. The subject matter, primary goals, and key terms have been approved by the authors. Since the study made use of publicly accessible data, ethical clearance was not necessary.

2.2 Selection criteria

Studies were deemed pertinent when they included T_2D patients along with considering the impact of the intervention of millet-based diets, were in the English language, and were published between January 1, 2002, and April 1, 2024. Concerning pre-defined selection criteria, 51 titles in all had their abstracts independently examined. After extracting and analyzing the pertinent data from the abstracts, the full texts of 24 abstracts were found. Studies were excluded from analysis if the impact of intervention of millet-based diets in T_2D was not quantified. The following were among the criteria for rejecting papers: subjects without T_2D, the intervention of other food groups without millets, and the published study's protocol or design without accurate findings. At last, twenty-one papers were identified that analyzed the significance of millet consumption in the prevention of T_2D. A brief description of various studies is presented in Figure 2.

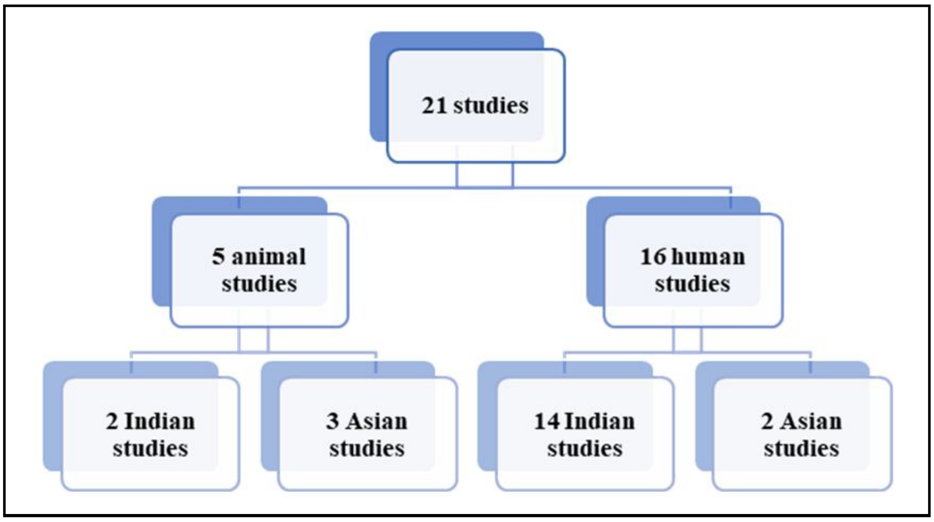


Figure 2: Description of various studies.

2.3 Data extraction

Foxtail millet, finger millet, barnyard millet, proso millet and/or a mixture of millets and/or a combination of millets, and pulses with other food groups were used in these studies. T_2D was found to be substantially decreased when millet-based foods were consumed over 21 days to 12 months. When millets were consumed, they were either in the form of a multimillet mix, single millet mix, millet protein concentrate, raw or heat-treated millets, millet flour, millet seed coat matter, dosa, paratha, pakoda, cake, low salty snacks, roti, bread, buns, mudde (balls) or porridge, *etc*. The intervention groups were given varying amounts of millet, ranging from 30 to 290 g (wet weight basis), either in a single meal or split into two meals daily or according to subjects' convenience. Moreover, the extracted data included references, study site and subject, study period, interventions of millets, and study outcome on subjects. In Table 3 of the results section, the data that was taken from the papers that describe these 21 investigations is summarised.

3. Results

To begin with, two studies on male Wistar rats revealed a significant decrease (33% - 41%) in glycated hemoglobin (HbA1c) levels in the diabetic experimental group compared to the diabetic control group, indicating the beneficial effect of the finger millet-based diet. Another two research studies on KK-Ay male mice observed that there were no significant changes in plasma glucose concentration during the 3 weeks of millet protein concentrate intervention, but one of these studies claimed that plasma insulin concentration in mice supplied the foxtail millet protein concentrate diet decreased 57% when compared to the casein diet. A Beijing, China-based animal study discovered that fasting blood glucose levels of male Sprague Dawley diabetic rats in all foxtail millet (FM) supplementation groups reduced significantly by 41.4% to 67.2% in comparison to diabetic control rats after 4 weeks, with the decrease being greatest in 48% FM rats. Along with this, the areas under the curve for the glucose tolerance test of rats from the 48% FM + Metformin and Metformin +ve control groups were significantly lower than those of diabetic control rats, followed by 4 weeks of FM supplementation. However, there were no significant differences in fasting insulin concentration or homeostasis model assessment of β-cell function (HOMA-β) among all groups.

A single investigation on normoglycemic healthy human subjects found a significant decrease of 18.82% and 7.65% in fasting blood sugar (FBS) and HbA1c levels due to supplementary finger millet and little millet-based roti, dosa, and dumpling for 6 weeks, respectively. In contrast, another study in Sri Lanka encountered a non-significant decrease of 4.59% in FBS by supplementing finger millet porridge for 8 weeks (3 days per week). In addition to this, a significant reduction of 7% in the FBS level was found in the case of the experimental group whereas, on the contrary, there was an increase in sugar level by 5% in the control group after 4 weeks of barnyard millet supplementation by Surekha *et al.* (2013).

Table 3: Efficacy of millets in prevention of type 2 diabetes

References	Study subject and site	Study period	Intervention	Study outcome
Animal studies				
Devi and Rajendran, 2023	Adult male Wistar rats (150-160 g) (24 animals divided equally into four groups) (Tamil Nadu, India)	4 weeks	Finger millet dosa for experimental diet (streptozotocin-induced diabetic rats). In control diet, finger millet and horse gram were replaced with corn starch and casein	41% reduction in HbA1c levels in the diabetic experimental group than the diabetic control group
Shobana *et al.*, 2010	Male Wistar rats (150-160 g) 4 groups. Streptozotocin-induced diabetic (12 rats each), non-diabetic (8 rats each) (Karnataka, India)	6 weeks	Control diet-54 per cent maize starch, 10 per cent cane sugar, 21 per cent casein, 10 per cent refined peanut oil, 4 per cent Bernhardt–Tommarelli modified mineral mixture and 1 per cent National Research Council vitamin mixture. The experimental diet supplied with 20% finger millet seed coat matter and 34% maize starch	33% reduction in HbA1c levels in the diabetic experimental group than in the diabetic control group
Choi *et al.*, 2005	KK-Ay 8-week-old male mice. (12 animals divided equally into two groups) (Tokyo, Japan)	3 weeks	Experimental group (type 2 diabetic) -38.3% foxtail millet protein concentrate (FMP). Control group-23.6% casein. The diet contained 20% protein for both groups. 10% sucrose was present in the diets of both group	There was no alteration in the concentration of plasma glucose, however, plasma insulin concentration given the FMP diet declined by 57% in comparison to the casein diet.
Park *et al.*, 2008	KK-Ay 5 weeks old male mice (24-26 g).(14 animals divided equally into two groups) (Tokyo, Japan)	3 weeks	Experimental group (type 2 diabetic) -33.7% proso millet protein concentrate (PMP). Control group-22.9% casein. The diet contained 20% protein for both groups.An oral glucose tolerance test (1.5 g glucose per kg body weight) was conducted on day 17	No significant differences in the concentration of plasma glucose during the study period of 3 weeks. The area under the curve value at oral glucose tolerance test (data not shown) was observed
Ren *et al.*, 2022	Male Sprague Dawley rats (8 weeks old)(40 animals divided equally into five groups) (Beijing, China)	4 weeks	5 Groups-diabetic control, 30% Foxtail millet (FM),48% FM, 48% FM + metformin, metformin +ve control excluding normal control group. 65.21 g of sucrose was used in the diet of diabetic control, 30% FM, 48% FM, 48% FM + metformin	FBG of diabetic rats was lowered significantly by 41.4% to 67.2% in all FM supplementation groups. The decline was highest in 48% of FM rats.
Human studies				
Geetha *et al.*, 2020	10 sedentary normoglycemic healthy subjects aged between 18-30 years (Karnataka, India)	6 weeks	Finger millet and little millet Roti, dumpling, dosa, *etc.*, equivalent to 50 g available carbohydrate. The raw weight of roti, dosa, and mudde was 80 g, 70 g, and 90 g respectively	Significant decrease of 18.82% and 7.65% in FBS and HbA1c
Kumari *et al.*, 2020	18 healthy subjects (Palwehera, Sri Lanka)	8 weeks (3 days per week)	Finger millet porridge (200 ml)	Non-significant decrease of 4.59% in FBS
Surekha *et al.*, 2013	11 randomly selected healthy staff; age ranging between 25-45 years. Seven members in the experimental group (female-4) and four in the control group (female-2) (Karnataka, India)	4 weeks	88 g barnyard millet health mix formulation with GI 59.1050 g carbohydrate equivalent or 88 g of the health mix was consumed in their homes in one or two meals daily. The glucose tolerance test was conducted following the methods of Wolever and Jenkins (1986) on 7 normal healthy volunteers	A significant reduction of 7% in FBS level was noticed in the case of the experimental group.

Lakshmi and Sumathi, 2002	6 NIDDM men (40-55 years) (Telangana, India)	4 weeks	Roti-90 g finger millet flour (FMF) Dosa-60 g FMF. Oral glucose tolerance test (75 g dissolved in 200 ml of water) was conducted.	Based on the data on mean peak rise over FBS after 1½ hours, the use of whole finger millet flour significantly declined blood glucose levels (25.96%-33.33%) than germinated finger millet flour.
Itagi *et al.,* 2012	15 diabetics and 15 non-diabetics (both genders were present). 9 type 2 diabetics and 9 non-diabetics were selected as an experimental group (Karnataka, India)	4 weeks	Foxtail millet diabetic mix Each subject consumed 87 g of mix (80 g of mix + 7 g spice mix) per day in breakfast/ lunch/ dinner according to their conveniences	Significant % reduction of 18.94% and 16.46% was observed after consumption of foxtail millet mix in plasma glucose of experimental diabetics and non-diabetic group.
Ugare *et al.,* 2014	9 diabetic and 6 non-diabetic volunteers (Karnataka, India)	4 weeks	Heat-treated grains of 73 g barnyard millet equivalent to 50 g of available carbohydrates in the form of upma or rice	Significant reduction of 6% and 7% in FBS of the diabetic and non-diabetic experimental group.
Tiwari and Srivastava, 2017	30 type 2 diabetics (17 male and 13 female) aged 40-50 years (equal no. of participants were presented in both the groups) (Uttarakhand, India)	2 months	200 g of finger millet buns per day (40% of finger millet flour + 60% of refined wheat flour with GI 36.57)	Significant percent differences were indicated in FBS and PP, *i.e.*, 13.75% and 14.43% respectively in the experimental group
Jali *et al.,* 2012	300 patients with type 2 diabetes (Karnataka, India)	3 months	80 g of foxtail millet diabetic mix	Consumption of a millet-based diet by diabetic patients lowered the HbA1c level (19.14%), FBS (13. 5%), PP (14.74%), and random glucose (4.47%)
Giri and Ravindra, 2015	30 women aged 70 years with type 2 diabetes (Karnataka, India)	3 months	Multi-purpose flour (100 g/ day) foxtail millet (45%), finger millet (20%), others (35%)	Significant decrease in FBS and PP, *i.e.*, 26.49% and 23.64% respectively
Singh *et al.,* 2020	60 subjects with type 2 diabetes (27 men and 33 women) (Uttar Pradesh, India)	3 months	Paratha, pakoda, cake, low salty snacks, roti (200-250 g) (60% millets)	Significant decrease in FBS (27.75%), PP (29.15%), and HbA1c (19.72 %) in diabetic subjects.
Shobhna *et al.,* 2020	94 diabetic subjects aged 40-60 years. (An equal no. of participants were presented in the control group and experimental group) (Telangana, India)	3 months	Multi-grain roti (bajra, jowar, ragi, foxtail, and others) raw 90 g provided 55 g equivalent carbohydrate. Replacement of one meal-Experimental group. No intervention-control group	There were no significant differences present in FBS in both experimental and control groups, but a significant decrease in insulin level (16.29%) and HbA1c level (7.61%) in the experimental group was reported.
Joshi and Srivastava, 2021	30 diabetic female subjects (equal no. of participants in both groups) (Uttarakhand, India)	3 months with discontinued last month	Jeera jhangora-100 g barnyard millet cooked as rice with GI 35.9. Glucose tolerance test (50 g dissolved in 200 ml of water) was conducted on 10 normal female adult human volunteers (24-26 years); from Golden Jubilee Hostel, G.B.P.U.A and T, Pant Nagar, Uttarakhand.	FBS and PP levels of the experimental group showed a significant decrease of 33.47 mg/dl and 58.33 mg /dl, respectively after consumption of barnyard millet for 2 months. Similarly, glycated hemoglobin levels also showed a significant reduction of 0.88%.

Anushia *et al.,* 2019	88 type 2 diabetic subjects (30-70 years) were equally divided into two groups (Tamil Nadu, India)	5 months	Millet-based diets in the lunch and dinner-experimental group. Regular diet-control group. Millets (Men-1400 kcal, Women-1200 kcal)	Significant decrease in FBS and PP, *i.e.*, 27.90% and 24.62% respectively, whereas a non-significant decrease of HbA1c (14.45%) was found in the experimental group.
Narayan *et al.,* 2016	150 T_2D patients (35-55years) (Tamil Nadu, India)	8 months	Foxtail millet dosa provided a GI of 59.25% (290 g foxtail millet batter provided 50 g equivalent carbohydrate) while for rice dosa GI value was 77.86% (140 g rice batter provided the same)	Non-significant difference was observed in the case of FBS. Significant decrease in PP, *i.e.,* 20.91% by patients consuming millet dosa
Vedamanickam *et al.,* 2020	80 type 2 diabetes patients (40-55 years) on a millet diet and 70 patients (40-60 years) on a non-millet diet (Tamil Nadu, India)	12 months	Millet chapattis (40-50 g)-patients on millet diet. Wheat chapattis-patients on a non-millet diet	Significant decrease in FBS and PP, *i.e.*, 22.59% and 21.11% by patients consuming millet chapattis in contrast to wheat chapattis
Ren *et al.,* 2018	64 pre-diabetic subjects (27 men and 37 women) (Peking University, China)	3 months	90 g foxtail millet steam bread (50 g raw foxtail millet). An oral glucose tolerance test (75 g) was performed before the post-prandial blood test.	Significant decrease of 7.01%, 7.84%, and 19.44% in FBG, PP, and HOMA-IR respectively.

FBS-Fasting Blood Sugar, FBG-Fasting Blood Glucose, PP-Post-Prandial, HbA1c-Glycated Hemoglobin, HOMA-IR-Homeostatic Model Assessment of Insulin Resistance .

After that, a study conducted by Lakshmi and Sumathi, 2002 on non-insulin-dependent diabetes mellitus men concluded that using whole finger millet flour positively affected blood glucose levels (25.96%-33.33%) than germinated finger millet flour. Itagi *et al.* (2012) conducted a study on 30 subjects, both diabetic and non-diabetic. The plasma glucose levels of the experimental diabetic and non-diabetic groups (18 subjects) were shown to significantly decrease by 18.94% and 16.46%, respectively, during four weeks of foxtail millet diabetic mix supplementation. Moreover, among the control group, the plasma glucose elevated up to 3.35%. Following 4 weeks of barnyard millet supplementation, a significant depletion in the FBS level within the range of 6% to 7% was noticed in the experimental groups (Ugare *et al*., 2014). Another study published in 2017 by Tiwari and Srivastava revealed that after two months of finger millet buns intervention, there were substantial percent variations in FBS and postprandial (PP), *i.e.*, 13.75% and 14.43%, respectively, in the experimental group of 15 type 2 diabetic patients. Jali *et al*. (2012) disclosed that diabetic subjects who consumed a foxtail millet-based diet for three months had lower HbA1c levels (19.14%), FBS (13.5%), PP (14.74%) and random glucose (4.47%).

Two human research studies on T_2D in India indicated that intervening millet-based diets for three months resulted in a significant decrease in FBS (26.49%-27.75%) and PP (23.64%-29.15%), however a different investigation in India reported non-significant changes in FBS, though a significant decrease in insulin level and HbA1c level, *i.e.*, 16.29% and 7.61%, accordingly was reported in the experimental group. Non-significant decrease of 12.17% in insulin level with a non-significant increase of 0.38% in HbA1c level was also observed in the control group. Considering barnyard millet supplementation on 15 experimental female diabetes subjects over three months with discontinued last month, the experimental group's FBS and PP levels indicated a substantial drop of 33.47 mg/dl and 58.33 mg/dl respectively. In a similar vein, the value of HbA1c also significantly decreased by 0.88 percent. Following a month of no longer receiving supplements, (the experimental group acted as the self-control group) the experimental group's FBS (14.8 mg/dl) and PP (11.13 mg/dl) levels significantly increased once more (Joshi and Srivastava, 2021). Significant decrease in FBS and PP, *i.e.,* 27.90% and 24.62%, respectively, whereas a non-significant decrease of HbA1c (14.45%) was found in patients consuming millet-based diets in lunch and dinner instead of eating rice and wheat for five months. Along with it, a non-significant decrease in FBS (19.37%) and HbA1c (23.59%) while a significant decrease in PP (32.01%) was observed in the control group (Anushia *et al.,* 2019). Patients consuming foxtail millet dosa contrary to rice dosa for 8 months had a non-significant difference in FBS but a significant decrease in PP, *i.e.,* 20.91%, according to Narayan *et al.* (2016) whereas Vedamanickam *et al.* (2020) noticed a significant decrease in FBS and PP, *i.e.,* 22.59% and 21.11%, by patients consuming millet chapattis contrast to non-millet chapattis for 12 months. Eventually, an Asian study discovered that consuming a millet-based diet minimized fasting blood glucose (FBG), PP, and homeostatic model assessment of insulin resistance (HOMA-IR)levels significantly in pre-diabetic subjects.

4. Discussion

According to various studies, including millet in the diet has several advantages for managing diabetes. Dietary fiber, flavonoids, phytic acid, amino acids, minerals, and polyphenols are the essential bioactive components present in the millets which supports the body. Vital amino acids such as phenylalanine, methionine, leucine, and isoleucine are found in large proportions in millets. Besides these, they have sufficient amounts of protein, riboflavin, thiamine, vitamin E, and vitamin B. Millets also include phytosterols, policosanols, and phenolics (phenolic acids, flavonoids, and tannins), which act as antioxidants and reduce the harm that free radicals do to the body. In addition to preventing the production of advanced glycation end products, phenolic substances impart antiglycation properties. Barnyard millet's substantial supply of p-coumaric and chlorogenic acids significantly reduced the amount of advanced glycation end products and prevented glycoxidation-induced alterations in protein structure (Anis and Sreerama, 2020; Jacob *et al.,* 2024). Proteins including globulin, albumin, and prolamin have been identified in millet seed cover, along with minerals like calcium, magnesium, iron, zinc, and phosphorus. In addition to this, antioxidant and antiaspirin qualities are enhanced by the polyphenols present in the millet seed layer (Agrawal *et al.,* 2023). Furthermore, millets include prebiotic components that are metabolised by gut-dwelling Indigenous bacteria to yield beneficial short-chain fatty acids and probiotics from the colon that have been demonstrated to have antidiabetic effects (Singh *et al*., 2022).

Particularly finger millet, which contains high quantities of phytic acid, decreases the digestion of carbohydrates and lowers blood glucose levels after meals (Gupta *et al.,* 2017). Consequently, diabetics might consider finger millet to be a viable dietary option. Resistant starch, which can delay stomach emptying and lower blood glucose levels after consuming food, is especially abundant in foxtail millet (Ren *et al*., 2018). Prolamin, also known as kefirin, is discovered in sorghum. This protein is less easily digested when cooked than other proteins found in cereals (De Mesa Stonestreet *et al.,* 2010). When ingested, omega-3 fatty acids, zinc, iron, and dietary fibers included in pearl millet have antioxidant effects (Satyavathi *et al.,* 2021). Individuals with diabetes can also benefit from the low GI and higher protein content of proso millet, barnyard millet, and foxtail millet. One of the main indicators of diabetes is polyphagia or the frequent need for food. To ensure steady postprandial body glucose homeostasis, millets shorten the time of stomach emptying. Alpha-glucosidase and pancreatic amylases are inhibited by polyphenolic ligands, which lower postprandial hyperglycemia by preventing the breakdown of complex carbohydrates by these enzymes. Millets have slowly digested starch, which in the gastrointestinal tract prolongs the process of breaking down and absorbing carbohydrates. Millet helps prevent diabetes because it releases less glucose into the blood for a longer amount of time than rice, which is a grain that is commonly ingested. Glycolipid values also change favourably in fibers high in millet. So, they proved to be the greatest substitute for rice. For diabetes individuals, controlling body weight is crucial. Millets can help with this (Ofosu *et al*., 2020; Almaski *et al*., 2022; Wang *et al*., 2022; Agrawal *et al.,* 2023).

Considering millets' high fiber content, rich nutrient profile, and low GI, particularly foxtail millet, finger millet, barnyard millet, and proso millet have displayed promise in the dietary control of type 2 diabetes. An additional justification in favour of these millets' acceptability for T_2D patients is their dearth of starch and sugar profiles. A comprehensive analysis of pertinent research, as shown in Table 3, suggests that millets could potentially be beneficial in managing and reducing the risk of T_2D. To begin with, meals composed of millet are recognized to have a low GI. The rate at which a food raises blood glucose levels after consumption is measured by the GI. Foods with a low GI profile release glucose more gradually and steadily, which helps to keep blood sugar levels constant. Added to that, it has been established that consuming millet-based diets diminishes blood glucose levels both fasting and postprandial (after eating) blood glucose levels. The amount of sugar in the blood following a time of fasting, usually measured after an overnight fast is known as FBG. The blood sugar levels recorded following a meal are referred to as postprandial blood glucose levels. These two measurements are crucial markers of blood sugar regulation in diabetics. Moreover, it has been discovered that millets lower HbA1c levels. The average blood glucose levels over the previous two to three months are measured by the HbA1c. Better long-term glucose management is indicated by lowering HbA1c levels, and this is important for controlling diabetes and lowering the risk of complications from the disease.

When compared to raw grains, processed grains are typically thought to have a more enticing appearance, flavour, and acceptability. Bioactive chemicals are changed during processing, which affects nutritional value and is effective in combating NCD. Flavonoids, dietary fiber, and total phenolic content, total flavonoid content, and antioxidant activity are all increased by germination, roasting, microwave, ultrasound, and cold plasma. Phenolics also have antiinflammatory and antioxidant qualities (Sunil *et al*., 2024). It has been demonstrated that the nutritional profile of grains, including their micronutrient content, starch, reducing and non-reducing sugars, and in vitro digestibility, changes as a result of germination. Antinutritional factors are chemicals that can impede the absorption of nutrients; germination can also impact these compounds. However, Lakshmi and Sumathi (2002) proposed that whole grains could prove more advantageous than germinated grains. This might occur because germinated grains undergo metabolic alterations or because whole grains contain antinutritional components that prevent the absorption of nutrients and the breakdown of sugar. Furthermore, throughout the intervention, which lasted from one month to a year, a total of twelve research studies on diabetes, one study on pre-diabetes, and a couple of studies involving normoglycemic healthy individuals observed that consuming at least 40 g and at most 150 g of millet-based diets significantly reduced blood glucose levels. Even with these results, millets did not always have a substantial effect on blood glucose levels. Nevertheless, millets have been shown to cause a non-significant reduction in blood sugar levels, according to one study on diabetes participants and one study on healthy participants. The limited length of millet consumption in this research may be the cause of this lack of substantial effect. Additionally, a significant drop in blood glucose levels was observed in four research studies including subjects with T_2D, but not across all parameters. Overall, most of the research studies indicated that millets have a constructive impact on diabetes by providing low GI meals, lowering fasting and postprandial blood glucose levels as well as the HbA1c level. Ultimately, the vast majority of research investigations concluded that adopting millet in the diet will help to control T_2D, while the precise impact will rely on a number of variables, including consumption frequency along with individual responses. To verify their effectiveness and improve dietary recommendations for the control of diabetes, more thorough research is needed, specifically on lesser-studied millets like barnyard and proso, as well as studies into the advantages of mixed millet diets.

5. Conclusion

The first "Global Report on Diabetes" was released by the WHO in 2016, emphasizing the dire global diabetes condition and the need for efficient methods to lessen the risk of T_2D. In an evolving nation like India, taking into account the ideologies of glycemic index and glycemic load in the field of nutrition can be advantageous in mitigating the rising incidence of diabetes. The present study's systematic review offers compelling evidence that the consumption of "nutri cereals" can bring down blood glucose levels, hence contributing to the prevention and control of T_2D. Therefore, millets should be included in nutrition and health initiatives, used to diversify staple foods throughout Asia and Africa, and supported as more comprehensive approaches to food system reform.

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Conflict of interest

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

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