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MILLET IS A VALUABLE CROP FOR THE PRODUCTION OF GROATS AND GRAIN-BASED PRODUCTS

Abstract

Millet, being one of the oldest cereal crops, has a wide geographical distribution and serves as a key dietary component in many regions of the world. Its cultivation is concentrated in areas with arid climates and unfavorable conditions for other crops. Thanks to its resilience to poor soils and ability to withstand prolonged periods of drought, millet has become an indispensable source of food and animal feed in many countries of Africa, Asia, and parts of Europe. The primary regions for millet cultivation include West Africa, India, China, as well as certain parts of North America, Central Asia, and Eastern Europe. In West Africa, for instance, countries like Niger, Mali, and Senegal are leading producers of this crop. Millet is a staple food crop there, used to prepare traditional dishes such as porridges and beverages. China plays a significant role in millet production, cultivating it for both domestic consumption and export. In North America, millet is grown primarily for fodder, with the United States being the main producer. In Europe, millet occupies a limited portion of agricultural land, but some countries have seen its cultivation gain popularity due to the rising demand for healthy foods and drought-resistant crops. France and Italy are the primary European producers of millet. The chemical composition of millet makes it a unique crop among cereals. It is rich in proteins, carbohydrates, fats, minerals, and vitamins. The foundation of millet's chemical composition lies in complex carbohydrates, which provide energy and are slowly digested, making them particularly important for maintaining stable blood glucose levels. Millet protein has high biological value and contains essential amino acids like methionine and lysine, which are often lacking in other cereal crops. Additionally, millet is rich in healthy fats, including unsaturated fatty acids, which help normalize cholesterol levels in the body. Millet contains a significant amount of B vitamins, including thiamine (B_1), riboflavin (B_2), niacin (B_3), and pyridoxine (B_6). These vitamins play a key role in metabolic processes, support the nervous system, and contribute to overall health. Millet is also a source of tocopherol (vitamin E), which has antioxidant properties and protects cells from oxidative stress. The mineral composition of millet includes substantial concentrations of potassium, magnesium, phosphorus, iron, zinc, and copper. These minerals are crucial for the proper functioning of the cardiovascular system, bone tissue, blood formation, and the immune system. The high iron content is particularly noteworthy, making millet an important food for preventing anemia. The presence of antioxidants such as polyphenols and flavonoids gives millet anti-inflammatory properties and a positive impact on reducing the risk of chronic diseases, including diabetes and cardiovascular disorders.

Keywords: millet, types of millet, chemical composition of grain, protein content, fat content, carbohydrate content, vitamin content, groat production, millet processing products.

Introduction

Millet is one of the oldest and most important cereal crops, playing a significant role in ensuring food security in many countries worldwide. This grain is renowned for its resilience to adverse conditions such as drought, high temperatures, and poor soils. Due to these characteristics, millet is successfully cultivated in various climatic zones, including regions with challenging agricultural conditions.

The history of millet cultivation as a cereal crop dates back thousands of years. Archaeological evidence suggests that millet was among the first cereal crops cultivated by humans. In East Asia, particularly in present-day China, millet cultivation began during the Neolithic period, approximately 8–7 thousand years ago. Chinese sources refer to millet as a staple food alongside rice. Ancient Chinese people used millet to prepare porridge, soups, and even alcoholic beverages.

At the same time, millet spread to Europe through migration and trade. It played an essential role in the diet of ancient civilizations, including Greece and Rome. During medieval Europe, millet was a primary grain for making porridge and bread. It was widely grown in regions with infertile soils where other crops, such as wheat or barley, yielded poor harvests.

On the African continent, millet has been cultivated since ancient times. In regions like modern-day Mali, Niger, and Sudan, millet became a staple food source. Its tolerance to heat and drought allowed local communities to successfully grow millet even under the harshest conditions. In West Africa, millet is the foundation for traditional dishes such as pounded porridge, fermented beverages, and other products.

India also has a long history of millet cultivation, where it is known by names like "ragi" and "jowar." In northern and central regions of the country, millet was used to prepare flatbreads, porridges, and beverages. Due to its nutritional value and ability to grow in arid areas, millet became an indispensable part of the Indian diet, particularly among the poorer population.

In North America, millet gained popularity only in recent centuries, primarily as a fodder crop. However, indigenous peoples may have used wild millet species long before colonization. In modern times, interest in millet has increased due to its nutritional value and gluten-free properties, making it popular among individuals with gluten sensitivity [1-4].

In the territory of modern-day Ukraine, millet has been cultivated since ancient times. Archaeological findings indicate its use during the Trypillian culture period. Over the centuries, millet remained a vital component of the rural diet, as it was easy to grow and provided stable yields even in unfavorable years.

Literary review

Today, millet is one of the most important crops in the world, and its cultivation continues to expand due to its drought resistance and minimal water requirements. This crop is widely utilized in various regions globally, including Asia, Africa, Europe, and the Americas, although its role and production volumes differ significantly depending on the region. Worldwide, the total area under millet cultivation exceeds 35 million hectares, and this figure continues to grow.

India is the largest millet producer globally, with over 13 million hectares of cultivated land. Annually, India produces about 10 million tons of millet, accounting for approximately one-third of global production. China ranks second in millet production, with about 1.5 million hectares under cultivation and a total annual output of approximately 4 million tons. Africa is a key region for millet cultivation, with many countries actively involved in growing this crop. For instance, Nigeria is the largest millet producer in Africa, with about 3 million hectares of cultivated land.

In North and South America, millet is grown on a smaller scale compared to Asia and Africa, but its agricultural importance is increasing, especially due to growing interest in alternative crops that can withstand extreme climatic conditions. In North America, the United States is the leading millet producer, with cultivation gaining popularity due to its drought resistance and ability to adapt to diverse climatic conditions. In the U.S., millet cultivation areas range from 100,000 to 150,000 hectares, depending on the year, demand, and economic feasibility. Millet in the U.S. is primarily used for fodder purposes, but the increasing demand for gluten-free products and healthy foods is driving the development of a consumer market for millet products, including millet flour, grains, and other food products.

In Europe, millet occupies a limited portion of agricultural land, but several countries are seeing a rise in its cultivation due to growing demand for healthy foods and drought-resistant crops. France and Italy are the primary millet-growing countries in Europe. In France, millet cultivation covers about 50,000–60,000 hectares, while in Italy, the area is around 20,000–30,000 hectares. The limited cultivation of millet in Europe is attributed to the prevalence of other high-yield crops, such as wheat, corn, and barley. However, in recent years, millet has been gaining attention as a crop well-suited to climate change, particularly in areas increasingly affected by droughts.

Overall, millet cultivation in Europe and the America is becoming increasingly significant due to its ability to adapt to diverse climatic conditions and the growing need for drought-resistant crops to ensure food security [5-9].

In Ukraine, millet is one of the primary cereal crops, cultivated for its adaptability to various climatic conditions and economic efficiency. The main regions of millet cultivation are the steppe and forest-steppe zones, where favorable climatic conditions allow for stable yields even with minimal moisture levels. A significant portion of millet-growing areas is located in Chernihiv, Poltava, Kharkiv, Odesa, and Mykolaiv regions. In 2024, the sown area of millet in Ukraine was approximately 92.6 thousand hectares, showing a growth trend compared to previous years. Chernihiv region leads in total production, accounting for over 20% of the total harvested grain in Ukraine.

The State Register of Plant Varieties Suitable for Distribution in Ukraine lists 35 varieties of common millet (Panicum miliaceum L.) used as cereal grains. The most widespread variety in Ukraine is Myronivs'ke 51, registered in 1978. Kyivs'ke 87 and Kyivs'ke 96 were registered in 1991 and 1999, respectively. In the first two decades of the 21st century, new millet varieties were almost annually added to the Register. The largest number of varieties was registered in 2006, including Denviks`ke, Zolushka, Konstantynivs`ke, Lana, and Tavriis`ke. Over the past four years, six new varieties have been added to the Register: Dyvovyzhne (2020), Kazkove dzherelo (2020), Kornberger Mittelfruhe (2020), Yardush (2021), Kesha (2022), and Peremozhne (2023). These data indicate continuous work on millet breeding in Ukraine and the availability of promising modern varieties to expand the raw material base for cereal factories.

The economic significance of millet in Ukraine is also driven by its use in the food and feed industries. The demand for high-quality millet grain for both domestic consumption and export stimulates the development of breeding programs and improvements in cultivation technologies. In the future, this crop could occupy a larger share of cultivated land in regions facing water scarcity and requiring drought-resistant plants.

In the food industry, millet is primarily used for the production of groats, flour, and flakes. Millet groats are one of the main products derived from this crop. In Ukraine, millet groats are widely used for preparing traditional dishes, such as porridges. Due to its high nutritional value, millet is actively included in baby food and in the diets of individuals adhering to a healthy lifestyle. Millet groats are rich in essential nutrients, including proteins, carbohydrates, minerals (magnesium, potassium, iron), and B vitamins [10-11].

In recent years, the popularity of gluten-free products has grown in Ukraine, and millet has become an important alternative flour source. Millet flour is widely used in the production of gluten-free baked goods, such as bread, cookies, pancakes, and other pastries, making it popular among people with celiac disease or other gluten intolerance-related disorders. Ukraine also has manufacturers specializing in gluten-free products, where millet serves as a key ingredient.

Another significant area of production is millet flakes. This is a popular breakfast product sold both as a ready-to-eat option and as an ingredient for further use. Millet flakes are convenient to prepare, cook quickly, and retain most of the grain's beneficial properties. They can be consumed on their own or added to milk, yogurt, or fruit salads. Some companies also produce mixed millet flakes combined with other grains, fruits, or berries to create new flavor profiles.

Formulation of the problem

In Ukraine, the consumption of millet-based products remains limited, although this crop holds significant nutritional importance. Historically, millet was one of the staple grains, especially in rural areas, where it was used to prepare porridge and various dishes. However, over time, millet's role in the food industry has significantly diminished, and there is a noticeable decline in its consumption across Ukraine. This trend can be attributed to several factors, including changing dietary habits, economic challenges, and competition from other grains such as wheat, corn, and rice, which are more commonly included in Ukrainians' diets.

According to recent statistics, millet product consumption in Ukraine does not exceed a few tens of thousands of tons annually. The primary millet-based products consumed in the country include groats, flour, and flakes.

One key factor contributing to the low consumption of millet products in Ukraine is the dominance of other grain crops like wheat, corn, and rice in people's diets. Wheat occupies a leading position in Ukraine's grain market and serves as the main raw material for producing bread, baked goods, pasta, and other staple foods. Corn is widely used for animal feed, as well as for producing corn oil and food products. Meanwhile, rice has become a popular ingredient in Ukrainian cuisine, further positioning it as a competitor to millet.

The decline in millet consumption is also linked to various economic and social factors. One major reason is its low popularity among producers, resulting in a limited variety of millet products on the market. Additionally, millet is often less profitable for large agricultural enterprises compared to more popular crops like wheat or corn. As a result, millet does not receive sufficient support from major processing companies, which leads to reduced production volumes and limits the availability of millet products on the market.

Another important factor is the shift in culinary habits. Modern Ukrainian consumers often prefer more accessible and familiar products that require less time to prepare. While millet porridge is highly nutritious, it demands more preparation time and is less commonly used than rice or wheat-based products. Furthermore, younger generations are generally unfamiliar with traditional millet dishes, further reducing demand for such products.

Challenges related to the consumption of millet products in Ukraine also include a lack of adequate infrastructure to promote this crop. The market offers an insufficient range of millet-based products, which could otherwise meet contemporary consumer needs. Products such as millet groats, flour, flakes, and gluten-free items are only gradually gaining popularity, but they remain relatively inaccessible and are represented by a limited number of brands. This lack of variety acts as a barrier to wider millet consumption.

An additional issue is the limited availability of information about millet. Many consumers are unaware of its health benefits and potential role in a balanced diet. Modern marketing seldom focuses on millet, which leads to low awareness among Ukrainians regarding its advantages. Millet is rich in valuable micronutrients such as magnesium, phosphorus, iron, and potassium, as well as B vitamins, making it a vital food for maintaining good health.

Despite this, there are certain prospects for increasing the consumption of millet products in Ukraine. One of these paths is the promotion of healthy eating and gluten-free products, which has gained popularity in recent years. Consumers are increasingly interested in products that do not contain gluten, and millet is one of the best alternatives to traditional grains. Additionally, it should be noted that millet has great potential for producing products for diabetics, as it has a low glycemic index, making it beneficial for people suffering from this disease.

Considering all the above factors, it can be stated that the consumption of millet products in Ukraine is currently limited but has significant growth potential in the future. This crop is not only a source of valuable nutrients but also has the potential to become an important tool in the development of healthy eating and reducing dependence on other cereal crops.

One of the main problems faced by millet processors in Ukraine is the instability of the production of this crop. Although millet can be grown in large areas in Ukraine, particularly in the southern and central regions, in practice, its sown areas are often limited, and the area under millet has significantly decreased compared to other cereals. The decrease in the area under millet is due to several factors, including the low profitability of this crop compared to others such as wheat, corn, or rice. This is because millet, although it does not require large amounts of water, has a lower yield compared to other crops, making it less profitable for farmers. As a result, millet production in Ukraine is not stable, which complicates the planning of processing this crop at the enterprise level.

Instability in the supply of raw materials for processing is one of the main problems for processing enterprises. High dependence on weather conditions and climatic factors, which can affect millet yields, means that the available supply may vary from year to year. As a result, processing enterprises are not always able to ensure a stable supply of raw materials for the production of millet products, leading to reduced production volumes and losses in economic efficiency. Unstable millet supply may also increase processing costs because enterprises may have to buy raw materials at higher prices or import them from other regions or countries, which further increases costs.

Another problem is the lack of proper infrastructure for millet processing in Ukraine. The processing technologies for millet in Ukraine are often outdated and do not always meet modern market requirements. Most enterprises involved in millet processing do not have enough modern equipment to produce high-quality products, which limits their capabilities in domestic and foreign markets. These enterprises lack specialized lines for the production of gluten-free millet products, which limits their potential to expand the product range and meet the growing demand for gluten-free food products in Ukraine and worldwide.

Millet processors also face the problem of insufficient demand for millet products in the domestic market. Despite the high nutritional value of millet, its products are not very popular among Ukrainian consumers, which limits the market for processors.

Another important problem is the high level of competition in the grain product market, where millet often loses in terms of price and availability. Wheat, corn, and rice have much larger market demand and are represented in a greater variety of products. Therefore, millet processors do not have a stable customer base and struggle to compete with large players who have a large amount of raw materials for processing.

Another significant problem is the lack of infrastructure for the sale of millet products in foreign markets. Ukrainian enterprises often have limited access to international markets and cannot compete with other countries where millet production has a more developed infrastructure and quality standards. For example, in African and Asian countries, where millet is one of the main cereal crops, well-developed processing and sales networks exist, allowing their producers to ensure higher sales volumes. Ukraine, with its intense competition in the grain market, struggles to sell its products in international markets, reducing the economic attractiveness of investments in this industry.

One of the main problems with exporting millet from Ukraine is the small volumes of production of this crop compared to other cereals that the country exports to the global market. Ukraine is one of the largest producers and exporters of wheat and corn, but millet export volumes cannot compare. According to recent data, millet production does not exceed several hundred thousand tons per year, which is significantly less compared to other cereal crops. As a result, there is a limited amount of raw material for export, which creates problems for the development of export supplies.

One way to expand millet exports from Ukraine is the development of gluten-free products made from millet. There is a growing demand for gluten-free products worldwide, particularly among people with gluten intolerance and those leading a healthy lifestyle. Millet is one of the best sources of gluten-free products, making it promising for expanding export supplies to countries where there is a high demand for gluten-free products, such as the USA, European Union countries, and Japan. However, to realize this potential, it is necessary to significantly expand millet production and processing, as well as create the appropriate infrastructure for manufacturing gluten-free products that meet high-quality standards.

Ensuring export potential also requires the development of specialized millet processing technologies for products that can be competitive in international markets. To do this, it is necessary to modernize production capacities and introduce new technologies that preserve all the beneficial properties of millet during processing. Currently, Ukraine does not have a developed technological base for producing a wide range of millet products, so to develop the export potential of this crop, it is important to invest in scientific research and development in this field, as well as in innovative processing methods.

In Ukraine, millet production is regulated by the standard DSTU 5026:2008 "Millet. Technical Conditions." The grain is classified by purpose into four classes. For the production of groats, it is recommended to use grain of the 1st and 2nd classes, for the production of malt – the 3rd class, and for animal feed and technical purposes – the 4th class grain. The standard allows the use of grain of any of the three types in the food industry, but at the same time establishes certain quality requirements. In particular, the grain size must be at least 90% for the 1st class and at least 80% for the 2nd class. The mass fraction of grain impurities should not exceed 5% for the 1st class and 8% for the 2nd class, while foreign matter impurities should not exceed 2% and 3.5%, respectively. The content of the kernel in the grain must be at least 76% for the 1st class and at least 74% for the 2nd class. For the production of starch and its derivatives, it is recommended to use caryopses millet with an amylopectin content of at least 95%. DSTU defines types of millet based on its botanical characteristics and classifies millet grain according to various features, such as grain shape and color.

Yellow millet is one of the most common types of millet in Ukraine. Its grains are yellow or yellow-orange. This type is grown for the production of groats and flour and is also widely used for animal feed. Yellow millet has high nutritional value and is easily processed.

White millet grain is light white or creamy. White millet is grown for groats, flour, and can also be used to produce food products such as flakes or grains for gluten-free diets. White millet is often valued for its purity and is used in the confectionery and food industries.

Red millet has a characteristic red or dark orange color. Red millet is often used for feed production but can also be used in the production of certain food products due to its special properties, such as high nutritional value.

Black millet is less common in Ukraine but is still grown in some regions. Its grains are dark gray or black, and it is mainly used in the feed industry, although it can sometimes be found in specific food products.

Different types of millet, including yellow, white, red, and black, have their characteristic properties and uses, depending on climatic conditions, regional needs, and processing technologies. The nature of these types, as well as their economic significance, can vary depending on the continent where millet is grown, as well as on traditional and modern uses.

Yellow millet, one of the most common types in the world, plays a significant role in the food industry and is widely used in many countries where millet is a primary source of food. It is grown in countries such as India, China, Mexico, and African countries, where millet is an important part of the diet, particularly in regions with a dry climate. Yellow millet is a key component of many traditional dishes such as groats, flour, flakes, and even bread, which are important sources of nutrients for people living in areas where other cereal crops, like wheat or rice, cannot be grown due to extreme weather conditions. Additionally, yellow millet is an important ingredient in the production of gluten-free products, such as gluten-free crackers, cookies, and noodles, which are an essential part of healthy eating.

Moreover, due to its high energy value, yellow millet is actively used in sports nutrition, especially in the production of various energy bars and powders.

White millet, which is light white or creamy in color, is mainly grown in India, China, Sub-Saharan Africa, and South America. This grain is used as a staple food product in many countries, especially in regions where climatic conditions support millet cultivation and where other cereal crops cannot be successfully grown. White millet is widely used for producing groats, flakes, and flour, which serve as the basis for various dishes and products. In Africa, white millet is a key ingredient in the production of products such as "kenkey" (fermented millet), which is an important source of energy and protein for the population. Furthermore, white millet has high nutritional value and is frequently used in gluten-free diets, especially for producing gluten-free crackers and flour.

Red millet, which has a characteristic red or dark orange color, is less widespread but still holds significant importance in certain regions of the world, particularly in India and Sub-Saharan Africa. Red millet is used for animal feed production, especially for cattle and poultry, due to its high protein and nutrient content. In India, red millet is used to make traditional food products such as porridge, pasta, and even flour for baking.

In African countries, red millet is an important part of the diet, particularly in areas where there is limited access to other types of grains. It is also used to produce fermented products, such as alcoholic beverages, and is actively used in the agro-industrial sector to produce feed for livestock.

Black millet is the rarest type among the main millet varieties and is grown in limited quantities, mostly in countries such as China, India, and some parts of Africa. Black millet is notable for its high content of antioxidants and other bioactive compounds, which makes it popular in the production of healthy food products.

This type of millet is also widely used in biotechnology, particularly in the production of natural dyes and antioxidant supplements. In Ukraine and other countries, black millet is used in animal feed production, particularly for poultry and cattle, due to its high nutritional value [12, 13].

Materials and methods

The aim of the study is to analyze the chemical composition of different types of millet: yellow, white, and black, in order to determine the most suitable type of millet for expanding the existing range of millet processing products in Ukraine. The analysis includes the mass fraction of protein, amino acid composition, mass fraction of fat, fatty acid composition, carbohydrate complex, vitamins, and mineral composition of the grain.

Results of the study and their discussion

Millet is an important source of calories, protein, vitamins, and minerals, and its cultivation and processing contribute to economic development and food security in many countries around the world. Protein is one of the main components of cereal crops, and its mass fraction in millet varies depending on the type of millet, as well as the growing and processing conditions.

Yellow millet has an average protein content compared to all types of millet, ranging from 8% to 12%, depending on the variety, growing conditions, and processing.

White millet, which is also popular among other types, has a protein content ranging from 10% to 13%. White millet generally has a slightly higher protein content compared to yellow millet, making it a good choice for use in the food industry. The increased protein content of white millet, along with its high purity, makes it an excellent ingredient for producing gluten-free products, such as flour, flakes, or cereals. Due to its high nutritional properties, white millet is a popular product in countries where providing high-protein food to the population is important, especially in areas where access to other sources of animal protein is limited. The protein content in white millet provides its high nutritional value for people who need higher levels of protein in their diet, such as children, athletes, people with high physical activity, or elderly people.

Red millet has a protein content ranging from 9% to 11%. Although this type of millet is primarily used in animal feed production, it is also used in human nutrition, especially in regions where other cereal crops cannot be grown due to unfavorable climatic conditions. Red millet contains less protein compared to white and yellow millet, but it remains an important source of protein in countries where other crops, such as wheat or rice, are not available or cannot be grown due to water and weather constraints.

Black millet, which is the rarest type among millet varieties, has a high protein content ranging from 11% to 13%. This type of millet is mainly used for specialized food products and animal feeds. Its high protein content makes black millet useful for producing biologically active supplements, particularly for sports nutrition. Black millet is an important source of protein for producing compound feeds and feed additives that ensure animal health.

The amino acid composition of millet grain, like in any other cereal crop, is an important aspect for evaluating its nutritional value, especially in the context of using millet as a protein source for human nutrition and animal feed. According to millet types, the amino acid composition can vary significantly, as different millet varieties have different amino acid levels, which depend on factors such as climatic conditions, agronomic methods of cultivation, and processing techniques.

Yellow millet, one of the most common types of millet, has a fairly balanced amino acid composition, making it a good source of essential amino acids for the human body. The main amino acids found in yellow millet are leucine, lysine, isoleucine, threonine, and valine. The content of leucine in yellow millet is particularly high, making it important for protein synthesis in the human body. Leucine is an essential amino acid that cannot be synthesized by the body and must come from food. Leucine is necessary for tissue regeneration, especially muscle tissue, which is a key aspect of diets for athletes and people involved in physical labor. Yellow millet also contains a significant amount of lysine, another essential amino acid that plays a key role in tissue growth and development, as well as collagen synthesis and other compounds in the body.

Isoleucine, threonine, and valine are amino acids belonging to the branched-chain amino acid group, which help maintain normal energy metabolism and preserve muscle mass. The balanced ratio of these amino acids in yellow millet allows it to be used as an important source of protein for nutrition in countries where access to animal protein is limited or economically unavailable.

White millet, which is also popular among other millet types, has a similar amino acid composition to yellow millet, but its lysine content is typically slightly higher. This makes white millet particularly valuable for diets where high lysine content is important for growth and development, as well as for the production of high-protein food products. Lysine is critical for calcium absorption, which is particularly important for children's and elderly nutrition, as well as for people who are actively engaged in physical exercise and require a high level of this amino acid for muscle recovery.

In addition, white millet contains a significant amount of methionine, an amino acid with antioxidant properties that participates in protein synthesis to help protect cells from oxidative stress. Methionine is important for the normal functioning of the immune system and liver health. Due to its high methionine content, white millet has the potential to be used as an additional source of this amino acid in diets where methionine is deficient.

In addition to amino acids, white millet contains a significant amount of sulfur-containing amino acids, such as cystine and cysteine, which are essential for the normal functioning of the skin, hair, and nails. These amino acids also contribute to the production of glutathione, a powerful antioxidant that helps protect cells from damage and promotes detoxification in the body.

Red millet has a slightly different amino acid profile, as this type of millet typically contains less lysine and threonine but may have higher levels of other amino acids, such as phenylalanine and tyrosine. Phenylalanine is an amino acid that plays an important role in the production of neurotransmitters, such as dopamine, which is important for brain function and the central nervous system. The tyrosine content in red millet supports the normal function of the nervous system, helping to normalize metabolism and improve emotional well-being.

While red millet is typically used as animal feed or, to a lesser extent, for human consumption, its amino acid composition also makes it useful for producing feed mixtures for pigs, poultry, and cattle. Red millet is an important source of essential amino acids for muscle tissue development in animals, which contributes to their growth and increased productivity.

Black millet, which is less common but has a high protein content, is an important source of amino acids that contribute to the overall strengthening of the body. Black millet contains a high concentration of antioxidants, making it useful for nutrition, especially for individuals with increased needs for protection against oxidative stress. Key amino acids found in black millet include methionine, cysteine, leucine, isoleucine, and valine. Black millet is highly valued for the production of health-focused foods, particularly for individuals following diets aimed at combating stress or disorders related to metabolism [14-17].

The fat content in different types of millet is an important indicator that determines their energy value, technological properties, and their use in the food and feed industries. The fat in millet is mainly composed of triglycerides, which consist of fatty acids such as oleic, linoleic, palmitic, and others. The fat content in millet typically ranges from 3% to 5%, although this can vary depending on the type of millet, growing conditions, and varietal characteristics.

Yellow millet, the most widely grown type, typically has a fat content of 3% to 4%. White millet generally has a slightly lower fat content, ranging from 2.5% to 3.5%. Additionally, white millet has a greater ability to stabilize fat during storage due to the reduced presence of oxidative components, making it desirable for producing long-shelf-life products like flour or flakes.

Red millet, often grown for products with more pronounced gelling properties, has a higher fat content compared to yellow and white millet. The fat content in red millet can range from 4% to 5%. This higher fat content is due to its unique genetic traits, leading to the formation of more triglycerides and higher proportions of saturated fatty acids such as palmitic acid.

The higher fat content in red millet gives it better organoleptic properties, such as a softer texture and a more intense flavor, making it attractive for producing specific products like flakes, drinks, or specialized food additives. However, the higher fat content also makes red millet less stable during storage compared to other types, as the fat can oxidize over time, decreasing the quality of the products.

The fatty acid composition of millet depends on several factors, including the variety, climatic conditions, agronomic practices, and post-harvest handling. As with other cereal crops, millet typically contains saturated, monounsaturated, and polyunsaturated fatty acids, which make up the fatty complex of the grain. The characteristics of millet's fatty acid composition may vary depending on the type of grain (yellow, white, or red millet) and determine its use in the food and feed industries.

The fatty acid profile of yellow millet is characterized by a significant presence of unsaturated fatty acids, particularly monounsaturated and polyunsaturated fatty acids. Oleic acid (C18:1) is one of the main monounsaturated fatty acids, with a content ranging from 25% to 35%. It is significant for human health as it lowers "bad" cholesterol levels in the blood and supports cardiovascular health.

Another important fatty acid in yellow millet is linoleic acid (C18:2), which is a polyunsaturated omega-6 fatty acid. The content of linoleic acid in the grain ranges from 30% to 45%. Linoleic acid is essential for humans and helps normalize cholesterol levels and supports the immune system. It's also noteworthy that oleic and linoleic acids may have a synergistic effect in reducing the risk of cardiovascular diseases.

In addition, yellow millet contains saturated fatty acids like palmitic (C16:0) and stearic (C18:0) acids. Palmitic acid, which makes up about 10-15% of the total fatty acids, is the primary saturated acid found in many vegetable oils.

White millet has some differences in its fatty acid composition. The primary feature is its high content of linoleic acid, which makes up about 40% of the total fatty acids.

The content of monounsaturated fatty acids in white millet is significantly lower than in yellow millet. Oleic acid is present in white millet at levels of 25%-30%, which is typical for most cereals. This also positively affects cholesterol levels, but compared to other crops like olives or avocados, this level is moderate.

White millet also contains a small amount of saturated fatty acids, making up around 10-12%. Palmitic acid is the predominant saturated fatty acid, and its concentration in white millet is similar to that of yellow millet.

Red millet has a slightly different fatty acid profile compared to other types. Its fat composition is characterized by a high content of oleic acid, which makes up about 35%-40% of the total fatty acids. This not only gives red millet high nutritional value but also special technological properties. Due to its high oleic acid content, red millet can be beneficial for foods that support cardiovascular health.

Linoleic acid is also present in red millet, but its content is somewhat lower than in yellow or white millet. It typically ranges from 25% to 35%, which still meets the standards for providing the body with essential polyunsaturated fatty acids.

Saturated fatty acids in red millet make up a moderate share, ranging from 10% to 15%. Palmitic acid dominates among saturated fatty acids, and there is a small amount of stearic acid. The main fatty acids found in all types of millet include oleic (C18:1), linoleic (C18:2), palmitic (C16:0), and stearic (C18:0) acids [18-20].

The carbohydrate complex of millet, like other cereal crops, consists of several main components: starch, fiber, sugars, and other soluble carbohydrates. These components are crucial for evaluating the energy value of the grain and its potential as a source of carbohydrates for human and animal nutrition. Since millet is grown in conditions where other crops cannot be effectively cultivated due to adverse climatic conditions, its carbohydrate complex plays an essential role in meeting the nutritional needs of the population, especially in countries with limited access to other energy sources.

Millet starch is the main carbohydrate in millet grain, and its content varies depending on the type of millet. Starch consists of two main components: amylose and amylopectin. Amylose is a linear polymer of glucose, consisting of glucose molecules connected by α-1,4-glycosidic bonds. Amylopectin, in contrast to amylose, is a branched polymer with additional α-1,6-glycosidic bonds between glucose molecules, which form side chains. The percentage ratio of amylose to amylopectin in millet grain is important for the physicochemical properties of starch, such as gel-forming properties, swelling capacity, as well as the rate and degree of hydrolysis during digestion.

Starch usually constitutes the largest portion of carbohydrates in millet grain, with its content ranging from 60% to 75%, depending on the type of grain and growing conditions. Yellow and white millet have similar starch content levels, with slight variations depending on the variety and agronomic conditions. The amylose content in millet grain is usually in the range of 25-30%, which is an average level for cereal grains, although some varieties may have a higher amylose content. High amylose content is characteristic of millet used for producing cereals and flour, as amylose contributes to the formation of solid structures during thermal processing, such as cooked cereals or baked products.

Amylopectin constitutes the majority of the starch in millet, and its presence affects the texture of products made from millet. Millet with a high amylopectin content will have a softer texture and be better suited for producing products like flakes or liquid dishes, where lightness and fluffiness are desired. Starch in millet is important for nutrition as it is the primary energy source for humans and animals, providing glucose, which is then converted into energy in metabolic processes.

Fiber is an important component of the carbohydrate complex in millet, contributing to the normalization of digestive system function in both humans and animals. The fiber in millet consists of various types of polymers such as cellulose, hemicellulose, and lignin. Cellulose is the main component of fiber and consists of glucose molecules connected by β-1,4-glycosidic bonds. Cellulose is not digested by human and animal enzymes and plays an essential role in maintaining normal bowel function. Hemicellulose is a more complex molecule consisting of various sugars, including arabinose, xylose, and mannose. It has properties that reduce the viscosity of digestive contents, facilitating digestion and reducing the risk of inflammatory processes in the intestine. Lignin is another component of fiber, but its content in millet is significantly lower compared to cellulose and hemicellulose. Lignin forms strong structures in plant cell walls and contributes to resistance to mechanical stress but is not digestible by humans and animals.

In millet grain, fiber makes up about 2-4% of the total mass, which is important for the proper functioning of the digestive system. Given the high fiber content in millet, products made from it tend to provide a prolonged feeling of fullness, which can be beneficial for weight control and the prevention of metabolic disorders.

Sugary substances in millet grain are primarily represented by monosaccharides such as glucose and fructose, as well as disaccharides, particularly sucrose. The sugar content in millet is usually low since most carbohydrates are in the form of starch. Millet contains about 2-4% total sugars, making it less sweet compared to other crops like corn or wheat.

Sugars in millet are a primary energy source that is quickly absorbed by the body during digestion. At the same time, the sugar content is important for technological processes such as flour production, flake production, or animal feed additives, where sugar usage can affect the consistency and flavor qualities of the final product. Millet also has a certain ability to increase the monosaccharide content after thermal processing, which can be useful for making sweet products or energy-dense items.

All types of millet – yellow, white, and red – have similar-sized carbohydrate complexes but with some differences in the ratio of components, which affect the texture, flavor qualities, and technological properties of products. Yellow millet is the most common and versatile type for producing cereals, flour, and feed due to its balanced carbohydrate composition, medium amylose and amylopectin content, and moderate fiber content. White millet, with its softer texture and lower fiber content, is mostly used in baby food or diets for individuals with digestive issues. Red millet, with its pronounced gelling properties, is ideal for producing products requiring high viscosity or specific consistency, such as flakes or other semi-finished products [21-23].

The vitamin content of millet grain, like that of other crops, is an important indicator of its nutritional value. Millet contains a number of vitamins essential for the normal functioning of the human body, such as B vitamins (including B_1, B_2, B_3, B_5, B_6, folic acid), as well as vitamin E and some others that play a role in metabolic processes. However, the vitamin content may vary depending on the type of millet, influenced by factors such as variety, growing region, and agronomic conditions.

Yellow millet is characterized by a relatively high content of B vitamins, which are important for supporting normal metabolism and the functioning of the nervous system. The main source of vitamins in the grain is the husk, so the quality of millet processing, particularly the degree of cleaning, can significantly affect the vitamin content in the final product.

Vitamin B_1 (thiamine) is one of the most important B vitamins, contributing to the normal functioning of the nervous system and participating in carbohydrate metabolism. The content of vitamin B_1 in yellow millet can range from 0.2 to 0.4 mg per 100 g of grain, which provides a significant portion of the daily requirement for humans. Like other B vitamins, this vitamin is water-soluble, so it is lost during processing, storage, and cooking, especially if exposed to high temperatures or prolonged contact with water.

Vitamin B_2 (riboflavin) in yellow millet is typically present in the amount of 0.1–0.2 mg per 100 g, which also contributes to a part of the daily human requirement for this vitamin. Riboflavin participates in energy metabolism processes and also helps normalize vision and skin health.

Vitamin B_3 (niacin) in yellow millet is found in the amount of 1.5–3 mg per 100 g of grain. It is necessary for the normal functioning of the cardiovascular system, skin, digestive system, and nervous system. Niacin also helps reduce cholesterol levels in the blood.

Vitamin B_5 (pantothenic acid), although present in small amounts, is important for hormone synthesis and the normal functioning of the nervous system. The content of this vitamin in yellow millet can range from 0.4 to 0.6 mg per 100 g.

Vitamin B_6 (pyridoxine) in yellow millet is present in the amount of 0.1–0.3 mg per 100 g. Pyridoxine is essential for the normal functioning of the brain, the formation of red blood cells, and amino acid metabolism.

Folic acid (B_9) is an important component in cell division and growth processes, especially crucial for women during pregnancy. The folic acid content in yellow millet is about 20 mcg per 100 g, providing part of the daily requirement.

Vitamin E (tocopherol), a powerful antioxidant, is present in yellow millet in the amount of about 0.8–1mg per 100 g of grain. Tocopherol helps protect cells from oxidative stress and supports the immune system.

White millet, like yellow millet, is rich in B vitamins, but due to its low fat content, white millet contains less vitamin E. Vitamin B_1 in white millet is found in the amount of 0.2–0.4 mg per 100 g, vitamin B_2 is present in the amount of 0.1–0.2 mg per 100 g, vitamin B3 is present in similar amounts – 1.5–3 mg per 100 g, vitamin B5 in white millet is found in the amount of 0.3–0.5 mg per 100 g, vitamin B6 in white millet is approximately 0.2–0.3 mg per 100 g, folic acid is found in white millet in the amount of about 15–20 mcg per 100 g, and vitamin E in white millet is typically in the range of 0.5–0.7 mg per 100 g.

Red millet contains many of the same B vitamins as other types but with some differences in content. Red millet, due to its high fatty acid content, has a higher vitamin E content compared to yellow and white types of millet.

The vitamin content in millet from different grain types is significantly similar but with some variations that affect its nutritional value and role in the human diet. Yellow, white, and red millet provide the body with essential vitamins, particularly from the B group and vitamin E, each of which is critical for normal body function [24-26].

Mineral substances are important components of millet grain that perform various functions in human life processes. They play a key role in maintaining acid-base balance, ensuring the normal functioning of the nervous system, aiding in energy metabolism processes, and participating in the synthesis of various enzymes, hormones, and tissues. Mineral substances can be divided into macroelements and microelements, each having specific significance for the body. The ash content of millet grain, which determines the amount of minerals in the grain, can vary depending on the millet type, agronomic conditions of cultivation, and grain processing.

Macroelements, including calcium, magnesium, potassium, phosphorus, sodium, and sulfur, are crucial for ensuring the normal functioning of the body. They are actively involved in metabolism, help maintain the structure of bones and teeth, regulate water-electrolyte balance, and support proper nerve and muscle function.

Calcium is the main structural component of bones and teeth. It also participates in the functioning of the nervous system and muscle contractions. Calcium plays an important role in blood clotting and in several enzymatic processes. The calcium content in millet grain is relatively moderate, typically ranging from 0.01 to 0.02 g per 100 g of grain. For cereal crops in general, calcium is not one of the primary minerals, as it is mainly concentrated in the root system and plant tissues on the surface. Therefore, it largely remains in the grain husk, increasing the calcium content in unprocessed grain.

Magnesium is an important element that supports the normal functioning of muscles and the nervous system, regulates blood pressure, and participates in DNA and RNA synthesis. Magnesium plays a vital role in energy metabolism and normalizes blood glucose levels. The magnesium content in millet can range from 0.1 to 0.2 g per 100 g of grain, which covers part of the daily human requirement.

Potassium is another essential macroelement that helps maintain water-salt balance in the body. Potassium is also vital for the normal functioning of the heart and helps maintain proper blood pressure. The potassium content in millet grain can be about 0.3–0.4 g per 100 g of grain. Potassium is the main element stored in plant cells and is critical for maintaining electrolyte balance.

Phosphorus is a key element for forming bones and teeth, and it is also an important component in energy processes within cells, as it is part of ATP (adenosine triphosphate) molecules. Phosphorus in millet can be present in the amount of 0.3–0.5 g per 100 g. This element participates in carbohydrate, protein, and fat metabolism, supporting normal body function.

Sodium, although necessary for the body, is present in relatively small amounts in millet grain. Sodium plays an important role in maintaining acid-base balance and water-electrolyte balance in the body, as well as in the functioning of muscle fibers and nerve cells. The sodium content in millet grain usually ranges from about 0.001–0.01 g per 100 g.

Sulfur is involved in the synthesis of amino acids such as cysteine and methionine, as well as in the formation of some vitamins. The sulfur content in millet can range from 0.05 to 0.1 g per 100 g, making it an important component for normal metabolic function.

Microelements include iron, zinc, copper, manganese, iodine, molybdenum, and other elements that are essential for normal body function, although they are found in very small quantities. Microelements play an important role in many biochemical processes, such as the synthesis of enzymes, hormones, and antioxidants, and they can significantly influence human health.

Iron is an essential component of hemoglobin, which transports oxygen in the blood. It also participates in many enzymatic processes and is important for normal cell metabolism. Iron in millet grain is typically found in the amount of 2–3 mg per 100 g. Iron is mainly present in the grain husk, so millet cleaning can significantly reduce its content.

Zinc is necessary for the normal functioning of the immune system, as well as for the synthesis of proteins and DNA. This element actively participates in processes of cell regeneration and growth. The zinc content in millet can be 1–2 mg per 100 g of grain.

Copper participates in many biochemical processes, including the synthesis of collagen and elastin, which is important for skin and blood vessel health. Copper content in millet is typically between 0.1 and 0.3 mg per 100 g.

Manganese is an element crucial for the normal functioning of enzymes involved in the metabolism of carbohydrates, proteins, and lipids. Manganese content in millet can range from 1 to 2 mg per 100 g of grain.

Iodine is necessary for the synthesis of thyroid hormones and is essential for normal endocrine system function. Since iodine is present in small amounts in the soil, its level in millet may be limited.

The ash content of millet grain, an important indicator of the mineral composition, reflects the content of all mineral elements remaining after the combustion of the organic components of the grain. Ash content in millet can range from 1.5 to 3.5% of the total grain mass [26-29].

Conclusions

Millet, as a crop, has unique characteristics that make it an important source of food for people and animal feed, and it is also used in industry and other sectors.

Studying different types of millet, such as white, yellow, red, as well as specialized varieties, reveals a rich composition of nutrients, including proteins, carbohydrates, fats, vitamins, and minerals. The chemical composition of millet varies depending on the type of grain, variety, growing conditions, and processing, but overall, it provides a wide range of biologically active substances that are important for human health.

The proteins in millet are noted for their high biological value, particularly due to the presence of all essential amino acids. Different types of millet have varying proportions of these amino acids, which affect their nutritional value and biological availability to the body. However, a comparison of the amino acid composition of different types of grain shows that millet proteins can meet the body's needs for essential amino acids, such as leucine, isoleucine, threonine, valine, and others, making them an important component of the diet.

The carbohydrate complex of millet includes a significant amount of complex carbohydrates, the main component of which is starch. Starch is the primary energy source for the body and is also of great importance in human nutrition. The fiber content in millet grain is also considerable, positively affecting the functioning of the gastrointestinal tract and promoting normal digestion. In particular, fiber helps lower cholesterol levels in the blood and improves the processes of intestinal peristalsis.

The fatty composition of millet contains essential fatty acids, including omega-3 and omega-6, which are important for normalizing lipid metabolism in the body. Furthermore, the fatty composition of millet indicates the presence of various saturated and unsaturated fatty acids, allowing it to be used as a source of healthy fats. The fatty acid composition varies depending on the type of millet, but in general, millet contains high levels of linoleic acid, which is crucial for maintaining a normal cardiovascular system.

The vitamin composition of millet grain includes B vitamins, as well as vitamin E, which is a powerful antioxidant. These vitamins perform essential functions in metabolism, regulating the nervous system, improving carbohydrate and protein metabolism, and supporting the health of the skin and hair. Vitamin E in millet grain has antioxidant activity, which helps reduce oxidative stress in the body's cells.

The mineral composition of millet is extremely important for its nutritional value. Macronutrients such as potassium, calcium, magnesium, phosphorus, as well as trace elements like iron, zinc, copper, and manganese are present in millet grain in varying proportions. For example, potassium is important for normalizing water-electrolyte balance and supporting normal heart function. Calcium and magnesium are vital for bone and tooth formation, as well as for normalizing the activity of the muscular and nervous systems. Iron and zinc are necessary for supporting normal immune function and hemoglobin synthesis.

The processing of millet into food products has significant potential for the economy. However, millet processors in Ukraine and other countries face certain challenges, such as the high cost of technological processes, limited domestic processing infrastructure, and problems with grain storage. Additionally, there is a need to optimize the use of different millet varieties depending on their properties and specifications to achieve the best results in the production of final products.

Thus, millet is an important cereal crop with high potential both for domestic consumption and export. Its chemical composition, including proteins, carbohydrates, fats, vitamins, and minerals, makes it an important food product for people and animal feed. The processing and export of millet from Ukraine have significant development potential but require addressing several issues, such as improving processing technologies and increasing production capacities.

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ПРОСО ЦІННА ЗЕРНОВА КУЛЬТУРА ДЛЯ ВИРОБНИЦТВА КРУП'ЯНИХ ПРОДУКТІВ

Анотація

Просо, будучи однією з найдавніших зернових культур, має широке географічне поширення і є ключовим елементом харчування в багатьох регіонах світу. Його вирощування зосереджене в районах із посушливим кліматом і несприятливими умовами для інших культур. Завдяки своїй невибагливості до ґрунтів і здатності витримувати тривалі періоди посухи, просо стало незамінним джерелом їжі та корму для тварин у багатьох країнах Африки, Азії та частково Європи. Основними регіонами вирощування проса є Західна Африка, Індія, Китай, а також окремі частини Північної Америки, Центральної Азії та Східної Європи. У Західній Африці, наприклад, такі країни, як Нігер, Малі та Сенегал, є провідними виробниками цієї культури. Просо тут є базовою харчовою культурою, з якої виготовляють традиційні страви, зокрема каші та напої. Китай відіграє значну роль у виробництві проса, вирощуючи його як для внутрішнього споживання, так і для експорту. У Північній Америці просо вирощується переважно для кормових цілей, а основними виробниками є США. В Європі просо займає обмежену частину сільськогосподарських угідь, але є кілька країн, де його вирощування набуває популярності завдяки зростаючому попиту на здорове харчування і стійкі до посухи культури. Франція, Італія є основними європейськими країнами, де вирощують просо. Хімічний склад проса робить його унікальною культурою серед зернових. Воно багате на білки, вуглеводи, жири, мінерали та вітаміни. Основу хімічного складу проса становлять складні вуглеводи, які забезпечують організм енергією і повільно засвоюються, що є особливо важливим для підтримання стабільного рівня глюкози в крові. Білок у просі має високу біологічну цінність, містить такі важливі амінокислоти, як метіонін і лізин, яких зазвичай бракує в інших зернових культурах. Крім того, просо багате на корисні жири, зокрема ненасичені жирні кислоти, що сприяють нормалізації рівня холестерину в організмі. Просо містить значну кількість вітамінів групи В, включаючи тіамін (B_1), рибофлавін (B_2), ніацин (B_3) і піридоксин (B_6). Ці вітаміни відіграють ключову роль у метаболічних процесах, підтримують нервову систему та сприяють загальному зміцненню організму. Просо також є джерелом токоферолу (вітамін Е), що має антиоксидантні властивості та сприяє захисту клітин від оксидативного стресу. Мінеральний склад проса включає значні концентрації калію, магнію, фосфору, заліза, цинку і міді. Ці мінерали важливі для нормального функціонування серцево-судинної системи, кісткової тканини, кровотворення та імунної системи. Особливу увагу заслуговує високий вміст заліза, що робить просо важливим продуктом для профілактики анемії. Наявність антиоксидантів, таких як поліфеноли і флавоноїди, забезпечує протизапальні властивості проса і його позитивний вплив на зниження ризику розвитку хронічних захворювань, включаючи діабет і серцево-судинні недуги.

Ключові слова: просо, типи проса, хімічний склад зерна, масова частка білка, масова частка жиру, масова частка вуглеводна, масова частка вітамінів, круп'яне виробництво, продукти переробки проса.

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