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## Unlocking the potential of vegetables in diabetes management

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## Abstract

The rising global burden of type 2 diabetes mellitus (T2DM) has intensified the need for effective, sustainable, and accessible management strategies. Antidiabetic vegetable crops have emerged as promising functional foods, offering significant health benefits due to their rich content of bioactive phytochemicals, including flavonoids, phenolic acids, terpenes, and alkaloids. These compounds exhibit antidiabetic activities through mechanisms such as enzyme inhibition ( $\alpha$ -amylase and  $\alpha$ -glucosidase), insulin sensitization, antioxidant action, and anti-inflammatory effects. This review explores the therapeutic potential of key vegetables, such as bitter melon, fenugreek, okra, and leafy greens in regulating blood glucose, enhancing insulin function, and mitigating oxidative stress. Furthermore, the integration of these vegetables into cropping systems supports sustainable agriculture and offers economic benefits by catering to the growing demand for nutraceuticals and functional foods. While experimental studies confirm the efficacy of these vegetables in diabetes management, further clinical validation is essential. The review underscores the dual role of antidiabetic vegetables in improving public health outcomes and promoting agroecological resilience.

## 1. Introduction

The potential of antidiabetic vegetable crops is increasingly being recognized as a viable alternative to synthetic drugs, which often come with adverse side effects such as weight gain and gastrointestinal issues (Rahman *et al.*, 2022; Ademoyegun, 2023). Green leafy vegetables (GLVs) like *Allium cepa*, *Allium fistulosum*, and *Petroselinum crispum* have shown significant antidiabetic properties through enzyme inhibition, particularly  $\alpha$ -glucosidase and  $\alpha$ -amylase, which are crucial in managing type 2 diabetes mellitus (T2DM). These vegetables, when combined, exhibit competitive inhibition similar to acarbose, a known antidiabetic drug, suggesting their potential as functional foods for diabetes management (Selective green leafy vegetables and their synergistic combination approach as natural antidiabetic agents: therapeutic potential, 2023). Additionally, biotechnological advancements have enabled the enhancement of bioactive compounds in transgenic plants, which can improve insulin sensitivity and beta-cell function, offering a promising avenue for diabetes treatment. Various horticultural crops, such as ginger, avocado, and bitter melon, have also been identified for their hypoglycemic activities, providing a natural therapeutic option with minimal side effects (Ademoyegun, 2023). The hydroethanolic leaf extract of *Koenigia polystachya*, for instance, has demonstrated significant antioxidant and antidiabetic potential in both *in vitro* and *in vivo* studies, further supporting the role of plant-based interventions in diabetes care (Kiba *et al.*, 2023). Moreover, the

roots of certain plants contain phytochemicals like flavonoids and phenolic compounds, which have been shown to inhibit enzymes that facilitate hyperglycemia, thus offering another layer of therapeutic potential (Ardalani *et al.*, 2021). The integration of these plant-derived compounds into modern therapeutic strategies not only offers a holistic approach to diabetes management but also aligns with the growing demand for natural and sustainable health solutions (Haque and Sana, 2015). Overall, the exploration and utilization of antidiabetic vegetable crops and their bioactive constituents (Table 1) present a promising frontier in the fight against diabetes, with the potential to improve patient outcomes and reduce reliance on synthetic medications (Ts and Jessykutty, 2017). This response explores the potential of antidiabetic vegetable crops in both agricultural and health sectors, supported by evidence from recent studies.

## 2. Potential of antidiabetic vegetables

## 2.1 Diverse phytochemical composition

Vegetables are rich in phytochemicals such as flavonoids, phenolic acids, alkaloids, and terpenes, which have been shown to exhibit antidiabetic properties. For instance, compounds like quercetin, catechins, and chlorogenic acid found in various vegetables have been reported to act as insulin sensitizers and enzyme inhibitors, contributing to blood glucose regulation (Garcia Gurrola *et al.*, 2024). The diverse phytochemical composition of antidiabetic vegetable crops is characterized by a wide array of bioactive compounds that contribute to their therapeutic potential in managing diabetes. These compounds include flavonoids, terpenoids, alkaloids, phenolic acids, and glycosides, which are prevalent in various plant species known for their antidiabetic properties. For instance, flavonoids such as quercetin and catechins, found in Mexican agrobiodiversity, have been identified for their roles as antioxidants and insulin sensitizers,

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while phenolic acids like chlorogenic and caffeic acids act as enzyme inhibitors (Garcia Gurrola *et al.*, 2024). Similarly, plants like *Momordica charantia* (bitter melon) and *Moringa oleifera* are rich in these phytochemicals, which are crucial for their hypoglycemic effects (The chemistry of antidiabetic plants, 2022). The Fabaceae, Liliaceae, and Lamiaceae families are particularly noted for their antidiabetic effects, with bioactive compounds such as triterpenoids and alkaloids playing significant roles in combating diabetes. Moreover, traditional medicinal plants like *Ocimum gratissimum* and *Vernonia colorata* have demonstrated high antioxidant capacities and hypoglycemic activities, attributed to their rich content of polyphenols and flavonoids. The therapeutic efficacy of these phytochemicals is further enhanced by their multi-mechanistic actions, including enhancing insulin sensitivity, reducing oxidative stress, and modulating insulin signaling pathways. Despite the promising laboratory and animal study results, there remains a scarcity of clinical trial data, highlighting the need for further research to validate these findings in human populations (Garcia Gurrola *et al.*, 2024). Overall, the phytochemical diversity in antidiabetic vegetable crops offers a promising avenue for developing novel, effective, and safer antidiabetic therapies, leveraging the rich agrobiodiversity and traditional knowledge systems (Tran *et al.*, 2020; Hemavathi *et al.*, 2024).

## 2.2 Role in sustainable agriculture

Vegetables such as okra (*Abelmoschus esculentus*) have been highlighted for their antidiabetic properties, which are attributed to their bioactive compounds that interact beneficially within the food matrix, offering a promising avenue for sustainable health applications (Durazzo *et al.*, 2018). Similarly, legumes are recognized for their glucose and lipid lowering effects, making them valuable in dietary formulations for diabetes management, thus supporting the notion of integrating such crops into sustainable agricultural systems (Singhal *et al.*, 2014). The exploration of various plants, fruits, and vegetables for their hypoglycemic effects underscores the potential of these natural resources in managing diabetes mellitus, which is a growing global health concern (Haque and Sana, 2015). Functional foods like *Moringa oleifera* and *Persea americana* are also noted for their role in combating metabolic diseases, including diabetes, through their phytochemical content, which suggests their integration into sustainable agricultural practices (Dukhi and Taylor, 2018). Bitter melon and ivy melon have shown promising hypoglycemic effects, mediated through mechanisms such as insulin secretion and enzyme modulation, highlighting the need for further research into their long term benefits and active principles (Platel and Srinivasan, 1997). The development of plant based therapies, including polyherbal formulations, offers a sustainable alternative to conventional diabetes treatments, emphasizing the importance of utilizing plant resources effectively. Vegetables like bitter melon and okra, rich in plant metabolites such as flavonoids and phenolics, play a crucial role in diabetes management by protecting pancreatic beta cells and inhibiting hyperglycemic processes (Balekundri *et al.*, 2024). The nutraceutical value of vegetables, due to their rich content of vitamins, minerals, and phytochemicals, further supports their role in sustainable agriculture and health promotion (Ahmad *et al.*, 2020). Green leafy vegetables have demonstrated significant antidiabetic potential through enzyme inhibition, suggesting their utility in developing functional foods for diabetes prevention (Selective green leafy vegetables and their synergistic combination approach as natural

antidiabetic agents: therapeutic potential, 2023). Finally, the consumption of fruits and vegetables is linked to reduced risks of non-communicable diseases, including diabetes, highlighting their importance in dietary strategies and sustainable agricultural practices (Krishnaswamy and Gayathri, 2018). These studies underscore the dual benefits of antidiabetic vegetables in promoting health and supporting sustainable agricultural systems.

## 2.3 Economic benefits

The potential economic benefits of antidiabetic vegetables are significant, as they offer a cost effective and sustainable approach to managing diabetes mellitus (DM), a condition with rising prevalence and substantial economic burden worldwide. Vegetables such as bitter melon and ivy melon have demonstrated hypoglycemic effects, potentially reducing the need for expensive pharmaceutical interventions and their associated side effects (Platel and Srinivasan, 1997). The consumption of legumes and pulses, which are rich in nutrients and possess antidiabetic properties, can lead to substantial healthcare savings. For instance, in Canada, a diet including 100 g/day of pulses could save between Can 31.6 million to Can 31.6 million to Can 315.5 million annually in healthcare costs related to type 2 diabetes (T2D) and cardiovascular disease (CVD) (Abdullah *et al.*, 2017). This economic advantage is further supported by the nutritional benefits of vegetables, which are rich in dietary fiber, vitamins, and minerals that contribute to improved glycemic control and reduced risk of diabetes-related complications (Dias and Imai, 2017). The integration of plant based diets, which are less costly and have fewer side effects compared to conventional drugs, is increasingly advocated as an effective strategy for diabetes management (Naveen and Baskaran, 2018; Rahman *et al.*, 2022). Moreover, the development of plant based antidiabetic agents and nutraceuticals could enhance the therapeutic landscape, offering safer and potentially more effective alternatives to synthetic drugs (Subramoniam, 2016; Kumar *et al.*, 2024). The economic implications extend beyond direct healthcare savings, as improved management of diabetes through dietary interventions can also reduce the incidence of secondary complications, thereby decreasing the overall societal burden of the disease (Singhal *et al.*, 2014). Thus, the strategic use of antidiabetic vegetables not only holds promise for individual health benefits but also presents a viable economic strategy for reducing the financial impact of diabetes on healthcare systems globally.

## 2.4 Health benefits of antidiabetic vegetables

Bitter melon, okra, cabbage *etc.*, vegetables have been recognized for their potential in regulating blood glucose levels, primarily through the inhibition of key enzymes involved in carbohydrate digestion, namely alpha amylase and alpha glucosidase. These enzymes play a crucial role in the breakdown of carbohydrates into glucose, and their inhibition can effectively reduce postprandial blood glucose levels, a significant concern in the management of type 2 diabetes mellitus (T2D) (Kumar *et al.*, 2011; Proença *et al.*, 2021). The antidiabetic properties of these vegetables are largely attributed to their rich content of bioactive compounds, including phenolic acids and flavonoids, which have been shown to possess significant inhibitory effects on these enzymes (Balekundri *et al.*, 2024; Assefa *et al.*, 2019). Bitter melon, in particular, contains specific phytochemicals such as charantin, p-insulin, and vicine, which have demonstrated hypoglycemic effects in clinical studies (Sharma Katoch, 2020). Furthermore, a randomized control trial highlighted

that a diet rich in bitter and strong-tasting vegetables, including cabbages, significantly improved glycemic control and insulin sensitivity in T2D patients compared to milder vegetable diets (Thorup *et al.*, 2021). The potential of these vegetables as natural alpha glucosidase inhibitors offers a promising alternative to synthetic drugs, which often come with gastrointestinal side effects (Assefa *et al.*, 2019; Gajbhiye *et al.*, 2018). This natural approach not only aids in managing blood glucose levels but also contributes to the overall dietary management of diabetes, providing a cost effective and accessible strategy for individuals with T2D (Tiwari, 2014). Thus, incorporating these vegetables into the diet can be a beneficial adjunct in the holistic management of diabetes, leveraging their enzyme inhibitory properties to maintain glucose homeostasis (Boachie *et al.*, 2021).

### 3. Insulin sensitization and secretagogue activities

Fenugreek and soybeans are the two vegetables that have shown significant potential in managing type 2 diabetes mellitus (T2DM) through their insulin sensitization and secretagogue activities. Fenugreek, a common medicinal plant, contains active components such as alkaloids, flavonoids, and saponins, which contribute to its antidiabetic properties. It is particularly rich in soluble fiber, which helps lower blood sugar by slowing carbohydrate absorption and improving glucose tolerance (Jn *et al.*, 2019). Studies have

demonstrated that fenugreek can enhance insulin sensitivity and reduce blood glucose levels, making it a valuable dietary component for diabetes management (Haxhiraj *et al.*, 2024). Additionally, fenugreek's ability to stimulate insulin release from pancreatic islets and reduce insulin resistance aligns with the mechanisms of action of some oral antidiabetic agents (Lea, 2013). On the other hand, vegetable soybeans have been recognized for their role in lowering blood sugar, improving glucose tolerance, and regulating blood lipids. They also protect and repair damaged islets of Langerhans, which are crucial for insulin production (Yinan *et al.*, 2014; Chengzhi *et al.*, 2013). The consumption of soybeans has been associated with reduced fasting and postprandial blood glucose levels, as well as improved lipid profiles, which are beneficial for individuals with T2DM (Yinan *et al.*, 2014; Chengzhi *et al.*, 2013). The antidiabetic effects of these vegetables are further supported by their antioxidant properties, which help mitigate oxidative stress and prevent diabetic complications (Tiwari, 2014). While the potential of fenugreek and soybeans in diabetes management is promising, it is essential to consider the standardization of dosages and potential interactions with conventional medications to ensure safe and effective use (Alp, 2023). Incorporating fenugreek and soybeans into the diet could offer a natural and complementary approach to managing T2DM, alongside conventional treatments (Haxhiraj *et al.*, 2024; Yinan *et al.*, 2014 ; Jn *et al.*, 2019).

**Table 1: Bioactive compounds from vegetables and their cardiovascular and metabolic health benefits**

Vegetable	Key bioactive compounds	Antidiabetic effects	Mechanism of action	References
<i>Daucus carota</i> L.	$\beta$ -Carotene, fiber, polyphenols	Reduces postprandial glucose, improves insulin function	Inhibits $\alpha$ -glucosidase, enhances insulin sensitivity, reduces oxidative stress	Yao <i>et al.</i> , 2022
<i>Solanum lycopersicum</i> L.	Lycopene, flavonoids	Reduces oxidative stress, improves insulin sensitivity	Lowers lipid peroxidation, protects pancreatic $\beta$ -cells, enhances antioxidant defense mechanisms	Srinivasan <i>et al.</i> , 2014
<i>Zingiber officinale</i> Roscoe	Gingerols, shogaols	Lowers blood glucose, improves insulin sensitivity	Enhances insulin secretion, improves glucose metabolism, protects $\beta$ -cells from oxidative damage	Li <i>et al.</i> , 2012
<i>Allium sativum</i> L.	Allicin, alliin	Enhances insulin secretion, reduces blood glucose	Increases insulin secretion, improves insulin sensitivity, reduces oxidative stress	Banerjee and Maulik, 2002
<i>Allium cepa</i> L.	Quercetin, sulfur compounds	Lowers blood glucose, enhances insulin secretion	Reduces insulin resistance, stimulates insulin release, protects pancreatic $\beta$ -cells	Kumari <i>et al.</i> , 2021
<i>Curcuma longa</i> L.	Curcumin	Lowers blood glucose, improves insulin sensitivity	Suppresses oxidative stress and inflammation, enhances $\beta$ -cell function, reduces insulin resistance	Gupta <i>et al.</i> , 2013
<i>Momordica charantia</i> L.	Charantin, polypeptide -p, vicine	Reduces blood glucose, enhances insulin secretion	Mimics insulin action, stimulates glucose uptake, inhibits glucose absorption, suppresses gluconeogenesis	Patel <i>et al.</i> , 2012
<i>Trigonella foenum-graecum</i> L.	Trigonelline, galactomannan	Decreases fasting blood sugar, improves glucose tolerance	Delays carbohydrate digestion, increases insulin secretion, enhances glucose utilization by muscles	Basch <i>et al.</i> , 2003
<i>Cinnamomum spp.</i> Schaeff.	Cinnamaldehyde, cinnamate, cinnamic acid	Reduces fasting blood sugar, improves insulin sensitivity	Enhances insulin receptor activity, increases glucose uptake, delays gastric emptying	Anderson <i>et al.</i> , 2004

<i>Brassica oleracea</i> L. var. <i>italica</i> Plenck	Sulforaphane	Improves insulin sensitivity, reduces fasting blood glucose	Activates Nrf2 pathway, reduces oxidative stress, enhances detoxi- fication processes	Zhang <i>et al.</i> , 2015
<i>Spinacia oleracea</i> L.	Flavonoids, thylakoids	Reduces postprandial blood glucose, improves satiety	Inhibits carbohydrate-digesting enzymes, slows gastric emptying, increases GLP-1 secretion	Montelius <i>et al.</i> , 2014
<i>Cucurbita mosch- ata</i> Duchesne ex Poir	Polysaccharides, flavonoids	Enhances insulin secretion, improves glucose metabolism	Stimulates insulin secretion, pro- motes $\beta$ -cell regeneration, reduces oxidative stress	Zhang <i>et al.</i> , 2018
<i>Moringa oleifera</i> Lam.	Isothiocyanates, querc- etin, chlorogenic acid	Reduces fasting glucose, impro- ves lipid profile	Enhances insulin signaling, inhibits $\alpha$ -amylase and $\alpha$ -glucosi- dase, reduces oxidative stress	Kunyanga <i>et al.</i> , 2011
<i>Solanum melongena</i> L.	Phenolic acids, flavon- oids	Lowers postprandial glucose levels	Inhibits $\alpha$ -glucosidase activity, reduces intestinal glucose absorption	Kwon <i>et al.</i> , 2008

#### 4. Antioxidant and antiinflammatory properties

The health benefits of antidiabetic vegetables, particularly those rich in phenolic compounds, are significant due to their antioxidant and antiinflammatory properties, which play a crucial role in mitigating oxidative stress a key factor in the development of diabetic complications. *Brassica oleracea* var. *gongylodes*, commonly known as kohlrabi, has been shown to possess potent antioxidant properties, as evidenced by its ability to significantly reduce fasting blood glucose levels and improve lipid profiles in diabetic rats. This is attributed to the presence of phenolic compounds such as chlorogenic acid, rutin, and sinapic acid, which enhance the enzymatic activities of catalase and superoxide dismutase, thereby improving the antioxidant status of diabetic subjects (Sharma *et al.*, 2015). Similarly, broccoli, another member of the *Brassica* family, has demonstrated significant hypoglycemic and antioxidant effects in diabetic rats, reducing oxidative stress markers and preserving pancreatic tissue integrity (Suresh *et al.*, 2016; Suresh *et al.*, 2017). The antioxidant properties of these vegetables are largely due to their high polyphenol content, which not only combats oxidative stress but also improves insulin sensitivity and preserves beta cell function, thus offering a promising adjuvant therapy in diabetes management (Krawczyk *et al.*, 2023; Pannucci *et al.*, 2023). Furthermore, the anti-inflammatory effects of phenolic compounds in these vegetables are crucial, as they inhibit pathways related to inflammation, such as nuclear factor- $\kappa$ B and mitogen-activated protein kinases, which are implicated in diabetes-related complications (Puangraphant *et al.*, 2022; Pannucci *et al.*, 2023). The efficacy of these vegetables in managing diabetes is further supported by their ability to scavenge free radicals and reduce oxidative damage, as demonstrated in various *in vitro* and *in vivo* studies (Jung *et al.*, 2014; Zhang and Tsao, 2016). Overall, the integration of phenolic-rich vegetables like kohlrabi and broccoli into the diet could serve as an effective strategy to mitigate oxidative stress and inflammation, thereby reducing the risk of diabetic complications (Dietary Polyphenols in Diabetes, 2022).

#### 5. Glycemic control

Consuming vegetables before carbohydrates has been shown to significantly improve glycemic control in individuals with type 2 diabetes mellitus (T2DM) by reducing postprandial blood glucose levels. This dietary practice is supported by multiple studies that highlight its effectiveness in managing blood glucose excursions and

improving long term glycemic control. For instance, a study conducted in Japan demonstrated that eating vegetables before carbohydrates reduced postprandial glucose excursions and improved glycemic control over a 2.5-year period in patients with T2DM (Imai *et al.*, 2014). Similarly, research in Indonesia found that T2DM patients who consumed vegetables before carbohydrates maintained more stable glucose levels and experienced a significant reduction in postprandial glucose spikes compared to those who consumed carbohydrates first (Indarto *et al.*, 2022). The mechanism behind this effect is partly attributed to the high dietary fiber content in vegetables, which slows down carbohydrate digestion and reduces the insulin required for glucose metabolism (Imai *et al.*, 2013). Additionally, the consumption of vegetables before carbohydrates may stimulate the secretion of incretin hormones, further aiding in the reduction of glycemic excursions (Imai *et al.*, 2013). A randomized controlled trial also confirmed that this simple meal plan was more effective in achieving glycemic control than traditional exchange based meal plans over a twenty four month period (Imai *et al.*, 2011). Furthermore, increased vegetable intake has been associated with improved glycemic control, as evidenced by a study among Indonesian adults with T2DM, which reported significant reductions in HbA1c, fasting blood glucose, and postprandial blood glucose levels (Yen *et al.*, 2022). These findings collectively suggest that the strategic consumption of vegetables before carbohydrates is a promising dietary intervention for managing blood glucose levels and preventing complications associated with T2DM.

#### 6. Challenges and limitations

##### 6.1 Variability in bioactive content

The bioactive content of vegetables can vary significantly based on factors such as environmental conditions, post-harvest storage, and processing methods. This variability may affect their antidiabetic efficacy (Sarkar *et al.*, 2022; Sharma *et al.*, 2015).

##### 6.2 Lack of clinical evidence

While preclinical studies have demonstrated the antidiabetic potential of various vegetables, there is a scarcity of clinical trials to confirm their efficacy in humans. This gap underscores the need for further research (Garcia Gurrola *et al.*, 2024; Piragine *et al.*, 2022).

### 6.3 Cultural and dietary preferences

The selection of vegetables for diabetes management may vary based on regional availability and cultural practices. This diversity necessitates localized approaches to promote the use of antidiabetic vegetables (Pundarikakshudu *et al.*, 2024; Tiwari, 2014).

## 7. Future thrust

### 7.1 Breeding and cultivation

Advances in agricultural practices, such as selective breeding and precision farming, can enhance the phytochemical content of vegetables, improving their antidiabetic potential (Purwanti *et al.*, 2022; Tang *et al.*, 2008).

### 7.2 Food processing and biofortification

Innovative processing techniques can optimize the retention and bioavailability of bioactive compounds in vegetables. Biofortification strategies, such as genetic modification, may also be explored to develop crops with enhanced antidiabetic properties (Sarkar *et al.*, 2022; Sharma *et al.*, 2015).

### 7.3 Integration into dietary guidelines

Public health initiatives should promote the inclusion of antidiabetic vegetables in dietary guidelines for diabetes prevention and management (Table 2). This approach can complement existing therapeutic strategies and improve glycemic control (Dias and Imai, 2017; Iddrisu and Chikwere, 2020).

**Table 2: Antidiabetic vegetables, and their bioactive components mode of consumption**

Category	Vegetable	Key bioactive compounds	Mechanism of action	Mode of consumption
<b>Cruciferous vegetables</b>	Broccoli	Sulforaphane, flavonoids, fiber	Improves insulin sensitivity, antioxidant effect	Raw (salads), steamed, stir fried, soups
	Cabbage (Red and Green)	Anthocyanins, glucosinolates	Lowers blood glucose, anti-inflammatory	Raw (salads), cooked, fermented (kimchi, sauerkraut)
	Cauliflower	Glucosinolates, fiber	Regulates glucose metabolism, improves gut health	Steamed, roasted, stir fried, pureed
	Brussels sprouts	Isothiocyanates, polyphenols	Enhances insulin action, reduces oxidative stress	Roasted, steamed, sautéed
<b>Cucurbits and gourds</b>	Bitter melon ( <i>Momordica charantia</i> )	Charantin, polypeptides, vicine	Increases insulin secretion, I glucose uptake	Juice, stir fried, stuffed, soups
	Ridge melon	Flavonoids, saponins	Lowers blood sugar, improves glucose metabolism	Stir fried, cooked with lentils, curries
	Bottle melon	Flavonoids, triterpenoids	Antioxidant, reduces post-prandial glucose levels	Juice, boiled, stir fried, soups
	Sponge melon	Phenolics, glycosides	Enhances glucose utilization, reduces inflammation	Stir fried, curries, soups
	Ivy melon	Triterpenoids, pectin	Inhibits carbohydrate digestion, improves insulin function	Stir fried, stuffed, curries
	Spiny melon	Alkaloids, flavonoids, saponins	Stimulates insulin secretion, lowers blood glucose	Stir fried, deep fried, curries
	Pumpkin and Squash	Carotenoids, polysaccharides	Regulates glucose homeostasis, antioxidant activity	Boiled, roasted, soups, mashed
	Cucumber	Fisetin, quercetin	Reduces glucose absorption, improves insulin sensitivity	Raw (salads, juices), pickled
<b>Leafy greens</b>	Spinach	Flavonoids, phenolic acids	Lowers blood sugar, improves pancreatic $\beta$ -cell function	Raw (salads, smoothies), cooked (soups, curries)
	Lettuce	Lactucaxanthin, $\beta$ -carotene	Regulates insulin levels, reduces glucose spikes	Raw (salads, wraps, sandwiches)
	Fenugreek ( <i>Trigonella foenum-graecum</i> )	4-Hydroxyisoleucine, diosgenin	Enhances insulin secretion, delays glucose absorption	Sprouted, soaked overnight, added to curries and dals
	Coriander	Polyphenols, essential oils	Reduces glucose levels, anti-inflammatory effect	Raw (garnish, chutneys), cooked (soups, curries)
	Mint (Peppermint, Spearmint)	Menthol, rosmarinic acid	Improves insulin activity, antioxidant action	Raw (salads, beverages, chutneys)

<b>Root and Bulb vegetables</b>	Carrots	Beta-carotene, quercetin	Reduces blood glucose, enhances insulin function	Raw (salads, juices), cooked (soups, stir-fries)
	Onions (Red and White)	Anthocyanins, quercetin	Inhibits glucose absorption, anti-inflammatory	Raw (salads, sandwiches), cooked (curries, stir-fries)
	Radish	Glucosinolates, coenzyme Q10	Lowers glucose uptake, anti-oxidant effect	Raw (salads, juices), pickled, cooked
	Beetroot	Betalains, flavonoids	Improves insulin sensitivity, reduces oxidative stress	Raw (salads, juices), boiled, roasted
	Turnip	Glucosinolates, isothiocyanates	Enhances insulin action, anti-oxidant properties	Boiled, roasted, stir fried
	Taro ( <i>Colocasia esculenta</i> )	Flavonoids, tannins, saponins	Regulates blood glucose, anti-inflammatory	Boiled, roasted, mashed
	Elephant foot yam	Betulinic acid, $\beta$ -sitosterol	Lowers blood sugar, antidiabetic activity	Boiled, stir fried, curries
	Yellow yam	Dioscorin, allantoin	Enhances insulin secretion, antioxidant effect	Boiled, mashed, roasted
	Sweet potatoes	Phenolic acids, anthocyanins	Regulates glucose homeostasis, improves insulin action	Boiled, baked, roasted
<b>Solanaceous vegetables</b>	Tomatoes	Lycopene, quercetin, kaempferol	Reduces oxidative stress, improves insulin function	Raw (salads, juices), cooked (soups, sauces)
	Eggplant (Brinjal)	Polyphenols, anthocyanins	Lowers blood sugar, regulates glucose metabolism	Roasted, grilled, stir fried, curries
	Chili peppers	Capsaicin, carotenoids	Improves glucose utilization, increases insulin sensitivity	Raw (salads, pickles), cooked (curries, stir fries)
	Bell peppers	Capsaicin, vitamin C, flavonoids	Enhances glucose uptake, anti-inflammatory action	Raw (salads, sandwiches), grilled, stir fried
<b>Leguminous vegetables</b>	French beans (green beans)	Fiber, phenolic compounds	Delays glucose absorption, improves gut microbiota	Steamed, stir fried, curries
	Cluster beans (guar beans)	Guar gum, flavonoids	Reduces postprandial glucose, improves digestion	Stir fried, curries, soups
	Peas	Pea glycoproteins, fiber	Regulates blood glucose, supports insulin function	Raw (salads), cooked (soups, curries)

## 8. Conclusion

Antidiabetic vegetable crops hold immense potential in both agricultural and health sectors. Their rich phytochemical composition, ability to regulate blood glucose levels, and antioxidant properties make them valuable resources for diabetes management. However, further research is needed to address the challenges associated with their efficacy, bioavailability, and cultural acceptance. By leveraging agricultural innovations and promoting their integration into dietary practices, these crops can play a pivotal role in combating the global diabetes epidemic. The vegetables listed above have been scientifically studied for their antidiabetic properties, with bioactive compounds such as flavonoids, polyphenols, carotenoids, and alkaloids playing a crucial role in regulating blood glucose levels. These compounds exert their effects through various mechanisms, including enhancing insulin secretion, promoting glucose uptake, inhibiting glucose

metabolizing enzymes, and providing antioxidant benefits. The mode of consumption raw, cooked, or processed significantly influences the bioavailability of these bioactive compounds. Juices and raw forms are recommended for water soluble compounds like flavonoids and polyphenols, while cooking improves the absorption of fat soluble nutrients such as lycopene and carotenoids. Additionally, fermented preparations like kimchi, sauerkraut, and pickles offer probiotic advantages, supporting gut health and further aiding glucose metabolism.

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### Conflict of interest

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

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