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PHYTOCHEMICAL BASIS AND PRODUCT DEVELOPMENT POTENTIAL OF MORUS ALBA L., CICHORIUM INTYBUS L. AND TRIGONELLA FOENUM-GRAECUM L. FOR ANTIDIABETIC FUNCTIONAL THERAPEUTIC PRODUCTS

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Abstract

Diabetes mellitus is a major metabolic disorder characterized by persistent hyperglycemia and associated disturbances in carbohydrate and lipid metabolism. The increasing global burden of type 2 diabetes has stimulated interest in plant-derived bioactive compounds and functional products that may complement established preventive and therapeutic approaches. This review evaluates the phytochemical composition, antidiabetic potential, and product-development prospects of Morus alba L. (white mulberry), Cichorium intybus L. (chicory), and Trigonella foenum-graecum L. (fenugreek), with particular emphasis on their suitability as raw materials for antidiabetic functional therapeutic products. Literature analysis indicates that M. alba leaves are characterized by 1-deoxynojirimycin, flavonoids, phenolic acids, and polysaccharides; C. intybus contains inulin, chicoric acid, chlorogenic acid, other caffeoylquinic acids, sesquiterpene lactones, and flavonoids; while T. foenum-graecum seeds are rich in galactomannan, 4-hydroxyisoleucine, steroidal saponins, trigonelline, polyphenols, proteins, and dietary fiber. These phytochemicals may influence postprandial glucose absorption, carbohydrate-hydrolyzing enzymes, insulin sensitivity, oxidative stress, and lipid metabolism through complementary mechanisms. Clinical and systematic-review evidence is particularly developed for mulberry leaf and fenugreek, whereas evidence for chicory remains more heterogeneous and is dominated by preclinical studies. The comparative analysis suggests that combining standardized plant materials may provide a rational basis for developing multifunctional antidiabetic products, provided that botanical authentication, chemical standardization, extraction conditions, dose optimization, stability, safety, and quality-control parameters are established. The review proposes a product-development framework linking phytochemical markers with biological activity and quality characteristics. Such an approach may contribute to the scientific development of

plant-based functional therapeutic products within the framework of commodity chemistry and evidence-based phytotherapy.

Keywords
Morus alba L.; Cichorium intybus L.; Trigonella foenum-graecum L.; antidiabetic activity; phytochemicals; 1-deoxynojirimycin; chicoric acid; chlorogenic acid; galactomannan; functional therapeutic product; commodity chemistry; phytotherapy.

1. Introduction

Diabetes mellitus has become one of the major global metabolic health challenges. According to the World Health Organization, approximately 830 million people worldwide were living with diabetes in 2022, and the prevalence has increased substantially over recent decades, particularly in low- and middle-income countries. Type 2 diabetes is characterized primarily by insulin resistance and inadequate compensatory insulin secretion and is associated with long-term damage to the cardiovascular system, kidneys, eyes and nervous system.

The growing prevalence of diabetes has increased scientific interest in dietary strategies, functional foods and plant-derived bioactive compounds that may contribute to glycemic control. However, the development of plant-based products requires more than demonstrating that a particular plant has traditionally been used for diabetes. Scientific product development requires identification of active chemical constituents, characterization of their mechanisms of action, standardization of raw materials, assessment of safety, determination of appropriate extraction or processing conditions and establishment of quality-control criteria. Among medicinal and food plants, *Morus alba* L., *Cichorium intybus* L. and *Trigonella foenum-graecum* L. represent three chemically distinct but potentially complementary sources of antidiabetic phytochemicals[1,2].

Morus alba leaves are particularly notable for the presence of the iminosugar 1-deoxynojirimycin (DNJ), together with flavonoids, phenolic acids and polysaccharides. DNJ is recognized as a potent α-glucosidase inhibitor and therefore has a mechanistically relevant role in reducing postprandial carbohydrate digestion.

Cichorium intybus contains inulin and oligofructose as well as caffeic acid derivatives, chicoric acid, chlorogenic acid, flavonoids and sesquiterpene lactones. These constituents

provide a biochemical basis for investigating chicory as a functional ingredient associated with glucose metabolism, oxidative stress and metabolic health[3].

Trigonella foenum-graecum, commonly known as fenugreek or shambala, contains substantial quantities of galactomannan and proteins, together with steroidal saponins, trigonelline, 4-hydroxyisoleucine, diosgenin and polyphenolic compounds. Its seeds have been extensively investigated for their potential influence on glucose and lipid metabolism.

The scientific relevance of these three plants is therefore not limited to their individual pharmacological activities. Their different phytochemical profiles suggest a possibility for rational botanical combination, in which several mechanisms associated with carbohydrate digestion, glucose absorption, insulin sensitivity, oxidative stress and metabolic regulation may be targeted simultaneously. Accordingly, the objective of this review was to analyze the phytochemical composition and antidiabetic potential of *M. alba*, *C. intybus* and *T. foenum-graecum* and to establish a scientific rationale for their further use as raw materials in the development of antidiabetic functional therapeutic products[4].

2. Materials and methods

Literature search strategy

A narrative-integrative literature review was conducted using scientific publications indexed in PubMed and other internationally recognized scientific databases. The literature search focused on publications addressing the phytochemical composition, biological activity, antidiabetic mechanisms, clinical evidence, extraction, standardization and product-development potential of *Morus alba* L., *Cichorium intybus* L. and *Trigonella foenum-graecum* L.

The following combinations of keywords were considered:

– "*Morus alba* antidiabetic";

– "mulberry leaf DNJ diabetes";

– "*Cichorium intybus* antidiabetic";

– "chicory chicoric acid diabetes";

– "*Trigonella foenum-graecum* diabetes";

– “fenugreek glycemic control”;

– “plant-based functional products diabetes”;

– “phytochemical standardization antidiabetic herbal products”.

Priority was given to systematic reviews, meta-analyses, randomized controlled trials, comprehensive phytochemical reviews and recent studies addressing chemical standardization and product development.

The literature was synthesized according to four major analytical dimensions:

1) chemical composition;

2) biological and antidiabetic activity;

3) potential mechanisms of action;

4) suitability for functional therapeutic product development.

Results and discussion

Phytochemical profile of *Morus alba* L.

Morus alba L., commonly known as white mulberry, has a long history of use as a food and medicinal plant. Leaves are particularly relevant for metabolic applications because they contain a combination of iminosugars, flavonoids, phenolic acids and polysaccharides. Reviews have identified DNJ, quercetin, rutin, isoquercitrin, chlorogenic acid and other phenolic constituents among the biologically important compounds associated with mulberry leaves[5,6].

Table 1

Major phytochemical groups and potential antidiabetic relevance of the three selected plants

Plant	Important phytochemical groups/markers	Potential metabolic relevance
Morus alba L.	1-Deoxynojirimycin, flavonoids, phenolic acids, polysaccharides	α-Glucosidase inhibition, postprandial glycemic regulation, antioxidant effects
Cichorium intybus L.	Inulin, chicoric acid, chlorogenic acid, caffeoylquinic acids, flavonoids, sesquiterpene lactones	Glucose metabolism, insulin sensitivity, antioxidant and metabolic effects
Trigonella foenum-graecum L.	Galactomannan, 4-hydroxyisoleucine, steroidal saponins, trigonelline, polyphenols	Delayed carbohydrate absorption, glycemic regulation, insulin-related effects and lipid metabolism

The importance of DNJ is particularly noteworthy. It is a naturally occurring iminosugar that structurally resembles glucose and inhibits intestinal α-glucosidases involved in carbohydrate digestion. Consequently, inhibition of these enzymes may reduce the rate of glucose release from complex carbohydrates and attenuate postprandial glucose excursions. Experimental evidence has also demonstrated that chlorogenic acid and rutin contribute to the antidiabetic activity of *M. alba* leaf extracts, suggesting that the biological effect of mulberry cannot necessarily be attributed to a single constituent.

This observation is important from the perspective of commodity chemistry: the quality of mulberry-based raw material should not be evaluated solely by total phenolic content. A marker-based approach including DNJ and selected phenolic constituents would provide a more informative basis for standardization. A systematic review and meta-analysis of mulberry leaf or mulberry leaf extract reported reductions in fasting blood glucose, HbA1c and fasting plasma insulin, although the authors emphasized that the overall evidence should be interpreted in the context of study characteristics and intervention duration. Thus, *M. alba* leaves represent a promising botanical raw material for the development of standardized functional products, especially products intended to modulate postprandial carbohydrate metabolism[7,8].

Phytochemical profile of *Cichorium intybus* L.

commonly known as chicory or qoqio‘t, belongs to the Asteraceae family. Different plant parts, including roots, leaves, flowers and aerial tissues, contain chemically diverse compounds. The root is particularly important because of its high content of inulin, a fructan-type polysaccharide widely used as a functional food ingredient. Chicory also contains chicoric acid, chlorogenic acid, caffeic acid derivatives, flavonoids, coumarins and sesquiterpene lactones[9].

The presence of both structural carbohydrates and phenolic compounds gives chicory an interesting position in the development of functional products. Unlike DNJ-rich mulberry, chicory may provide a broader combination of fiber-related and phenolic mechanisms. A systematic review evaluating chicory in diabetes included 23 eligible studies, of which three involved humans and twenty involved animal models. Fifteen of nineteen studies assessing glycemic parameters reported an improvement, while evidence

also suggested favorable effects on lipid profiles, oxidative stress and inflammation. However, the authors emphasized the need for additional research, particularly in humans, to establish precise mechanisms and clinical effectiveness.

A particularly interesting experimental study investigated a chicory root extract rich in chicoric acid and caffeoylquinic acids. LC-MS analysis showed that chicoric acid accounted for 64.2% of the extract and caffeoylquinic acids for approximately 19.6%. The extract improved glucose tolerance and reduced basal hyperglycemia in streptozotocin-induced diabetic rats. These findings suggest that chicory may be valuable not only because of its nutritional fiber content but also as a source of phenolic markers associated with glucose metabolism and antioxidant activity.

From a product-development perspective, chicory may therefore provide two complementary functional dimensions: fiber-based functionality + phenolic bioactivity. This combination makes *C. intybus* particularly interesting for powdered functional mixtures, instant herbal beverages and composite plant-based products.

Phytochemical profile of *Trigonella foenum-graecum* L.

Trigonella foenum-graecum L., commonly known as fenugreek or shambala, is an important food and medicinal plant belonging to the Fabaceae family. Its seeds contain substantial amounts of proteins, dietary fiber and galactomannan. In addition, steroidal saponins, trigonelline, 4-hydroxyisoleucine, diosgenin and various flavonoids and phenolic compounds have been identified.

Galactomannan is particularly relevant to product development because its viscosity and dietary-fiber characteristics may influence carbohydrate digestion and glucose absorption. 4-Hydroxyisoleucine has also attracted attention because of its relationship with insulin secretion and glucose metabolism. Clinical evidence concerning fenugreek is more developed than for many other traditional antidiabetic plants. An updated systematic review and meta-analysis published in 2025 included 26 randomized controlled trials and reported significant improvements in fasting blood glucose, two-hour postprandial glucose, HbA1c and insulin, although the authors emphasized the need for higher-quality studies.

Another systematic review and meta-analysis involving 10 studies and 706 participants reported significant reductions in fasting blood glucose, two-hour glucose and HbA1c, while no significant reduction in HOMA-IR was observed. No severe adverse events were reported, although mild gastrointestinal effects occurred in some participants[10,11,12].

These findings indicate that fenugreek is a particularly important component for the proposed botanical combination.

Comparative analysis of antidiabetic mechanisms

The three plants demonstrate different but potentially complementary mechanisms.

Morus alba L. The dominant mechanistic pathway is associated with: DNJ → α-glucosidase inhibition → delayed carbohydrate hydrolysis → reduced postprandial glucose elevation. Additional mechanisms involve antioxidant activity, modulation of glucose uptake and improvement of metabolic parameters. Reviews have described mulberry leaf activity in relation to α-glucosidase and α-amylase inhibition, oxidative stress, lipid metabolism and insulin resistance.

Cichorium intybus L. The potential pathways include: chicoric acid + chlorogenic acid + caffeoylquinic acids → insulin-sensitizing and antioxidant effects → improved glucose metabolism.

In addition, inulin provides a dietary-fiber component with potential relevance to gastrointestinal and metabolic functionality. Experimental evidence supports glucose tolerance and insulin-sensitizing effects of chicory-derived phenolic fractions, but clinical evidence remains comparatively limited[13].

Trigonella foenum-graecum L. The proposed mechanisms include: galactomannan → delayed carbohydrate absorption 4-hydroxyisoleucine → insulin-related effects polyphenols and saponins → antioxidant and metabolic modulation.

Clinical meta-analyses consistently indicate a potentially favorable effect of fenugreek on glycemic parameters, although heterogeneity among preparations, doses and study designs remains an important limitation[14,15].

Scientific rationale for a composite antidiabetic product

The central scientific hypothesis of the present review is that the three plants can be considered not merely as independent medicinal raw materials, but as potentially complementary

Commodity chemistry perspective

From the perspective of commodity chemistry, medicinal plant material should be considered as a specific type of commodity whose quality is determined by botanical identity, chemical composition, technological processing, safety and functional properties[16].

For the proposed product, the following quality-control sequence can be recommended:

1. Authentication of raw materials

The botanical identity of each plant should be confirmed using macroscopic, microscopic and, where necessary, chromatographic or DNA-based methods.

2. Determination of physicochemical characteristics

The following parameters should be evaluated:

– moisture content;

– total ash;

– acid-insoluble ash;

– extractive values;

– particle-size distribution;

– bulk density;

– pH of extracts.

3. Phytochemical standardization

The following marker compounds can be considered:

Raw material	Proposed marker compounds
Morus alba L.	DNJ, chlorogenic acid, rutin, quercetin
Cichorium intybus L.	Chicoric acid, chlorogenic acid, caffeoylquinic acids, inulin
Trigonella foenum-graecum L.	Galactomannan, 4-hydroxyisoleucine, trigonelline, total saponins

HPLC/UPLC-based methods would be particularly useful for phenolic acids and flavonoids, while suitable chromatographic or spectrophotometric procedures may be selected for DNJ, inulin, galactomannan and total saponins[17].

Biological standardization

Chemical composition alone should not determine product quality. Biological screening may include:

– α-glucosidase inhibition;

– α-amylase inhibition;

– antioxidant activity;

– glucose uptake assays;

– insulin-sensitivity-related assays.

Safety evaluation

The raw materials and final product should be evaluated for:

– microbial contamination;

– heavy metals;

– pesticide residues;

– aflatoxins/mycotoxins where relevant;

– toxicologically relevant contaminants;

– stability during storage.

This approach transforms the product from an empirically mixed herbal preparation into a scientifically characterized functional commodity.

Proposed formulation concept

Based on the literature, a conceptual product-development scheme can be proposed [18,19].

Table 2

Proposed functional roles of the three plant components

Component	Main role	Chemical basis	Expected functional contribution
Morus alba leaf	Glycemic control	DNJ, flavonoids, phenolic acids	α-Glucosidase inhibition and antioxidant support
Cichorium intybus root/herb	Metabolic and fiber component	Inulin, chicoric acid, chlorogenic acid	Fiber functionality, glucose metabolism and antioxidant support
Trigonella foenum-graecum seed	Fiber and metabolic component	Galactomannan, 4-hydroxyisoleucine, saponins	Delayed carbohydrate absorption and metabolic support

The final ratio should be determined through experimental optimization rather than assumed from literature alone. A rational optimization strategy may involve a mixture-design approach, in which different proportions of the three plant materials are tested and evaluated according to a predefined response function.

For example: Optimization criteria = α-glucosidase inhibition + antioxidant capacity + phytochemical marker content + sensory acceptability + technological stability. This approach would be particularly appropriate for a doctoral research project because it connects the chemical composition of raw materials with the actual quality of the resulting product[20].

Potential forms of the antidiabetic functional product

Based on the technological properties of the selected plant materials, several product forms can be considered:

1. Herbal tea/phyto-collection

A dried and standardized mixture of appropriately processed plant materials could be developed as an infusion product.

2. Instant functional powder

Plant materials could be dried, milled and standardized to produce a powder intended for preparation as a functional beverage.

3. Dry extract composition

Standardized extracts could be combined into a dry composite formulation.

4. Functional food ingredient

The plant composition could potentially be incorporated into selected food matrices, provided that stability, sensory acceptability and safety are demonstrated.

5. Encapsulated botanical product

Microencapsulation may be investigated to improve stability of selected phytochemicals and facilitate standardized dosing.

Importantly, the final product category should be determined according to the intended use, composition, dose, regulatory requirements and demonstrated evidence. The term “antidiabetic” should not be used as a therapeutic claim for a

Discussion

The comparative evaluation demonstrates that the three selected plants possess distinct phytochemical profiles that may complement one another. The principal advantage of *Morus alba* is the presence of DNJ and a broad spectrum of flavonoids and phenolic compounds. Its strongest scientific rationale lies in the modulation of carbohydrate digestion and postprandial glycemia. Clinical and meta-analytic evidence provides additional support for this potential. *Cichorium intybus* contributes a different chemical profile dominated by inulin and caffeic acid derivatives, particularly chicoric and chlorogenic acids. Experimental data indicate that chicory-derived phenolic extracts can improve glucose tolerance and insulin sensitivity; however, clinical evidence remains less extensive. Fenugreek provides an additional functional dimension through galactomannan, 4-hydroxyisoleucine, saponins and other constituents. Its relatively extensive clinical evidence makes it a particularly valuable component for the proposed formulation. Recent meta-analyses indicate favorable effects on fasting glucose, postprandial glucose and HbA1c, although the heterogeneity of interventions must be considered.

However, the presence of plausible complementary mechanisms does not automatically establish synergism. Synergistic interaction must be experimentally demonstrated using appropriate mixture designs, dose–response studies and statistical models. This distinction is essential for scientifically rigorous product development.

Conclusion

The literature analysis demonstrates that *Morus alba* L., *Cichorium intybus* L. and *Trigonella foenum-graecum* L. represent promising plant raw materials for the development of standardized functional products intended to support glucose and metabolic health.

Morus alba is characterized by DNJ, flavonoids and phenolic compounds, providing a strong mechanistic basis for modulation of carbohydrate digestion and postprandial glycemia. *Cichorium intybus* provides inulin and caffeoylquinic/chicoric acids with potential relevance to glucose metabolism, antioxidant activity and metabolic health. *Trigonella foenum-graecum* is distinguished by galactomannan, 4-hydroxyisoleucine, steroidal saponins and other bioactive compounds, with comparatively strong clinical evidence for improving glycemic parameters.

The major scientific value of combining these plants lies in their potentially complementary phytochemical and biological profiles. Nevertheless, the development of an effective product requires experimental determination of the optimal ratio rather than an arbitrary combination. From the perspective of commodity chemistry, the proposed product should be developed through a sequence involving botanical authentication, physicochemical characterization, phytochemical standardization, biological screening, mixture optimization, technological processing, safety evaluation and stability testing. The proposed research framework therefore establishes a scientifically justified transition:

plant raw material → chemical composition → biological activity → optimized composition → standardized functional product.

Further experimental research should determine the optimal *Morus alba* : *Cichorium intybus* : *Trigonella foenum-graecum* ratio, identify suitable chemical markers, evaluate synergistic effects and establish quality-control parameters for the final product. The findings provide a scientific foundation for further doctoral research aimed at obtaining antidiabetic functional therapeutic products from locally available plant materials.

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