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Development of a plant-based functional dietary supplement containing sprouted oats, barley, licorice root, and Jerusalem artichoke: Justification of raw materials and optimization of dosage

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ABSTRACT

Background: The global rise in diabetes mellitus highlights the urgent need for functional dietary supplements with proven bioactivity. Jerusalem artichoke, germinated oats, germinated barley, and licorice root are natural sources of prebiotic fibers and bioactive compounds with synergistic metabolic benefits.

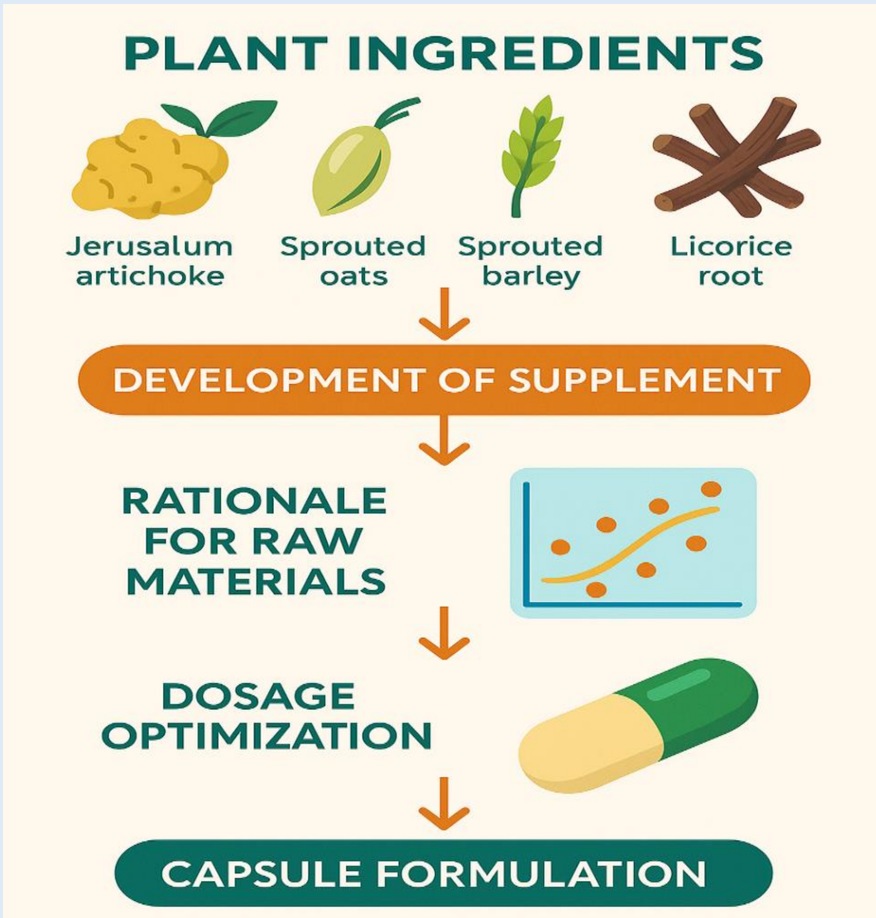
Objective: This study aimed to develop a plant-based functional dietary supplement for individuals with impaired carbohydrate metabolism, optimize its composition, and evaluate its technological, sensory, and functional properties.

Methods: Four formulations with varying proportions of Jerusalem artichoke, germinated oats, germinated barley, and licorice root were prepared. Water-holding capacity (WHC), bulk density, and flowability were determined according to adapted national standards. Inulin content was estimated using a validated calculation model based on published compositional data for each ingredient, followed by Pearson's correlation and one-way ANOVA to determine optimal composition. All measurements were performed in triplicate, and results were expressed as mean ± standard deviation (SD).

Results: The formulation containing 60% Jerusalem artichoke, 12.5% germinated oats, 12.5% germinated barley, and 15% licorice root demonstrated balanced inulin content (10.88%), optimal WHC (0.701 g/g), good flowability (34°), and favorable sensory properties. Pearson's correlation showed the strongest positive association between Jerusalem artichoke content and inulin level (r = 0.670), while ANOVA revealed no significant differences in inulin content between 50–70 g Jerusalem artichoke (p = 0.61).

Conclusion: The optimized formulation is technologically feasible for encapsulation and offers functional benefits for individuals with diabetes. This study introduces a novel synergistic blend of germinated cereals and medicinal plant material, emphasizing reproducibility through transparent methodology and statistical validation.

Keywords: functional dietary supplement, Jerusalem artichoke, germinated oats, germinated barley, licorice root, inulin, diabetes



Graphical Abstract: Development of a plant-based functional dietary supplement containing sprouted oats, barley, licorice root, and Jerusalem artichoke: justification of raw materials and optimization of dosage

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INTRODUCTION

In recent decades, interest in functional nutrition and plant-based dietary supplements (DS) has markedly increased for the prevention and maintenance of health. Among plant ingredients, those with high biological activity and low toxicity are particularly valuable in the development of functional products. Sprouted grains and medicinal plants show notable promise as sources of bioactive substances, as germination significantly enhances enzyme activity, vitamin levels, antioxidant compounds, and reduces antinutritional factors, thereby improving micronutrient digestibility [1-3].

A key focus in functional supplement development is metabolic health support, particularly for the prevention and adjunctive management of type 2 diabetes mellitus (T2DM). The World Health Organization reports a steady rise in diabetes prevalence, reinforcing the urgency to develop natural products that support carbohydrate metabolism [4].

Dietary fiber, especially soluble types like inulin, plays a crucial role in metabolic health. Inulin features a low glycemic index and has been shown to reduce blood glucose and cholesterol levels through lipid modulation and antioxidant action [5,6]. Jerusalem artichoke (Helianthus tuberosus L.) is a promising inulin source with high bioavailability. Germinated cereals (oats and barley) contribute β-glucans, which have documented effects on glucose metabolism and satiety [7]. Meanwhile, licorice root provides glycyrrhizic acid and flavonoids with anti-inflammatory and glycemic regulatory properties [8-10].

Given these attributes, combining Jerusalem artichoke, germinated oats, germinated barley, and licorice root may yield a synergistic blend that enhances carbohydrate metabolism and metabolic health. This study aims to develop and optimize such formulations, with a focus on their technological feasibility and functional potential for individuals at risk of or managing T2DM.

The objectives were:

1. To formulate blend combinations and assess their technological (e.g., water-holding capacity, flowability) and sensory properties (e.g., aroma, taste, texture);
2. To estimate the inulin content and evaluate its correlation with ingredient proportions;
3. To identify the most promising formulation for further analytical validation and potential clinical testing.

METHODS

Raw Materials: Jerusalem artichoke powder (supplier: KVM Trade, Almaty, Kazakhstan), sprouted oats and sprouted barley (obtained under controlled laboratory germination conditions, 45-48 h at 15-18 °C, relative humidity 85%), and dried licorice root (KVM Trade, Almaty, Kazakhstan) were used. All raw materials were ground to a particle size of ≤ 300 µm using a laboratory mill (Analytical mill IKA A 11 basic).

Functional rationale for formulation:

The selection of these ingredients was based on their functional properties reported in recent studies. Their main bioactives and health-promoting effects are summarized in Table 1.

Table 1. Literature-Based Functional Roles of Supplement Components

Component	Main Bioactives	Functional Effects (based on literature)	References
Jerusalem artichoke	Inulin; prebiotics	Supports glycemic control, improves liver lipid metabolism, prebiotic effects	5,11
Sprouted oats	β-glucans	Improves postprandial glucose response, enhances satiety, supports weight management	12-13
Sprouted barley	β-glucans, antioxidants	Aids in glucose regulation, reduces diabetes risk, enhances metabolic health	14
Licorice root	Glycyrrhizic acid, flavonoids	Exhibits antioxidant, anti-inflammatory, and glycemic regulatory effects	15

Formulation Development: Four experimental formulations (F1–F4) were prepared by mixing the powdered components in different proportions (Table 2). The inulin content of each formulation was estimated using the calculation model:

$$I_f = \sum_{i=1}^{n} (P_i * I_i)$$

where I_f is the inulin content in the formulation (%), P_i is the percentage of ingredient i in the formulation, and I_i is the literature-based inulin content (%) for that ingredient (Jerusalem artichoke – 15%, germinated oats – 10%, germinated barley – 5%, licorice root – 0%).

Water-Holding Capacity (WHC): WHC was determined according to an adapted method from GOST 7636-85 using a centrifuge (Laboratory centrifuge with heating TAGLER CLMN 1-8).

Flowability: The angle of repose was measured in accordance with pharmaceutical criteria.

Sensory Evaluation: A panel of 10 trained assessors evaluated color, aroma, taste, and texture using a 5-point scale.

Statistical Analysis: All measurements were conducted in triplicate (n = 3). Results are reported as mean ± SD. Pearson's correlation and one-way ANOVA were used to assess statistical significance ($p < 0.05$).

RESULTS AND DISCUSSION

Four formulations of dietary supplements (Samples 1–4) were developed using Jerusalem artichoke, sprouted oats, sprouted barley, and licorice root in varying proportions (Table 2). Jerusalem artichoke was consistently included as the main source of inulin, while the proportions of sprouted cereals and licorice root varied to assess their effects on technological and sensory properties. Sample 1 contained the highest proportion of licorice root (20 g), while Sample 3 had the largest fraction of sprouted cereals (45 g in total). Such variation in composition allowed comparative evaluation of the impact of individual components on functional and technological characteristics.

Table 2. Composition of dietary supplement samples

Samples of dietary supplements	Herbal Ingredients for Dietary Supplements			
	Jerusalem artichoke (g)	Sprouted oats (g)	Sprouted barley (g)	Licorice root (g)
Sample 1	70	5	5	20
Sample 2	70	10	10	10
Sample 3	50	25	20	5
Sample 4	60	12,5	12,5	15

As shown in Table 2, Jerusalem artichoke was the dominant component in all formulations, accounting for 70 g in Samples 1 and 2. In contrast, Sample 3 contained the lowest amount of Jerusalem artichoke (50 g), but the highest proportion of sprouted cereals (25 g oats and 20 g barley), which allowed us to evaluate the influence of increased cereal fractions on technological and sensory properties. Sample 1 was characterized by the highest licorice root content (20 g), whereas Sample 2 and Sample 4 contained more balanced proportions of all ingredients. Such variation in composition enabled comparative analysis of how the proportions of inulin-rich tubers, β-glucan-rich cereals, and licorice root affected the functional and technological parameters of the developed supplement. The functional relevance of Jerusalem artichoke inulin, particularly for improving glycemic control and modulating gut microbiota in type 2 diabetes models, has been demonstrated in previous studies Li et al. (2022) [14].

Since the technological behavior of dietary supplement powders is largely determined by their compositional structure, the subsequent stage involved an evaluation of their physical and functional properties. Among these, particular attention was paid to the water-holding capacity (WHC), as this parameter plays a critical role in powder flowability, capsule filling efficiency, gastrointestinal swelling, and ultimately in the controlled release of bioactive compounds [13-15]. The WHC values of the four formulations are summarized in Table 3.

Table 3. Water-holding capacity of dietary supplement formulations.

Sample	WHC (g/g)
1	1.022
2	0.316
3	0.205
4	0.701

The results show substantial variation in WHC among the formulations. Sample 1 exhibited the highest WHC (1.022 g/g), which can be attributed to its higher content of licorice root (20 g), known for its polysaccharides and saponins that enhance water absorption. In contrast, Sample 3, which contained the lowest proportion of Jerusalem artichoke (50 g) and the highest fraction of sprouted cereals, showed the lowest WHC (0.205 g/g). This result suggests that while germinated oats and barley contribute dietary fiber, their structural characteristics provide limited hydration compared to inulin-rich tubers.

Sample 4 demonstrated an intermediate WHC value (0.701 g/g), which appears to be optimal for supplement formulation. Moderate hydration promotes swelling and satiety without excessive gelation, thus ensuring better capsule flowability and uniform release of bioactive compounds. Similar trends were observed in previous studies where combinations of inulin and β-glucans produced synergistic hydration effects [16-17].

The flowability of the powders was evaluated by measuring the angle of repose. This indicator reflects interparticle friction and indirectly characterizes the ability of the powder to flow uniformly during processing. All samples demonstrated angles within the acceptable range (<40°), confirming their suitability for encapsulation. Notably, Sample 4 again exhibited the most favorable flow characteristics, further supporting its selection as the optimal formulation. Flowability is a critical parameter for the production of dietary supplements in capsule or tablet form, as it determines the uniformity of dosing and packaging. The angle of repose values of the studied samples are presented in Table 4.

Table 4. Flowability indicators of powder compositions

Sample	Angle of repose (°)	Flowability characteristics
1	42	Mediocre
2	35	Good
3	46	Poor
4	34	Good

Samples 2 and 4 demonstrated the most favorable flowability (35° and 34°, respectively), indicating their suitability for industrial processing. In contrast, Sample 3 exhibited poor flowability (46°), which can be attributed to the higher content of sprouted cereals. Germinated oats and barley are rich in β-glucans, which tend to increase interparticle cohesion, thereby reducing powder flow [18].

Inulin is one of the key functional ingredients responsible for the hypoglycemic and prebiotic effects of the developed supplement. The inulin content of each formulation was calculated based on literature values for raw materials (15% in Jerusalem artichoke, 10% in sprouted oats, 5% in sprouted barley, absent in licorice root) [19-20]. The results are presented in Table 5.

Table 5. Inulin content in dietary supplement formulations (per 100 g mixture).

Sample	Jerusalem artichoke (g)	Sprouted oats (g)	Sprouted barley (g)	Licorice root (g)	Inulin content (%)
1	70	5	5	20	11.25
2	70	10	10	10	12.00
3	50	25	20	5	11.00
4	60	12.5	12.5	15	10.88

The highest inulin concentration was observed in Sample 2 (12.0%), which combined a high Jerusalem artichoke fraction with moderate proportions of sprouted cereals. Sample 4 contained slightly lower inulin (10.88%) due to reduced Jerusalem artichoke content, but its balanced composition favored better technological and sensory performance. These findings align with studies showing that optimal levels of inulin (~10–12%) are sufficient to provide prebiotic and glycemic benefits while maintaining acceptable product texture.

Organoleptic properties play a decisive role in consumer acceptance of dietary supplements. The sensory characteristics and moisture content of the four formulations are presented in Table 6.

Table 6. Organoleptic indicators of dietary supplement formulations.

Samples	Organoleptic characteristics					Humidity, %
	Appearance	Color	Smell	Taste	Consistency	
Sample 1	Coarse powder	Beige-gray	Strong, herbal	Sweet, with an unpleasant aftertaste	Slightly lumpy	7,2
Sample 2	Slightly uneven	Light beige	Herbal	Tart	Average	6,9
Sample 3	Heterogeneous	Grey	Cutting	Bittersweet	Lumpy	7,4
Sample 4	Homogeneous	Beige	Pleasant, herbal	Moderately sweet	Bulk	6,5

Samples 1 and 3 demonstrated less favorable sensory profiles, characterized by high moisture content (>7%) and undesirable aftertastes, which may negatively affect storage stability and consumer acceptance. In contrast, Sample 4 exhibited the most balanced sensory characteristics, with a uniform beige appearance, pleasant herbal aroma, moderately sweet taste, and the lowest moisture level (6.5%).

Based on the conducted research of the composition of the biologically active supplement, it was established that the best indicators for technological and organoleptic properties were demonstrated by Sample 4, including: Jerusalem artichoke - 60 g, sprouted oats - 12.5 g, sprouted barley - 12.5 g, licorice root - 15 g.

To assess the contribution of individual plant components to the formation of the inulin content in the composition of the developed dietary supplement, a correlation analysis was carried out. The quantities of Jerusalem artichoke, sprouted oats, sprouted barley and licorice root (g) were considered as independent variables, and the content of inulin (%) was considered as a dependent variable. The results of the analysis are presented in the table below.

Table 7. Results of correlation analysis between dietary supplement components and inulin content

Variable	**Correlations (inulin content) Marked correlations are significant at p < 05000 N=4 (Casewise deletion of missing data)**				
	Jerusalem artichoke (g)	Sprouted oats (g)	Sprouted barley (g)	Licorice root (g)	Inulin content %
Jerusalem artichoke (g)	1,000000	-0,946233	-0,940019	0,674200	0,670260
Sprouted oats (g)	-0,946233	1,000000	0,989198	-0,872440	-0,396106
Sprouted barley (g)	-0,940019	0,989198	1,000000	-0,877876	-0,389346
Licorice root (g)	0,674200	-0,872440	-0,877876	1,000000	-0,095048
Inulin content %	0,670260	-0,396106	-0,389346	-0,095048	1,000000

The results of the correlation analysis showed that the greatest positive correlation with the inulin content was found in the Jerusalem artichoke mass (r = 0.670), while the mass of oats (r = –0.396), barley (r = –0.389) and licorice root (r = –0.095) did not demonstrate a significant correlation with this indicator. A statistically significant relationship was found only between oats and barley (r = 0.989, p < 0.05), which is explained by their parallel increase in the structure of the recipes

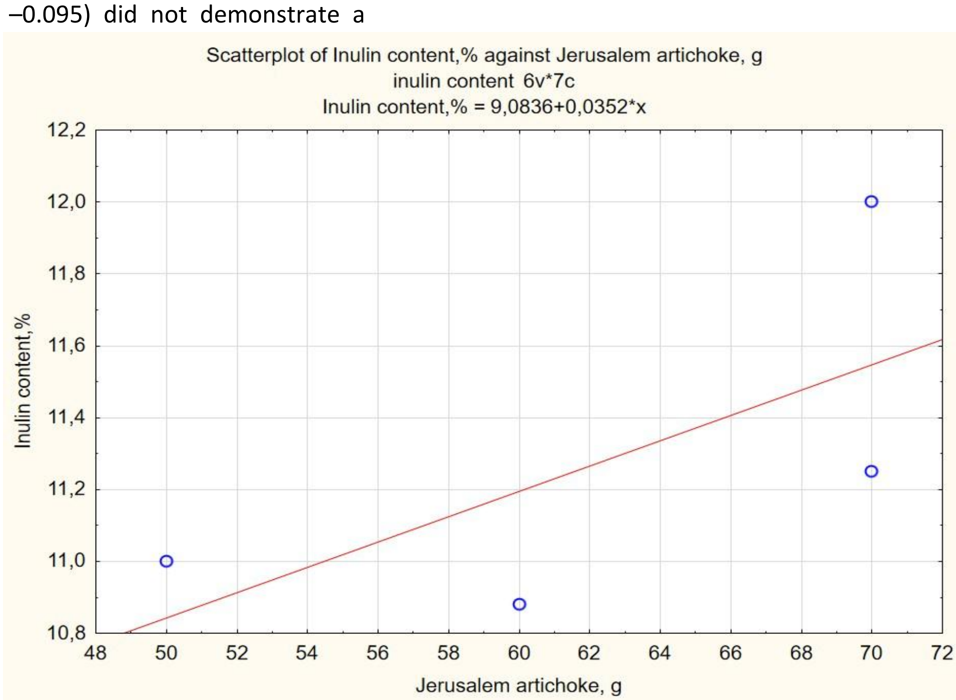

Figure 1. Scatter plot of the dependence of inulin content on the mass of Jerusalem artichoke in the samples.

As can be seen from the graph, with an increase in the amount of Jerusalem artichoke, there is a tendency for the inulin content to increase. The constructed linear regression has the equation: Inulin content, % = 9.0836 + 0.0352 × (Jerusalem artichoke, g), which indicates that each additional 10 g of Jerusalem artichoke increases the inulin content by approximately 0.35%

The obtained correlation dependencies confirmed that the main source of inulin in the composition is Jerusalem artichoke. In this regard, and also taking into account the technological advantages of sample No. 4, a dispersion analysis (ANOVA) was carried out to assess the feasibility of reducing the Jerusalem artichoke dosage without significant loss of functional properties.

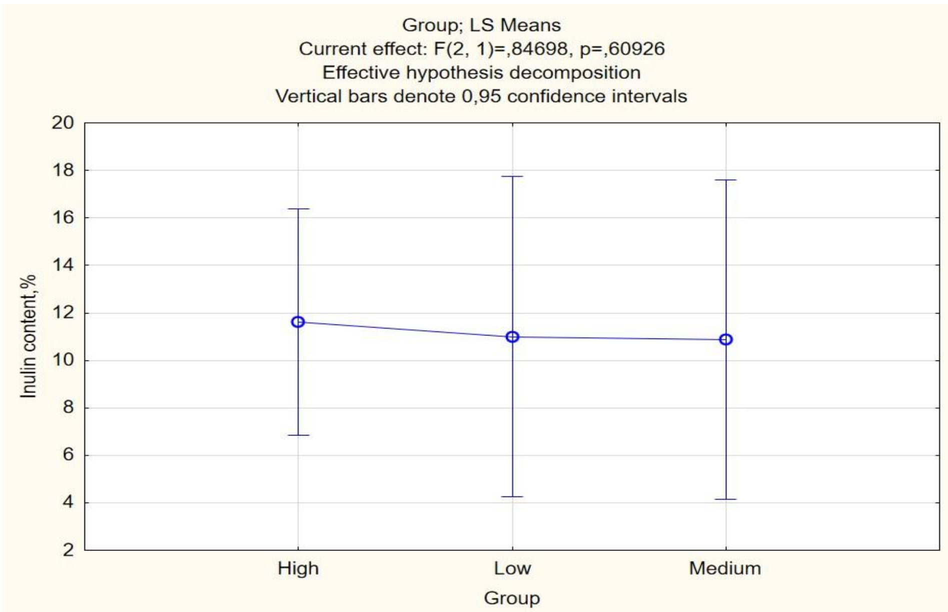

Figure 2. Average values of inulin content (%) in samples with different levels of Jerusalem artichoke addition

When comparing samples with different Jerusalem artichoke content (50, 60 and 70 g), no statistically significant differences in inulin content were found ($p = 0.61$). This allows us to conclude that reducing the Jerusalem artichoke content in the dietary supplement formulation does not result in a significant decrease in inulin content, and the composition can be optimized to meet economic and technological indicators.

Based on the results of the correlation and

Based on dispersion analyses and technological characteristics, sample No. 4 was selected as the optimal one. Its composition provided a balanced inulin content, satisfactory organoleptic and physicochemical properties, and potential for encapsulation. Based on this variant, the development of a capsule form of a biologically active supplement with a functional focus was continued. With a capsule weight of 500 mg, the distribution of components is shown in Table 4.

Table 8. Composition of the encapsulated form of the dietary supplement based on the selected sample

Components of the dietary supplement	Component mass, mg	Mass fraction, %
Jerusalem artichoke	300	60%
Sprouted oats	62,5	12,5%
Sprouted barley	62,5	12,5%
Licorice root	75	15%
Total	500	100%

The developed dietary supplement is an effective means of maintaining optimal inulin levels in patients with diabetes. The use of natural plant components, combined with innovative processing methods, ensures the preservation of biologically active substances. The encapsulated form allows for convenient, accurate dosing of the supplement, making the product helpful in maintaining health and normalizing metabolic processes.

CONCLUSION

As a result of the study, a plant-based dietary supplement was developed, comprising sprouted oats, barley, licorice root, and Jerusalem artichoke. Correlation analysis confirmed that Jerusalem artichoke is the primary source of inulin in formulation. Considering both the functional properties and technological characteristics of the developed samples, Sample No. 4—with a reduced amount of Jerusalem artichoke—was selected as optimal for further development in capsule form. ANOVA analysis confirmed that the reduction in Jerusalem artichoke content within the proposed formulation does not significantly affect inulin levels or compromise the functional properties of the supplement. The findings can be applied to the development of effective, balanced dietary supplements that support the immune system and manage metabolic disorders, including type 2 diabetes.

Author Contributions: All authors contributed to this study.

Competing Interests: The authors declared no conflict of interest.

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