



(REVIEW ARTICLE)



Exploring the effects of beta vulgaris on GLP-1 secretion and metabolism: Mini review

Sushma Papireddypalli, B Dhanush, T R Harini Ganga, Geethanjali Bukke and Somasekhar Reddy Kanala *

Department of Pharmacology, Raghavendra Institute of Pharmaceutical Education and Research (RIPER), Krishnamreddy Palli Cross, Chiyvedu (Post), Anantapur, Andhrapradesh, India – 515 721.

International Journal of Science and Research Archive, 2025, 15(01), 275-282

Publication history: Received on 24 February 2025; revised on 01 April 2025; accepted on 03 April 2025

Article DOI: <https://doi.org/10.30574/ijrsra.2025.15.1.0924>

Abstract

Beetroot, also known as Beta vulgaris, is a popular root vegetable that is valued for both its medicinal and nutritional qualities. According to recent research, it may play a role in regulating insulin secretion and glucose metabolism, particularly in how it regulates the release of glucagon-like peptide-1 (GLP-1). Blood glucose levels are regulated by the crucial incretin hormone GLP-1, which increases insulin production in response to food intake. Explore how Beta vulgaris affects GLP-1 secretion and metabolism in general. Beta vulgaris's bioactive substances, including betalains, nitrates, and fiber, have been demonstrated to have antioxidant, vasodilatory, and anti-inflammatory properties that may affect metabolic processes. The study explores the effects of Beta Vulgaris ingestion on GLP-1 levels and its possible implications for enhancing insulin sensitivity and glucose homeostasis by looking at both in vitro and in vivo models. The study also assesses the wider metabolic impacts, such as modifications to lipid profiles, obesity, and mitochondrial function. The findings could contribute to a better understanding of Beta vulgaris's function in metabolic health and its potential as a dietary intervention for those with obesity, type 2 diabetes, and insulin resistance. This study opens the door for more research and possible treatment uses in metabolic diseases by clarifying the molecular mechanisms through which Beta vulgaris may affect GLP-1 production and metabolic control.

Keywords: Beta vulgaris; Glucagon like peptide-1; Type 2 diabetes; Incretin hormone; Insulin resistance; Betalains

1. Introduction

Beta vulgaris, is a very nutrient-dense root vegetable that is high in dietary fiber, vitamins, minerals, and antioxidants [1]. Its deep red color and anti-inflammatory and antioxidant qualities are attributed to bioactive substances such as betalains [2]. Because of its high nitrate content, beetroot is well known for its cardiovascular advantages, which include decreasing blood pressure and enhancing blood circulation [3]. It has also proven the potential in improving insulin sensitivity and glucose metabolism [4]. As a result, beta vulgaris is becoming more well-known for its potential use in the treatment of metabolic diseases such type 2 diabetes, obesity and insulin resistance [5].

An incretin hormone called GLP-1 (glucagon-like peptide-1) is mostly generated in the intestines in reaction to food consumption [6]. By stimulating the pancreas to secrete more insulin in a glucose-dependent way, it plays a crucial part in metabolic regulation and helps keep blood sugar levels within normal ranges [7]. Glucagon is a hormone that raises blood sugar, while GLP-1 prevents its release, which helps maintain glucose homeostasis [8]. GLP-1 can also help with weight control and general metabolic balance by decreasing hunger and slowing stomach emptying [9]. GLP-1 is involved in glucose metabolism, but it also enhances insulin sensitivity and supports the health of beta cells in the pancreas [10]. Because of these roles, GLP-1 plays a key role in the treatment of diseases like type 2 diabetes and obesity [11]. Treatments that target GLP-1 or its pathways are therefore now essential for treating metabolic diseases, providing better blood sugar management as well as possible advantages for appetite control and weight loss [12]. Beta vulgaris, may have an impact on insulin control and glucose metabolism, it is crucial to investigate how it affects GLP-1 secretion.

* Corresponding author: Kanala Somasekhar Reddy.

Beta Vulgaris may help regulate blood sugar, enhance insulin sensitivity, and helps in weight management by increasing GLP-1 secretion [13]. Natural dietary approaches may be developed as a result of this research to support conventional therapies for these prevalent metabolic diseases [14].

1.1. Nutrients and bioactive compounds of Beta vulgaris

Beta vulgaris consist of bioactive compounds like betalains (betacyanins, betaxanthins), flavonoids, polyphenols, saponins and nitrates. It also consists of minerals like potassium, sodium, Phosphorous, calcium, magnesium, copper, iron, zinc, manganese. Beta vulgaris are good source of carbohydrates, vitamins (vitamin A, vitamin C, vitamin B6, vitamin B9) and fiber [15].

1.2. GLP-1 Secretion and Mechanisms

The hormone GLP-1 (glucagon-like peptide-1), is crucial for controlling glucose metabolism and stimulating the release of insulin [16]. It is mostly released by L-cells in the colon and ileum of the small intestine in reaction to meal consumption [17]. GLP-1 contributes significantly to the incretin effect, which increases insulin production in a way that is dependent on glucose. When nutrients, especially lipids and carbohydrates, are present in the intestine, GLP-1 is released [18]. Nutrients are broken down and absorbed in the duodenum and jejunum, which is where the presence of food initiates the process [19]. GLP-1 stimulates the pancreas to release more insulin, but only when blood glucose levels are high. By suppressing glucagon secretion, it stops the liver from producing glucose [20].

GLP-1 also helps regulate food intake by slowing stomach emptying and promoting satiety. By influencing the brain, it can also decrease appetite. A number of variables, such as pharmaceutical drugs, gut flora, and dietary components, affect GLP-1 production [21]. GLP-1 secretion can be stimulated by specific foods, such as proteins and vegetables high in fiber, and its secretion is also modulated by the gut flora [22]. Its levels can be directly raised by pharmacological treatments such as GLP-1 receptor agonists. A balanced diet and regular exercise are two lifestyle factors that have a major impact on GLP-1 secretion [23]. While a nutritious diet helps support gut health and optimal GLP-1 levels and metabolic regulation, physical activity enhances insulin sensitivity and may increase GLP-1 secretion [24].

1.3. Mechanisms Linking Beta Vulgaris to GLP-1 Secretion

Beta vulgaris and GLP-1 secretion are linked through a number of biological processes that improve glucose metabolism and insulin control [25]. It has been demonstrated that beta vulgaris stimulates the release of GLP-1 and acetylcholine through its bioactive components, including betalains and nitrates [26]. Acetylcholine contributes to the parasympathetic nervous system's activity, which in turn causes the intestines to secrete GLP-1. In order to increase insulin secretion in a glucose-dependent manner and lower blood sugar levels, GLP-1 release is necessary [27].

Additionally, beta vulgaris affects insulin sensitivity pathways and GLP-1 receptor function. Inhibiting glucagon release and encouraging insulin secretion, elevated GLP-1 levels help in preserving glucose homeostasis. To further support its anti-hyperglycemic benefits, Beta Vulgaris also increases the function of GLUT4 transporters, which help muscle cells absorb glucose [28].

Table 1 Comparison of Animal and Human Studies on Beta Vulgaris and GLP-1

Study Type	Findings	Effect on GLP-1	Effect on Metabolism
Animal Studies	Increased plasma acetylcholine and GLP-1 levels after Beta Vulgaris consumption	GLP-1 levels increased, contributing to enhanced insulin secretion	Improved blood glucose control and insulin sensitivity
Human Studies	Clinical trials show improved post-meal glucose response	GLP-1 secretion was significantly higher following Beta Vulgaris intake following Beta Vulgaris intake	Reduction in fasting blood glucose, insulin resistance, and appetite

2. Potential mechanisms of Beta Vulgaris in GLP-1 Modulation

2.1. Nitrate metabolism and GLP-1

The high nitrate concentration of Beta vulgaris, is one of the main ways that influences GLP-1 secretion. Bacteria in the mouth transform beta vulgaris nitrates into nitrites, where the body subsequently transforms into nitric oxide (NO)[29]. Nitric oxide has a major impact on vascular health and blood flow, both of which may have an indirect effect on GLP-1 secretion [30]. It has been demonstrated that nitric oxide activates pathways that enhance glucose absorption and increase insulin sensitivity, both of which are advantageous for metabolic health [31].

Furthermore, studies indicate that the metabolic byproducts of nitrate conversion, specifically nitric oxide, can trigger the intestinal release of GLP-1[32]. Blood sugar levels can be regulated by this GLP-1 release, which can also decrease hunger, halt stomach emptying, and increase insulin secretion [33]. Beta vulgaris may potentially have anti-hyperglycemic properties due to the rise in GLP-1 release triggered by nitrate metabolism. Furthermore, nitric oxide may promote healthy glucose metabolism and improve overall metabolic function by lowering oxidative stress and inflammation [34].

2.2. Antioxidant Effects

Beta vulgaris, has a bright red hue because it is high in antioxidants, especially betalains. Since oxidative stress and inflammation are major causes of insulin resistance and metabolic dysfunction, these antioxidants are important in lowering them [35]. The antioxidants in Beta vulgaris may indirectly promote GLP-1 production by scavenging free radicals and lowering oxidative damage [36].

Reduced secretion and disturbed glucose metabolism can result from oxidative stress, effects on the gut cells that make GLP-1. Beta vulgaris's antioxidant qualities may shield these cells and preserve or improve their capacity to release GLP-1[37]. Consequently, elevated GLP-1 levels can promote improved glucose metabolism, control blood sugar levels, and enhance insulin production [38].

Additionally, antioxidant activity may assist improve insulin sensitivity by lowering systemic inflammation, which is frequently high in metabolic diseases such as obesity and type 2 diabetes [39]. The antioxidant properties of beta vulgaris are essential for controlling glucose metabolism and improving general metabolic health because they promote GLP-1 secretion and reduce oxidative stress [40].

2.3. Gut Health and Microbiota

Beta vulgaris affects gut health and microbiota, it may have an effect on GLP-1 secretion. Beta vulgaris's dietary fiber acts as a prebiotic, encouraging the development of good gut flora [41]. The regulation of several hormones, including GLP-1, which is released by the intestinal L-cells in response to food consumption, depends on a healthy gut flora[42]. According to studies, some gut bacteria may increase GLP-1 release, which would improve glucose metabolism and insulin sensitivity [43].

The fiber and other bioactive substances included in beta vulgaris may also help in lowering intestinal inflammation and preserving the integrity of the intestinal lining, therefore enhancing gut health [44]. Beta Vulgaris can indirectly affect GLP-1 secretion and enhance metabolic health by promoting a diverse and healthy gut microbiota [45]. Beta vulgaris is a useful dietary component for controlling illnesses like type 2 diabetes and obesity because it may improve glucose homeostasis through the microbiota-gut-brain axis. Gut health can also help control, hunger which helps with weight management [46].

2.4. Increased GLUT4 Transporters

Beta vulgaris, has the capacity to enhance the expression of GLUT4 transporters, which is one possible way that it may regulate GLP-1 secretion [47]. In response to insulin, GLUT4 (Glucose Transporter Type 4) is an essential protein that promotes the uptake of glucose into muscle and fat cells. Increased GLUT4 transporter present on the cell membrane promotes glucose absorption, which raises insulin sensitivity and total glucose metabolism [48].

It has been demonstrated that beta vulgaris, particularly in skeletal muscle, increases the function of GLUT4 transporters through its bioactive components, such as nitrates [49]. This process facilitates the entry of glucose into cells, where it can be stored as glycogen or used as energy, hence lowering blood glucose levels. In order to maintain glucose homeostasis, GLP-1 promotes insulin production and inhibits glucagon release, which is supported by the

increased glucose uptake brought on by GLUT4 activation [50]. The benefits of GLP-1 may be enhanced by increased GLUT4 transporters in skeletal muscles, which improve insulin sensitivity and decrease insulin resistance, which is frequently observed in metabolic diseases like type 2 diabetes. Therefore, Beta Vulgaris might be crucial for boosting glucose metabolism and GLP-1's ability to control hyperglycemia [51].

Table 2 Mechanisms Linking Beta Vulgaris to GLP-1 Secretion

Mechanism	Bioactive Compound	Effect on GLP-1 Secretion	Implications for Metabolism
Nitrate Metabolism	Nitrates	Conversion to Nitric Oxide (NO) increases blood circulation, aiding GLP-1 release	Supports improved insulin sensitivity, blood glucose regulation
Antioxidant Action	Betalains	Reduces oxidative stress, improves gut health, enhancing GLP-1 release	Anti-inflammatory effects, improves insulin response
Gut Health and Microbiota	Dietary Fiber	Supports gut microbiota, SCFAs production stimulates GLP-1 secretion	Enhances glucose uptake, promotes gut health
Neurotransmitter Pathway	Acetylcholine	Activates parasympathetic pathways, leading to GLP-1 release	Stimulates insulin secretion and enhances glucose metabolism

2.5. Drug interactions and adverse effects with beta vulgaris

Beta vulgaris's primary pigment betalain, functions as a competitive inhibitor of the CYP3A4 enzyme, which is essential for drug metabolism [52]. This dose-dependent inhibition raises the possibility that betalain may change medications, that are CYP3A4 substrates metabolized, which could change the effectiveness of the medication or raise the risk of adverse effects [53]. Although betalain inhibits CYP3A4, it has no direct effect on CYP1A2, CYP2B6, or CYP2C9, or any other cytochrome P450 enzyme. Although this suggests a particular interaction profile, care should be used when taking Beta vulgaris with medications that are metabolized by CYP3A4 [54].

Beeturia is a harmless disorder in which urine turns pink or red after eating beets. However, there are certain potential hazards linked with its usage [55]. Beetroot includes a high concentration of oxalates, which may raise the risk of kidney stones, especially in people who are prone to them [56]. Beetroot, in rare situations can produce allergic reactions such as rashes or itching. Because of its high fiber content, excessive beetroot eating might cause gastrointestinal problems such as bloating, cramps, or diarrhea [57]. Furthermore, excessive beetroot juice consumption can result in a considerable drop in blood pressure, known as hypotension [58].

2.6. Future Clinical Applications and Research Directions

Although beta vulgaris has shown encouraging promise in enhancing metabolic health, there are still a number of unresolved issues [59]. To completely comprehend the precise processes by which Beta Vulgaris affects GLP-1 secretion and glucose metabolism, more research is required [60]. It is also necessary to determine the dosage, frequency, and length of time to consume Beta vulgaris in order to get the most benefit. Beta vulgaris's safety and long-term effects need more research, especially in people with metabolic diseases including type 2 diabetes and obesity [61]. More research is required to determine any possible synergies or contraindications between Beta vulgaris and other medicinal substances, such as GLP-1 receptor agonists [62].

Future clinical studies should concentrate on assessing the efficacy of Beta vulgaris supplementation in various groups, especially those with obesity, type 2 diabetes, or insulin resistance, in order to fill these gaps [63]. The effect of Beta Vulgaris on GLP-1 levels, insulin sensitivity, and glucose metabolism could be evaluated by randomized controlled studies [64]. The possible advantages of combining dietary changes with pharmaceutical therapies may also be ascertained by research that looks at how Beta vulgaris interacts with GLP-1 receptor agonists [65]. Additionally, since these may be important components of its therapeutic potential, clinical research should examine how Beta vulgaris affects gut health, gut microbiota, and appetite regulation [66]. Investigating Beta vulgaris's long-term impact on metabolic health management might yield important information for clinical applications in the prevention and management of metabolic diseases [67].

3. Conclusion

Beta vulgaris, has shown great promise in enhancing general metabolic health and regulating GLP-1 secretion. Bioactive substances found in Beta vulgaris, including dietary fiber, nitrates, and antioxidants, increase GLP-1 production, which is essential for insulin release, glucose metabolism, and appetite control. In diseases like type 2 diabetes and obesity, in particular, this action helps to increase insulin sensitivity, blood glucose management, and glucose uptake. The medicinal potential of Beta vulgaris is noteworthy, particularly when paired with GLP-1-based treatments such as GLP-1 receptor agonists.

Beta vulgaris may have a synergistic impact when combined with these treatments, improving insulin secretion, controlling blood sugar, and metabolic health in general. A promising approach to improve outcomes in metabolic illnesses, especially type 2 diabetes and obesity, Beta vulgaris is used as a natural supplement to pharmaceutical therapy. In order to maximize the clinical usage of Beta vulgaris for metabolic diseases, more study is essential. The precise methods by which Beta Vulgaris influences GLP-1 secretion, the best dosages, and the long-term safety of this medication require for further research. To confirm Beta Vulgaris's function in improving therapeutic outcomes, clinical trials investigating its conjunction with GLP-1 medications are crucial. New approach for integrating Beta vulgaris into therapeutic procedures may become available with further investigation. A promising approach to improving outcomes in metabolic illnesses, especially type 2 diabetes and obesity, is the use of Beta vulgaris as a natural supplement to pharmaceutical therapy. In order to maximize the clinical usage of Beta vulgaris for metabolic diseases, more study is essential.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

- [1] Ojo OA, Gyebi GA, Ezenabor EH, Iyobhebhe M, Emmanuel DA, Adelowo OA, Olujinmi FE, Ogunwale TE, Babatunde DE, Ogunlakin AD, Ojo AB. Exploring beetroot (Beta vulgaris L.) for diabetes mellitus and Alzheimer's disease dual therapy: in vitro and computational studies. *RSC advances*. 2024;14(27):19362-80.
- [2] Sadowska-Bartosz I, Bartosz G. Biological properties and applications of betalains. *Molecules*. 2021 Apr 26;26(9):2520.
- [3] Bonilla Ocampo DA, Paipilla AF, Marín E, Vargas-Molina S, Petro JL, Pérez-Idárraga A. Dietary nitrate from beetroot juice for hypertension: a systematic review. *Biomolecules*. 2018 Nov 2;8(4):134.
- [4] Abdalla MM. Therapeutic potential of adiponectin in prediabetes: strategies, challenges, and future directions. *Therapeutic Advances in Endocrinology and Metabolism*. 2024 Jan;15:20420188231222371.
- [5] Thiruvengadam M, Chung IM, Samynathan R, Chandar SH, Venkidasamy B, Sarkar T, Rebezov M, Gorelik O, Shariati MA, Simal-Gandara J. A comprehensive review of beetroot (Beta vulgaris L.) bioactive components in the food and pharmaceutical industries. *Critical Reviews in Food Science and Nutrition*. 2024 Jan 25;64(3):708-39.
- [6] Krieger JP. Intestinal glucagon-like peptide-1 effects on food intake: Physiological relevance and emerging mechanisms. *Peptides*. 2020 Sep 1;131:170342.
- [7] Nirmalan N, Nirmalan M. Hormonal control of metabolism: regulation of plasma glucose. *Anaesthesia & Intensive Care Medicine*. 2020 Nov 1;21(11):578-83.
- [8] González-García I, Milbank E, Diéguez C, López M, Contreras C. Glucagon, GLP-1 and thermogenesis. *International journal of molecular sciences*. 2019 Jul 13;20(14):3445.
- [9] Camilleri M. The role of gastric function in control of food intake (and body weight) in relation to obesity, as well as pharmacological and surgical interventions. *Neurogastroenterology & Motility*. 2024 Feb;36(2):e14660.
- [10] Rowlands J, Heng J, Newsholme P, Carlessi R. Pleiotropic effects of GLP-1 and analogs on cell signaling, metabolism, and function. *Frontiers in endocrinology*. 2018 Nov 23;9:672.
- [11] Wang JY, Wang QW, Yang XY, Yang W, Li DR, Jin JY, Zhang HC, Zhang XF. GLP-1 receptor agonists for the treatment of obesity: role as a promising approach. *Frontiers in endocrinology*. 2023 Feb 1;14:1085799.

- [12] Clemmensen C, Finan B, Müller TD, DiMarchi RD, Tschöp MH, Hofmann SM. Emerging hormonal-based combination pharmacotherapies for the treatment of metabolic diseases. *Nature Reviews Endocrinology*. 2019 Feb;15(2):90-104.
- [13] Sayyar A, Oladi M, Hosseini M, Nakhaee S, Ataie Z, Farrokhfall K. Effect of red beetroot juice on oxidative status and islet insulin release in adult male rats. *Diabetology & metabolic syndrome*. 2022 Apr 23;14(1):58.
- [14] Clemente-Suárez VJ, Martín-Rodríguez A, Redondo-Flórez L, López-Mora C, Yáñez-Sepúlveda R, Tornero-Aguilera JF. New insights and potential therapeutic interventions in metabolic diseases. *International journal of molecular sciences*. 2023 Jun 26;24(13):10672.
- [15] Bangar SP, Sharma N, Sanwal N, Lorenzo JM, Sahu JK. Bioactive potential of beetroot (*Beta vulgaris*). *Food Research International*. 2022 Aug 1;158:111556.
- [16] Gribble FM, Reimann F. Metabolic Messengers: glucagon-like peptide 1. *Nature metabolism*. 2021 Feb;3(2):142-8.
- [17] Kuhre RE, Deacon CF, Holst JJ, Petersen N. What is an L-cell and how do we study the secretory mechanisms of the L-cell?. *Frontiers in Endocrinology*. 2021 Jun 8;12:694284.
- [18] Holst JJ. The incretin system in healthy humans: the role of GIP and GLP-1. *Metabolism*. 2019 Jul 1;96:46-55.
- [19] Moini J, Ferdowsi K. Digestion, Absorption, and Metabolism. In *Handbook of Nutritional Disorders 2024* (pp. 18-42). CRC Press.
- [20] Müller TD, Finan B, Clemmensen C, DiMarchi RD, Tschöp MH. The new biology and pharmacology of glucagon. *Physiological reviews*. 2017 Apr;97(2):721-66.
- [21] Camilleri M. The role of gastric function in control of food intake (and body weight) in relation to obesity, as well as pharmacological and surgical interventions. *Neurogastroenterology & Motility*. 2024 Feb;36(2):e14660.
- [22] Qin W, Ying W, Hamaker B, Zhang G. Slow digestion-oriented dietary strategy to sustain the secretion of GLP-1 for improved glucose homeostasis. *Comprehensive Reviews in Food Science and Food Safety*. 2021 Sep;20(5):5173-96.
- [23] Cornell S. A review of GLP-1 receptor agonists in type 2 diabetes: a focus on the mechanism of action of once-weekly agents. *Journal of clinical pharmacy and therapeutics*. 2020 Sep;45:17-27.
- [24] Qin W, Ying W, Hamaker B, Zhang G. Slow digestion-oriented dietary strategy to sustain the secretion of GLP-1 for improved glucose homeostasis. *Comprehensive Reviews in Food Science and Food Safety*. 2021 Sep;20(5):5173-96.
- [25] Abiola JO, Oluyemi AA, Idowu OT, Oyinloye OM, Ubah CS, Owolabi OV, Somade OT, Onikanni SA, Ajiboye BO, Osunsanmi FO, Nash O. Potential role of phytochemicals as glucagon-like peptide 1 receptor (GLP-1R) agonists in the treatment of diabetes mellitus. *Pharmaceuticals*. 2024 Jun 5;17(6):736.
- [26] Madadi E, Mazloum-Ravasan S, Yu JS, Ha JW, Hamishehkar H, Kim KH. Therapeutic application of betalains: A review. *Plants*. 2020 Sep 17;9(9):1219.
- [27] Hoffman S, Adeli K. Glucagon-like peptide (GLP)-1 regulation of lipid and lipoprotein metabolism. *Medical Review*. 2024 Aug 27;4(4):301-11.
- [28] Salehi M, Purnell JQ. The role of glucagon-like peptide-1 in energy homeostasis. *Metabolic Syndrome and Related Disorders*. 2019 May 1;17(4):183-91.
- [29] Sayyar A, Oladi M, Hosseini M, Nakhaee S, Ataie Z, Farrokhfall K. Effect of red beetroot juice on oxidative status and islet insulin release in adult male rats. *Diabetology & metabolic syndrome*. 2022 Apr 23;14(1):58.
- [30] Ribeiro-Silva JC, Tavares CA, Girardi AC. The blood pressure lowering effects of glucagon-like peptide-1 receptor agonists: a mini-review of the potential mechanisms. *Current opinion in pharmacology*. 2023 Apr 1;69:102355.
- [31] Pitocco D, Zaccardi F, Di Stasio E, Romitelli F, Santini SA, Zuppi C, Ghirlanda G. Oxidative stress, nitric oxide, and diabetes. *The review of diabetic studies: RDS*. 2010 May 10;7(1):15.
- [32] Abot A, Fried S, Cani PD, Knauf C. Reactive oxygen species/reactive nitrogen species as messengers in the gut: impact on physiology and metabolic disorders. *Antioxidants & Redox Signaling*. 2022 Aug 1;37(4-6):394-415.

- [33] Camilleri M, Lupianez-Merly C. Effects of GLP-1 and other gut hormone receptors on the gastrointestinal tract and implications in clinical practice. *Official journal of the American College of Gastroenterology| ACG*. 2022 May 12;10-4309.
- [34] Abiola JO, Oluyemi AA, Idowu OT, Oyinloye OM, Ubah CS, Owolabi OV, Somade OT, Onikanni SA, Ajiboye BO, Osunsanmi FO, Nash O. Potential role of phytochemicals as glucagon-like peptide 1 receptor (GLP-1R) agonists in the treatment of diabetes mellitus. *Pharmaceuticals*. 2024 Jun 5;17(6):736.
- [35] Székely D, Máté M. Red beetroot (*Beta vulgaris* L.). In *Advances in Root Vegetables Research* 2022 Sep 26. IntechOpen.
- [36] Dinda B, Dinda M. Natural products, a potential source of new drugs discovery to combat obesity and diabetes: their efficacy and multi-targets actions in treatment of these diseases. In *Natural Products in Obesity and Diabetes: Therapeutic Potential and Role in Prevention and Treatment* 2022 Mar 9 (pp. 101-275). Cham: Springer International Publishing.
- [37] Winiarska A, Knysak M, Nabrdalik K, Gumprecht J, Stompór T. Inflammation and oxidative stress in diabetic kidney disease: the targets for SGLT2 inhibitors and GLP-1 receptor agonists. *International Journal of Molecular Sciences*. 2021 Oct 6;22(19):10822.
- [38] Holst JJ. The incretin system in healthy humans: the role of GIP and GLP-1. *Metabolism*. 2019 Jul 1;96:46-55.
- [39] Pérez-Torres I, Castrejón-Téllez V, Soto ME, Rubio-Ruiz ME, Manzano-Pech L, Guarner-Lans V. Oxidative stress, plant natural antioxidants, and obesity. *International journal of molecular sciences*. 2021 Feb 11;22(4):1786.
- [40] Al-Harbi LN, Alshammari GM, Shamlan G, Binobead MA, AlSedairy SA, Al-Nouri DM, Arzoo S, Yahya MA. Nephroprotective and anti-diabetic potential of *Beta vulgaris* L. Root (Beetroot) methanolic extract in a rat model of type 2 diabetes mellitus. *Medicina*. 2024 Feb 26;60(3):394.
- [41] Chou WL. Therapeutic potential of targeting intestinal bitter taste receptors in diabetes associated with dyslipidemia. *Pharmacological Research*. 2021 Aug 1;170:105693.
- [42] Abdalqadir N, Adeli K. GLP-1 and GLP-2 orchestrate intestine integrity, gut microbiota, and immune system crosstalk. *Microorganisms*. 2022 Oct 19;10(10):2061.
- [43] Madsen MS, Holm JB, Pallejà A, Wismann P, Fabricius K, Rigbolt K, Mikkelsen M, Sommer M, Jelsing J, Nielsen HB, Vrang N. Metabolic and gut microbiome changes following GLP-1 or dual GLP-1/GLP-2 receptor agonist treatment in diet-induced obese mice. *Scientific reports*. 2019 Oct 30;9(1):15582.
- [44] Thiruvengadam M, Chung IM, Samynathan R, Chandar SH, Venkidasamy B, Sarkar T, Rebezov M, Gorelik O, Shariati MA, Simal-Gandara J. A comprehensive review of beetroot (*Beta vulgaris* L.) bioactive components in the food and pharmaceutical industries. *Critical Reviews in Food Science and Nutrition*. 2024 Jan 25;64(3):708-39.
- [45] Guo Q, Hou X, Cui Q, Li S, Shen G, Luo Q, Wu H, Chen H, Liu Y, Chen A, Zhang Z. Pectin mediates the mechanism of host blood glucose regulation through intestinal flora. *Critical Reviews in Food Science and Nutrition*. 2024 Jul 25;64(19):6714-36.
- [46] Brewer-Smyth K. Brain Food: The Impact of Diet, Nutrition, and Nutraceuticals on the Brain and the Microbiota-Gut-Brain Axis. In *Adverse Childhood Experiences: The Neuroscience of Trauma, Resilience and Healing throughout the Life Course* 2022 Nov 8 (pp. 303-357). Cham: Springer International Publishing.
- [47] Abiola JO, Oluyemi AA, Idowu OT, Oyinloye OM, Ubah CS, Owolabi OV, Somade OT, Onikanni SA, Ajiboye BO, Osunsanmi FO, Nash O. Potential role of phytochemicals as glucagon-like peptide 1 receptor (GLP-1R) agonists in the treatment of diabetes mellitus. *Pharmaceuticals*. 2024 Jun 5;17(6):736.
- [48] Wang T, Wang J, Hu X, Huang XJ, Chen GX. Current understanding of glucose transporter 4 expression and functional mechanisms. *World journal of biological chemistry*. 2020 Nov 27;11(3):76.
- [49] Mirmiran P, Houshialsadat Z, Gaeini Z, Bahadoran Z, Azizi F. Functional properties of beetroot (*Beta vulgaris*) in management of cardio-metabolic diseases. *Nutrition & metabolism*. 2020 Dec;17:1-5.
- [50] Qaid MM, Abdelrahman MM. Role of insulin and other related hormones in energy metabolism—A review. *Cogent Food & Agriculture*. 2016 Dec 31;2(1):1267691.
- [51] Wu L, Zhou M, Li T, Dong N, Yi L, Zhang Q, Mi M. GLP-1 regulates exercise endurance and skeletal muscle remodeling via GLP-1R/AMPK pathway. *Biochimica et Biophysica Acta (BBA)-Molecular Cell Research*. 2022 Sep 1;1869(9):119300.

- [52] Lim SH, Bae S, Lee HS, Han HK, Choi CI. Effect of Betanin, the Major Pigment of Red Beetroot (*Beta vulgaris* L.), on the Activity of Recombinant Human Cytochrome P450 Enzymes. *Pharmaceuticals*. 2023 Aug 30;16(9):1224.
- [53] Kaur S, Tekade M, Pawar B, Vasdev N, Gupta T, Sreeharsha N, Tekade RK. Connecting biotransformation with toxicity. In *Public Health and Toxicology Issues Drug Research, Volume 2* 2024 Jan 1 (pp. 27-55). Academic Press.
- [54] Tekade RK, editor. *Public Health and Toxicology Issues in Drug Research, Volume 2: Toxicity and Toxicodynamics*. Elsevier; 2024 Mar 26.
- [55] Skrajnowska D, Bobrowska-Korczak B. The Effects of Diet, Dietary Supplements, Drugs and Exercise on Physical, Diagnostic Values of Urine Characteristics. *Nutrients*. 2024 Sep 17;16(18):3141.
- [56] Ghanati K, Oskoei V, Rezvani-Ghalhari M, Shavali-Gilani P, Mirzaei G, Sadighara P. Oxalate in plants, amount and methods to reduce exposure; a systematic review. *Toxin Reviews*. 2024 Jul 2;43(3):411-22.
- [57] Abdulmumeen HA, Risikat AN, Sururah AR. Food: Its preservatives, additives and applications. *International Journal of Chemical and Biochemical Sciences*. 2012 Oct 10;1(2012):36-47.
- [58] Jones T, Dunn EL, Macdonald JH, Kubis HP, McMahan N, Sandoo A. The effects of beetroot juice on blood pressure, microvascular function and large-vessel endothelial function: a randomized, double-blind, placebo-controlled pilot study in healthy older adults. *Nutrients*. 2019 Aug;11(8):1792.
- [59] Chen X, Xing X, Lin S, Huang L, He L, Zou Y, Zhang X, Su B, Lu Y, Zheng D. Plant-derived nanovesicles: harnessing nature's power for tissue protection and repair. *Journal of Nanobiotechnology*. 2023 Nov 24;21(1):445.
- [60] Kandunuri KK. The effects of herbal extracts and compounds on the glucose metabolism in Hep G2 cells (Doctoral dissertation, London Metropolitan University).
- [61] Abu-Ellail FF, Salem KF, Saleh MM, Alnaddaf LM, Al-Khayri JM. Molecular breeding strategies of beetroot (*Beta vulgaris* ssp. *vulgaris* var. *conditiva* Alefeld). *Advances in Plant Breeding Strategies: Vegetable Crops: Volume 8: Bulbs, Roots and Tubers*. 2021:157-212.
- [62] Ríos JL, Andújar I, Schinella GR, Francini F. Modulation of diabetes by natural products and medicinal plants via incretins. *Planta Medica*. 2019 Aug;85(11/12):825-39.
- [63] Srivastava S, Kumar V, Kapil L, Prasad S, Khan S, Singh C, Singh A. Functional Foods and Spices in the Management of Metabolic Syndrome. In *Nutraceuticals in Obesity Management and Control* 2025 Feb 21 (pp. 211-283). Apple Academic Press.
- [64] Bahadoran Z, Norouzirad R, Mirmiran P, Gaeini Z, Jeddi S, Shokri M, Azizi F, Ghasemi A. Effect of inorganic nitrate on metabolic parameters in patients with type 2 diabetes: A 24-week randomized double-blind placebo-controlled clinical trial. *Nitric Oxide*. 2021 Feb 1;107:58-65.
- [65] Mahankali S, Kalava J, Garapati Y, Domathoti B, Maddumala VR, Sundramurthy VP. A Treatment to Cure Diabetes Using Plant-Based Drug Discovery. *Evidence-Based Complementary and Alternative Medicine*. 2022;2022(1):8621665.
- [66] Peddio S, Padiglia A, Cannea FB, Crnjar R, Zam W, Sharifi-Rad J, Rescigno A, Zucca P. Common bean (*Phaseolus vulgaris* L.) α -amylase inhibitors as safe nutraceutical strategy against diabetes and obesity: An update review. *Phytotherapy Research*. 2022 Jul;36(7):2803-23.
- [67] Kumar M, Nugraha SE, Nabila N. Efficacy of *Beta vulgaris* L. ethanol extract treating diabetic: An in silico and in vivo study in rat model. *Adv. Anim. Vet. Sci*. 2025;13(3):552-64.