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# Functional food processing technology on anti-diabetic potential of bitter melon (*Momordica charantia* Linnaeus)

## Abstract

Bitter melon (*Momordica charantia* Linnaeus) also known as bitter gourd, karela, and bitter squash is a cucurbit vegetable vine with a pantropical distribution. Primarily native to Asia but now widely cultivated throughout the world. For years it is used as a traditional remedy for the cure of diabetes, and its fruits are eaten as a vegetable. Reversal from the prediabetic stage using health-promoting foods such as Bitter Melon (BM) could be one solution towards effective diabetes management. Several BM phytochemicals that demonstrated varied biological activities including antihyperglycemic and antidiabetic effects are reported. Application of food technology is likely to aid both in retaining and reaping the potential health benefits of this food nutraceutical via varied processing techniques that otherwise are lost before (or) upon consumption. However, given the enormous, yet discrete existing literature reports on the valued qualities of BM, the review of processed BM on its antidiabetic potential is relatively a new topic to be explored. This review addresses the studies that have applied food processing technology on BM and those that measured such processing effects on its antidiabetic potential, intended to deliver the complete overview exploring the efficacy and safety of processed BM to reap health benefits.

**Keywords:** bitter melon, functional foods, functional food processing technology, food nutraceutical, prediabetes, diabetes type 2

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## Introduction

Millions of people are affected by chronic ailments and conditions that impose vigilant control of their diet as part of curative action.[1] Diabetes is deemed as one of the five primary causes of mortality in the globe with an estimated growth in incidence to 366 million by 2030.[2-4] According to the 2020 CDC National diabetic statistics report, more than 34.2 million people were diagnosed with type 2 diabetes in the year 2018 and an estimated 88 million to have prediabetes in the US population.[1] Regardless of the progression of medication, the management of this disorder stays mostly futile. Therefore, it is crucial to discover new nature-based nutraceuticals to alleviate diabetes or prediabetes. Thus, researchers worldwide are focused on identifying functional foods and devising methods to derive maximum health benefits from them. Bitter Melon (BM) is one such health-promoting vegetable that showed promising results in type II diabetic and prediabetic control among preclinical trials.[2,5,6,7] Application of food processing technology will aid in retaining and reaping the potential health benefits of this vegetable through varied processing techniques that otherwise are lost before or up-on consumption.

Bitter Melon (*Momordica charantia Linnaeus*) similarly identified as bitter gourd, karela, balsam pear, bitter apple, and bitter squash is a high nutritive cucurbit vegetable vine with a pantropical distribution.[8,9] Primarily native to Asia but now widely cultivated throughout the world.[9] Research has shown that BM contains over thirty medicinal elements, that have shown to exhibit many health benefits including a few for antitumor and anti-diabetic potentials.[2,8,10] Thus, catching enormous attention in recent years as a complementary medicine and /or for medical nutrition therapy in developed countries. So far in-vitro and in-vivo research suggest bitter melon's potential in glycemic control. However, clinical studies seemed to have unconvincing or even conflicting results and so, the effect in human health is still under debate.[2,7,9-14,92-96] However, given the enormous, yet discrete existing literature reports on the valued qualities of BM, the review of processed BM on its antidiabetic potential is relatively a new topic to be explored. Hence this review paper is attempting to fulfill these unmet needs. Notably, this timely review centers on the two-fold efficiency of the processed BM against the prediabetes and type-2 diabetes that could potentially prevent its progression to advanced stages and lead to the restoration of normal health. Additionally, this evaluation also refers to the considerable disparity in our understanding concerning the different processing techniques of BM interactions, which can be predicted from the available studies on varied processing techniques, and on the effect of BM on prediabetes and type 2 diabetes. This has significant implications, provided that a huge portion of individuals taking BM as food-based home remedies, and /or as functional food nutrition is whether reaping the similar or dissimilar antidiabetic effects. Accordingly, to enhance our understanding of the potential health benefits and safety concerns upon intake when consumed as a processed vegetable. This review has potential public health implications in terms of not only the reversal of prediabetes but also for the prevention of progression of type 2 diabetes. This narrative review may perhaps be carefully rendered to the clinical implication related to not only the efficacy of processed BM but also for any possible concerns concerning its intake by diabetic populations.

## Bitter melon nutrition sketch & bioactive compounds

BM fruits are rich in several phytonutrients, antioxidants, vitamins, and minerals which all add to its significant resourcefulness in curing a broad scope of ailments.[2,8] The whole BM fruits contain 93.2% water, 18.02% protein, 0.76% fats of its dry weight, respectively and have several vitamins: C, A, E, B1, B2, B3 and B9.[2,8,15] The fruits contain

the highest calories (241.66 Kcal/100 g) followed by its foliage (213.26 Kcal/100 g,) and seed (176.61 Kcal/100 g) respectively.[2,16] Fruits are also a good source of minerals such as K, Ca, Zn, Mg, P, Fe, and fiber.[2,8] Therapeutic benefit and the bitter taste of BM fruit has been assigned to the anthraquinones, phenols, terpenes, flavonoids, glucosinolates, and isoflavones.[2,8,17]

Many clinical findings have stated that BM extract from the fruit and seeds contain numerous bioactive elements that give hypoglycemic action.[2,18,19] The BM saponins namely momordicine II, 3-hydroxycucurbita-5, 24-dien-19-al-7, and 23- di-O-β-glucopyranoside, revealed substantial insulin mimicking action in mouse β-cell line at the strength of 10 and 25 µg/mL.[2,20] The key bioactive elements in BM responsible for its hypoglycemic effects contain charantin, polypep-tide-p, and vicine.[2] Charantin is a triterpenoid in BM which is a possible component for its hypoglycemic properties.[2,21-26] Polypeptide-p from BM seeds is treated as plant-based insulin to regulate glucose levels naturally.[2,27-29] Vicine is another key element found in BM seeds that are known for its hypoglycemic effects.[2,30,31] Many other BM elements such as momordicosides K and L, I, and II have been recognized and isolated by several extraction methods.[2,8,32]

## Antidiabetic components of Bitter Melon & their potential physiological mechanisms

The core elements of BM which are accountable for its hypoglycemic effects include phenols, lipid, protein, alkaloid, triterpene, and steroid.[8,33,34] Bioactive elements such as p-insulin, momordicoside S/T, charantin, linoleic acid, momordicine, polypeptide-p, vicine, conjugated linolenic and linoleic acid isolated from whole fruit, seed, as well as pulp offer hypoglycemic activity with a varied course of actions.[2,8,18-20,35-37] The diversity of actions[38,39] has elicited substantial awareness from researchers in drug innovation and subsequent rise in clinical findings examined its anti-hyperglycemic impacts in type 2 diabetics. Nevertheless, such findings have delivered contradictory results relative to its clinical efficiency,[40] and lack of methodical documentation of undesirable impacts was instigated.[41] Figure 1 below depicts the potential antidiabetic potential of BM. While several glycosides have been isolated, 4 triterpenoids provide AMP-activated protein kinase action as a credible hypo-glycemic process of BM.[42] These triterpenoids have said to hamper the assimilation of glucose by impeding glucosidase then regulate the movement of disaccharidases in the gut. This promotes the production as well as delivery of thyroid hormones along with adiponectin. Intake of BM has reported aiding in the carriage of glucose in the cells, fatty acids in mitochondria, alteration of insulin discharge, rise altitudes of detaching protein in fat cells and skeletal muscles.[43] Momordicine II, 24-dien-19-al-7, 23- di-O-β-glucopyranoside (4), 3-hydroxycucurbita-5 extracted like saponins exhibited substantial insulin like action in mouse beta cells at the strength of 10 and 25 µg/mL.[44] A review report studies that tested the in-vitro and in-vivo antidiabetic effect of BM juices, powders, extracts, and isolated compounds. The study reported that these forms of BM did one or more of these activities; increased pancreatic insulin discharge, reduction in gut glucose intake while improving its intake in peripheral tissues.[11] Further, the anti-diabetic properties of BM intake include hindering gut α-glucosidase as well as glucose transfer, guarding pancreatic beta cells, improving insulin excretion, enhancing hepatic glucose removal, diminishing gluconeogenesis, and yet improving insulin resistance. Likewise, the expressions of peroxisome-proliferator-activated receptors could also be activated and up-regulated.[2,7,9-11]

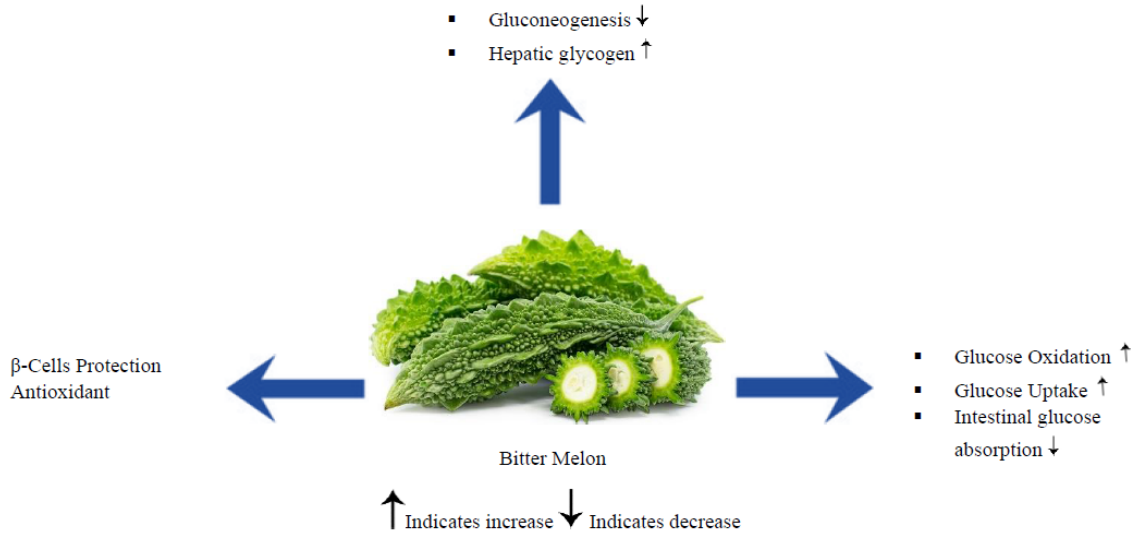


**Figure 1** Bitter Melon potential anti-diabetic effects.

A study showed a decrease of fructosamine numbers among diabetics when treated for four weeks with BM intake of 2000 mg/day dose.[19] Randomized clinical trial double-blind, pilot trial with BM are inconclusive and a shortfall in appropriated study design, sample, and duration of the study. Besides, although there have been several studies examining the antidiabetic properties of BM in both animals and humans, minimal research has examined these effects regarding prediabetics.[2] The substantiation of the impacts of BM on glucose control in prediabetics has hardly been implied from findings among diabetics.[5,7] There is also very little data regarding the safety of BM upon intake.[8,33] The recommended dose of BM in the encapsulated form is 100–200 mg three times daily, the beverage is 50–100 ml/day and for the dry powder 3–15 g daily.[45] However, the optimum dose has also not been established at this time. Besides, recent meta-analysis underlined the lack of data from clinical studies and the want for additional well-designed and properly conducted research.[8,46] This highlights the need for properly designed clinical studies measuring BM in general and a review for processed BM antidiabetic potential and safety studies to provide directions and implications to public health.

## Bitter Melon as functional food & food processing technology for Type2 & Pre-Diabetes

The application of Functional Food processing Technology (FFT) aims at identification, extraction, and characterization of foods and serves as a source of practical approach that can be utilized to innovate in health food sectors. Such function of FFT is said to both aid in retaining and reaping the potential health benefits of this functional food through FFT which otherwise are lost before (or) upon consumption. Hence our review intends to document the existing evidence on the role of FFT in BM antidiabetic effects. This review has potential public health implications in terms of not only reversal of prediabetes but also for the prevention of progression of type two diabetes.

Food processing techniques such as juicing, canning, freezing, drying, and grinding are used to retain nutritive value and enhance the storage time of various foods. Numerous studies have undertaken trials for the preservation of BM by various techniques such as steeping preservation, processing of BM into rings,[47,48] sun drying and dehydration of BM[47,48] hot air drying of BM slices.[47,49] Further, a study reported that BM juicing had more soluble oxalate content than that measured in the cooked BM.[50] Freeze drying offered great value dry BM products because of its continual honeycomb setup with less shrunken structures.[51] A new technology known as superfine grinding is a valuable tool for delivering sheer powder.[52,53] Related with other samples crushed with old-style motorized methods, sheer powder allows decent physical attributes such as dispersibility and solubility. At present, this technology needs persisted operational in biotechnology as well as foodstuffs through a terrific possibility for other diverse industrial functions.[52,54] The powder with particle size > 10–25 μm is labeled as sheer material it has a slim even fragment size allotment with an adequate surface area that protects effortless solubility, flowability, and dispersibility.[52,53,55] Lately, superfine grinding technology remained widely used in the food processing industry. The sheer grinding could cause obvious alterations in chemical configuration parting of the granulometric portions,[52,56] and the hydration rate and the bioavailability of materials improved.[52,57] This improves digestion and absorption upon intake.[52,58,59] Such technologies are to help solve existing complex scientific research problems and public health concerns. So, not only innovative technologies but also traditional technologies must be activated. Concurrently, much advanced technological abilities must be developed by employing discoveries from the associated fields to permit food technology to perform its essential role. Hence, the necessity for this methodical review and evaluation is to integrate information on the safety and efficiency of processed BM as complementary to established remedies for blood sugar control in diet-induced diabetes. This methodical review is intended to answer the following queries: (1) What is the efficiency of processed BM preparations in regulating plasma glucose levels? (2) Do such processed BM preparations are reliable to treat pre-diabetes and type 2 diabetics? (3) Do the processing impacts of BM preparations affect its safety and/or efficiency? To our knowledge, this is the first review study that documents these pieces of evidence. The findings will bring a better understanding of the effects and applications of varied food processing techniques on BM and the effect of such applications on the clinical impacts in care for prediabetes and type 2 diabetics and emphasize gaps for potential investigation.

In a study conducted in-vitro using BM fruit juice (4.5 ml) measured the outcome of pasteurization on its antidiabetic activity revealed significant but marginal reduction in antidiabetic activity throughout storage for ninety days besides thermal pasteurization at 65 °C has proven to have greater sensory quality.[60] BM fruit juice was orally administrated at 10 ml/kg body weight for four weeks in rats induced with type 1 diabetes shown the anti-hyperglycemic and antioxidant activity of BM. However, it did not measure the possible adverse effects.[61] Another study measuring BM beverage at 1.25–3 g in prediabetic humans upon its acute ingestion before the second oral glucose tolerance test reported a lowered postprandial glucose levels in half of the study participants but then none on insulin response. So, although BM beverage intake has proven to support in maintaining blood glucose levels, it stayed un-clear why just a section of participants reacted positively in this study.[5] BM juice given orally to diabetic rats (10 mL/kg/day) for 35 days revealed tremendous antidiabetic effect and therefore has the excellent ability as a novel resource for diabetic care.[62] Yet, another processing study on BM juice pasteurized and debittered followed by in-vitro study on 100 μL of juice with α-amylase enzyme and/or α-glucosidase enzyme reported a marginal but significant reduction in α-glucosidase inhibition activity without affecting α-amylase activity.[63] However, this study also did not measure the safety concerns and adverse effects. A study reported α-amylase inhibitory activities from a novel bioactive polysaccharide extract of BM fruit. However, no adverse effects measured. The fruit juice lyophilized extract (5 microg x ml -μ) orally ad-ministered to stimulate 14C-D-glucose reported increased uptake in L6 myotubes.[44] A 1-10 microg ml (-μ) of the BM juice tested in vitro and in vivo revealed BM juice acts like insulin at a concentration of 5 microg ml (-μ), reveal its antidiabetic potential and additionally it can promote similar to insulin activity through protein intake into skeletal muscle cells.[64] Yet another study on BM juice hypoglycemic effect confirmed and provided enough evidence to explain its role and efficacy in curing diabetes.[65] Further, a study on BM skin, flesh, and whole fruit powder for eight weeks each in rats revealed a maximum reduction of 4.29% in blood glucose levels and 2.73% enhancement insulin level for whole fruit intake.[66]

A randomized experimental design using 2 diabetic mice fed BM powder for five weeks using saponins from BM group (L-SMC 20, M-SMC 40 and H-SMC 80 mg/kg body weight) and polysaccharides from BM (PMC: 500 mg/kg body weight) revealed BM saponins, especially M-SMC 40mg/kg body weight played a more important role than polysaccharides in improving the indicators of progression diabetes.[67] A 10% of ethanolic extract segmented in ethyl acetate as processed BM powder from fruit extract were given orally to diabetic rats at different amounts for 30 days, revealed BM fruit extract safe for oral consumption and stimulated promising hypoglycemic activity.[68] However, in-vivo human randomized, double-blind, placebo-controlled trial that applied BM powder as two capsules 3 grams per day for three times after meals, for 3 months reported no definitive conclusion of effect on HbA1C levels.[69] One study reported that BM freeze-dried powder at the amount of 0.5, 1, and 3% fed for 14 days in diabetic rats reported no harmful impact of taking BM powder on developmental factors and absolute liver load.[70] Yet another study used freeze-dried BM single dose 50 mg/kg and 100 mg/kg given to healthy human subjects did not show a decline in glucose levels following oral glucose intake.[71]

A study in type 2 diabetic male rats that measured the influence of Lactobacillus Plantarum fermentation on the composition and

hypoglycemic impacts of BM polysaccharides.[72] In this study, an oral intake of 10 mL/kg body weight over four weeks revealed Lactobacillus Plantarum fermentation might improve the hypoglycemic impacts of BM polysaccharides in rats by altering assembly of polysaccharides to improve gut microbiota and increase the making of short-chain fatty acids.[72] Another study on Lactobacillus Fermentum 0.05% cells (W/V), extracts of plant fruit BM 200mg/Kg weight of mice, administered individually and in combination with java plum 100 mg/Kg weight revealed these natural extracts had hypoglycemic as well hypolipidemic activity.[73] Yet, another study reported in-vitro Lactobacillus Plantarum BET003 extracted from BM fruit was utilized to ferment its juice and an anti-diabetic test was performed on fresh and fermented BM juices. The results revealed reduced bitterness, lowered sugars, aglycones assembly, and additional metabolites along with enhanced inhibition of α-glucosidase activity in fermented juice.[74]

An experimental processing study to increase the shelf-life of BM fruit slices, conducted a drying operation by using hot air oven dryer at different thickness of fruit slice (3,6 and 9mm) and temperature (60, 70 and 80°C) revealed no significant variable losses of nutrients, however, this study didn't measure its antidiabetic potential.[75] Another experimental processing and in-vitro study that conducted three drying methods, namely, hot air at 70°C for 4 h, freeze at −20°C for 24 h and then freeze-dried at −50°C and infrared radiation drying at 70°C for 3 h to dry BM fruit slices until the moisture fell around 6% (wet basis). The grounded powder of 100mg from these samples were tested in follow up vitro study that revealed the infrared dried BM samples had greater sugar and uronic acid levels plus stronger antioxidant and bile acid-binding ability in lab experiments.[76] The hot air drying and quality evaluation to obtain drying characteristics and overall product quality, for BM fruit slice were reported in a study. This study documented that the temperature had the highest level of influence on the synthetic evaluation index, and it was followed by air velocity, layer thickness, and initial mass, sequentially.[77] A study working on the expansion of hurdle UV-C technology for pasteurization and shelf-life extension of BM fruit juice to efficiently develop an end product with only slight variations of its nutritional constituents with the microbial safety revealed the BM fruit juices preserved with UV-C (253.7 nm) seem to be promising in the industry, however, it did not measure antidiabetic potential.[78]

A study tested and measured fresh and wok-fried BM fruits and juice for total soluble and insoluble oxalate contents revealed that both these are in moderately low amounts and the volume of intake would pose little negative impact upon ingestion.[50] Another study tested glycosylated BM seed protein isolate for improved emulsifying and foaming properties concluded improvement of this ingredient in baking food products.[79] Yet another study measuring the processing effects of several methods on the moisture, fat, and protein content of the BM to control the effect of these processing methods on momordicosides K and L contents in methanolic extracts of fresh and processed samples revealed presence of these contents in all except for those blanched and BM with MY 68 agents momordicosides K and L.[80] However, none of these processing studies measured BM antidiabetic potential and safety concerns when consumed.

The BM formulation in brush border membrane vesicles assay that was tested reported a significant inhibitory effect on glucose uptake into brush border mem-brane vesicles, however, did not measure potential safety concerns.[81] In a study, MCPIIa polysaccharide isolated from BM fruit is taken orally, once a day, for 28 days was tested in diabetic mice revealed that BM/MCPIIa could be effective as a hypoglycemic agent.[82] A tyrosine primed seed fruit extract was used to test its efficacy on diabetes revealed that this extract could effectively be further tested for preclinical and clinical studies to manage hyperglycemia.[83] Another, study on BM polysaccharide nanoparticles measured the 3 types of bio-active polysaccharides (TP, GLP, and MCP) in protein adsorption assay revealed improved antimicrobial efficiency significantly and displayed prolonged antibacterial activity.[84] The antidiabetic effect was not measured. The 3 sequences of BM / Momordica Charantia (MC)2 analogs peptides, compounds II-1, II-2, and III-3 were evaluated in diabetes mice for 20 days of intervention and were tested for anti-hyperglycemic effects. The data suggested that II-1, II-2, and III-3 might be con-tenders for potential care to diabetes. Further, a study revealed that the BM juice sample treated with potassium meta-bisulfite retained the highest nutrient stability. Anti-diabetic effect not measured.[48]

A study reported methanolic fruit extract of 500g of BM powder were infused in methanol and given orally to diabetic rats displayed a dose dependent hypo-glycemic activity in-vivo.[85] BM fruit aqueous extract orally given 20 mg/kg for four weeks in rats has a significant role in the repair of pancreatic beta cells.[86] In a study using BM seed extract 15 mg/kg bodyweight for 18 days revealed that the BM seeds contain an efficient hypoglycemic amino acid that may be used in the cure of diabetes devoid of noticeable toxic effects.[87] Yet in another study, ethanolic extract of BM fruit pulp given to diabetic rats for 400 mg/kg per day for 28 days disclosed that the variation of pancreatic beta cells could be engaged in the investigational examination of hypoglycemic impacts of BM extract.[88] Besides, transdermal films (2 $cm^2$, 10 mg/patch) comprising the herbal drug element portioned from ethanolic extract of BM (290 mg) fruits for 7 days documented effectively reduced the blood glucose level.[89] Yet another study on an alcoholic extract of BM whole fruit 25 mg, 50 mg, and 75 mg doses in the rat reported a decline in the blood sugar level considerably for all the doses. The key highlights of this study have been the lowered glucose levels in the intervention group that remained static for 15 days even after the discontinuation of the intervention added no deadly impact was detected in the liver.[90] Further, acetone isolate of complete BM fruit powder received in varied doses of 25, 50, and 75 mg/100 g of body weight for diabetic rats reported lowering blood sugar levels and recovery of damaged beta cells was revealed.[91] In conclusion while, most of the in vivo and animal studies showed promising results on processed BM antidiabetic potential results from properly designed human studies remained inconclusive. Added neither of these studies explored associated adverse events if any when consumed. Data is very limited and needs to be addressed.

Prediabetes and diabetes are of public health concern globally. There is a need for and worldwide attention towards alternative safe modalities of care and treatment. This review investigated both safety and anti-diabetic efficacy of processed BM in prediabetes and type 2 diabetes. Also, included are the experimental processed bitter melon studies that necessarily did not mention the antidiabetic potential. The findings will give improved insight on clinical outcomes in dealing with diabetics and possible implications of reversal of prediabetes and highlight gaps for future research. From our review, we found that there is scant evidence of the efficacy of processed BM on its anti-diabetic potential both in prediabetes preclinical and clinical and for type 2 diabetes among properly designed randomized clinical trials. Blinded studies are also very few hence the risk for bias in the potential studies is up high. Hence the results are inconclusive to lead to any optimal dietary recommendations of processes BM for intake to reap antidiabetic health benefits.

Assessments of bioactive elements have revealed that BM is abundant in nutrients and phytochemicals of which a few have hypoglycemic potential. The BM juices, powders, extracts, and isolated elements have been examined both in the lab and in-vivo. While clinical trials are poorly designed and/or less reliable in results, a few trials indicated hypo-glycemic potential and safety for use of BM in managing diabetics among humans. The impending need for well-designed randomized clinical trials beginning with pre-clinical trials will assist to comprehend what type of BM variety, quantity, formulation, and time length of administration is ideal. Such inferences will assist in designing appropriate clinical trials which are essential to establish the efficacy of BM in treating diabetes among humans.

Evidence concerning the standardization of this vegetable for its practice as the hypoglycemic medication is sparse. Although very few properly designed studies have reported about the adverse outcome upon BM intake, the studies so far reporting such events incuded in vitro and vivo experiments. These studies revealed that BM can also exert toxic or adverse outcomes in various dosage conditions. There also seemed to be a need for novel approaches concerning the use of functional food such as BM to be validated through large-scale population trials, reflecting validated proxy conclusion points to assess the efficacy of BM as a functional food in prevention and treatment of chronic ailments like prediabetes and type 2 diabetes.

This comprehensive analysis addresses and reports the processed constituents of BM and examines their anti-diabetic activities along with their undesirable outcomes. The present systematic review reveals some antidiabetic medicinal potency of BM, however, the evidence seems inconclusive especially among studies that used processed BM to measure its antidiabetic potential among studies measuring antidiabetic potential among prediabetes. The need for properly designed experimental, and randomized clinical trials that measure antidiabetic effects of processed BM, and the associated adverse effects upon its intake is emphasized in the review. Further, large population trials for BM acceptability as a functional food is also required. Hence the need for these gaps to be addressed and the current review directs the future research studies to utilize and apply this information as a base to design the research to yield beneficial data that can be transformed to recommended dietary intake applications for public health, pro-motion and medical nutrition therapy recommendations for a cure.

## Conclusions

While the research on BM has rapidly developed recently, the application of food processing technology on BM have drawn further consideration, and even retain a rising trend, although mechanisms in several of the studies yet continue to be established. Properly designed RCT and population trials must be the focus of future research. With much further research on BM, the association between the applications of FFT on its antidiabetic efficacy will be clarified. Besides potential adverse outcomes must also be examined further. Primarily, the potential adverse impacts on the human body upon intake, particularly upon long-term intake, have not been examined. Secondly, studies aiming at reversing prediabetes using processed BM are much scant and are almost required as this is the stage, we can reverse it to attain normal blood glucose levels. Later, most existing studies are invitro and preclinical trials, thus, their effect on people has not been determined yet. Finally, large population-based trials are needed to understand and optimize the dietary intake recommendations for its acceptability as a functional food and to yield potential health benefits. Consequently, randomized clinical trials are necessary before to appropriate BM intake in dietary recommendations, medical nutrition therapy, and even supplemental and nutraceutical productions. The application of BM in food and nutraceutical fields are yet in the early processing stages. The health gains are nevertheless far from being completely utilized. Since BM has a variety of health functions, it may be a potential contender as a hypoglycemic agent, under the premise of establishing safety.

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## Conflicts of interest

The authors declare no conflicts of interest.

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