

Nutritional Values of Teff (*Eragrostis tef*) in Diabetic Patients: Narrative Review

Mezgebu Legesse Habte¹, Etsegenet Assefa Beyene², Teka Obsa Feyisa¹, Fitalew Tadele Admasu³, Anmut Tilahun³, Getahun Chala Diribsa⁴

¹Department of Medical Biochemistry, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia; ²Department of Biochemistry, College of Health and Medical Sciences, Addis Ababa University, Addis Ababa, Ethiopia; ³Department Medical Biochemistry, College of Health Sciences, Debre Tabor University, Debre Tabor, Ethiopia; ⁴Department of Medical Physiology, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia

Correspondence: Mezgebu Legesse Habte, Tel +251 934095576, Email Mezgebu.Legesse@haramaya.edu.et

Introduction: Teff (*Eragrostis tef*) is an indigenous crop in Ethiopia and exists in white, red, and mixed varieties. Several types of research confirmed that teff is rich in many essential amino acids, slowly digesting carbohydrates, essential fatty acids, minerals, vitamins, fibers, and other components. Since teff has a low glycemic index, is enriched in essential amino acids and fatty acids, and contains nutritionally balanced minerals, vitamins, and their precursors, it could be a promising food for the prevention and management of diabetes. People with diabetes mellitus are recommended to feed on a diet having a low glycemic index and enriched in essential nutrients.

Objective: This review aimed to summarize the nutritional composition of teff (*Eragrostis tef*) and its value in diabetic patients.

Methodology: We searched Web of Science, PubMed, Medline, Embase, and Google Scholar for studies on the nutritional composition of teff and its value for diabetic patients published in English since 2010.

Conclusion: According to available data, teff is a nutritionally valuable food type for diabetic patients.

Keywords: essential amino acids, essential fatty acids, diabetes, glycemic index, nutrition, teff

Introduction

Teff (*Eragrostis tef*) is a tropical grain crop that belongs to the grass family and common food in Ethiopia and Eritrea. Physically, teff is the smallest grain, which is 1.0 mm in length and 0.60 mm in width and consumed as a whole grain. Mainly, teff grain exists in three main varieties; white (Magna), brown (key), and mixed (sergegna). All varieties of teff have almost similar chemical composition except brown (red) which is rich in iron and commonly used for prevention, treatment, and management of iron deficiency anemia.¹ According to many published pieces of research, teff contains balanced ingredients like carbohydrates, fiber, lipids, and essential amino acids, and it is the best source of iron, calcium, and zinc.² Since teff is proven to be free from gluten, a large number of researchers are conducting a study on the nutritional composition of teff and its processing qualities. The gluten-free nature of teff makes it preferable for celiac patients.³ A study done by Gebru et al showed that teff injera, which is a common food in Ethiopia and Eritrea, is rich in necessary minerals, vitamins, healthy fiber, essential amino acids, and carbohydrates with a low glycemic index. In addition, teff injera and bread have slower staling property and longer shelf life as compared to others. As a result, teff injera and bread are used to manage and treat different chronic diseases.⁴

Injera is the most common food item in Ethiopia, and it is mainly made up of teff, especially in the urban area. Injera can also be prepared from a mixture of teff flour and other grain flour like barley, wheat, maize, and others in different proportions. Ethiopians and Eritreans utilize teff in the forms of injera, bread (dabo), porridge (genfo), and others. In Ethiopia, different stews or sauces like Doro wat, tibs, Shiro, beyanetu, siga wat, kitfo, misir wat, and different dairy products are being consumed with teff injera. Almost all hotels and restaurants in Ethiopia use teff injera for scooping stews, meat, vegetable, etc.⁵ Nowadays, people are starting to prepare pasta, macaroni, and other industrial food products from teff flour.⁶

Diabetic mellitus (DM) is becoming a huge public health problem in the world especially in developing countries.⁷ According to the International Diabetes Federation report, in 2020, more than half a billion people are living with diabetes worldwide and this figure will increase by more than 20% in the coming 10 years. Several studies showed that the prevalence of DM is higher among people who live in urban areas and developing countries.⁸ Available data showed that the mortality rate as a result of diabetes is getting increased from time to time.⁹

Nutritional compositions of individual food consumed frequently affect the occurrence of non-communicable diseases mainly diabetes, hypertension, cardiovascular diseases, cancer, and others.¹⁰ Even though food plans vary from person to person, there are shared qualities of diet that play role in preventing and managing diabetes. A diet with a low glycemic index, enriched in essential amino acids, fatty acids, and fiber, containing a sufficient number of vitamins and minerals, is recommended for the prevention and management of diabetes.¹¹ Many studies indicate that the quality of food is more crucial than the quantity of food for the prevention and management of diabetes. The nutritional intervention significantly reduces both acute and chronic diabetic complications in diabetic patients and becomes more effective when combined with physical exercise.^{12,13} A study done by Demir et al showed that individuals who consume teff in their daily life have better control of blood glucose and atherogenic lipoproteins.¹⁴ Diabetic-specific food formula is characterized by having a balanced composition of essential amino acids, essential fatty acids, vitamins, and minerals. In addition, it needs to have low carbohydrates with a low glycemic index, and all of these are the quality of teff.¹⁵ This review aims to summarize the nutritional value of teff for the prevention and management of diabetes mellitus.

Methodology

Information used to write this paper was searched from Web of Science, PubMed, Medline, Embase, and Google Scholar by using key terms “teff”, “*Eragrostis tef*”, “Nutritional value”, and “diabetic patients”. Published papers in the English language since 2010 were used. To write this narrative review more than 500 published papers were collected and finally 74 articles were used and cited according to their relevance.

Nutritional Values of Teff for Diabetic Patients

Glycemic Index (GI) of Teff and Diabetes

Glycemic index (GI) is one of the common parameters, which is used to measure how much specific food increases the blood glucose level within a given time. The glycemic index of foods is expressed on a scale of 1 to 100, based on how fast they increase blood sugar levels after ingestion.¹⁶ Based on the value of GI, different food items can be categorized into the low glycemic diet (less than 55), medium glycemic diet 55 to 69, and high glycemic (greater than 70).¹⁷

According to several studies, food items with low and medium GI have better health benefits as compared to high glycemic index foods, especially for those with chronic diseases like diabetes and hypertension.¹⁸ The International Diabetic Federation showed that diabetic patients can reduce and delay both acute and chronic complications by restricting a high glycemic index diet.¹⁹ Studies done by Dereje et al and Assefa et al showed that all variants of teff have a low glycemic index, which makes it a preferred food for diabetic patients.^{20,21} The carbohydrate composition of food ingredients determines its GI. Quantitatively, teff grain contains 73g/100g of carbohydrate, which is comparable with the amount of carbohydrate in wheat 75g/100g, and rye 76g/100g. But, the GI and glycemic load of wheat are (54 and 11.5) and rye is (45 and 29) which is higher than teff. The glycemic index and glycemic load of food are also determined by the quality of carbohydrates it contains. Teff contains a mixture of complex carbohydrates which is slowly digested and absorbed into the bloodstream. According to a study done by Dereje et al, the glycemic index of teff injera, corn injera, and white wheat bread is 35.6, 97.3, and 50.7, respectively.^{18,22} An experimental study done to assess the GI of teff injera in healthy human and mice showed that it is low; in average 36.7 (Table 1). A published article done by Mechanick et al showed that a diet with a low glycemic index is beneficial for diabetic patients in decreasing cardiovascular disease risks. Thus, teff could be a good ingredient for diabetic-specific food formulas.²³

Table I Glycemic Index of Teff

No.	Author	Publication Year	Study Subjects	Glycemic Index	Average
1.	Dereje et al ¹⁵	2019	Healthy human	35.6 (95% CI 26.2–46.1) (teff injera)	36.7
2.	Assefa et al ¹⁶	2017	Healthy mice	35.2 (white teff injera) 39.3 (red teff injera)	

Essential Amino Acid Composition of Teff and Diabetes

Besides the appearance, texture, and flavor, the quantitative and qualitative composition of essential amino acids in foods determines their quality.²⁴ Some studies showed that the quality of life highly depends on the quality of food. The mental, emotional, social, and psychological well-being of individuals are influenced by the quality of foods they consume.²⁵ Individuals who suffer from non-communicable chronic diseases like diabetes mellitus should give special attention to the quality of foods they feed.²⁶ Different clinical trials reported that oral supplementation of essential amino acids for diabetic patients can decrease insulin resistance, blood glucose, and glycated hemoglobin, thereby reducing acute and chronic diabetic complications.^{27–29} Diet rich in essential amino acids, and other supplements are used to prevent and treat different chronic diseases including diabetes.^{27,30}

Most Ethiopian traditional foods are organic and assumed that they have a positive effect on the prevention and treatment of non-communicable diseases like diabetes, cardiovascular diseases, hypertension, cancer, and others.³¹ Teff is enriched in all essential amino acids as compared to other crops.³² Teff is free from gluten which makes it essential for the treatment of celiac disease and contains balanced essential amino acids that have nutritional benefits to the community, especially for diabetic patients.³ A study done by Lemecha et al on mice showed that teff can improve glucose tolerance, control body weight, and regulate inflammation and all of these are used to reduce acute and chronic complications of diabetes mellitus patients.³³ In addition, teff has an anti-mutagenic effect and prevents different types of mutation; as a result, adding teff to the daily diet can prevent and treat cancer.³⁴

Essential amino acids directly or indirectly play an indispensable role in preventing and managing different chronic diseases such as diabetes, cardiovascular disease, cancer, etc. In some clinical cases like diabetes, the need for essential amino acids increases by many folds, and food rich in these essential amino acids becomes more valued. According to some studies, teff is a promising crop for diabetic patients because of its essential amino acid composition.³ According to published studies, greater than 10% of the dry mass of teff is protein and more than 40% of this is an essential amino acid. Indispensable amino acid, lysine, which plays a great role in general protein metabolism, is found in large amounts in teff.^{4,35} Essential amino acid, lysine, is very important in assisting mineral absorption from the intestine, synthesis of different body proteins, and regulating blood glucose. Lysine is one important component of carnitine. The catabolic product of lysine amino acid, acetoacetyl CoA, is a substrate for the Krebs cycle.³⁶ A clinical trial on type 2 DM patients done by Mirmiranpour et al showed that L-lysine can significantly reduce advanced glycation end products (AGEs), glycated hemoglobin, and risk of infection. In addition, T2DM patients who get enough lysine have better wound healing capacity.³⁷ Teff flour contains up to 12mg/g of lysine amino acid, which is the highest compared to other grains. In general, existing data support that diabetic patient are benefited from essential amino acids of teff.³²

Essential Fatty Acid Composition of Teff and Diabetes

Essential fatty acids, which are obtained only from the diet, are crucial for the survival of humans. Missing these ingredients from the food individuals eat leads to different deficiency disorders. Essential fatty acids are the main precursor of biologically important metabolites like prostaglandins (PGs), thromboxanes (TXs), leukotrienes (LTs), neurotransmitters, and lipoxins (LXs), resolvins, isoprostanes and hydroxy- and hydroperoxyl eicosatetraenoates.³⁸ As a result, the quality of food is determined by the qualitative and quantitative composition of essential fatty acids.³⁹ The availability of essential fatty acids in the diet becomes more valuable at the growing stage and in some clinical cases.⁴⁰ Individuals with chronic non-communicable diseases such as diabetes, hypertension, cardiovascular diseases, and different types of cancers are highly benefited from essential fatty acids. Getting a sufficient amount of essential fatty

acids from the diet is used to manage the effect of those non-communicable diseases. In addition, essential fatty acids help in the improvement of treatment outcomes.^{41,42}

According to a study done by Amare et al, teff contains more than 3 grams of fat per 100 grams. In addition, teff is rich in essential fatty acids such as linoleic (C18:2, cis, cis-9,12), oleic (C18:1 cis 9), and α -linolenic (C18:3). The presence of a higher percentage of α -linolenic acid and other polyunsaturated fatty acids in teff is used to protect diabetic patients from developing cardiovascular disease, atherosclerosis, and hypertension.^{3,43,44} Different studies indicated that diabetic patients can control dyslipidemia by adding omega-3 fatty acids to their daily diet and teff could be the best source.⁴⁵ Diabetic patients who can get a sufficient amount of omega-3 fatty acids can improve insulin resistance and inflammatory disorder. Teff, which is an important source of omega-3 fatty acids, shows antioxidant effects and benefits diabetic patients and patients suffering from other chronic diseases.⁴⁶ In addition, polyunsaturated fatty acids play a great role in delaying diabetic peripheral neuropathy and preventing the development of retinopathy and for this teff contains a high percentage of polyunsaturated fatty acids.^{34,47–49} Based on its essential fatty acids composition, world nutritionists nowadays, recommend teff as one of the important components of diabetic-specific food formulas.⁵⁰ Diabetic patients who get more than a gram of omega-3 fatty acids significantly reduce triglycerides, thereby controlling dyslipidemia-induced cardiovascular disease. In addition, omega-3 fatty acids can control glycated hemoglobin and atherogenic lipoprotein.⁵¹ Available studies support the idea that diabetic patients can get enough amount of essential fatty acids from teff and it is a promising food type used to manage acute and chronic diabetic complications.^{2,20,52,53}

Fiber Composition of Teff and Diabetes

Fiber is another important component of the diet and determines the quality of foods. Prevention, treatment, and management of different diseases are highly dependent on the qualitative and quantitative availability of fiber in individual daily diets. Especially, individuals with chronic non-communicable diseases such as diabetes, hypertension, cardiovascular diseases, and cancer need to consume fiber-rich diets.^{54,55} Some published articles showed that type 2 diabetic patients who consume enough amount of fiber in their diet can improve blood glucose homeostasis, insulin resistance, blood lipids, body weight, inflammations, and reduce hemoglobin A1c level, thereby preventing the risk of premature mortality in adults with diabetes.^{56,57} A study done by Fujii et al showed that diabetic patients taking a better amount of dietary fiber significantly reduce abdominal obesity, hypertension and metabolic syndrome, albuminuria, low estimated glomerular filtration rate, and chronic kidney disease.⁵⁸ Dietary fiber plays a significant anti-inflammatory, antioxidant, hypocholesterolemic, hypoglycemic, and antihypertensive role for all populations. For diabetic patients, the role of fiber becomes more critical.⁵⁹

According to studies, teff contains enough fibers, which can benefit diabetic patients. Teff, a wonderful grain, originated from Ethiopia, and the best ingredient to prepare traditional Ethiopian food called “Enjera” is small in size and used as a whole grain.⁶⁰ The cover of teff grain contains slowly digestible carbohydrates and fiber, which benefit diabetic patients more. As compared to other grains, teff contains higher crude fiber, total and soluble dietary fibers.³ An experimental study done by Dereje et al indicated that teff injera contains around 2.58 grams of crude fiber per 100 grams, which is higher than other grains’ fiber.²⁰ This fiber content in combination with other factors makes it teff highly important grain used in the treatment and management of diabetes.^{61,62}

Vitamins and Minerals Composition of Teff and Diabetes

Vitamins and minerals are highly essential micro-nutrients for life and are primarily obtained from the diet we eat. As a result, the quality of food is highly dependent on the composition of vitamins and minerals. They are needed in small amounts and perform an indispensable role in the general health of individuals. People who can obtain the recommended amount of vitamins and minerals have a high chance to be healthy.⁶³ In addition, people with non-communicable chronic diseases like diabetes have to obtain the required amounts of vitamins and minerals from the food they eat. Some studies showed that diabetic patients who obtain sufficient vitamins and minerals from the diet they eat, significantly reduce acute and chronic complications.^{64,65}

Teff contains an essential amount of minerals (P, K, Mg, Ca, Fe, Mn, and Zn), which are necessary for normal biological processes. Compared to other cereals, teff contains a healthy concentration of calcium, iron, polyphenols, and

phytate.^{44,66,67} A deficiency of manganese and magnesium is common in people with diabetes. Both are a key co-factor in glucose metabolism. Magnesium has a major role in cellular defenses against oxidation damage in diabetes and this helps to reduce its complication. The deficiency of magnesium may increase insulin resistance and interrupt the insulin secretion process. In diabetes, potassium-containing diet supplementation may improve insulin sensitivity and the effectiveness of the insulin hormone.^{68,69}

Zinc is an essential element in insulin metabolism that regulates more than 100 enzymes for protein folding, and gene expression, as well as in the production and neutralization of reactive oxygen species. Zinc is a vital ingredient for the appropriate processing, storage, secretion, and action of insulin in pancreatic cells and its disturbances are associated with diabetes. Zinc reduces cytokine production and its deficiency may cause cytokine-induced damage in the autoimmune attack, destroying the islet cell in T1DM.⁷⁰

Teff contains a high concentration of calcium that can prevent weight gain, accumulation of fat, and osteoporosis which often lead to diabetes.⁴ A study done by Koubová et al indicated that teff is an important grain recommended as a safe and valuable mineral and trace element source.⁷¹ Besides these, teff contains less amount of phytic acid and inositol phosphates, which can inhibit the bioavailability of iron and zinc. Compared to other cereals, fermentation of teff increase the bioavailability of minerals and the generation of the vitamin B family. A high concentration of iron in teff, especially in red teff, is used to prevent and treat iron-deficiency anemia.⁷² Some literature shows that teff seeds contain more than 20mg/100gram iron which, is higher than in other cereals. In addition, teff is a very important source of vitamins and their precursors.⁶ According to a review done by Satheesh and Fanta, teff is enriched in vitamin A, B complex, C, K, and α -tocopherol, which are highly essential for the immunological quality of individuals. Vitamin B6 supplements may be able to improve glucose tolerance, particularly for those who are suffering from gestational diabetes. It also plays a major role in the prevention of diabetes-related complications. Vitamin C is important in lowering the amount of sorbitol in type 1 diabetic patients. Sorbitol is an unsafe sugar that may lead to an increased risk of diabetic complications such as neuropathy, retinopathy, and kidney insufficiency. In type 2 diabetics, vitamin C may play a role in improving glucose tolerance. Vitamin D plays a role in boosting insulin sensitivity, which is vital for blood glucose regulation.^{4,70} Furthermore, teff contains different polyphenols, which are effective antioxidants. All these factors make teff an important daily food ingredient for diabetic patients.^{2,50,73}

Strength and Limitations of the Study

In this narrative review, 74 published articles are used. The review tried to explain the compositions of teff and its functions in diabetic patients. In addition, the review is easy to understand by the community, and it provides information on the nutritional values of teff for diabetic patients. However, this narrative review lacks research that is done on the direct function of teff for diabetic patients.

Conclusion

Teff could be a good food ingredient and people can be benefited more from it. Overall, this review summarized several studies published on the nutritional values of teff (*Eragrostis tef*). In general, its nutritional compositions make teff to be one of the healthy nutrients recommended for diabetic patients. Particularly, having a low glycemic index and load, containing essential amino acids and fatty acids, balanced minerals and vitamins, and high fiber compositions make it a reliable and promising food that can ameliorate diabetic complications. Finally, we would like to recommend that further studies involving diabetic patients should be conducted on teff to determine the mechanism by which it can decrease blood glucose levels in diabetic patients.

Data Sharing Statement

All necessary data and materials related to the article are included in the article.

Acknowledgment

We would like to express our sincere thanks to Haramaya University.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis, and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This review article is not funded by any person or organization.

Disclosure

The authors declare that they have no conflicts of interest in relation to this work.

References

1. Abebaw G. *The Study of Some Engineering Properties of Teff [ERAGROSTIS Teff (ZUCC.) Trotter]*. GRAINS AND ITS FLOUR: Haramaya University; 2018.
2. Do Nascimento KO, Paes SD, de Oliveira IR, Reis IP, Augusta IM. Teff: suitability for different food applications and as a raw material of gluten-free, a literature review. *J Food Nutr Res*. 2018;6(2):74–81. doi:10.12691/jfmr-6-2-2
3. Baye K. *Teff: Nutrient Composition and Health Benefits*. International Food Policy Research Institute; 2014.
4. Gebru YA, Sbhatu DB, Kim K-P. Nutritional composition and health benefits of teff (*Eragrostis tef* (Zucc.) trotter). *J Food Qual*. 2020;2020:1–6. doi:10.1155/2020/9595086
5. Kefale B. Evaluation of Injera prepared from composite flour of Teff and Barley variety. *J Food Sci Nutr Ther*. 2020;6(1):038–40.
6. Zhu F. Chemical composition and food use of teff (*Eragrostis tef*). *Food Chem*. 2018;239:402–415. doi:10.1016/j.foodchem.2017.06.101
7. Wolde HF, Derso T, Bikis GA, et al. High hidden burden of diabetes mellitus among adults aged 18 years and above in Urban Northwest Ethiopia. *J Diabetes Res*. 2020;2020. doi:10.1155/2020/9240398
8. Saeedi P, Petersohn I, Salpea P, et al. Global and regional diabetes prevalence estimates for 2019 and projections for 2030 and 2045: results from the International Diabetes Federation Diabetes Atlas. *Diabetes Res Clin Pract*. 2019;157:107843. doi:10.1016/j.diabres.2019.107843
9. Lin X, Xu Y, Pan X, et al. Global, regional, and national burden and trend of diabetes in 195 countries and territories: an analysis from 1990 to 2025. *Sci Rep*. 2020;10(1):1–11. doi:10.1038/s41598-019-56847-4
10. Naicker A, Venter C, MacIntyre UE, Ellis S. Dietary quality and patterns and non-communicable disease risk of an Indian community in KwaZulu-Natal, South Africa. *J Health Popul Nutr*. 2015;33(1):1–9. doi:10.1186/s41043-015-0013-1
11. Gray A, Threlkeld RJ. Nutritional recommendations for individuals with diabetes. 2015.
12. Ley SH, Hamdy O, Mohan V, Hu FB. Prevention and management of type 2 diabetes: dietary components and nutritional strategies. *Lancet*. 2014;383(9933):1999–2007. doi:10.1016/S0140-6736(14)60613-9
13. American Diabetes Association. Nutrition recommendations and interventions for diabetes: a position statement of the American Diabetes Association. *Diabetes Care*. 2007;30(suppl 1):S48–S65. doi:10.2337/dc07-S048
14. Demir EG, Tarakçı NG, Samancı RA, et al. The effect of teff seed on hematological findings and anthropometric measurements. *Ethiop J Health Sci*. 2022;32(3):641–650. doi:10.4314/ejhs.v32i3.21
15. Todd AS, Forbes JM, Deane AM, Presneill JJ, Sturgess DJ. Diabetes-specific formulae versus standard formulae as enteral nutrition to treat hyperglycemia in critically ill patients: protocol for a randomized controlled feasibility trial. *JMIR Res Protoc*. 2018;7(4):e9374.
16. Wolever TM, Brand-Miller JC, Abernethy J, et al. Measuring the glycemic index of foods: interlaboratory study. *Am J Clin Nutr*. 2008;87(1):247S–57S. doi:10.1093/ajcn/87.1.247S
17. Jamurtas AZ, Tofas T, Fatouros I, et al. The effects of low and high glycemic index foods on exercise performance and beta-endorphin responses. *J Int Soc Sports Nutr*. 2011;8(1):1–11. doi:10.1186/1550-2783-8-15
18. Sacks FM, Carey VJ, Anderson CA, et al. Effects of high vs low glycemic index of dietary carbohydrate on cardiovascular disease risk factors and insulin sensitivity: the OmniCarb randomized clinical trial. *JAMA*. 2014;312(23):2531–2541. doi:10.1001/jama.2014.16658
19. Saeedi P, Salpea P, Karuranga S, et al. Mortality attributable to diabetes in 20–79 years old adults, 2019 estimates: results from the International Diabetes Federation Diabetes Atlas. *Diabetes Res Clin Pract*. 2020;162:108086. doi:10.1016/j.diabres.2020.108086
20. Dereje N, Bekele G, Nigatu Y, Worku Y, Holland RP. Glycemic index and a load of selected Ethiopian foods: an experimental study. *J Diabetes Res*. 2019;2019. doi:10.1155/2019/8564879
21. Assefa M, Umata M, Gnanasekaran N. Glycemic index of some traditional Ethiopian foods. *Int J Biochem Res Rev*. 2017;18(4):1–10. doi:10.9734/IJBICRR/2017/34471
22. Akansha KS, Chauhan ES. Nutritional composition, physical characteristics and health benefits of teff grain for human consumption: A. 2018.
23. Mechanick JI, Marchetti A, Hegazi R, Hamdy O. Diabetes-specific nutrition formulas in the management of patients with diabetes and cardiometabolic risk. *Nutrients*. 2020;12(12):3616. doi:10.3390/nu12123616
24. Molnár PJ. Food quality indices. *Food Qual Standards*. 2009;2(10):89.
25. Sarojnini C, Hei A. Fish as an important functional food for a quality life. In: *U: Functional Foods*, (Lagouri, V, Ured). London: IntechOpen; 2019:77–97.
26. Deed G, Barlow J, Kawol D, Kilov G, Sharma A, Yu Hwa L. Diet, and diabetes. *Aust Fam Physician*. 2015;44(5):288–292.
27. Solerte SB, Gazzaruso C, Schifino N, et al. Metabolic effects of the orally administered amino acid mixture in elderly subjects with poorly controlled type 2 diabetes mellitus. *Am J Cardiol*. 2004;93(8):23–29. doi:10.1016/j.amjcard.2003.11.006

28. Bifari F, Ruocco C, Decimo I, Fumagalli G, Valerio A, Nisoli E. Amino acid supplements and metabolic health: a potential interplay between intestinal microbiota and systems control. *Genes Nutr.* **2017**;12(1):1–12. doi:10.1186/s12263-017-0582-2
29. Eustace JA, Coresh J, Kutche C, et al. Randomized double-blind trial of oral essential amino acids for dialysis-associated hypoalbuminemia. *Kidney Int.* **2000**;57(6):2527–2538. doi:10.1046/j.1523-1755.2000.00112.x
30. Ueyama H, Kanemoto N, Minoda Y, Taniguchi Y, Nakamura H. 2020 Chitranjan S. Ranawat Award: perioperative essential amino acid supplementation suppresses rectus femoris muscle atrophy and accelerates early functional recovery following total knee arthroplasty: a prospective double-blind randomized controlled trial. *Bone Joint J.* **2020**;102(6 Suppl A):10–18.
31. Tadesse NS, Beyene GF, Hordofa TB, Hailu AA. Traditional foods and beverages in Eastern Tigray of Ethiopia. *J Ethnic Foods.* **2020**;7(1):1–12. doi:10.1186/s42779-020-00050-8
32. Gebru YA, Hyun-I J, Young-Soo K, Myung-Kon K, Kwang-Pyo K. Variations in amino acid and protein profiles in white versus brown teff (*Eragrostis tef*) seeds, and effect of extraction methods on protein yields. *Foods.* **2019**;8(6):202. doi:10.3390/foods8060202
33. Lemecha M, Morino K, Seifu D, et al. Improved glucose metabolism by *Eragrostis tef* potentially through beige adipocyte formation and attenuating adipose tissue inflammation. *PLoS One.* **2018**;13(8):e0201661. doi:10.1371/journal.pone.0201661
34. da Silva Goersch MC, Schäfer L, Toniai M, et al. Nutritional composition of *Eragrostis tef* and its association with the observed antimutagenic effects. *RSC Adv.* **2019**;9(7):3764–3776. doi:10.1039/C8RA09733J
35. Tomé D, Bos C. Lysine requirement through the human life cycle. *J Nutr.* **2007**;137(6):1642S–5S. doi:10.1093/jn/137.6.1642S
36. Ranasinghe P, Jayawardena R, Chandrasena L, Noetzel V, Burd J. Effects of Lysulin™ supplementation on pre-diabetes: study protocol for a randomized controlled trial. *Trials.* **2019**;20(1):1–9. doi:10.1186/s13063-019-3269-8
37. Mirmiranpour H, Bathaie SZ, Nakhjavani M, et al. The preventive effect of L-lysine on lysozyme glycation in type 2 diabetes. *Acta Med Iran.* **2016**;54:24–31.
38. Nagy K, Tiuca I-D. Importance of fatty acids in the physiopathology of the human body. In: *Fatty Acids*. IntechOpen; **2017**.
39. Kaur N, Chugh V, Gupta AK. Essential fatty acids as functional components of the foods-a review. *J Food Sci Technol.* **2014**;51(10):2289–2303. doi:10.1007/s13197-012-0677-0
40. Castro-Correia C, Sousa S, Norberto S, et al. The fatty acid profile in patients with newly diagnosed diabetes: why it could be unsuspected. *Int J Pediatr.* **2017**;2017:1–5.
41. Li D. Omega-3 fatty acids and non-communicable diseases. *Chin Med J.* **2003**;116(3):453–458.
42. Tokunaga M, Takahashi T, Singh R, et al. Diet, nutrients and non-communicable diseases. *Open Nutraceuticals J.* **2012**;5(1):146–159. doi:10.2174/1876396001205010146
43. Amare E, Grigoletto L, Corich V, Giacomini A, Lante A. Fatty acid profile, lipid quality and squalene content of teff (*Eragrostis tef* (Zucc.) Trotter) and Amaranth (*Amaranthus caudatus* L.) varieties from Ethiopia. *Appl Sci.* **2021**;11(8):3590. doi:10.3390/app11083590
44. Haileselassie B, Dargie S, Estifanos A. Mineral composition of grain and straw of teff (*Eragrostis tef*) grown on Vertisols. *Ethiop J Agric Sci.* **2019**;29(2):83–91.
45. Chauhan S, Kodali H, Noor J, Ramteke K, Gawai V. Role of omega-3 fatty acids on lipid profile in diabetic dyslipidemia: a single-blind, randomized clinical trial. *J Clin Diagn Res.* **2017**;11(3):OC13. doi:10.7860/JCDR/2017/20628.9449
46. Azadbakht L, Rouhani MH, Surkan PJ. Omega-3 fatty acids, insulin resistance, and type 2 diabetes (Editorial Article). **2011**.
47. Yorek MA. The potential role of fatty acids in treating diabetic neuropathy. *Curr Diab Rep.* **2018**;18(10):1–10. doi:10.1007/s11892-018-1046-9
48. Brown TJ, Brainard J, Song F, Wang X, Abdelhamid A, Hooper L. Omega-3, omega-6, and total dietary polyunsaturated fat for prevention and treatment of type 2 diabetes mellitus: systematic review and meta-analysis of randomized controlled trials. *BMJ.* **2019**;366. doi:10.1136/bmj.l4697
49. Yee P, Weymouth AE, Fletcher EL, Vingrys AJ. A role for omega-3 polyunsaturated fatty acid supplements in diabetic neuropathy. *Invest Ophthalmol Vis Sci.* **2010**;51(3):1755–1764. doi:10.1167/iovs.09-3792
50. Satheesh N, Fanta SW. Review on the structural, nutritional, and anti-nutritional composition of Teff (*Eragrostis tef*) in comparison with Quinoa (*Chenopodium quinoa* Willd.). *Cogent Food Agric.* **2018**;4(1):1546942. doi:10.1080/23311932.2018.1546942
51. Chewcharat A, Chewcharat P, Rutirapong A, Papatheodorou S. The effects of omega-3 fatty acids on diabetic nephropathy: a meta-analysis of randomized controlled trials. *PLoS One.* **2020**;15(2):e0228315. doi:10.1371/journal.pone.0228315
52. Strolin H, Kriketos A, Calvert G, Baur L, Jenkins A. Fatty acids, triglycerides and syndromes of insulin resistance. Prostaglandins and plasma lipid and lipoprotein metabolism in humans: a critical review. *Diabetes Care.* **2007**;30(4):1012–1024. doi:10.2337/dc06-1332
53. Tietel Z, Simhon E, Gashu K, et al. Nitrogen availability and genotype affect major nutritional quality parameters of teff grain grown under irrigation. *Sci Rep.* **2020**;10(1):1–15. doi:10.1038/s41598-020-71299-x
54. Harris PJ, Ferguson LR. Dietary fiber: its composition and role in protection against colorectal cancer. *Mutation Res.* **1993**;290(1):97–110. doi:10.1016/0027-5107(93)90037-G
55. Mayor S. *Eating More Fiber Linked to Reduced Risk of Non-Communicable Diseases and Death, Review Finds*. British Medical Journal Publishing Group; **2019**.
56. Wolfram T, Ismail-Beigi F. Efficacy of high-fiber diets in the management of type 2 diabetes mellitus. *Endocr Pract.* **2011**;17(1):132–142. doi:10.4158/EP10204.RA
57. Reynolds AN, Akerman AP, Mann J. Dietary fiber and whole grains in diabetes management: systematic review and meta-analyses. *PLoS Med.* **2020**;17(3):e1003053. doi:10.1371/journal.pmed.1003053
58. Fujii H, Iwase M, Ohkuma T, et al. Impact of dietary fiber intake on glycemic control, cardiovascular risk factors and chronic kidney disease in Japanese patients with type 2 diabetes mellitus: the Fukuoka Diabetes Registry. *Nutr J.* **2013**;12(1):1–8. doi:10.1186/1475-2891-12-159
59. Barber TM, Kabisch S, Pfeiffer AF, Weickert MO. The health benefits of dietary fibre. *Nutrients.* **2020**;12(10):3209. doi:10.3390/nu12103209
60. Tadele E, Hibistu T. Empirical review on the use dynamics and economics of teff in Ethiopia. *Agric Food Security.* **2021**;10(1):1–13. doi:10.1186/s40066-021-00329-2
61. Jovanovski E, Khayyat R, Zurbau A, et al. Should viscous fiber supplements be considered in diabetes control? Results from a systematic review and meta-analysis of randomized controlled trials. *Diabetes Care.* **2019**;42(5):755–766. doi:10.2337/dc18-1126
62. Weickert MO, Pfeiffer AF. Metabolic effects of dietary fiber consumption and prevention of diabetes. *J Nutr.* **2008**;138(3):439–442. doi:10.1093/jn/138.3.439
63. World Health Organization. *Vitamin and Mineral Requirements in Human Nutrition*. World Health Organization; **2004**.

64. Martini LA, Catania AS, Ferreira SR. Role of vitamins and minerals in prevention and management of type 2 diabetes mellitus. *Nutr Rev.* 2010;68(6):341–354. doi:10.1111/j.1753-4887.2010.00296.x
65. Forouhi NG, Misra A, Mohan V, Taylor R, Yancy W. Dietary and nutritional approaches for prevention and management of type 2 diabetes. *BMJ.* 2018;2018:361.
66. Baye K. Nutrient composition and health benefits. IFPRI book chapters. *Intl Food Policy Res Inst.* 2018;67:371–396.
67. Shumoy H, Raes K. Tef: the rising ancient cereal: what do we know about its nutritional and health benefits? *Plant Foods Human Nutr.* 2017;72(4):335–344. doi:10.1007/s11130-017-0641-2
68. Koh ES, Kim SJ, Yoon HE, et al. Association of blood manganese level with diabetes and renal dysfunction: a cross-sectional study of the Korean general population. *BMC Endocr Disord.* 2014;14(1):1–8. doi:10.1186/1472-6823-14-24
69. Huerta MG, Roemmich JN, Kington ML, et al. Magnesium deficiency is associated with insulin resistance in obese children. *Diabetes Care.* 2005;28(5):1175–1181. doi:10.2337/diacare.28.5.1175
70. Dubey P, Thakur V, Chattopadhyay M. Role of minerals and trace elements in diabetes and insulin resistance. *Nutrients.* 2020;12(6):1864. doi:10.3390/nu12061864
71. Koubová E, Sumczynski D, Šenkárová L, Orsavová J, Fišera M. Dietary intakes of minerals, essential and toxic trace elements for adults from *Eragrostis tef* L.: a nutritional assessment. *Nutrients.* 2018;10(4):479. doi:10.3390/nu10040479
72. Irge DD. Chemical composition and nutritional quality of wheat, teff (*Eragrostis tef* (Zucc) Trotter), barley (*Hordeum vulgare* L.), and rice (*Oryza sativa*)-a review. *Food Sci Qual Manag.* 2017;59:6–12.
73. Zięć G, Gambuś H, Lukaszewicz M, Gambuś F. Wheat bread fortification: the supplement of teff flour and chia seeds. *Appl Sci.* 2021;11(11):5238. doi:10.3390/app11115238

Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy

Dovepress

Publish your work in this journal

Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy is an international, peer-reviewed open-access journal committed to the rapid publication of the latest laboratory and clinical findings in the fields of diabetes, metabolic syndrome and obesity research. Original research, review, case reports, hypothesis formation, expert opinion and commentaries are all considered for publication. The manuscript management system is completely online and includes a very quick and fair peer-review system, which is all easy to use. Visit <http://www.dovepress.com/testimonials.php> to read real quotes from published authors.

Submit your manuscript here: <https://www.dovepress.com/diabetes-metabolic-syndrome-and-obesity-targets-and-therapy-journal>