Antidiabetic properties of analog rice from local raw materials: a systematic review

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ABSTRACT

Type 2 diabetes mellitus (T2DM) is a common disease, where about 90% of Indonesians suffer from high white rice consumption. According to various reports, analog rice from many raw materials has benefits for T2DM. This review aimed to identify nutritional content that can be found in various local raw materials for T2DM. In addition, this review explained the antidiabetic effects and mechanisms of the nutritional content. PRISMA guidelines were utilized as the basis of this systematic review. Relevant and related studies were determined by databases such as PubMed, Google Scholar, and Garuda. The identification process in those databases resulted in 284 articles, with only 56 articles included based on the final paper criteria. The primary keywords for the identification process include analog rice, T2DM, antidiabetic, glycemic index (GI), and fiber. Meanwhile, the secondary keywords are based on the review's local raw materials, such as purple yam, corn, banana, sorghum, and cassava. As a result, studies found nutritional compounds with antidiabetic properties inside analog rice made from different local raw materials. which each of them has different mechanisms to overcome T2DM. Therefore, the consumption of analog rice from purple yam, corn, banana, sorghum, and cassava has the potential to prevent T2DM.

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1. INTRODUCTION

Rice consumption in Indonesia is very high, with around 114.6 kg of rice consumed per capita in 2017 [1]. It is the primary carbohydrate source for Indonesians as it contributes to 55% of calories consumed. Due to the high rice consumption with a moderate glycemic index (GI) of around 64 [2], Indonesia has a high rate of type 2 diabetes mellitus (T2DM) patients. In 2013, International Diabetes Federation reported that around 8.5 million cases of T2DM in Indonesia and would increase drastically in the following year [3].

Based on other research, analog rice production using low GI materials can solve the T2DM problem. For example, purple sweet potato-based analog rice with the addition of Tilapia fishbone nano-calcium contains a low GI of 19.19 [4]. Analog rice made from a modified cassava flour product through a fermentation process by lactic acid bacteria modified cassava flour (MOCAF), purple sweet potato flour, and barley flour also has a GI of 33.15 [5]. Moreover, analog rice made from corn, sorghum, and sago palm contains a low GI of 47.09 [6].

There are several matters that have not been discussed thoroughly by the previous researchers. Therefore, those topics require further research in the future. An example of research discusses the antioxidant potential of analog rice made from sago baruk and purple sweet potato and does not include the antidiabetic effect of the antioxidant [7]. Another research only discussed the bioactive compounds contained in analog rice made from

MOCAF and sorghum as anticancer potential [8], and other research also only discussed the formulation of MOCAF, purple sweet potato flour, and barley flour on antioxidants, nutritional value, and GI of analog rice [5]. From those researches, it showed that most of them only discuss the bioactive compounds in certain materials but didn't explain further about the mechanisms through which the bioactive compounds interact with T2DM.

Besides the GI effect in analog rice, this review discussed deeply different bioactive compounds found in various materials (purple sweet potato, corn, cassava, banana, and sorghum) that mainly contribute to lowering the risk of T2DM. It is due to bioactive compounds being one of the key components of certain materials and each of them has its own benefits and advantages. Other than that, this review also explained the antidiabetic mechanism of different bioactive compounds.

High rice consumption can cause T2DM due to the high GI. Because of that, researchers found out that analog rice has a lower GI that prevents T2DM. However, other than GI, bioactive compounds also contribute to preventing T2DM, and each of them has its mechanisms. Hence, this review aimed to identify the nutritional content of various raw materials for T2DM. In addition, this review explained the antidiabetic effects and mechanisms of the nutritional content.

2. RESEARCH METHOD

2.1. Type of study

This systematic review provided insight into nutritional compounds and their mechanisms in analog rice with different raw materials using standardized scientific literature. The methods for conducting this systematic review were based and guided on the preferred reporting items for systematic review and meta-analyses (PRISMA) guidelines. The systematic review seeks to collect all available empirical researchers with a systematic method to obtain answers to specific questions. PRISMA is a widely accessible protocol for performing a systematic review method (https://prisma-statement.org/).

2.2. Search strategy and study selection

The initial search was conducted on February 26, 2022, with consecutive searches conducted until March 12, 2022. The timeframe for selected primary articles was between 2012 and 2022 due to the increasing scientific output of analog rice-related papers representing the trend toward analog rice. Studies in English and Indonesian were the target for possible inclusion. Garuda and Google Scholar were used to search for Indonesian language studies. This study also used English papers from PubMed and Google Scholar. Those databases were chosen since they are considered applicable to evidence synthesis. Original articles, review articles, and conference papers were selected as references in this review. However, unpublished studies were not selected since no relevant and related articles can be found or used.

2.3. Search string

The search was carried out by combining 2 to 3 strings, focusing on the discussion of various analog rice materials and the antidiabetic properties offered by the nutrients and bioactive compounds contained. Most search engines offer advanced search features that apply Boolean operators, using "AND" and "OR". Possible search strings can be using ("analog rice") AND various kinds of materials in the form of ("purple sweet potato" OR "*ubi ungu*"), ("corn" OR "*Zea mays*" OR "*jagung*"), ("banana" OR "*Musa paradisiaca*" OR "*pisang*"), ("sorghum"), ("cassava" OR "MOCAF" OR "tapioca") AND nutritional components such as ("fiber") OR ("phenolics" OR "anthocyanin"), OR ("type 2 diabetes mellitus"), also the properties of the materials ("antidiabetic" OR "glycemic index").

2.4. Inclusion criteria and data extraction

The systematic review followed PRISMA guidelines as the main method to identify, screen, and collect primary articles. The authors selected the articles manually with the inclusion criteria based on the research goal, which included: i) relevant title; ii) material specifications met this review requirement (e.g., only yellow corn and purple sweet potato variety); iii) showed only T2DM antidiabetic properties; iv) full text was provided. On the other hand, studies with irrelevant titles, material specifications, and only abstract text were excluded. In addition, the research from blogs, books, web pages, and magazine articles was also excluded from the review process due to the lack of specific scientific rigor in that research. From each paper, data extraction codes for this initial mapping stage include the author(s) name, year of publication, publication status, main objectives, keywords or key points, subject (bioactive compound, sample, criteria, total (N)), study characteristics (type and design), results (explanation about nutritional content/bioactive compound related to T2DM and mechanisms of the bioactive compound), and notes or important comments toward the study.

3. RESULTS AND DISCUSSION

The initial search in Google Scholar retrieved 217 studies, the PubMed search generated 41 studies, and the search in Garuda retrieved 26 studies, thus resulting in a total of 284 studies. The result found was deducted to 162 after duplicate removal. The following screening based on the titles and abstracts decreased the article number to 120 studies. Further article evaluation excluded 64 studies, which due to less detailed topics and explanations. As a result, the number of included final articles was 56 articles. From this total of 56 articles, there were several secondary articles in the form of reviews. The final 56 papers are included, as shown in Figure 1. From the total articles of 56 studies, each of them has its own purpose for different raw materials. Of those studies, 12 studies were found for sorghum, nine studies were found for corn, 17 studies were found for purple sweet potato, 12 studies were found for banana, and six studies were found for cassava.

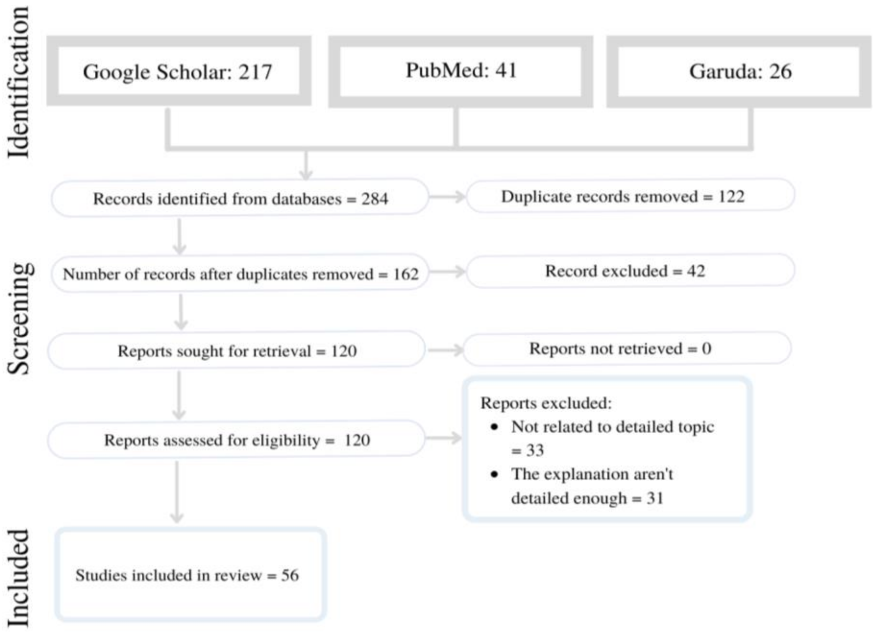

Figure 1. Systematic review PRISMA diagram

3.1. Nutritional content

Based on the nutritional content of each material, Table 1 shows the nutrition components variation for each material. The components consisted of carbohydrates, protein, fat, moisture, ash, dietary fiber, and energy, with the amount of each component based on 100 grams of the materials. Materials with the highest and lowest energy consecutively are MOCAF and banana. Meanwhile, purple sweet potato has the most considerable carbohydrate content. Other than that, the materials with the highest protein contents were sorghum at 91%. Lastly, purple sweet potato has the highest dietary fiber in terms of dietary fiber. From the table, purple sweet potatoes were the best recommended analog rice material due to high carbohydrate, water-soluble polysaccharides, and fiber that reduce carbohydrate absorption and provide a low amount of calories. Although bananas were representable material for analog rice, it was not recommended due to the high moisture content, which results in low nutrition content after the process of extrusion [9]–[13]. All symbols that have been used in the equations should be defined in the following text.

Table 1. Comparison between various raw materials and white rice

Components (per 100 gram)	Raw matzerial of the analog rice					
	Purple sweet potato [9]	Sorghum [10]	Corn [11]	Banana [12]	MOCAF [13]	White rice [14]
Energy (Cal)	90	339	129	89	373	360
Carbohydrate (%)	86.28	76.51	30.3	22.84	85	79.34
Protein (%)	8.09	9.1	4.1	0.75-1.3	2.8	6.6
Fat (%)	0.61	3.1	1.3	0.07-0.7	0.6	0.58
Moisture (%)	7.92	6.36	63.5	71.3-78.2	11.9	7.73
Ash (%)	0.65	2.07	2.08	0.43-1	2.0	0.6
Dietary fiber (%)	6.89	2.86	5	1.7-3.7	2.0	0.5-0.9

3.2. Type of nutritional compounds

Purple sweet potato contains nutritional compounds such as polyphenol and resistant starch. Those nutritional compounds can fight against T2DM. Specific polyphenols in purple sweet potato are anthocyanin, and the total is 119 mg/mL [15]. Anthocyanins are flavonoids also known as natural red to purple pigments and include potentially antidiabetic and antioxidant flavonoids [16]. Anthocyanin can suppress oxidative stress by donating a hydrogen atom to a free radical and increasing insulin sensitivity and secretion [17]. Resistant starch is a complex carbohydrate that is hard to digest. There is 15.31 g/100 g resistant starch in purple sweet potatoes. Resistant starch is related to a low glycemic index. Consumption of low glycemic index food can improve insulin sensitivity [4].

For sorghum, there are many findings that nutritional components in sorghum have benefits for T2DM. The primary nutrients residing in sorghum and other materials are the phenolic and flavonoid compounds. Studies found that around 10.98–33.64 mg/g of the phenolic compound can be found depending on the sorghum variance [18]. The high amount of phenolic compounds is enough to prevent T2DM in human adults due to the α-glucosidase and α-amylase inhibitory activity abundant in those compounds [19]. For the flavonoids, there are about 12 types of flavonoid glycosides found in the sorghum and have antidiabetic properties [20]. Other than that, there are findings of a specific compound usually found in sorghum in the form of fatty acids called azelaic acid. The studies found that azelaic acid has significant antidiabetic properties in the experiment involving mice with different treatments, such as untreated, standard, and high fat diet (HFD) [21], [22]. Another compound with antidiabetic properties is resistant starch which presents in a high amount of around 10.97% [23]. Resistant starch found in purple sweet potato, sorghum, and MOCAF is a carbohydrate that escapes digestion in the small intestine and thus reaches the large intestine. Resistant starch has several mechanisms for the treatment and prevention of T2DM in the human body, such as lowering blood sugar levels by reducing the absorption of the available carbohydrate content in food [24], [25].

There are also several beneficial antidiabetic compounds for T2DM found in corn, such as polyphenols, feruloylated arabinose, and free phenolic fractions. In 100 gram extract of corn, there is a total phenolic content ranging from 36.54 to 63.39 mg GAE/100 gram [24]. The corn extract showed α-amylase and α-glucosidase inhibition in a concentration-dependent manner. A study also showed that feruloylated arabinose in corn bran can inhibit the activity of α-glucosidase in a dose-dependent manner [26]. Corn sample extracts contain free and bound phenolic fractions. Based on a study, the free phenolic fractions such as vanillin, vanillic, ferulic, and ρ-coumaric showed inhibition against α-glucosidase [27].

Banana contains some bioactive compounds that are beneficial in working against T2DM, such as phenolics, carotenoids (lutein), phytosterols, and flavonoids. This material contains about 4.95–47 mg GAE/g dry matter of phenolics [28], 1.59–14.15 µg/g of the banana pulp of carotenoids, specifically lutein [29], 2.8–12.4 g.kg DW of phytosterols [30], and 196 mg/g quercetin equivalent of flavonoids [31]. Phenolics, phytosterols, and flavonoids have similar mechanisms of action that are effective in preventing the occurrence of T2DM, which is through the inhibition of α-amylase and α-glucosidase. On the other hand, carotenoids prevent T2DM by scavenging reactive oxygen species (ROS).

MOCAF has bioactive compounds that can reduce the risk of T2DM. MOCAF is rich in phenolic compounds with 51.35 mg/g consisting of caffeic acid, catechins, rutin, catechin gallate, gallocatechin, and kaempferol. Phenolic compounds prevent T2DM by binding to negative oxygen ions and free hydroxyl radicals and inhibiting key enzymes α-amylase and α-glucosidase. In addition, MOCAF also contains starch and fiber, which inhibits the increase in blood sugar because it is resistant to the hydrolysis enzyme process. The increase in blood glucose is slowed down [32].

3.3. Nutritional compounds' mechanisms

α-glucosidase is an enzyme that plays a role in the hydrolysis of food into glucose and other monosaccharides. The increased activity of α-glucosidase can cause the sugar content in the blood to improve, which is referred to as hyperglycemia which is very dangerous for people with T2DM. Inhibiting the α-glucosidase enzyme can inhibit glucose absorption and decrease blood sugar or keep blood sugar in a low state. To prevent and inhibit T2DM, it can be related to the phytochemical and antioxidant content contained in raw materials such as purple sweet potato, sorghum, corn, banana, and MOCAF, used in analog rice [24].

Through a study, polyphenolic compounds such as flavonoid have been reported to inhibit the activity of the α-glucosidase enzyme. The hydroxyl group in polyphenolic compounds plays an essential role in the α-glucosidase inhibition process [24]. Polyphenol compounds can bind to enzyme complexes to suppress the activity of carbohydrate-degrading enzymes such as α-glucosidase. The activity of the sucrase-isomaltase complex can be partially or wholly inhibited depending on the content of the polyphenolic compounds present. At the same time, the anthocyanin content can only inhibit the maltase activity of the sucrase-isomaltase complex [26]. Mechanism of the bioactive compounds as shown in Table 2.

Table 2. Mechanism of the bioactive compounds

Raw material	Nutritional compound	Concentration	Target mechanisms
Purple sweet potato	Polyphenol (anthocyanin)	119 mg/mL	Increase insulin secretion, reduce oxidative stress, and inhibit α-glucosidase and α- amylase [17], [33]–[37]
	Resistant starch	15.31 g/100 g	Glycemic index [4]
Sorghum	Phenolics (tannin)	10.98–33.64 mg/g	α-glucosidase and α-amylase [18], [38]–[40]
	Flavonoids	0.016 mg QE/g	α-glucosidase [20], [41]
	Azelaic acid	–	Increase in plasma glucose and insulin) [21], [22]
	Resistant starch	10.97 %	Glycemic index [23], [42], [43]
Corn	Polyphenols	36.54 to 63.39 mg GAE/g	α-glucosidase and α-amylase [24]
	Feruloylated arabinose	–	α-glucosidase [26]
	Free fractions phenolic (vanillin, vanillic, ferulic, ρ-coumaric)	0.12 to 2.46 mg/100 g DW	α-glucosidase [27], [44]
	Dietary fiber	11.21%	Glycemic index [6], [45]–[48]
Banana	Phenolics	4.95–47 mg GAE/g DM	α-glucosidase and α-amylase [28], [49]
	Carotenoids (lutein)	1.59–14.15 µg/g pulp	ROS [29], [50]
	Phytosterols	2.8–12.4 g·kg DW	α-glucosidase and α-amylase [30], [51]
	Flavonoids	196 mg/g QE	α-glucosidase [31], [41]
MOCAF	Phenolics	51.35 mg/g	α-glucosidase and α-amylase [32]
	Resistant starch	–	Glycemic index [8]

Other than α-glucosidase, α-amylase is one of the most important enzymes found in the body, which aims to increase the digestibility of carbohydrates, especially starch, linked by one of the bonds such as the α-1.4 glycosidic bond. The enzyme aims to break down carbohydrates, especially with the long-chained like starch, oligosaccharides, and disaccharides, by hydrolyzing the bond and making the chain much shorter and simpler. Because of that, it will result in a much easier digestible carbohydrate form (usually glucose) which is easier to absorb and enter the blood as blood glucose for energy and transportation purposes. But when the enzyme hydrolyses all the carbohydrates that enter the body, it results in high glucose absorption and digestion, resulting in one of the diseases such as T2DM due to the excess blood glucose in the human body [25].

To prevent the T2DM disease, one of the solutions is to consume foods that contain α-amylase inhibitors as the substance. Raw materials such as purple sweet potato, sorghum, corn, banana, and MOCAF, used in analog rice, are rich in a substance that acts as α-amylase inhibitors. The most common substances that act as α-amylase inhibitors are polyphenols, phenolics, phytosterols, flavonoids, and many more derivatives. These substances have also been reported to be comparable to the inhibitory potential similar to acarbose which are standard drugs usually used as the control for the α-amylase inhibitory [52]. The inhibitors directly block the enzyme's active site, which prevents the long-chain carbohydrate from entering the enzyme. Other than that, these inhibitors are also reported to have insulin-like effect for the glucose digestibility which is good for inhibition effect [53]. Because of that, it limits the digestibility of carbohydrates in the gastrointestinal tract due to long-chained carbohydrates being harder to absorb in the human body rather than a simpler form like glucose. The long-chained carbohydrate will likely not be absorbed and enter the colon as one of the resistant starches and produce short-chain fatty acids (SCFA). The limitation of digestibility of carbohydrates also results in lower glucose in blood vessels which prevents the disease of T2DM in the human body. Assays like dinitro salicylic acid (DNSA) and starch-iodine test assay are used to detect and determine the degree of inhibition of the α-amylase enzyme [54], [55].

In diabetic patients, glycated proteins, such as albumin, glycosylated hemoglobin, and lens crystalline, are formed non-enzymatical in the glycation reaction. This reaction creates Schiff base, Amadori product, and advanced glycosylation end products (AGEs). Reactive oxygen species (ROS) that can increase insulin resistant and deteriorate β-cell function, which can cause T2DM, are also formed in the process [56]. Nrf2 signaling pathway is significant in regulating antioxidant genes' transcription, such as enzymes related to GSL synthesis and NQO1, Superoxide dismutase (SOD), catalase, and HO-1. Nrf2 is known to decrease in T2DM patients, increasing oxidative stress. Antioxidants can decrease damage caused by oxidative stress in diabetics so that blood glucose levels are controlled and possible risks of complications can be decreased [57], [58]. For instance, carotenoids, such as lutein, can increase immunity and lower the risk of diabetes [50], [59]. They work against ROS by reducing ROS levels and reversing down-regulation of antioxidant enzymes and Nrf2, HO-1, catalase, and SOD 2 in APRE-19 cells. Lutein can promote translocation of Nrf2 nuclear that was blocked when high glucose was needed to grow cells [60]. Activation of Nrf2 with lutein can also increase regulatory protein kinase B and proteins ERK activation, which can protect the retina from retinopathy caused by diabetes [61].

T2DM can cause various complications in human organs due to chronic hyperglycemic conditions, increasing the formation of AGEs and other free radicals. Chronic hyperglycemia also causes the lowering of

SOD, an endogenous antioxidant that can break superoxide ions, thereby reducing oxidative stress [62]. Hyperglycemia causes oxidative stress development by the increasing production of free radicals such as ROS [63]. ROS will bind with PUFA to create PUFA peroxide that can produce oxyradical and react with H^+ and create lipid hydro-peroxide. Furthermore, lipid hydroperoxide and oxyradical will form malondialdehyde (MDA) [64]. One of the indicators that determine oxidative stress in humans is MDA level. Anthocyanin can lower blood glucose levels by blocking oxidative stress and increasing antioxidant enzyme activities [35], [65], [66]. This occurrence can decrease the formation of AGEs, reduce the MDA level in the blood, and increase the SOD level. Anthocyanin can also be used as an exogenous antioxidant by T2DM sufferers [62].

The ineffectiveness of the insulin hormone can cause T2DM because insulin secretion does not work properly, such as insulin resistant or pancreatic β-cells disruption. Insulin resistant occurs due to β-cells being damaged, damaged pancreatic β-cells result in a decrease in glucose receptors in the pancreas, which also reduces insulin receptors in peripheral tissues. Those damages can lead to insulin deficiency. Purple sweet potato and sorghum contain antioxidant compounds in the form of anthocyanin and azelaic acid, which can improve insulin secretion and increase plasma glucose. T2DM patients need exogenous insulin. Insulin will bind with extracellular α-subunit and transform the shape into an energy in the form of adenosine triphosphate (ATP) bond in the intracellular β-subunit component. Through enzyme tyrosine kinase, ATP bonds will trigger phosphorylation, and glucose receptors will transport using glucose transporter (GLUT). The primary glucose transporter is GLUT-4 in muscle and fat cells. Anthocyanin can help to increase the expression of GLUT-4 [65]. Besides that, anthocyanin can trigger a potent incretin hormone, also known as glucagon-like peptide-1 (GLP-1). This hormone can stimulate insulin secretion through proliferation and help to keep pancreatic β-cells [67], [68].

Azelaic acid has pharmacological properties which provide significant hepatic key enzymes. The hepatic key enzyme contributes to carbohydrate metabolism. Azelaic acid can be used as a T2DM treatment because azelaic acid can increase the liver glycogen content. By improving the activity of hexokinase and glucose-6-phosphate, azelaic acid can reduce T2DM. Hexokinase is one of the key enzymes contributing to glucose phosphorylation into glucose-6-phosphate. The deficiency of hexokinase can decrease glycolysis and the use of glucose for energy. Azelaic acid can increase hexokinase activity which can restore insulin levels and plasma glucose in diabetic patients [21]. Azelaic acid can also restore insulin sensitivity by improving regulation expression genes such as insulin receptor, phosphatidylinositol-3-kinase, and insulin-like growth factor, prioritizing the use of high glucose to reduce blood glucose. Azelaic acid affects liver metabolism by improving insulin signal molecules. Azelaic acid can modulate gene expression related to the production of glycogen mediated by insulin [22].

Resistant starch (RS) found in purple sweet potato, sorghum, and MOCAF can reduce the glycemic load due to reducing the available carbohydrate content of the food. RS also can reduce subsequent meals' glycemic responses [69]. Furthermore, gut microbiota can ferment RS and produce short chain fatty acids (SCFAs), including acetate (mainly by Bifidobacterium spp. and Bacteroides spp.), propionate (mainly by Bacteroides spp.), and butyrate (mainly by Fusobacterium and Butyrivibrio), which can help improve glycemic control through various mechanisms. SCFA is produced mainly in low pH cecum and proximal colon. The produced SCFA can improve glucose handling in muscular and hepatic by activating GPR41/43 on muscle and liver cells. SCFA also increases digestive peptide YY (PYY) and glucagon-like peptide-1 (GLP-1) hormone secretion, increasing insulin response and sensitivity, reducing gastric emptying, and decreasing energy intake [9]. GLP-1 hormone secretion stimulates an increase in the pancreas β-cell mass and pancreatic insulin content. An increase in the pancreas β-cell mass is needed to secrete more insulin and achieve glucose homeostasis. SCFA can also improve insulin sensitivity by AMP-activated protein kinase (AMPK) activation. AMPK can increase glucose utilization in skeletal muscle tissues through the Rab-GTPase-activating protein TBC1D1, which induces GLUT4 vesicles fusion with the cell membrane. AMPK also inhibits gluconeogenesis in liver tissue by inhibiting various transcription factors such as nuclear hepatocyte factor (HNF 4) and CREB regulated transcription coactivator 2 (CRTC2) [70]. Furthermore, glucose and lipid metabolism can be mediated by AMPK and regulate transcription factors such as phosphoenolpyruvate carboxykinase (PEPCK), glucose-6-phosphate (G6Pase), peroxisome proliferator-activated receptor α (PPARα), sterol regulatory element-binding protein 1c (SREBP-1c), and carbohydrate responsive element-binding protein (ChREBP) [9]. It is known that a high level of free fatty acids in the circulation can reduce insulin sensitivity in non-adipose tissue such as the heart and skeletal muscles. Additionally, insulin resistant and T2DM are associated with overweight and obesity. Expanded stressed adipose tissue due to fat deposits causes the activation of inflammatory pathways and increases pro-inflammatory cytokines secretion. Pro-inflammatory cytokines can interfere with insulin signaling pathways. RS is necessary to inhibit fat storage by producing SCFA, thus reducing adiposity [69].

Similar to RS, dietary fiber found in corn is also an indigestible carbohydrate that gives lower GI [71]. Soluble dietary fiber is known to reduce glycemic response. It can increase the viscosity in the stomach and intestines, resulting in a decrease in the digestible carbohydrates amount and absorbed simple sugars. It gives satiety, increases intestinal transit time, and reduces postprandial glucose. Hormone levels (GLP-1 and PYY) in the digestive tract, nutrient absorption, and insulin secretion also increase. Dietary fiber increases insulin sensitivity and stabilizes blood sugar [6].

The review results imply to inform the public about lowering the risk of T2DM. T2DM is a disease that cannot be cured but can be lowered by self-management. One management is by consuming food with bioactive compounds that affect antidiabetic properties [72]. Analog rice from various local sources is proven to contain nutritional compounds that have antidiabetic properties and can lower the risk of T2DM by consuming it adequately. The review also informs the mechanism that each bioactive compound goes through to reduce the risk of T2DM. Figure 2 summarizes the mechanism of T2DM from various analog rice.

The authors found challenges limiting the data and type of studies included in the review. The main limitation is the lack of studies that come from unpublished articles. It is because the authors did not manage to find the unpublished article that meets the review's inclusion criteria. Moreover, this review only explains the common bioactive compounds in various raw materials of analog rice. It is also possible that other compounds can potentially overcome T2DM problems that have not been mentioned and explained in this review. Other than that, the review also does not specify the raw material species used in the analog rice. Because of that, it is also very possible for different species of the same raw material to have different compositions and concentrations of bioactive compounds.

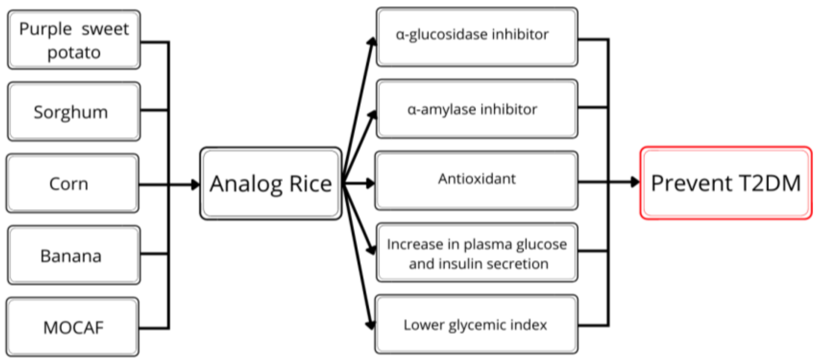

Figure 2. Mechanism of T2DM prevention from different raw materials in analog rice

4. CONCLUSION

Type 2 diabetes mellitus (T2DM) is a disease which often occurs in Indonesia. Therefore, prevention of T2DM is needed to reduce the risk. Consumption of analog rice is one of the solutions to reduce the risk of T2DM in the human body. Each raw material used in analog rice has different nutritional compounds present inside, and each of them has its different mechanisms to prevent T2DM. Some of the mechanisms that contribute can be either as the inhibitor of the enzyme (α-glucosidase and α-amylase), preventing oxidative stress, improving insulin secretion and plasma glucose, and lowering the glycemic index. From the findings in this systematic review, the authors suggest doing further research, such as conducting clinical trials to determine the mechanism of effects of each nutritional compound on T2DM patients.

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