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Potential of Indonesian Community Food Sources which are Rich in Fiber as an Alternative Staple Food for Type 2 Diabetics: A Scoping Review

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Abstract

BACKGROUND: Staple foods as a source of carbohydrates contribute most of human energy needs. Based on Perkeni's recommendation, diabetic patients can consume at least 45–60% of carbohydrate sources. In addition, several previous studies have shown that increasing the adequacy of dietary fiber above 20–25 g/day can improve glycemic control.

AIM: Our scoping review investigated the potential of Indonesian food sources, namely, sorghum and corn as a source of carbohydrates and also fiber as a substitute rice for diabetic patients.

METHODS: We systematically used electronic databases searched such as PubMed, Science Direct, Web of Science, Portal Garuda, Sinta Ristekbrin, and Google Scholar. We choose the relevant documents used experimental animals and humans' studies then published between 2011 and 2021.

RESULTS: In total, 17 relevant articles discuss the relationship between giving corn or sorghum with blood glucose levels of animal studies and human. Some studies showed that the effect of eating sorghum or its derivatives can reduce blood glucose. As well as, the other articles indicated eating corn or its derivatives also decrease glycemic response of healthy people and experimental animals. Corn and sorghum contain dietary fiber in the form of resistant starch and have low glycemic index compare with white rice. Furthermore, corn also contains essential fat, mineral, β-Carotene, and isoflavone, while sorghum also includes phenolic components such as phenolic acids and flavonoids.

CONCLUSIONS: Sorghum and corn have the potential as an alternative staple food to achieve a better glycemic response in diabetic patients.

Introduction

Indonesia and several countries in the world are still struggling to deal with the COVID-19 pandemic. Comorbid disease is one of the important factors in the treatment of COVID-19 patients. Diabetes mellitus is one of the main comorbid diseases that are often found in COVID-19 patients [1]. Poor glycemic control in diabetic patients is related to immune system dysfunction [2]. Hyperglycemic conditions experienced by patients with diabetes mellitus can cause disturbances in cytokine production, phagocytosis, and the ability of immune cells to kill microbes [3]. Hyperglycemia in patients with diabetes mellitus is caused by a carbohydrate metabolism disorder due to reduced/absence of insulin produced by pancreatic beta cells. In field practice, good glycemic control can be achieved by applying the general pillars of diabetes mellitus management that are diet, exercise, medication, and education.

Eating disorder, especially in food choices of source of carbohydrate and fiber, becomes the major problem in diabetes patient. Primanda *et al.* (2011) and Puri (2019) mention that several problems related to the diet of diabetics include the ability to determine the amount of energy needs, selection of carbohydrate sources, fiber consumption, salt use, and consumption of sodium sources and intake of fat sources [4], [5]. Perkeni (Perkumpulan Endokrinologi Indonesia) recommends carbohydrate consumption between 45% and 65% of total energy needs diabetes patient. Rice (*Oryza sativa* L.) is the staple food for a greater number people in Asia [6], [7]. Rice is one of the sources of carbohydrate. White rice is predominantly consumed by many people without exception diabetes patients. Some studies showed that white rice has a high glycemic index (GI) and glycemic load, low in fiber, polyphenols, and micronutrients such as magnesium that may benefit in glucose metabolism [8], [9], [10]. Consumption of white rice is often associated with increased blood glucose levels in diabetic patients. Diversification of staple foods is very important as an effort to control blood glucose levels in diabetics.

Corn is one of the commodities that have the potential to develop as an alternative source of carbohydrates that high in fiber [11]. In the context of food diversification, corn can be an option because of its high production level, nutritional content, and relatively easy processing and people are used to eating corn. Fiber in 100 g of corn is higher than 100 g of white rice which is 2.2 g with a lower GI about 62 [12]. Corn is rich in functional food components, including dietary fiber, essential fatty acids, isoflavones, minerals (Ca, Mg, K, Na, P, Ca, and Fe), anthocyanins, beta-carotene (provitamin A), essential amino acid, and more [13], [14]. A study was using boiled corn showed that healthy respondents who consumed boiled corn had lower blood glucose elevation compared to eat white rice 30–180 min after eating [15]. The other study showed different result that some corn meal preparation such us pap, roasted corn, boiled corn, and cornflakes can increase GI between 71 and 88 [16].

Sorghum is an ancient cereal grain that belongs to the grass family (*Poaceae*). Some farmers in India, Thailand, and Indonesia, especially Java and Nusa Tenggara, cultivate sorghum in the traditional way. However, several developed countries, such as the United States, Australia, and several European countries, have managed modern sorghum plants using advanced technology such as quality hybrid seeds and fertilization tailored to soil fertility and plant needs [17], [18]. Sorghum contains bioactive compounds including phenolics, sorghum is a food source of antioxidants due to the presence of phenolic components such as phenolic acids, flavonoids, and condensed tannins as well as pagan fibers such as resistant starch and beta-glucan [19], [20].

The objective of our scoping review is to provide several evidence that related potential of corn and sorghum as a substitute for the main staple food (rice). The basic question that may arise is the effect of consumption of corn or sorghum on increasing blood glucose levels. Furthermore, other substances contained in corn or sorghum also have benefits for diabetes patients in controlling blood glucose levels.

Methods

This scoping review will be carried out some stages: (1) Identifying the research question, (2) identifying relevant studies through electronic databases (i.e., PubMed, Science Direct, Web of Science, Portal Garuda, Google Scholar, and Sinta Ristekdikti), (3) selection of studies to be included based on inclusion criteria such as we using the following search strategy: ("corn" OR zea mays OR corn flour; "sorghum" OR sorghum flour; "alternative staple food for diabetic patient" OR fiber contain in staple food; staple food AND GI OR GI of corn processing OR GI of sorghum processing). Then, the studies must have (a) treatment/intervention; (b) been published from January 1, 2011, to December 31, 2020; (c) provided an information about blood glucose response the respondent; and (d) reported the processed form used (4) charting and categorizing extracted data in a pretested data extraction form; and (5) collating, summarizing, and reporting the results. Detail process identifying of studies is presented in Figure 1.

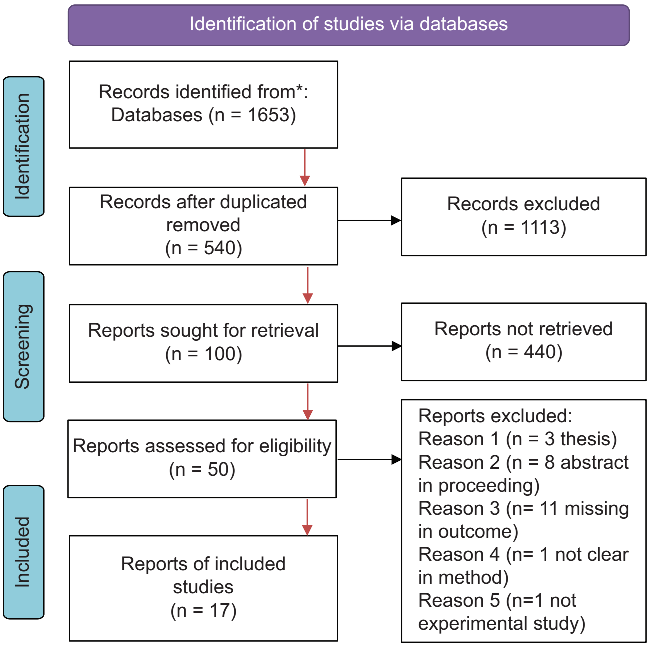

Figure 1: PRISMA 2009 flow diagram – effect of giving corn or sorghum on glucose levels

Results

Totally, we got 17 articles that suitable with our topic. The main characteristic of the article is presented in Table 1. Nine articles presented about the effect of giving corn and its processed products to blood glucose levels healthy people, diabetes patient, and experimental animals. Then, there were eight articles that met the inclusion criteria regarding the topic of sorghum. Most of the articles contain research study designs using experimental with some samples using Wistar rats or humans. Overall, each study discusses the main effect of corn or sorghum in blood glucose levels.

All articles are taken using experimental methods. Most of the samples in the research articles obtained were experimental animals (Wistar rats), healthy humans, and diabetes patients, respectively, there were nine articles, four articles, and three articles. The intervention that gives to subjects in articles in the form of extracts, flour, or food/meal. Whole article using glucose levels as an indicator of the effect of giving corn/sorghum. However, there were some additional results such as composition and nutritional value of extract/flour/or food, body weight, fat profile, liver function, and insulin levels. In general, giving corn or sorghum to

Table 1: Original article included in review

No.	Authors and years	Study design, sample, variable, Instrument, analysis	Outcome of analysis factors	Summary of results
Corn				
1	Inayah *et al.*, 2020 [21]	Design: Quasi-experimental with pre-post-test one-group design Sample: 7 healthy adults, 18–30 years old Variable: Glycemic index and glycemic load of instant corn rice with adding tempeh flour and blood glucose levels Analysis: Paired t-test	Incremental area under the blood glucose response curve (IUAC)	Instant corn rice with tempeh fluor supplementation has GI 31.75 and GL 17.08
2	Zhang *et al.*, 2016 [22]	Design: A randomized trial Sample: 13 diabetes participants (6 males and 7 females) Variable: Rice mix, glycemic control Analysis: Stata/IC 10.1 for Macintosh (Stata Corporation, College Station, TX, USA)	Baseline characteristics of study participants, nutritional composition of two test meals, comparison of postprandial glycemic responses between the two test meals	The rice mix as an alternative to white rice could be a practical self-help approach to improve blood glucose control in people with T2D. Using education and culturally tailored ingredients may help overcome barriers to dietary change
3	Asmarani *et al.*., 2015 [23]	Design: Pre-post-test with control group design Sample: 20 Wistar rats (5 control group, 15 intervention group) Variable: Corn flour with tempeh flour supplementation intervention and blood glucose levels Analysis: One-way ANOVA test with a Tukey *post hoc* analysis	blood glucose levels before and after the intervention	Corn flour with tempeh flour supplementation has an effect on reducing blood sugar level
4	Dada *et al.*, 2015 [16]	Design: Quasi-experimental interventional study design Sample: 32 participants (11 males and 21 females) Variable: Corn meals intervention and glycemic responses Analysis: Student's t-test	Baseline characteristic patients, glycemic response indices of corn meals	Methods of preparing a meal from corn affect glycemic response
5	Soong *et al.*, 2015 [24]	Design: Quasi-experimental interventional study design Sample: 12 healthy adult, 21–50 years old Variable: Muffin made with wheat, rice, corn, oat, and barley, glycemic responses (IAUC). Amylose contain Analysis: Repeated ANOVA, one-way ANOVA with Tukey's test	Baseline characteristic subject, random blood glucose	GI of muffins baked with wheat, rice, corn, oat, and barley flour is 74, 79, 73, 53, and 55. Corn, oat, and barley muffins have amylose higher than other. Amylose in food related with GI potency
6	Djunaidi *et al.*, 2014 [25]	Design: Laboratory experimental design Sample: 30 rats Variable: The composite flour (50% sweet potato, 30% corn, and 20% cowpea) and hypoglycemic effect Analysis: One-way analysis of variance (ANOVA) and Duncan's multiple range test (DMRT)	Blood glucose level, body weight, and feed intake weight	The composite flour could reduce plasma glucose level on diabetic rats and did not give negative effects on body weight and food consumption
7	Luhovyy *et al.*, 2014 [26]	Design: Experimental study Sample: 30 respondents (Male) Variable: The effects of whole grain high-amylose maize flour as a source of resistant starch, blood glucose, satiety, and food intake Analysis: ANOVA, and the Tukey–Kramer *post hoc* test	Blood Glucose levels, Satiety, and Food Intake	HAM flour as a source of RS and incorporated into a cookie was associated with better glycemic control in young men
8	Forester *et al.*, 2012 [27]	Design: Experimental study Sample: 10 rats Variable: Epigallocatechin-3-gallate, blood glucose levels Analysis: Two-tailed Student's t-test	Blood glucose levels	EGCG acutely reduces postprandial blood glucose levels in mice when coadministered with CCS and this may be due in part to inhibition of α-amylase. The relatively low effective dose of EGCG makes a compelling case for studies in human subjects
9	Brites *et al.*, 2011 [28]	Design: Experimental study Sample: 36 Wistar rats Variable: Maize and resistant starch enriched breads, postprandial glycemic responses Analysis: One-way analysis of variance using the Proc GLM in the SAS software (SAS Institute, Cary, NC) and Duncan's Test	Feed intake, body weight gain, liver weight, fecal pH, postprandial blood glucose response, blood triglycerides, and total cholesterol	Maize bread has a lower glycemic index than wheat bread, and the magnitude of the effect of RS on glycemic response depends of type of bread
Sorghum				
10	Gallo *et al.*, 2021 [29]	Design: Double-blind, crossover, randomized clinical trial Sample: 13 healthy male Variable: Gluten-free sorghum bread genotypes on glycemic and antioxidant responses Analysis: One-way ANOVA with Tukey *post hoc* test (food composition. Antioxidant status-ORAC and FRAP; glucose and insulin AUC between glucose and test meal. Two ways repeated ANOVA for examine the effect of test meal on postprandial glycemic and insulinemic response with *post hoc* Bonferroni	Subject characteristics, bread chemical composition, postprandial glucose, insulin response antioxidant capacity	All sorghum bread showed significantly more fiber than rice bread (control). Brown sorghum bread was classified as low GI, bronze and white as medium GI, and control as high GI. Brown sorghum bread presented a low carbohydrate content, a significant amount of fiber, and a significantly lower 3 h AUC glucose response than those of the control, aside from the highest antioxidant activity value ($p \leq 0.001$)
11	Hymavathi *et al.*, 2020 [30]	Design: A pre- and post-experimental study Sample: 15 diabetic patients Variable: Lipids and glucose levels Analysis: One-way repeated measurement ANOVA was used to test the significant effect of RS rich rawa supplementation by comparing pre and post results of all the parameters. Fisher's least significant difference was used to find out the difference between the pairs	Nutritional composition of RS rich rawa, IMT, lipid, and glucose levels	Supplementation of 65 g of RS rich rawa (broken sorghum) for 90 days, significantly reduced body mass index (BMI), fasting glucose (FG), TC (total cholesterol) and LDL-C (low-density lipoprotein) (p,0.05) in diabetic subjects (n = 15), while a non-significant reduction was found in HbA1c, eAG (estimated average glucose), TG, HDL-C and VLDL-C

(*Contd...*)

Table 1: (*Continued*)

No.	Authors and years	Study design, sample, variable, Instrument, analysis	Outcome of analysis factors	Summary of results
12	Salazar-Lopez *et al*., 2020 [31]	Design: True experimental Sample: 24 male Wistar rats Variable: Extruded sorghum bran (ESB) or raw sorghum bran (RSB) (Sorghum bran supplementation), the plasma glucose, triglycerides (Tg), total cholesterol (TC), high-density lipoprotein-cholesterol (HDL-C), and low-density lipoprotein-cholesterol (LDL-C) concentrations Analysis: To compare the dietary groups, a one-way analysis of variance (ANOVA) followed by a Tukey comparison test was used. The level of significance was $p < 0.05$. Tests of the correlations between the response variables were calculated using standard Pearson correlation	Phenolic profile, adipocyte's size in abdominal tissue of rats, plasma glucose, lipid profile, antioxidant activity	The intake of HFD supplemented with ESB or RSB hindered the fat storage in adipocytes of abdominal tissue, dyslipidemia, and the loss of glucose homeostasis. A positive correlation between inflammation biomarkers (interleukin-1β and interleukin-6), and glucose homeostasis was observed, while a negative correlation between antioxidant capacity (TEAC) and interleukin-1β and interleukin-6 was observed
13	Shiekuma *et al*., 2019 [32]	Design: Randomized control trial Sample: Diabetic rats Variable: Sorghum-tigernut a fasting blood glucose level. Analysis: Analysis of variance (ANOVA)	Proximate composition sorghum-tigernut flour blend, body weight of the rats, fasting blood glucose levels of diabetic rats	The sensory of blend flour can acceptable. Giving flour mix shows a decrease fasting blood glucose level in 48 and 72 h after test diet
14	Olawole *et al*., 2018 [33]	Design: True experimental Sample: 36 healthy female Wistar albino rats with diabetes mellitus Variable: Formulation of sorghum diet, blood glucose, and liver Analysis: One-way ANOVA with *post hoc* Dunnett's	Effect of fermented sorghum diet on blood glucose before and after induction of alloxan, alanine transaminase activity in the erythrocyte, ALT activities in the liver ant AST activities in the liver of alloxan-induced diabetic rats	The sorghum-treated groups also showed statistically significant ($p < 0.05$) decrease in liver dysfunction indices and markers of oxidative damage compared with the control. In addition, statistically, the diets significantly decreased ($p < 0.05$) the relative expression of superoxide dismutase, glutathione peroxidase, glucokinase, phosphofructokinase, and hexokinase genes in the experimental animals compared with the control
15	Poquette *et al*., 2014	Design: Randomized crossover Sample: 10 boys Variable: Sorghum seeds to decrease insulin and glucose levels	Flour composition and starch analysis, muffin composition and starch analysis, glucose and insulin yield	The average blood glucose level was reduced after consuming sorghum grains, particularly at 45–120 min intervals. The average glucose was significantly reduced by about 26%
16	Park *et al*., 2012 [34]	Design: True experimental Sample: 21 rats with high fat diet Variable: Sorghum extract on insulin sensitivity through PPAR in diabetic rats Analysis: One-way analysis of variance, followed by Duncan's multiple-range test	Dietary intake, body weight and various organ weight. Lipid profile, glucose, insulin, AUC of glucose, GOT and GPT	Serum levels of glucose were significantly lower in mice that got 0.5% sorghum extract and 1% sorghum extract
17	Kim and Park, 2012 [35]	Design: Experimental Sample: 25 male Wistar rats Variable: Sorghum extract, hepatic gluconeogenesis Analysis: (ANOVA) followed by Duncan's multiple range test	Dietary intake, body weight, organ weight. Lipid profile, insulin, glucose, glutamic oxaloacetic transaminase, glutamic pyruvic transaminase, AUC of glucose	Administration of SE and G reduced the concentration of triglycerides, total and LDL-cholesterol and glucose, and the area under the curve of glucose in non-diabetic rats

AST: Aspartate transaminase, ALT: Alanine aminotransferase, GPT: Glutamic pyruvic transaminase, GOT: Glutamic oxaloacetate transaminase.

research subjects in selected articles showed a positive response where giving corn/sorghum could reduce blood glucose levels.

Discussion

Corn and sorghum are source of carbohydrate besides rice. The present study shows role of corn and sorghum in health benefit as functional foods [36]. Foods can be categorized as functional foods if it is natural food or contain two or more components that can be beneficial to human health [36], [37]. Corn is not only contained carbohydrate, vitamin, and mineral but also specific phytochemical such as phenolic acids. Corn contains carbohydrates by 70–75% and some vitamin (carotenoids, thiamine, riboflavin, niacin, pyridoxine, folate, ascorbic acid, Vitamin E, and Vitamin K), minerals (calcium, magnesium, phosphorus, potassium, sodium, and zinc), and resistant starch [14], [38]. Fiber in corn about 2.2 g/100 g if compared with white rice 0.2 g/100 g [39]. In the other studies, fiber content in corn product like boiled corn was 2.03 mg [15].

Dietary fiber is defined as a component in plants that is not enzymatically degraded into subunits that can be absorbed in the stomach and small intestine [40]. Fiber that is still intact in the large intestine is then fermented by bacteria in the large intestine to form short chain fatty acid which can induce the secretion of the hormones glucagon-like peptide-1, gastric inhibitory polypeptide, and peptide YY which will increase insulin sensitivity and ultimately cause a decrease in blood glucose levels [41].

In general, food that has been eaten will be digested in the gastrointestinal tract and then will be converted into a form of sugar called glucose. Intake of adequate amounts of fiber can help control blood glucose levels by increasing gastric distention which is associated with increased blood glucose levels. Fiber provides a feeling of fullness because it cannot be digested in the stomach so that the digestive process becomes slow which results in a low blood glucose response [42].

Corn fiber is readily digestible after it is cooked or thermally processed become some products. Consumption corn in human and animal laboratory related with improving sensitivity of insulin, increase satiety, and decrease of lipoid profile. The other ingredients in corn that can be used for human nutrition include high-amylose, high-protein, and high-oil corn [11]. The polyphenol content found in corn can also affect blood glucose metabolism. Polyphenols can inhibit either starch hydrolyzing enzymes in the mouth and small intestines or glucose transporter residing on brush border membranes, thereby reducing the amount of glucose in blood circulation [43], [44].

All studies about the effect of corn product in human in the form of rice corn, mix rice, flour, and muffin showed lowering glycemic response of the subject [16], [21], [22], [24], [26]. The same thing was also shown from giving corn to experimental animals [23], [25], [27], [28]. The decrease in blood glucose was also associated with the fiber content and GI value in the given composite flour diet where corn is also an ingredient of the composite flour diet. The benefits of foods with low GI values and high fiber can cause postprandial blood glucose levels and lower insulin responses so that they can improve lipid profiles and reduce the incidence of insulin resistance [37]. From several research reports conducted on humans and experimental animals, it can be concluded that giving corn or its processed products has an effect on reducing blood glucose levels. This result may associate with high-fiber content and a low GI value in corn that causing the absorption of glucose into the blood to be slow and can give a taste. Satiety is longer due to the slow rate of gastric emptying.

Sorghum is a plant that is rich in phytochemicals and has a low GI. Sorghum seeds contain 10.4% higher protein than rice [13]. The protein in sorghum divided into prolamin proteins (such as kafirins) and non-prolamin proteins (such as globulins, glutelins, and albumins). In addition, sorghum also contains antioxidants, mineral elements, especially Fe, fiber, oligosaccharides, and β-glucan, are a non-starch polysaccharide carbohydrate component contained in sorghum seeds, making it a potential source of functional food [29].

Several studies have identified grain sorghum as a potential functional ingredient in food applications, and studies using sorghum have shown strong evidence of decreased plasma glucose levels after consumption in animal models. Sorghum has been known as slow-digesting foods; however, limited research has explored its health effects in humans. There are only two in eight studies that have used direct subjects to humans who were given the intervention of consuming sorghum in form muffin in a 1-week period, then glucose and insulin levels were observed 15 min before and after treatment. The average glucose was significantly reduced by about 26% [45]. Meanwhile, Salazar-Lopert et al (2020) reported that giving sorghum as a substitute for rice in diabetes patients for 90 days showed good glycemic control based on the results of the patient's glucose and lipid profile [31].

The dietary fiber and tannin content in sorghum seeds have nutritional potential. Sorghum is an excellent alternative for gluten-free applications [29], [46]. With the increasing demand for healthier and gluten-free products, sorghum has great potential to be processed in a variety of food applications as a healthy food, carbohydrate diet and also has the potential to assist in controlling glucose and insulin levels in humans.

The phenolic components in sorghum have the function of lowering blood sugar levels. There is also research on sorghum extract which shows that administration of sorghum extract can reduce blood glucose levels in diabetic rats and improve insulin sensitivity in mice fed a high-fat diet. Phenolic extract of sorghum can also decrease serum glucose and increase serum insulin in diabetic rats as evidenced by two studies [34], [35]. The other study giving sorghum to experimental animals in the form of flour, bread, and fermentation also showed similar response in lowering blood glucose, improving hepatic enzyme, and profile lipid [31], [32], [33]. Decrease in blood glucose occurs due to phytochemicals compounds contained in sorghum. The phenols contained can stimulate glucose and fat metabolism, so as to prevent the accumulation of glucose and fat in the blood. In its mechanism, phenolic compounds will inhibit glucose synthesis by inhibiting the enzymes glucose 6-phosphatase and fructose 1,6-bisphosphatase which play a role in reducing the formation of glucose from substrates other than carbohydrates so that blood glucose levels will decrease [35], [47].

The dietary fiber content of sorghum is thought to cause a decrease in blood glucose levels. Dietary fiber has the ability to lower blood glucose through the mechanism of inhibiting the absorption of glucose into the blood [13], [20]. Sorghum is one of the food sources of antioxidants because of the presence of phenolic components such as phenolic acids, condensed tannins, and flavonoids that can provide hypoglycemic effects and reduce oxidative stress in the treatment of diabetes mellitus patients.

Conclusions

Sorghum and corn have the potential as an alternative staple food to achieve a better glycemic response in diabetic patients. Corn and sorghum processed products that can be an alternative food for diabetes mellitus patients can be in the form of bread and muffins. In addition, corn and sorghum can also be given as a substitute for flour and rice.

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