UDC 631.529:635.49.
AGRIS J11
https://doi.org/10.33619/2414-2948/132/41

PRODUCTION OF AMARANTH LEAF TEA (*Amaranthus cruentus* 'Valentina') BY FERMENTATION AND ANALYSIS OF ITS CHEMICAL COMPOSITION

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ПРОИЗВОДСТВО ЧАЯ ИЗ ЛИСТЬЕВ АМАРАНТА (*Amaranthus cruentus* 'Valentina') МЕТОДОМ ФЕРМЕНТАЦИИ И АНАЛИЗ ЕГО ХИМИЧЕСКОГО СОСТАВА

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Abstract. This study developed a technology for producing functional tea from the green leaves of amaranth (*Amaranthus cruentus* L. 'Valentina') using a fermentation-based processing method. The chemical composition of the resulting tea was analyzed, and its potential as a value-added food product was evaluated. For the first time under the conditions of Azerbaijan, amaranth leaves were processed using a technology adapted from conventional black tea production, and the nutritional value of the resulting product was assessed on a scientific basis. The findings demonstrate that the leaves of *Amaranthus cruentus* 'Valentina' represent a promising raw material for the production of fermented functional tea. The relatively high protein content and the determined chemical parameters provide a basis for assessing the nutritional and biological potential of the product. The study is also relevant to the development of new income-generating opportunities for farmers, diversification of the domestic herbal tea market, and reduction of dependence on imported tea products. The adaptation of a conventional black tea processing approach to amaranth leaves provides an opportunity to convert plant-based raw materials into value-added products. Under the agroecological conditions of Azerbaijan, the feasibility of processing Amaranthus cruentus 'Valentina' leaves into a fermented tea product was investigated, and the principal chemical characteristics of the resulting product were determined. These findings provide a preliminary scientific basis for further studies aimed at optimizing fermentation duration, temperature regimes, particle size, and drying parameters, as well as for the precise instrumental determination of total phenolic compounds, flavonoids, betalains, antioxidant activity, vitamins, and mineral elements in the final product.

Аннотация. Разработана технология производства функционального чая из зеленых листьев амаранта (*Amaranthus cruentus* L. 'Valentina') методом ферментации. Был проведен анализ химического состава полученного чая и оценен его потенциал как пищевого продукта с добавленной стоимостью. Впервые в условиях Азербайджана листья амаранта были обработаны по технологии, адаптированной для производства обычного черного чая, а пищевая ценность полученного продукта была оценена с научной точки зрения. Результаты исследования показывают, что листья амаранта *Amaranthus cruentus* 'Valentina' являются перспективным сырьем для производства ферментированного функционального чая. Относительно высокое содержание белка и определенные химические показатели дают

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Т. 12. №11 2026
https://doi.org/10.33619/2414-2948/132

основания для оценки питательной ценности и биологического потенциала продукта. Исследование актуально с точки зрения создания новых возможностей для получения дохода фермерами, диверсификации внутреннего рынка травяных чаев и снижения зависимости от импортной чайной продукции. Адаптация традиционного подхода к обработке черного чая для обработки листьев амаранта дает возможность превращать растительное сырье в продукты с добавленной стоимостью. Полученные результаты создают предварительную научную основу для дальнейших исследований, направленных на оптимизацию продолжительности ферментации, температурных режимов, размера частиц и параметров сушки, а также на точное инструментальное определение общего содержания фенольных соединений, флавоноидов, беталаинов, антиоксидантной активности, витаминов и минеральных элементов в конечном продукте.

Keywords: amaranth, fermentation, functional tea, protein, energy value, value addition.

Ключевые слова: амарант, ферментация, функциональный чай, белок, энергетическая ценность, добавленная стоимость.

In recent years, increasing attention has been paid to healthy and balanced nutrition, the production of food products enriched with biologically active compounds of natural origin, and the diversification of functional foods. Polyphenols, flavonoids, pigments, vitamins, minerals, and other biologically active compounds present in plant-based raw materials play important roles in antioxidant, anti-inflammatory, and other physiological processes in the human body. In this context, the development of next-generation functional beverages, particularly teas produced from natural plant-based raw materials, has emerged as a promising area of research [4].

Amaranth (*Amaranthus cruentus* L.) is a valuable plant that has been used since ancient times for food, feed, and medicinal purposes. In recent years, it has been established that not only amaranth seeds but also its leaves possess considerable nutritional and biological value. Amaranth leaves are characterized by their richness in proteins, mineral elements, vitamins, phenolic compounds, flavonoids, carotenoids, and other phytochemicals. The dark red to purple coloration of the leaves of *Amaranthus cruentus* ‘Valentina’ suggests a potentially high content of biologically active pigments and antioxidant compounds. The preservation of biologically active substances during the processing of plant-based raw materials and the enhancement of their bioavailability are important considerations in the development of functional food products. In this regard, fermentation is considered a promising technological approach for converting plant leaves into functional tea products. The biochemical changes occurring in plant tissues during fermentation may affect the composition and concentration of phenolic compounds, antioxidant activity, as well as the color, taste, and aroma characteristics of the resulting product. Appropriate control of the fermentation process may enhance the functional properties of the raw material while producing a tea product with improved sensory characteristics and greater consumer appeal [6, 11].

The production of tea from amaranth leaves through fermentation is also important for expanding the utilization of this plant as a non-conventional food raw material. The development of such products enables the efficient use of local plant resources, broadens the range of naturally derived functional beverages, and facilitates the development of novel food products rich in biologically active compounds. Furthermore, investigating the chemical composition of the resulting tea is essential for the scientific assessment of its nutritional and biological value [3].

In this context, the determination of total phenolic compounds, flavonoids, antioxidant activity, pigments, vitamins, minerals, and other major chemical constituents in fermented amaranth leaves is

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Т. 12. №11 2026
https://doi.org/10.33619/2414-2948/132

of particular importance. At the same time, investigating the effects of fermentation duration and processing conditions on the chemical composition and functional properties of the final product may contribute to the identification of optimal technological parameters. The study entitled "Production of Functional Tea from Amaranth (*Amaranthus cruentus* 'Valentina') Leaves Using a Fermentation Method and Analysis of Its Chemical Composition" addresses a relevant research topic at the intersection of modern food biochemistry, plant biotechnology, and functional nutrition. The findings may contribute to the evaluation of amaranth leaves as an alternative plant-based raw material, the improvement of their processing technology, and the establishment of a scientific basis for the development of functional tea products enriched with biologically active compounds [8, 10].

Materials and Methods

The study was conducted at an experimental educational farm in Azerbaijan on an experimental plot with a total area of 8 m². The study site is characterized by a temperate continental climate. The soil is classified as meadow-gray soil and has moderate fertility. Neither mineral nor organic fertilizers were applied during cultivation, with the aim of obtaining environmentally clean plant material. The plant material used in the study was the red-leaved form of Amaranthus cruentus 'Valentina'. This cultivar is distinguished from other cultivars by its intense red coloration, abundant leaf biomass, high protein content (25–30%), and betacyanin content. The seeds were sown with an inter-row spacing of 50 cm and an intra-row spacing of 10 cm. Crop management consisted of weed removal and, when necessary, light irrigation. Leaves of *Amaranthus cruentus* 'Valentina' were used as the experimental material. The leaves were manually harvested before the flowering stage, during the middle stage of vegetation, when the plants had reached a height of 40–50 cm. The total experimental plot area was 8 m², yielding an average of approximately 10 kg of fresh leaves per 1 m² and a total of 80 kg of fresh leaf material. After harvesting, the leaves were cleaned of mechanical impurities and subsequently subjected to fermentation. The tea production process consisted of four consecutive stages: withering, crushing, fermentation, and drying. The leaves were withered for 24 h under shaded and well-ventilated conditions and were subsequently mechanically crushed. The crushed leaf mass was fermented under pressure at a temperature of 25–30 °C for 20 h. Upon completion of fermentation, the material was dried at 45–50°C [2].

The total protein content of the fermented tea samples was determined using the Kjeldahl method. This method is based on the determination of total nitrogen in the sample and the calculation of crude protein content from the measured nitrogen concentration using an appropriate standard methodological approach. Dry matter and moisture contents were determined using a KERN moisture analyzer. The contents of NDF (Neutral Detergent Fiber), ADF (Acid Detergent Fiber), and cellulose fractions were determined using an appropriate fiber analyzer. These parameters were used to characterize the structural components of the plant cell wall and to evaluate the fiber fraction of the product obtained after fermentation [5, 9].

Rapid instrumental assessment of the overall chemical composition of the tea samples was performed using NIR (Near-Infrared) spectroscopy with a DA 3500 NIR analyzer used in the laboratory. NIR spectroscopic analysis is based on the measurement of the spectral characteristics of samples in the near-infrared region and enables the rapid and non-destructive determination of key chemical composition parameters.

Discussion

In recent years, trends toward healthier diets and the search for alternatives to synthetic beverages have contributed to a rapid increase in demand for herbal teas. According to global market statistics, the herbal tea market was valued at approximately USD 3.5 billion in 2023 and is projected to reach USD 5.2 billion by 2030. Consumers are increasingly seeking natural, organic, and functional products that provide nutritional value and contribute to energy intake. In this context, amaranth

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Т. 12. №11 2026
https://doi.org/10.33619/2414-2948/132

(*Amaranthus* spp.) possesses considerable potential as an alternative plant-based raw material. Its leaves are rich in protein (20–30%), essential amino acids such as lysine, threonine, and methionine, vitamins (A, C, E, K, and B-complex vitamins), minerals (iron, calcium, magnesium, zinc, and potassium), and biologically active compounds, including betacyanins, phenolic acids, and flavonoids. This nutritional and phytochemical profile highlights the potential of amaranth as a valuable plant-based resource compared with other leafy vegetables, such as spinach, lettuce, and beet leaves [1].

However, fresh amaranth leaves have a high moisture content, which makes them highly perishable, limits their storage stability, and may be associated with a certain degree of bitterness. Fermentation technology can be applied to overcome these limitations, extend the shelf life of the raw material, and improve the taste, aroma, and convenience of the resulting product for consumers. When the fermentation-based processing approach traditionally developed for black tea (*Camellia sinensis*)—including withering, crushing, fermentation (oxidation), and drying—is adapted to amaranth leaves, it may improve the sensory characteristics of the product while preserving, and potentially enhancing, its nutritional value and substantially extending its storage stability.

Furthermore, this technology can add value to agricultural products through primary processing and create an additional source of income for small-scale farmers. In Azerbaijan, the domestic demand for herbal tea products is currently met largely through imports. The production of tea from locally sourced plant materials could contribute to reducing import dependence, supporting local entrepreneurship, and creating additional employment opportunities in rural areas.

Taking all of these factors into consideration, the aim of the present study was to produce functional tea from the leaves of the ‘Valentina’ cultivar of amaranth using a fermentation method based on black tea processing technology; determine the chemical composition of the resulting tea through laboratory analyses; evaluate its nutritional value; and assess its economic potential.

The experiment was conducted on a total area of 8 m². During the vegetation period, 10 kg of fresh green leaves were harvested per 1 m². The fermentation technology consisted of four stages: withering of the leaves in the open air for 1 day, mechanical crushing, fermentation under pressure for 20 h, and drying at 45–50 °C. The chemical composition of the resulting tea sample was analyzed using a rapid analytical method in the laboratory of the Scientific Research Institute of Animal Husbandry. The results showed that the tea contained 28.39% protein, 7.01% crude ash, 6.71% NDF (Neutral Detergent Fiber), 26.29% ADF (Acid Detergent Fiber), 2.43% cellulose, and an energy value of 12.94 MJ/kg. The high protein content and relatively low fiber content distinguish the product from other herbal teas and may contribute to its mild, non-bitter, and nutritionally valuable characteristics.

According to the economic calculations, approximately 1 kg of finished tea can be obtained from 1 m² of cultivated area, corresponding to a potential yield of approximately 10 tons per hectare. For the first time under the conditions of Azerbaijan, amaranth leaves were processed using a technology adapted from conventional black tea production, and the nutritional characteristics of the resulting product were scientifically evaluated. The study is therefore relevant to the development of new income-generating opportunities for farmers, diversification of the domestic herbal tea market, and reduction of dependence on imported tea products.

During harvesting, the leaves were collected manually before the onset of flowering, during the middle stage of vegetation, when the plants were 40–50 cm in height and had accumulated substantial amounts of dry matter and protein. A yield of 10 kg of fresh green leaves per m² was obtained, resulting in a total harvest of 80 kg of fresh leaves from the 8 m² experimental area. Harvesting was carried out in the morning after the dew had evaporated, when the leaves were at their highest level of freshness. According to the fermentation-based tea production technology, the processing procedure consisted of four stages:

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Т. 12. №11 2026
https://doi.org/10.33619/2414-2948/132

1) Withering: Freshly harvested leaves were spread in a thin layer (3–5 cm) in an open, shaded, and well-ventilated area for 24 h. During this stage, the leaves became more pliable and the initial enzymatic processes were initiated. As a result of withering, the moisture content of the raw material decreased from approximately 80–85% to about 55–60%.

2) Crushing: The withered leaves were moderately crushed using a specialized mechanical crusher. This stage is particularly important because the disruption of cell walls facilitates the release of cell sap containing polyphenols, enzymes, proteins, and sugars and increases contact with atmospheric oxygen. The degree of crushing has a direct influence on the quality characteristics of the final tea. Therefore, crushing intensity was considered an important technological factor affecting the subsequent fermentation kinetics, physical structure, and organoleptic properties of the product.

3) Fermentation: The crushed leaf mass was placed in stainless-steel containers and kept under pressure for 20 h. Fermentation was carried out within a temperature range of 25–30 °C. During this stage, transformations of phenolic compounds occurred through the activity of naturally occurring oxidative enzymes in the leaf tissue. These biochemical changes resulted in noticeable modifications in the color and aroma characteristics of the raw material. Following fermentation, the leaf mass developed a dark reddish-brown color, a characteristic fruity-floral aroma, and a milder taste.

4) Drying: In the drying stage, the fermented leaf mass was dried in a specialized dryer at 45–50 °C until a constant weight was achieved. The relatively low drying temperature was selected to preserve the quality characteristics of the product and to minimize the potential adverse effects of excessive heat on biologically active components. The drying process terminated enzymatic reactions occurring within the leaf tissue, reduced water activity, and improved the storage stability of the final product. At the end of the technological process, a finished tea product was obtained from the fermented amaranth leaves.

CHEMICAL COMPOSITION OF AMARANTH (*Amaranthus cruentus* ‘Valentina’) TEA

Parameter	*Result*	*Evaluation*
Crude protein	28,39%	Very high – a potential protein source
Crude ash	7,01%	Within the normal range – indicative of mineral content
NDF (Neutral Detergent Fiber)	6,71%	Low – associated with a soft texture
ADF (Acid Detergent Fiber)	26,29%	Within the normal range
Crude cellulose	2,43%	Low to very low fiber content
Energy value	12,94 MC/kq	High energy value

The chemical composition of the finished fermented amaranth tea sample was determined using a rapid analytical method in the laboratory of the Scientific Research Institute of Animal Husbandry. Prior to analysis, the tea sample was homogenized. To improve the reliability of the measurements, all analyses were performed in triplicate, and the mean values were calculated from the obtained results. Within the framework of the study, the principal chemical parameters relevant to the nutritional and feed-related characteristics of the product were determined, including crude protein, crude ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), crude cellulose, and energy value. NDF and ADF were used for the determination of fiber fractions, while the energy value was estimated using an approach based on the NRC (2001) standards. According to the chemical analysis, the fermented amaranth tea contained 28.39% crude protein, 7.01% crude ash, 6.71% NDF, 26.29% ADF, and 2.43% crude cellulose, with an energy value of 12.94 MJ/kg. The obtained results indicate that the product is characterized by a relatively high protein content. In particular, the comparatively low level of crude cellulose may be considered a favorable characteristic in terms of the product's potential consumption properties.

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Т. 12. №11 2026
https://doi.org/10.33619/2414-2948/132

Analysis of the data presented in Table shows that the tea sample obtained through the fermentation of *Amaranthus cruentus* 'Valentina' leaves is characterized by a high protein content. The total protein content of 28.39% is an important indicator of the product's nutritional and biological potential. The crude ash content of 7.01% indicates a considerable presence of mineral substances in the sample. The NDF content of 6.71% and crude fiber content of 2.43% indicate that the product has a relatively low fiber fraction. The ADF content of 26.29% suggests that the structural components of the plant cell wall are retained at a certain level. The energy value of 12.94 MJ/kg is also an important parameter indicating the high energy potential of the product.

The obtained results demonstrate that the fermentation-based processing of *A. cruentus* 'Valentina' leaves enables the production of a plant-based tea product with a high protein content. Although the low NDF and cellulose values indicate a relatively low fiber load in the product, it is not possible to confirm solely on the basis of chemical analysis that these characteristics directly contribute to "softness" or "pleasant taste." Therefore, separate organoleptic and sensory analyses are recommended for evaluating these properties. At the same time, in order to conduct a quantitative comparison of amaranth tea with other traditional herbal teas in terms of protein and mineral content, the respective tea samples should be analyzed using the same methodology and on the same dry-matter basis, and the obtained results should be evaluated comparatively using appropriate statistical methods.

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Поступила в редакцию
14.09.2026 г.

Принята к публикации
28.09.2026 г.

Ссылка для цитирования:

Bayramova A., Asgarova A. Production of Amaranth Leaf Tea (*Amaranthus cruentus* ‘Valentina’) by Fermentation and Analysis of Its Chemical Composition // Бюллетень науки и практики. 2026. Т. 12. №11. С. 388-394. https://doi.org/10.33619/2414-2948/132/41

Cite as (APA):

Bayramova, A., & Asgarova, A. (2026). Production of Amaranth Leaf Tea (*Amaranthus cruentus* ‘Valentina’) by Fermentation and Analysis of Its Chemical Composition. *Bulletin of Science and Practice, 12*(11), 388-394. https://doi.org/10.33619/2414-2948/132/41

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