



REVIEW ON BIOACTIVE CONSTITUENTS AND ANTI-HYPERGLYCEMIC MECHANISMS OF SEA BUCKTHORN: FROM ETHNO PHARMACOLOGY TO EVIDENCE-BASED APPLICATION

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Abstract:

Sea buckthorn (*Hippophae rhamnoides* L.) has been recognized for its potential to manage hyperglycemia. This review synthesizes findings from various studies on the anti-hyperglycemic effects of sea buckthorn extracts and oils. Animal models have shown that sea buckthorn can significantly lower blood glucose levels and improve insulin sensitivity. Mechanisms include enhancement of insulin signaling, inhibition of glucose absorption in the intestines, and modulation of glucose transporter proteins. Human studies corroborate these findings, demonstrating improvements in postprandial glycemic control and reductions in fasting plasma glucose levels after sea buckthorn consumption. The bioactive compounds, such as flavonoids and fatty acids, contribute to these effects through antioxidant activity and free radical scavenging. Overall, sea buckthorn presents a promising natural therapeutic option for diabetes management, warranting further research to elucidate its benefits and applications fully.

Key Words: Sea Buckthorn; Type 2 Diabetes Mellitus; GLUT4; Hyperglycemia; Phytochemicals

Introduction:

India remains the country with the largest diabetic population globally. According to recent findings published in The Lancet, approximately 101 million individuals in India, accounting for 11.4% of the population, are currently living with diabetes ^[1]. Managing type 2 diabetes mellitus (T2DM) remains a critical global health concern, especially considering its high prevalence reaching 8.5% according to the World Health Organization (WHO) report from 2016 ^[2]. Prediabetes, characterized by impaired glucose regulation (IGR), encompasses conditions such as impaired glucose tolerance (IGT) and impaired fasting glycemia (IFG). These critical intermediate states often precede the onset of T2DM ^[3].

A viable therapeutic strategy for mitigating postprandial hyperglycemia in diabetic patients involves inhibiting carbohydrate absorption after meals. Alpha-glucosidase is an enzyme responsible for breaking down glycosidic bonds in oligosaccharides. Inhibitors of this enzyme can thus play a crucial role in reducing postprandial hyperglycemia by slowing the conversion of carbohydrates into glucose ^[4].

Plant extracts have been traditionally utilized in various medicinal systems for treating diabetes and are now recognized as viable alternatives for diabetic therapy. However, the mechanisms through which many of these extracts function remain unclear. Natural α -glucosidase inhibitors derived from plants are promising for managing postprandial hyperglycemia ^[5].

Diabetes mellitus is associated with disruptions in antioxidant defense mechanisms ^[6]. Using antioxidants as part of the treatment can help in preventing and delaying diabetic complications ^[7]. This aligns with the "unifying hypothesis," which suggests that oxidative stress induced by hyperglycemia may be the underlying cause of all diabetic complications ^[8]. Hence, alongside blood glucose control, managing oxidative stress presents another pathway for treating diabetes.



Figure 1: Sea buckthorn oil, seeds and plant (Source: Pinterest)

Seabuckthorn (*Hippophae rhamnoides L.*), a spiny deciduous shrub, has its origins in Europe, Central Asia, and the temperate zones of South Asia, encompassing India and China^[9]. Within India, it flourishes in the arid, high-altitude regions of Himachal Pradesh, Jammu Kashmir, and Uttarakhand^[5].

Recent research has highlighted the potential benefits of seabuckthorn berries in glycemic control. Animal studies have demonstrated that seabuckthorn protein and fruit oil extracts can lower blood glucose levels and improve insulin resistance^[10, 11, 12]. According to reviews by Padwad et al., seabuckthorn is rich in bioactive compounds such as fat-soluble vitamins (A, E, and K) and flavonoids (isorhamnetin, kaempferol, myricetin, quercetin)^[13]. These flavonoids may help manage blood sugar by decreasing glucose absorption, boosting insulin secretion and sensitivity, and regulating hepatic glucose output^[14, 15]. Furthermore, seabuckthorn may influence neuroendocrine, immune, antioxidant, and anti-inflammatory pathways^[16, 17, 18], which could contribute to better glycemic control.

This review aims to consolidate current research on the antihyperglycemic effects of sea buckthorn, highlighting its mechanisms of action, efficacy in animal and human studies, and potential applications in diabetes management. By exploring the bioactive compounds and their impact on glucose metabolism, this review seeks to provide a comprehensive understanding of how sea buckthorn can be utilized as a natural remedy for controlling blood sugar levels and improving overall metabolic health.

Materials and Methods:

Literature Search:

A comprehensive literature review was conducted using various scientific databases, including PubMed, ScienceDirect, and Google Scholar, to gather relevant information on the anti-diabetic and anti-hyperglycemic effects of Sea Buckthorn (*Hippophae rhamnoides L.*). Keywords used in the search included "Sea Buckthorn," "*Hippophae rhamnoides*," "anti-diabetic," "anti-hyperglycemic," "ethnopharmacology," and "medicinal plants." Studies published from the year 1990 to 2024 were included to ensure the inclusion of the most recent findings.

Inclusion and Exclusion Criteria:

Articles were selected based on their relevance to the ethno pharmacological properties of Sea Buckthorn, specifically focusing on its role in managing diabetes and hyperglycemia. Studies that detailed the phytochemical composition, mechanisms of action, and clinical or preclinical evaluations of Sea Buckthorn extracts were included. Exclusion criteria involved studies that did not focus on the anti-diabetic or anti-hyperglycemic effects or lacked sufficient data to support their findings.

Data Extraction:

The data extraction process involved reviewing the selected articles to gather information on the phytochemical constituents of Sea Buckthorn, its mechanisms of action against diabetes, and any reported clinical or preclinical outcomes. Particular attention was paid to studies that evaluated the effects of Sea Buckthorn on glucose metabolism, insulin sensitivity, and oxidative stress.

Data Synthesis:

The extracted data were synthesized to provide a comprehensive overview of the ethno pharmacological potential of Sea Buckthorn in diabetes management. The synthesis involved categorizing the

findings based on the type of study (e.g., in vitro, in vivo, clinical trials) and the specific anti-diabetic and anti-hyperglycemic effects observed.

Role of *Hippophae rhamnoides* L. in Modulating Hyperglycemia:

Anti-Diabetic and Anti-Hyperglycemic Effects of Bioactive Compounds:

Diabetes is a disorder of the endocrine system characterized by abnormal metabolism of carbohydrates, fats, and proteins due to issues with insulin secretion or action ^[19]. When diabetes remains uncontrolled, it can give rise to various complications, including hyperlipidemia, hypertension, atherosclerosis, hyperinsulinemia, retinopathy, kidney disease, and peripheral neuropathy ^[20]. Researchers have delved into the potential of sea buckthorn as a management strategy for diabetes.

The herb sea buckthorn, which has long been utilized for its many health advantages, has shown promise in the management of diabetes. Emerging research highlights the potential anti-diabetic effects of sea buckthorn. This remarkable plant appears to impact glucose metabolism and insulin secretion. Moreover, sea buckthorn seed protein (SSP) shows promise in improving oral glucose tolerance, enhancing insulin sensitivity, and influencing liver glucose metabolism genes via the AMPK/SIRT1 pathway in diabetic mice. Additionally, sea buckthorn fruit extracts exhibit inhibitory effects on α -amylase and α -glucosidase enzymes responsible for breaking down polysaccharides into glucose thus potentially reducing postprandial blood glucose levels. In individuals with impaired glucose regulation (IGR) or pre-diabetes, sea buckthorn fruit puree may slightly lower fasting blood sugar levels ^[21, 22].

Recent studies investigating the antidiabetic effects of sea buckthorn pulp oil in human islet cells reveal that this oil boosts insulin secretion in response to glucose. It achieves this by activating G protein-coupled receptors within pancreatic β -cells, with palmitoleic acid emerging as the key active fatty acid component ^[23].

The antioxidant characteristics and α -glucosidase inhibitory activities of sea buckthorn leaf extracts were investigated by Kim and colleagues ^[24]. Six compounds were identified, which include 1-feruloyl- β -D-glucopyranoside, isorhamnetin-3-O-glucoside, isorhamnetin-3-O-rutinoside, kaempferol-3-O- β -D-(6"-O-coumaryl) glycoside, quercetin 3-O- β -D-glucopyranoside, quercetin 3-O- β -D-glucopyranosyl-7-O- α -L-rhamnopyranoside. The butanol fraction, rich in phenolic compounds, exhibited the highest radical-scavenging activity and the strongest α -glucosidase inhibitory effect ^[24, 25].

Sea buckthorn seed proteins have been shown to include four different branched-chain amino acid polypeptides: Asp-Leu/Ile-Val-Gly-Glu, Leu/Ile-Pro, Leu/Ile-Pro-Glu-Asp-Pro, Leu/Ile-Pro-Leu/Ile ^[26].

Sea buckthorn proteins also influence gut microbiota. In murine studies, these proteins play a significant role in reducing body weight and blood glucose levels. Notably, they restore the balance of beneficial gut bacteria, including *Bifidobacterium*, *Lactobacillus*, *Bacillus*, and *Clostridium globularis*. Metagenomic sequencing further reveals that sea buckthorn treatment leads to alterations in the intestinal microbial community, with ARDRA (Amplified Ribosomal DNA Restriction Analysis) confirming heightened microbial diversity evidenced by increased Shannon (H) and Simpson (E) indices ^[27].

Combining sea buckthorn with other berries can enhance its beneficial effects. Studies have shown that children with type I diabetes who consumed a concentrate of blueberry and sea buckthorn experienced improvements in blood sugar and lipid levels. This combination may be effective in preventing cardiovascular diseases, diabetes, and related complications ^[28].

The efficacy of polyphenols in treating type 2 diabetes is not solely due to the polyphenols themselves but also their bioavailability, which is influenced by their chemical structure, the matrix they are part of, dosage, and diet ^[29]. Polyphenol-rich extracts have been effective in lowering blood glucose levels and impacting gut microbiota ^[30]. Their synergistic effect can reduce the abundance of *Firmicutes*, *Clostridiales*, and *Lachnospiraceae* while increasing butyrate concentrations. In a study conducted by Roopchand and colleagues ^[31], dietary polyphenols were found to have several beneficial effects. Notably, they reduced the expression of inflammatory markers and glucose absorption genes (such as Glut2) in the intestines. Additionally, these polyphenols influenced the gut microbiota by increasing the abundance of *Akkermansia muciniphila* while decreasing the *Firmicutes*-to-*Bacteroidetes* ratio.

Various bioactive compounds found in sea buckthorn, such as polyphenols like isorhamnetin, quercetin, and epicatechin, contribute to its ability to ameliorate disturbed glucose metabolism by stimulating GLUT4 translocation to the plasma membrane, enhancing glucose clearance from circulation, and lowering circulating glucose levels by approximately 10% ^[32, 33].

Additionally, sea buckthorn's polyphenol fraction has been shown to improve glycemic control and regulate key metabolites, demonstrating its potential in treating metabolic syndrome, including hyperglycemia ^[34, 33]. It also suggests that sea buckthorn might play a role in preventing diabetic complications associated with hyperlipidemia and oxidative stress ^[35].

These findings highlight the promising role of sea buckthorn phytochemicals in managing hyperglycemia and supporting overall metabolic health.

Numerous research studies have investigated the potential of sea buckthorn supplementation in managing diabetes (Table 1-5).

Animal Studies:

Table 1: The Therapeutic Effect of Sea buckthorn berries

Model	Active Compounds	Treatment/ Groups	Findings	Effects/ Mechanisms	References
db/db mice	Flavanol glycosides in sea buckthorn juice	Oral administration of sea buckthorn juice 5 mL/kg/day and sea buckthorn juice with 25, 50, 100 mg/kg/day L-quebrachitol for 10 weeks	Lowers food intake, weight gain, and blood glucose levels	Decreases expression of insulin receptor β in the liver; Enhances glucose tolerance and pancreatic tissue integrity.	[36]
Alloxan-induced diabetic mice	Flavonoids	Oral administration of ethanol-extracted sea buckthorn 2, 20, 40 mg/kg/day for 4 weeks	Lowers blood sugar levels and BUN content	Boosts insulin level, liver (muscle) glycogen content, and maltase level.	[37]
Rats	L-quebrachitol	Sea buckthorn juice (enriched and non-enriched with L-quebrachitol)	Lowered random blood glucose, weight growth, food intake, and liver expression of insulin receptor β ; Increased fasting plasma insulin levels	Positive effects on glucose tolerance and pancreatic tissue integrity	[36]

Table 2: The Therapeutic Effect of Sea buckthorn leaves

Model	Active Compounds	Treatment/ Groups	Findings	Effects/ Mechanisms	References
Alloxan-induced diabetic Wistar rats	Polyphenol	Oral administration of methanol-extracted sea buckthorn leaves 200, 400 mg/kg/day for 45 days	Enhances endogenous antioxidant enzymes (SOD, GSH peroxidase levels); Lowers malondialdehyde level	Improves antioxidant defense against reactive oxygen species.	[38]
Insulin-resistant HepG2 cells	L-resveratrol	Incubation with 200 μ L sea buckthorn leaf L-resveratrol extract (0.5, 1.0, 2.0, 4.0 mg/mL, diluted with DMEM)	Reduces expression of G6Pase; Enhances expression of PPAR α ; Inhibits α -amylase activity	Boosts glucose consumption; Decreases TG and NEFA.	[39]
High-sugar diet-fed mice	SB subsp. <i>chinensis</i> Rousi polysaccharide	Oral administration of ethanol-extracted sea buckthorn leaves 240, 480, 960 mg/kg/day for 4 days	Increases α -glucosidase inhibitory effect	Improves glucose tolerance; Reduces blood glucose level.	[40]
Normal and alloxan-induced diabetic Wistar rats	Methanol extract	Normal control, Diabetic control, Diabetic + Sea buckthorn leaf methanol extract	Reduced fasting blood glucose; Increased SOD and GSH; Decreased malondialdehyde	Enhanced antioxidant defenses, reduced oxidative stress	[38]
Insulin-resistant (IR) cells	L-resveratrol extract (SQE), L-resveratrol standard (QS)	-	Potent inhibitory effects against α -amylase, enhanced glucose uptake, reduced TG and NEFA levels	Competitive inhibition of α -amylase, upregulated PPAR α , downregulated glucose 6-phosphatase	[39]

Table 3: The Therapeutic Effect of Sea buckthorn seeds

Model	Active Compounds	Treatment/ Groups	Findings	Effects/ Mechanisms	References
6–8 weeks old db/db mice	Hydrophobic branched chain amino acid polypeptide	Oral administration of purified sea buckthorn seed meal 0.5, 1, 2 g/kg/day for 8 weeks	Lowers fasting blood sugar levels, weight, and insulin resistance.	Increases GLUT4 and PI3K protein levels; Lowers AKT, GSK-3 β , and PI3K/Akt protein expression; Boosts glycogen synthase activity and muscle glycogen content	[26]
Streptozotocin-induced diabetic mice	Protein	Oral administration of purified sea buckthorn seed 50, 100, 200 mg/kg/day for 4 weeks	Lowers body weight and blood glucose level; Increases gut microbial diversity (H) and Simpson index value (E).	Recovers <i>Bifidobacterium</i> , <i>Lactobacillus</i> , <i>Bacteroides</i> , <i>Clostridium coccoides</i> colony	[27]
Streptozotocin-induced diabetic ICR mice	Protein	Oral administration of purified sea buckthorn seed 50, 100, 200 mg/kg/d for 4 weeks	Decreases weight; Lowers FBG	Lowers CRP, IL-6, TNF- α , and NF- κ B levels; Reduces inflammatory factors and lipid level.	[11]
Streptozotocin-induced diabetic rats	Seed residue extract	Normal control, Diabetic control, Diabetic + Glyburide (5 mg/kg), Diabetic + Sea buckthorn seed residue extract (400 mg/kg)	Reduced blood glucose, triglycerides, and nitric oxide; Increased SOD activity and GSH levels	Hypoglycemic effects, lipid-lowering properties, antioxidant activity	[12]

db/db mice with type 2 diabetes	Specific polypeptides	-	Reduced fasting blood glucose, increased muscle glycogen content	Upregulated GLUT4, downregulated AKT and GSK-3 β , enhanced GS activity, elevated PI3K protein levels	[26]
Streptozotocin (STZ)-induced diabetic ICR mice	Sea buckthorn seed protein (SSP)	Diabetic control, Diabetic + Sea buckthorn seed protein (SSP)	Decreased insulin levels, inflammatory markers, body weight, and fasting blood glucose (FBG)	-	[11]

Table 4: The Therapeutic Effect of Sea buckthorn oil

Model	Administration	Active Compounds	Findings	Effects/ Mechanisms	References
High-fat diet-fed SD rats and HepG2 cells	Incubation with sea buckthorn fruit oil (50, 100, 200, 400 μ M, diluted with DMEM)	Palmitoleic acid from sea buckthorn seed oil	-	Boosts the expression of PI3K and GS; Inhibits GSK-3 β expression	[10]
High-fat diet-fed SD rats and HepG2 cells	Oral administration of sea buckthorn fruit oil 50, 100, 150 mg/kg/day for 4 weeks	Palmitoleic acid from sea buckthorn seed oil	Improves insulin indices.	Enhances glucose uptake; Lowers blood glucose;	[10]
High-fat and sugar diet-fed SD rats	Oral administration of purified sea buckthorn fruit oil 50, 100, 150 mg/kg/day for 4 weeks	Palmitoleic acid	Enhances GS in skeletal muscle; Relieves insulin resistance;	Activates the PI3K pathway; Lowers blood glucose.	[41]
Diabetic rats and HepG2 cells	-	Fruit oil extract	Enhanced glucose absorption in insulin-resistant cells, reduced blood glucose and insulin levels	Modified PI3K/Akt signaling pathway, promoted PI3K and glycogen synthesis (GS) expression, suppressed GSK-3 β expression	[10]

Human Studies:

Table 5: Sea Buckthorn improves glucose metabolism in humans

Participants/ Study Model	Active Compounds	Administration	Findings	References
Randomized, controlled, crossover study on Overweight and obese male subjects	Danish sea buckthorn berries	-	Decreased and delayed insulin response, improved glycemic profile following a sucrose-containing meal	[42]
Clinical trials on Individuals with impaired glucose regulation (IGR)	-	-	Improved oral glucose tolerance test (OGTT) results, potential as a dietary supplement for managing glucose levels	[43]
Study on Overweight and obese individual	Leaf extract and flavonoid glycoside extract	-	Improved insulin sensitivity, reduced markers of inflammation	[35]
Glucose-treated human islet EndoC-betaH1 cells	Palmitoleic acid from sea buckthorn pulp oil	Incubation with sea buckthorn pulp oil (10 μ M, diluted with DMEM)	Activates G protein-coupled receptors in pancreatic β -cells; Increases glucose-induced insulin secretion.	[23]
Type I diabetic children	-	Dietary supplement of sea buckthorn and blueberry concentrates	Decreased glycated hemoglobin, increased C peptide concentrations	[44]

Potential Mechanisms of Action:

The anti-hyperglycemic effects of sea buckthorn appear to be mediated through multiple mechanisms, including:

- Delaying and reducing postprandial insulin response ^[42]
- Improving glucose clearance from the bloodstream ^[42]
- Enhancing insulin sensitivity ^[35]
- Reducing inflammation associated with insulin resistance ^[35]

Comparative Effectiveness of Sea Buckthorn with Other Hypoglycemic Agents:

The effectiveness of sea buckthorn as a hypoglycemic agent has also been compared with other known hypoglycemic agents. The findings indicate that sea buckthorn products, including oils and extracts, show promising hypoglycemic effects. These effects are comparable to some traditional hypoglycemic agents, making sea buckthorn a potential natural alternative for managing blood glucose levels. The comparative studies highlight sea buckthorn's potential to reduce blood glucose levels and improve insulin sensitivity, thereby supporting its use as a hypoglycemic supplement ^[42].

Promising for Diabetes Management:

- The research indicates that sea buckthorn and its bioactive compounds, such as flavonoids and fatty acids, have the potential to be developed into nutritional supplements or functional foods for the management of diabetes and prediabetic conditions.
- The unique mechanisms of action, compared to many anti-diabetic drugs, make sea buckthorn a promising complementary approach for improving glucose metabolism.

Discussion:

The comprehensive body of research analyzed in this review underscores the significant potential of *Hippophae rhamnoides* L. (Sea Buckthorn) as an effective natural therapeutic agent for managing hyperglycemia and diabetes. The consistent findings across various in vitro, in vivo, and clinical studies reveal that sea buckthorn, particularly its bioactive compounds such as flavonoids^[13], fatty acids, and polysaccharides, play a crucial role in modulating glucose metabolism and enhancing insulin sensitivity^[14, 15].

One of the key mechanisms through which sea buckthorn exerts its anti-diabetic effects is by influencing glucose homeostasis. The bioactive compounds in sea buckthorn, including isorhamnetin and quercetin, have been shown to enhance the translocation of GLUT4 to the plasma membrane, thereby increasing glucose uptake in muscle cells and reducing blood glucose levels^[32, 33]. Additionally, the inhibition of enzymes like α -amylase and α -glucosidase by sea buckthorn extracts helps to slow down carbohydrate digestion and absorption, which is crucial in managing postprandial glucose spikes^[21, 22, 24, 25].

Moreover, sea buckthorn's ability to modulate insulin secretion and improve pancreatic function further supports its role as an anti-diabetic agent. A major component of sea buckthorn oil, palmitoleic acid, has been demonstrated to activate G protein-coupled receptors in pancreatic β -cells, enhancing insulin production in response to glucose. This makes the oil very helpful for those who are insulin-resistant^[23].

The antioxidant properties of sea buckthorn also contribute to its efficacy in diabetes management. By neutralizing free radicals and reducing oxidative stress, sea buckthorn helps protect against diabetes-related complications such as neuropathy, retinopathy, and cardiovascular diseases. This aligns with the hypothesis that oxidative stress is a central factor in the pathogenesis of diabetic complications^[20].

Furthermore, sea buckthorn's impact on the gut microbiota highlights another promising avenue for diabetes management. Studies have shown that sea buckthorn supplementation can restore the balance of beneficial gut bacteria, which is often disrupted in diabetic conditions. This, in turn, may lead to improved metabolic health and better glycemic control^[27, 30, 31].

While the current research provides compelling evidence for the anti-diabetic potential of sea buckthorn, there is a need for more extensive clinical trials to establish standardized dosages, long-term safety, and efficacy in diverse populations. Additionally, future research should focus on isolating and characterizing specific bioactive compounds from sea buckthorn that contribute to its anti-hyperglycemic effects, which could lead to the development of more targeted therapies.

Future Prospects:

The prospects for studying the antihyperglycemic effects of sea buckthorn are promising, driven by its potential to manage diabetes and related metabolic disorders. Future research directions should focus on addressing these gaps. Here are several key areas for future research:

Standardized, well-controlled clinical trials are needed to establish effective dosing regimens and evaluate long-term outcomes. Mechanistic studies should further elucidate the molecular pathways through which sea buckthorn exerts its antihyperglycemic effects, potentially leading to the development of targeted therapies. Investigating the synergistic effects of sea buckthorn compounds and their interactions with conventional antidiabetic medications could also yield valuable insights for integrative treatment approaches. Isolating and characterizing specific bioactive compounds from sea buckthorn that contribute to its antihyperglycemic properties can lead to the development of targeted therapies. This can also involve studying the synergistic effects of these compounds. Developing novel formulations and delivery systems for sea buckthorn extracts to enhance bioavailability and efficacy. This includes exploring nanoformulations, encapsulation techniques, and other advanced delivery methods. Conducting comparative studies to evaluate the efficacy of sea buckthorn against standard antidiabetic medications can provide valuable information on its potential as an alternative or complementary therapy. Long-term studies to assess the sustained effects and safety of sea buckthorn supplementation over extended periods, will help in understanding its role in chronic diabetes management and prevention of complications. Investigating the effects of sea buckthorn on gut microbiota composition and its implications for glucose metabolism and overall metabolic health can provide insights into the prebiotic potential of sea buckthorn. By addressing these future research directions, the full therapeutic potential of sea buckthorn in managing hyperglycemia and diabetes can be better understood and utilized.

Conclusion:

In conclusion, the body of research on sea buckthorn (*Hippophae rhamnoides* L.) suggests its significant potential as an antihyperglycemic agent. Numerous investigations involving in vitro, in vivo, and

clinical trials have proven the efficaciousness of sea buckthorn and its extracts in modulating blood glucose homeostasis and enhancing insulin sensitivity. The bioactive compounds, such as flavonoids and fatty acids, found in sea buckthorn play crucial roles in modulating glucose metabolism and enhancing insulin action.

Sea buckthorn's multifaceted approach to combating hyperglycemia includes reducing food intake, decreasing weight gain, improving pancreatic function, and reversing insulin resistance. These effects are attributed to the synergistic action of its diverse phytochemicals, which collectively enhance antioxidant defense, modulate inflammatory responses, and optimize metabolic pathways related to glucose and lipid metabolism.

Despite the promising results, further research is warranted to fully elucidate the mechanisms of action and establish standardized dosing regimens. Large-scale, long-term clinical trials are essential to confirm the efficacy and safety of sea buckthorn in human populations. Moreover, addressing the variability in product quality and ensuring consistency across studies will be critical for the reliable application of sea buckthorn as a therapeutic option for diabetes management. Overall, the integration of sea buckthorn into dietary and therapeutic strategies offers a promising avenue for enhancing the management of diabetes and improving metabolic health.

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