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IMPROVEMENT OF THE AMINO ACID COMPOSITION OF A MUNG BEAN-BASED FUNCTIONAL BEVERAGE THROUGH THE APPLICATION OF A METABOLIC MODULATOR DURING SPROUTING

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The object of this study is sprouted mung bean seeds (Vigna radiata L.) of the "Zhasyl dän" variety, used as a raw material for developing a functional beverage with improved protein quality. The study addresses the limited biological value of plant proteins associated with their amino acid composition

Seeds were germinated in distilled water (control) and in a 2% sucrose solution for 24, 48, and 72 hours. Amino acid composition was analyzed using high-performance liquid chromatography (HPLC) with fluorescence detection.

Sucrose addition led to a clear increase in amino acid content during germination, with the strongest effect observed after 48 hours. Total amino acid content increased from 21,539 to 26,656 mg/100 g dry weight (+23.8%). The most noticeable changes were found for essential amino acids, including lysine (+20.7%), valine (+23.9%), and branched-chain amino acids (leucine and isoleucine, +26.2%). Glutamic and aspartic acids also increased by about 24%, which may be linked to improved taste characteristics.

In general, sucrose influenced metabolic processes and resulted in a 20–25% increase in amino acid content without the use of microbial cultures. The optimal germination time was around 48 hours.

These results suggest that controlled germination with carbohydrate addition can be used as a simple approach to improve plant protein quality in functional food products

Keywords: Vigna radiata; germination; sucrose supplementation; amino acid profile; HPLC; essential amino acids; metabolic modulation; sprouted mung bean

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1. Introduction

Ensuring global food and protein security remains a major challenge. Despite progress in food technologies, a large part of the population still does not receive enough high-quality protein and essential micronutrients. A key issue is "hidden hunger", when calorie intake may be sufficient, but the diet lacks essential amino acids, vitamins, and minerals [1]. This problem is particularly relevant in urban populations, where processed foods form a significant part of daily nutrition.

Current dietary patterns are often dominated by refined carbohydrates and fats, while overall nutritional value remains low. As a result, deficiencies in protein and micronutrients become more pronounced, and the risk of diet-related diseases increases [2]. This has led to growing interest in functional foods based on plant raw materials that are affordable and can be easily incorporated into everyday diets without major changes.

Functional beverages represent a convenient option, as they are easy to consume and allow adjustment of nutrient composition. According to GOST R 56543–2015, a product is considered functional if it provides 15–50% of the recommended daily intake of biologically active compounds per serving. This requires careful selection of both raw materials and processing approaches.

However, many plant-based beverages are mainly designed to supplement vitamins and minerals. Their protein content, especially in terms of essential amino acids, often remains insufficient. For this reason, plant proteins are increasingly considered as an alternative to animal sources, offering both nutritional and practical advantages. They are more accessible, more sustainable, and allow increasing the overall nutritional value of products. Among them, legumes stand out due to their relatively high protein content and balanced amino acid composition [3].

Mung bean (*Vigna radiata* L.) is a good example. It contains around 20–25% protein and also includes a number of bioactive compounds, such as γ-aminobutyric acid and glutamine. Because of this, it is often seen as a promising ingredient for functional foods.

At the same time, in its raw form, mung bean protein is not fully available for digestion. To improve this, different processing methods are used. One of the simplest and most effective is germination. During this process, enzymes inside the seed become active. Proteins begin to break down, and the amino acid composition changes [4].

Germination can significantly improve the nutritional value of mung bean. It increases digestibility, reduces antinutritional compounds, and leads to the formation of useful metabolites. However, how effective this process depends on the conditions. In particular, the composition of the medium plays an important role. Sucrose is not only an energy source – it can also influence metabolic activity during germination and affect how these changes occur [5].

Taken together, these points show that improving the amino acid composition of plant raw materials is still a relevant task, especially for the development of functional beverages.

2. Literature review and problem statement

Many studies have shown that processing methods can improve the nutritional quality of legumes. During germination, the seed becomes metabolically active. Enzymes start working, storage proteins begin to break down, and amino acids become more available. As a result, protein is easier to digest [6].

At the same time, germination is still being actively studied. It is clear that it can improve amino acid composition and increase the content of bioactive compounds. But the results are not always stable. In some cases, the changes are significant, in others – much less noticeable. This makes it difficult to control the process and reproduce the same results.

The reason is that germination is quite a complex process. It depends on many factors – from the properties of the seed to environmental conditions. Even small differences can affect the outcome. In addition, when more complex approaches are used, such as microbial cultures, the process becomes more expensive and harder to scale for real production.

A possible way to overcome these difficulties is the use of metabolically active additives capable of regulating endogenous biochemical pathways without introducing external microbial systems. Such an approach is particularly relevant for plant-based food development, where legumes are recognized as sustainable and nutritionally valuable protein sources [7]. These findings emphasize the strategic importance of legumes in future food systems and support the search for scalable protein-enhancing technologies. It has also been demonstrated that plant proteins function not only as nutrient carriers but as structural and functional components in modern food matrices [8], reinforcing the importance of improving their qualitative characteristics.

Despite the high nutritional potential of mung bean, the bioavailability of its proteins in the native form remains limited. Germination has been reported to reduce antinutritional factors such as phytates, protease inhibitors, and lectins, thereby improving protein digestibility [9]. These findings confirm that enzymatic transformations during processing directly affect protein quality and bioavailability.

The efficiency of germination-based strategies largely depends on substrate composition and metabolic regulation. In this context, sucrose has been identified as an important carbon source influencing metabolic pathways during sprouting. It has been shown that sucrose supplementation enhances antioxidant activity and accumulation of bioactive compounds in mung bean sprouts, while physiological studies have demonstrated that soluble sugars regulate metabolic activity in legume cotyledons [10]. These findings indicate that carbohydrate availability can act as a metabolic regulator during early seed development.

However, despite the availability of advanced chromatographic techniques for amino acid quantification [11], systematic analysis of time-dependent amino acid dynamics under metabolic modulation remains insufficient. These findings confirm that reliable analytical tools exist, yet they are not consistently applied in germination studies focusing on protein quality.

Some attempts to overcome protein-related limitations in plant-based foods involve the use of starter cultures and controlled processing systems. Nevertheless, such strategies increase technological complexity and may limit industrial scalability. An alternative approach based on simple carbohydrate supplementation has been partially explored [12–14], yet its targeted impact on amino acid transformations during germination has not been comprehensively characterized. These findings suggest the potential of metabolic regulation but do not provide a systematic analysis of amino acid profile modulation.

Although germination has been extensively studied in legumes such as soybean and lupin, data on the targeted modulation of amino acid composition in mung bean remain limited. Moreover, while sucrose is applied during germination processes, its effect on the spectrum of free amino acids determined by HPLC has not been sufficiently investigated.

All this shows that it makes sense to study in more detail how amino acids change in mung bean seeds during germination, especially if the process is influenced by simple additives. This is important if it is necessary to develop practical and affordable ways to improve plant protein quality for functional foods.

Even though germination of legumes has been studied quite widely, there is still not much detailed information on how amino acid composition can be specifically controlled in mung bean. In particular, the role of sucrose in changing the profile of free amino acids, especially based on chromatographic data, is not well described.

3. The aim and objectives of the study

The aim of this work was to improve the amino acid composition of a functional beverage based on mung bean by modifying the germination process. The focus was on using a simple approach that could be applied in practice and help increase the nutritional value of plant proteins.

To reach this aim, the following objectives were defined:

– to track how amino acid composition changes during germination;

– to evaluate the effect of sucrose on the accumulation of non-essential amino acids;

– to identify the most suitable germination time based on amino acid levels;

– to assess the potential use of sucrose-treated sprouts as a protein ingredient for functional beverages.

4. Materials and methods

4. 1. The object and hypothesis of the study

The study was based on a functional beverage made from sprouted mung bean seeds. The results were used to improve its protein quality.

It was expected that adding sucrose during germination would increase amino acid content compared to germination in water. This assumption was based on the idea that sucrose may influence internal biochemical processes in the seed.

The sprouting device was assumed to provide stable conditions, including temperature and humidity, which are important for enzyme activity. The selected sucrose concentration (2%) was chosen as a level that could affect metabolism without interfering with sprout growth.

The experiments were carried out under simplified conditions. Germination was performed at a constant temperature without changing environmental parameters. Microbial effects were not taken into account, and no microorganisms were added. The analysis focused only on amino acid composition, without considering other properties.

4. 2. Raw material

Mung bean seeds (*Vigna radiata* L., cv. Zhasyl dän) were obtained from a local supplier. Seeds were sorted to remove damaged or immature units. The initial moisture content was 11–12%.

4. 3. Germination procedure

Germination was done using a household sprouting machine (China). It allows to control temperature (10–35°C), keep high humidity (up to 90%), and supply water automatically.

Two groups were used:

– control – seeds with distilled water;

– treatment – seeds with 2% sucrose solution (prepared in distilled water).

Before starting, the seeds were washed for a 2–3 minutes and then soaked in water (1:3 ratio).

The germination lasted 72 hours. Samples were taken at the beginning (0 h), and then after 24, 48, and 72 hours. In total, seven samples were collected for further analysis.

During germination, the seeds were rinsed by hand every 8–12 hours. In the treatment group, the sucrose solution was added again after each rinsing.

4. 4. Sample preparation

After each stage, the sprouts were washed and lightly dried with paper. Then they were labeled and sent to a laboratory in Almaty for analysis.

4. 5. Amino acid determination

Amino acids were measured using standard laboratory methods. The samples were first treated with acid, then extracted, and after that analyzed.

The analysis was done using HPLC with fluorescence detection. A standard column and usual conditions were used. The results were calculated as mg per 100 g of dry weight.

4. 6. Statistical analysis

All measurements were done three times. The results are shown as average values with standard deviation.

Data processing and graphs were made using GraphPad Prism (GraphPad Software, USA).

4. 7. Supplementary materials

The full protocol is available in Zenodo [15]. It includes detailed information about sample preparation, analysis steps, and amino acid data.

5. Results of metabolic modulation of amino acid composition during sprouting

5. 1. Dynamics of total amino acid content during sprouting under metabolic modulation

Germination of Vigna radiata seeds led to a consistent increase in total amino acid content across all samples. In the control (0 h), the total amino acid pool was 21,539 mg/100 g DW.

In seeds germinated without sucrose, values increased to 23,471 mg/100 g DW (24 h) and peaked at 25,956 mg/100 g DW (48 h), followed by a slight decrease at 25,166 mg/100 g DW (72 h).

Sucrose supplementation produced higher values at all stages: 23,995 mg/100 g DW (24 h), 26,656 mg/100 g DW (48 h), and 25,758 mg/100 g DW (72 h).

These trends are illustrated in Fig. 1.

The general pattern of carbohydrate-stimulated amino acid accumulation during germination is consistent with earlier observations in legume bioprocessing.

A detailed profile of individual amino acids across all samples is provided in Table 1.

Table 1

Amino acid composition of mung bean seeds under different germination conditions (mg/100 g)

Amino acid	Control (0 h)	No sugar (24 h)	No sugar (48 h)	No sugar (72 h)	With sugar (24 h)	With sugar (48 h)	With sugar (72 h)
1	2	3	4	5	6	7	8
Aspartic acid + Asparagine	2658	2875	3245	3142	2938	3315	3213
Threonine	605	654	714	708	668	729	724
Serine	1142	1248	1397	1297	1275	1428	1326
Glutamic acid + Glutamine	3966	4324	4760	4643	4417	4916	4743
Glycine	725	799	879	839	816	898	857
Alanine	853	939	1049	1069	959	1071	1091
Valine	1178	1299	1430	1379	1350	1459	1408
Methionine	278	299	329	324	306	337	332

Continuation of Table 1

1	2	3	4	5	6	7	8
Leucine + Isoleucine	2895	3170	3493	3398	3233	3654	3489
Tyrosine	699	758	839	789	775	857	806
Phenylalanine	1486	1604	1798	1727	1642	1836	1796
Lysine	1523	1652	1799	1779	1688	1838	1816
Histidine	618	680	748	711	694	765	724
Arginine	1679	1829	1996	1927	1867	2040	1969
Proline	956	1042	1149	1121	1061	1173	1142
Cysteine	73	79	87	84	82	90	87
Tryptophan	205	220	244	229	224	250	235

Note: values are presented as mean concentrations (mg/100 g dry weight). Control (0 h) – unfermented seeds; "No sugar" – germination without sucrose; "With sugar" – germination with 2% sucrose.

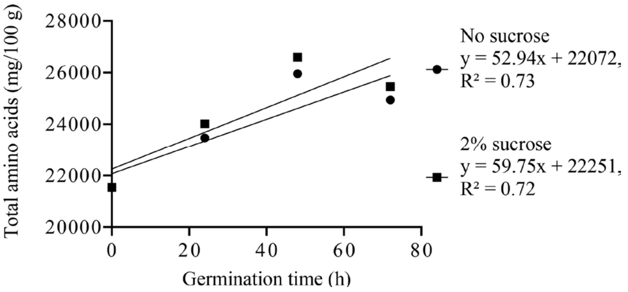

Fig. 1. Total amino acid content during sprouting

5. 2. Effect of metabolic modulation on non-essential amino acid composition during sprouting

Non-essential amino acids represented the largest fraction of the amino acid profile. Glutamic acid + glutamine increased from 3966 to 4916 mg/100 g (48 h, sucrose). Glutamate enrichment is a known indicator of storage protein breakdown during germination [16].

Aspartic acid + asparagine increased from 2658 to 3315 mg/100 g. Arginine rose from 1679 to 2040 mg/100 g. Similar arginine increases have been reported in legume-based systems. Tyrosine increased from 699 to 857 mg/100 g.

Alanine, glycine, serine, and proline showed increases of 22–26%, consistent with reported nitrogen remobilization in early sprouting. Cysteine exhibited the smallest increase but still rose by ≈23%. A heat map of all amino acids under different germination conditions is shown in Fig. 2.

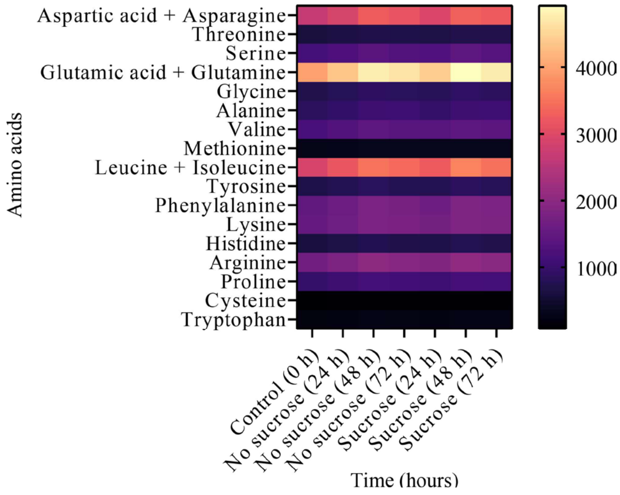

Fig. 2. Heatmap of amino acid composition during mung bean germination

Overall, the heatmap visualization confirms that sucrose supplementation intensified the accumulation of most non-essential amino acids, particularly glutamic and aspartic acid derivatives, which are closely associated with active nitrogen remobilization during sprouting. The pronounced increase at 48 h indicates that this period corresponds to the highest metabolic activity.

5. 3. Identification of the metabolically optimal sprouting duration

Amino acid levels peaked at 48 h, after which a minor decline (3–5%) was observed. This metabolic transition reflects the shift from proteolysis to biosynthetic incorporation typical of late germination stages (Fig. 3).

Changes in selected amino acids (Glu + Gln, Leu + Ile, Valine, and Tryptophan) during germination of mung bean seeds under control conditions and in the presence of 2% sucrose. Data points represent experimental values; solid lines indicate linear regression.

Linear regression equations and coefficients of determination (R^2) are as follows:

– Glu+Gln (No sucrose):

$$y = 10.28x + 4053,\ R^2 = 0.7995; \tag{1}$$

– Glu+Gln (Sucrose):

$$y = 11.79x + 4086,\ R^2 = 0.7646; \tag{2}$$

– Leu+Ile (No sucrose):

$$y = 7.633x + 2964,\ R^2 = 0.7882; \qquad \text{`(3)}$$

– Leu+Ile (Sucrose):

$$y = 9.179x + 2987,\ R^2 = 0.7392; \tag{4}$$

– Valine (No sucrose):

$$y = 3.058x + 1211,\ R^2 = 0.7446; \tag{5}$$

– Valine (Sucrose):

$$y = 3.329x + 1229,\ R^2 = 0.7121; \tag{6}$$

– Tryptophan (No sucrose):

$$y = 0.4000x + 210.1,\ R^2 = 0.5753; \tag{7}$$

– Tryptophan (Sucrose):

$$y = 0.4833x + 211.1, R^2 = 0.6247. \quad (8)$$

In all samples, amino acid levels increased up to 48 hours. After that, a slight decrease of about 3–5% was observed. This likely happens because, after active protein breakdown, amino acids begin to be used for the formation of new compounds.

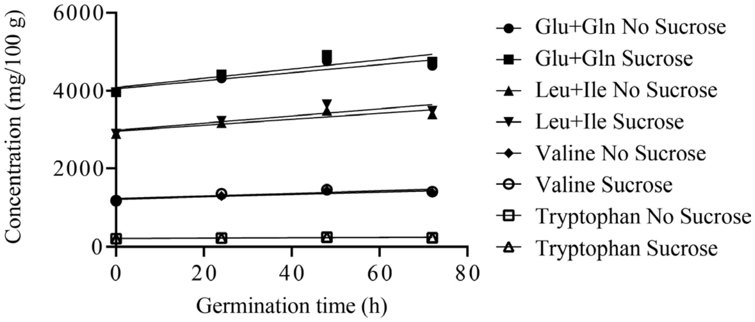

Fig. 3. Dynamics of selected amino acids during mung bean germination

The data in Fig. 3 show that the highest amino acid content is reached at 48 hours. This suggests that this time can be considered the most suitable duration for germination.

5. 4. Integrated effect of sucrose supplementation on amino acid profile

When sucrose was added, the total amino acid content increased by about 13–25% compared to the control. At the same time, the balance between essential and non-essential amino acids remained largely unchanged.

The increase was most noticeable for glutamate and aspartate, which are linked to umami taste. Levels of important amino acids such as lysine, tryptophan, and arginine also became higher.

The amino acid composition after 48 hours of germination is shown in Fig. 4.

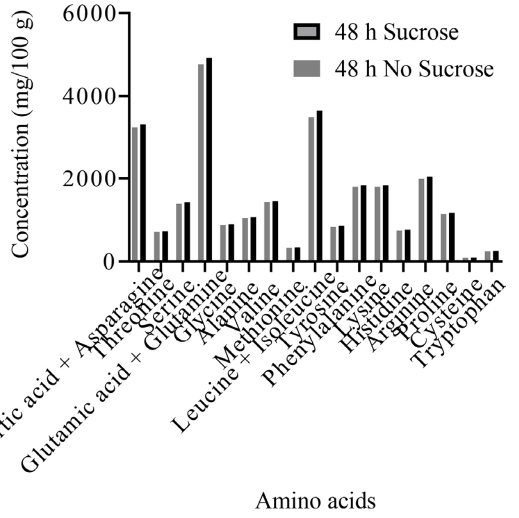

Fig. 4. Amino acid profile at 48h with and without sucrose

Overall, sucrose supplementation exerted a clear stimulatory effect on amino acid metabolism during germination without altering the relative balance between essential and non-essential amino acids. The selective increase in glutamate and aspartate levels suggests intensified nitrogen remobilization and may contribute to improved sensory characteristics, while elevated levels of lysine, tryptophan, and arginine highlight the nutritional relevance of metabolic modulation for functional food applications.

6. Discussion of the effect of sucrose-modulated germination on amino acid accumulation in mung bean seeds

Germination of mung bean seeds led to a steady increase in total amino acid content. When sucrose was added, this increase became more pronounced. As shown in Fig. 1 and Table 1, amino acids accumulated over time and reached their highest values at 48 hours.

This can be explained by what happens inside the seed during germination. Enzymes become active first, then storage proteins begin to break down, and free amino acids are released. Similar changes have been reported earlier for other legumes.

The largest increases were seen for glutamic and aspartic acids. Their levels rose by about 23–25% with sucrose (Table 1, Fig. 2). These amino acids are directly involved in nitrogen metabolism, so their growth reflects higher metabolic activity. In simple terms, the seed is actively using and processing its internal reserves. Comparable patterns have also been described in other studies on germinated legumes.

Overall, the increase in amino acids follows the same trend reported in earlier work, where enzyme activation leads to protein breakdown and release of amino acids [17]. However, in this study the effect was stronger when sucrose was present. Both essential and non-essential amino acids showed a more noticeable increase compared to germination in water. This suggests that sucrose may influence metabolic processes, not just serve as an energy source.

A similar effect was observed for essential amino acids. Lysine, valine, leucine, and isoleucine all increased in the presence of sucrose (Fig. 4). One possible explanation is that additional carbohydrates provide more carbon for amino acid synthesis. As a result, the seed can form amino acids more actively. Similar relationships between carbohydrate availability and amino acid formation have been reported for legumes.

The increase in tryptophan supports this explanation. Taken together, the results suggest that sucrose can affect metabolic activity during germination. Earlier studies mainly focused on antioxidant properties and bioactive compounds [18], while here the main focus was on changes in amino acids over time. This helps to better understand how simple factors like carbohydrate availability can influence protein quality.

More detailed data show that all essential amino acids increased during germination, with the highest values observed at 48 hours. For example, lysine increased from 1,523 mg/100 g at 0 h to 1,799 mg/100 g after 48 hours in water, and to 1,838 mg/100 g with sucrose. This supports the idea of more active protein breakdown during germination.

Valine increased from 1,178 to 1,430–1,459 mg/100 g, while leucine + isoleucine increased by approximately 26%, reaching up to 3,654 mg/100 g in sucrose-treated samples. Methionine rose from 278 to 337 mg/100 g, and tryptophan increased from 205 to 250 mg/100 g.

The increase in tryptophan is consistent with previously reported trends in sprouted legumes under carbohydrate-enriched conditions [19]. Overall, these changes reflect active metabolic mobilization rather than shifts in amino acid proportions.

A notable result was the accumulation of arginine, which increased by more than 20% under sucrose supplementation (Table 1). Given its function as a major nitrogen storage and transport amino acid in germinating seeds, this increase indicates intensified nitrogen redistribution, consistent with earlier observations in germination -based studies on legume matrices.

Analysis of temporal dynamics showed that amino acid concentrations peaked at 48 h of germination (Fig. 3), followed by a minor decline of 3–5%. This decrease likely reflects a metabolic shift from intensive proteolysis to the incorporation of amino acids into newly synthesized proteins or secondary metabolites, confirming 48 h as a metabolically optimal stage for amino acid enrichment.

In addition to nutritional enhancement, sucrose supplementation increased glutamate and aspartate levels, which are associated with umami taste perception. Similar biochemical changes have been linked to improved sensory properties in germinated mung bean products [20], suggesting potential benefits for flavor development in plant-based formulations.

From a technological perspective, the absence of visible spoilage during 72 h of germination and the maintenance of metabolic activity under sucrose-modulated conditions suggest acceptable process stability under the tested conditions (Fig. 1–3). Such effects have been associated with mild germination conditions that suppress undesirable microflora while supporting beneficial metabolic transformations, which is relevant for simple and household-scale sprouting systems.

This study has several limitations. First, the experiments were done only at laboratory scale, and no microorganisms were used. The analysis was focused only on amino acids. Other important changes, such as organic acids or pH, were not measured. In addition, no sensory evaluation was carried out, so it is not clear how the product would be perceived by consumers.

These points can be improved in future work. It would be useful to include more types of analysis, both chemical and sensory. Also, it makes sense to study other metabolic indicators and not only amino acids. Further studies could test different carbohydrates, apply the method to other legumes, and check how stable the results are at larger scale.

At the same time, the results show that using sucrose during germination is a simple and effective way to increase amino acid content in mung bean. This approach can be useful for developing functional ingredients. It may also be applied in the production of functional beverages with a more controlled amino acid composition. Overall, this method looks practical and does not require complex technologies.

7. Conclusions

1. Germination of mung bean seeds led to a clear increase in total amino acid content over time. In the control group, the value reached 25,956 mg/100 g dry weight. This shows that even without additional treatment, germination itself improves amino acid availability due to enzyme activity and breakdown of storage proteins.
2. Non-essential amino acids changed differently during sprouting. Glutamic and aspartic acids increased by about 23–25%, while arginine increased by more than 20%. This reflects active nitrogen metabolism during the process.
3. The results show that 48 hours is the most effective time for germination. After that, a slight decrease (about 3–5%) in total amino acids was observed. Most likely, this happens because amino acids start being used to form new proteins and other compounds.
4. When sucrose was added, amino acid content increased by 13–25%. This confirms that such sprouts can be used as a protein source in functional beverages. The method is simple, can be scaled, and does not require microorganisms.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

Manuscript has associated data in a data repository. Data confirming the results of this study are available in the Zenodo repository at the following link: https://doi.org/10.5281/zenodo.15094675.

Use of artificial intelligence tools

The authors declare the limited use of artificial intelligence tools during the preparation of the manuscript.

The AI tool used was ChatGPT (OpenAI, GPT-4 series).

Artificial intelligence was applied exclusively for language editing and stylistic refinement of the manuscript, including improvement of academic English, clarification of sentence structure, and enhancement of text coherence in the Introduction, Results, Discussion, and Conclusion sections.

All scientific content, including experimental design, data acquisition, data analysis, interpretation of results, tables, figures, and conclusions, was developed exclusively by the authors.

The authors carefully reviewed, verified, and edited all AI-assisted text to ensure scientific accuracy, consistency with the experimental data, and compliance with journal requirements.

The use of artificial intelligence did not influence the scientific conclusions of the study, which are fully based on experimentally obtained results and the authors' own analysis.

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Authors' contributions

Aliya A. Makenova: Investigation; **Saltanat J. Mussayeva**: Supervision; **Dina R. Dautkanova**: Project administration; **Zhibek K. Ussembayeva**: Methodology; **Nurlan B. Dautkanov**: Data Curation.

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