ANALYSIS OF THE BIOLOGICAL COMPOSITION OF SUNFLOWER SEEDS AND THE EFFICIENCY OF THEIR DRYING METHODS

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Abstract. Sunflower seeds represent a vital raw material in both the food industry and agricultural sectors. They are composed of essential nutrients, including proteins, lipids, carbohydrates, vitamins, and minerals, the concentrations of which are influenced significantly by the applied drying method. Drying is a critical post-harvest operation that ensures the preservation of seed quality, prolongs shelf life, and prevents pest infestation. Currently, several drying techniques are employed for sunflower seeds, including air convection, infrared, vacuum, and microwave drying. This article provides a comparative analysis of these drying technologies, focusing on their operational principles, energy efficiency, and effects on seed quality parameters. Modern drying approaches offer enhanced nutrient retention and facilitate the optimization of industrial processing efficiency.

Keywords. Sunflower seeds, drying technologies, biochemical composition, lipids, proteins, vitamins, minerals, vacuum drying, infrared drying, microwave drying, air convection drying, energy efficiency, quality preservation.

Annotatsiya. Kungaboqar urug‘lari oziq-ovqat sanoati va qishloq xo‘jaligi sohalarida muhim xom ashyo hisoblanadi. Ular tarkibida oqsillar, yog‘lar, uglevodlar, vitaminlar va minerallar kabi zaruriy oziq moddalari mavjud bo‘lib, ularning miqdori tanlangan quritish usuliga sezilarli darajada bog‘liqdir. Quritish hosil yig‘ib olingandan keyingi muhim bosqich bo‘lib, urug‘ sifatini saqlab qolish, ularning saqlanish muddatini uzaytirish va zararkunandalardan himoya qilish imkonini beradi. Hozirda kungaboqar urug‘lari uchun havo konveksiya, infraqizil, vakuum va mikroto‘lqinli quritish usullari qo‘llaniladi. Ushbu maqolada mazkur quritish texnologiyalari solishtirma tahlil qilinadi, ularning ishlash prinsiplari, energiya samaradorligi va urug‘ sifati ko‘rsatkichlariga ta’siri ko‘rib chiqiladi. Zamonaviy quritish usullari oziq moddalarning yaxshi saqlanishiga va sanoat jarayonlarini optimallashtirishga yordam beradi.

Kalit so‘zlar: Kungaboqar urug‘i, quritish texnologiyalari, biokimyoviy tarkib, yog‘lar, oqsillar, vitaminlar, minerallar, vakuumli quritish, infraqizil quritish,

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mikroto‘lqinli quritish, havo konveksiya quritishi, energiya samaradorligi, sifatni saqlash.

Аннотация. Семена подсолнечника являются важным сырьем как для пищевой промышленности, так и для сельского хозяйства. Они содержат необходимые питательные вещества, такие как белки, липиды, углеводы, витамины и минералы, концентрация которых существенно зависит от выбранного метода сушки. Сушка является критически важной послеуборочной операцией, обеспечивающей сохранение качества семян, продление их срока хранения и предотвращение заражения вредителями. В настоящее время применяются различные методы сушки семян подсолнечника: конвективная, инфракрасная, вакуумная и микроволновая. В статье приведен сравнительный анализ этих технологий, рассматриваются принципы их работы, энергоэффективность и влияние на показатели качества семян. Современные методы сушки обеспечивают лучшее сохранение питательных веществ и способствуют повышению эффективности переработки на производстве.

Ключевые слова: семена подсолнечника, технологии сушки, биохимический состав, липиды, белки, витамины, минералы, вакуумная сушка, инфракрасная сушка, микроволновая сушка, конвективная сушка, энергоэффективность, сохранение качества.

Introduction.

Sunflower seeds occupy a prominent position in both the food and agricultural industries due to their diverse applications. Beyond their conventional use in vegetable oil extraction, they serve as valuable components in human nutrition, livestock feed, and even pharmaceutical formulations. One of the most critical factors in maintaining the quality of sunflower seeds is the drying process, which is essential not only for extending shelf life but also for retaining the nutritional integrity of the product. The adoption of appropriate drying technologies ensures the preservation of vital nutrients such as vitamins and minerals and contributes to maintaining the seeds’ biological value. In industrial settings, the implementation of energy-efficient and effective drying methods is crucial for optimizing production. This study explores the biochemical profile of sunflower seeds, establishes the significance of drying parameters, and evaluates various drying techniques in terms of their advantages and limitations.

Significance of biochemical composition and drying requirements in sunflower seeds. Sunflower seeds are recognized as a strategic raw material in both agriculture and food production systems. Besides their primary application in edible oil manufacturing, they have gained importance in the renewable energy sector as a source of biofuel. Their biochemical composition comprises a variety

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of macronutrients and micronutrients that collectively define their nutritional and energetic value.

Major biochemical constituents of sunflower seeds. Lipids (Fats) [40–50%] – Sunflower seeds exhibit a notably high lipid content, predominantly composed of unsaturated fatty acids, such as oleic and linoleic acids. These components are known for their beneficial effects on cardiovascular health. Unsaturated fats also contribute to reducing systemic inflammation and regulating cholesterol levels within the human body[1]. Specifically, sunflower seeds are a rich source of **oleic** and **linoleic acids,** two essential unsaturated fatty acids known to support cardiovascular health. These lipids contribute to reducing systemic inflammation and play a regulatory role in maintaining optimal blood cholesterol levels.

Proteins [20–30%] – The protein fraction of sunflower seeds is characterized by a high content of **essential amino acids,** which are indispensable for human metabolism and cellular function. Due to the presence of a complete amino acid profile, sunflower seeds serve as a valuable plant-based protein source, particularly beneficial for individuals adhering to vegetarian or vegan diets[1][2]. Due to their complete amino acid profile, sunflower seeds are regarded as an important plant-based protein source, making them especially valuable in vegetarian and vegan nutrition.

Carbohydrates [10–20%] – The carbohydrate content in sunflower seeds functions primarily as an **energy source** for the human body. These carbohydrates are predominantly composed of **dietary fiber** and **complex polysaccharides**, which contribute to improved gastrointestinal function and support the stabilization of blood glucose levels. The high fiber content also plays a role in promoting satiety and maintaining metabolic health[2] [7].

Vitamins [E, B1, B2, B6] – Sunflower seeds are a valuable source of several essential vitamins that contribute to the **normal physiological functioning of cells.** Notably, **vitamin E** exhibits potent **antioxidant properties**, protecting cellular structures from **oxidative stress** and contributing to the maintenance of healthy skin. The presence of B-complex vitamins, such as **thiamine (B1), riboflavin (B2), and pyridoxine (B6),** plays a crucial role in energy metabolism, enzyme function, and nervous system support.[3].

Minerals [phosphorus, magnesium, iron, potassium] – Sunflower seeds are abundant in essential minerals that contribute to the **structural integrity of the skeletal system** and the **proper functioning of muscular tissues**. In particular, **magnesium** is critical for the **transmission of nerve impulses** and the **regulation of muscle contractions,** while **phosphorus** supports bone mineralization**, iron** is

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involved in oxygen transport and hemoglobin synthesis, and **potassium** aids in maintaining fluid balance and neuromuscular activity..[3].

The importance of drying requirements for sunflower seeds. The drying process is a critical post-harvest operation that significantly influences the **preservation of seed quality** and the **extension of shelf life**. By reducing the **moisture content** to an optimal level, drying inhibits the growth of **bacteria and fungi**, which are known to deteriorate seed integrity and safety. Elevated moisture levels, particularly those exceeding **10%**, promote rapid microbial proliferation within the seeds, resulting in biochemical degradation and reduced product quality. To ensure **safe long-term storage** and to maintain **nutritional and microbiological stability**, it is recommended to maintain seed moisture content within the **6–8% range** during the drying process[3].

Main objectives of the drying process:

Preserving seed quality – Properly dried seeds retain their beneficial nutrients and maintain quality over extended periods.

Ensuring microbiological safety – Seeds with high moisture content are prone to fungal and bacterial growth; drying effectively prevents such risks.

Extending shelf life – The shelf life of dried seeds can be prolonged by several ears.

Optimizing technological processes – Oil extraction from dried seeds is significantly more efficient.

Modern drying technologies play a vital role in preserving the biological value of sunflower seeds and increasing production efficiency. Today, air convection, infrared, vacuum, and microwave drying methods are widely used in the industry. Each method varies in effectiveness, and the choice depends on production capacity, energy consumption, and the desired quality characteristics of the seeds.

Drying equipment used for sunflower seeds and their analysis. The quality and efficiency of sunflower seed drying largely depend on the equipment used. The drying process extends the storage period of the seeds, preserves their nutritional value, and protects them from pests. Below is a detailed analysis of the most commonly used drying methods along with their advantages and disadvantages.

Air convection dryers. Air convection dryers are among the most commonly used methods for drying agricultural products, including sunflower seeds. In this method, moisture from the seeds is evaporated using a stream of heated air [4]. These dryers, based on simple technology, are notable for their low cost and their ability to dry large volumes of product simultaneously. In this drying

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method, moisture is evaporated evenly, making it suitable for large-scale production. However, exposure to high temperatures may lead to the loss of essential nutrients in the seeds. Additionally, the process is time-consuming and energy-intensive, which can result in increased operational costs.

Infrared dryers. Infrared dryers operate by applying heat directly through radiation, causing moisture to evaporate from the internal structure of the seeds. This method is widely used in both agriculture and the food industry due to its effectiveness in penetrating the material and reducing drying time[2][4]. Infrared radiation is significantly more energy-efficient, allowing the drying process to be completed much faster. This method offers excellent nutrient preservation and possesses sterilization properties, meaning it helps prevent the growth of bacteria and fungi. However, infrared dryers are more expensive compared to other methods and require specialized equipment. If the drying process is not properly controlled, there is a risk of overdrying the seeds or reducing their overall quality.

Vacuum dryers. Vacuum dryers operate by evaporating moisture under reduced pressure conditions. This method is designed to maximize the preservation of nutrients and is particularly suitable for delicate or sensitive products[3]. Vacuum drying minimizes nutrient degradation and helps preserve the natural color, shape, and flavor of the product. Therefore, this method is highly suitable for manufacturers who prioritize product quality. However, vacuum dryers are very expensive and may not be feasible for small-scale producers. Additionally, the equipment requires advanced technical knowledge, and the drying process can be longer compared to other methods.

Microwave dryers. Microwave dryers use microwave energy to heat the water molecules inside the seeds, causing moisture to evaporate. This method is commonly used for the rapid drying of food and agricultural products[1][4]. Microwave dryers are extremely fast, improving production efficiency and minimizing nutrient loss. In addition, this method is environmentally friendly and consumes relatively low energy. However, high energy demands in certain phases may increase operational costs. The drying process requires precise control; otherwise, the product may overheat, leading to a decline in quality. Moreover, microwave technology remains an expensive option for many manufacturers.

The choice of sunflower seed drying method and technology is crucial for preserving product quality and enhancing energy efficiency. Each method has its own unique advantages and disadvantages. While air convection dryers are simple and cost-effective, microwave dryers are highly efficient and offer superior nutrient retention. Vacuum and infrared drying technologies, on the other hand, provide the highest quality preservation of the seeds.

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The quality and efficiency of sunflower seed drying largely depend on the equipment used. Drying extends the seeds' shelf life, helps retain nutrients, and protects the product from pests. Below is a detailed analysis of the most widely used drying methods, along with their respective advantages and disadvantages.

Analysis of drying methods. The efficiency and practicality of each drying method vary based on their operating principles, energy consumption, and ability to preserve nutrients. Air convection dryers are suitable for drying large volumes of product using simple and low-cost technology; however, high temperatures may degrade seed quality. Infrared dryers promote energy savings and maximum nutrient retention, though they are costly and require specialized equipment. Vacuum dryers deliver the highest product quality, but this method is expensive and technologically complex. Microwave dryers are the fastest and most efficient, and despite their higher energy consumption, they ensure excellent nutrient preservation and enhance product quality.

Recent studies indicate that the application of combined drying technologies can significantly improve overall efficiency. For example, integrating infrared and vacuum drying methods can help reduce thermal impact while maximizing nutrient retention[4]. This combined method is particularly effective in industrial sectors where high-quality products are required. Infrared drying is efficient in eliminating microorganisms, while vacuum technology helps preserve essential vitamins and minerals within the product.

The combination of **microwave and infrared drying technologies** is also considered an effective solution, offering both rapid processing and improved nutrient retention[5]. Microwave drying directly heats and evaporates water molecules inside the product, significantly accelerating the drying process. Infrared radiation, on the other hand, ensures more uniform drying on the surface of the product, which positively impacts the final quality. This combination has shown promising results, particularly in plant-based products such as sunflower seeds.

To improve energy efficiency, increasing attention is being given to low-temperature drying technologies. Studies have shown that using lower temperatures over longer drying times allows for better retention of nutrients within the product[6]. This method is considered an environmentally friendly technology, consuming less energy compared to traditional drying methods. However, due to the relatively longer processing time, additional time and technological coordination are required when handling large volumes of product.

Additionally, **innovative drying technologies based on ionization** are also being tested. When combined with infrared and electromagnetic radiation, this technology accelerates the breakdown of water molecules within the product,

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thereby increasing the efficiency of the drying process[7]. This approach minimizes nutrient loss and helps better preserve the product's flavor.

Research findings indicate that the **effectiveness of various drying methods depends largely on the degree of combination** applied. For example, combining vacuum and infrared drying can result in up to **30% energy savings** compared to conventional air convection drying. The **microwave–infrared combination** enables more uniform moisture evaporation within the product and contributes to better flavor retention[8].

The selection of the drying method and technology for sunflower seeds is crucial for preserving seed quality and improving energy efficiency. Each method has its own specific advantages and disadvantages. While air convection dryers are simple and cost-effective, microwave dryers offer high efficiency and excellent nutrient retention. Vacuum and infrared drying technologies provide the highest level of quality preservation.

According to recent research, combined drying technologies are significantly more effective than traditional methods, offering greater energy savings and improved product quality retention.

Drying Method	Advantages	Disadvantages
Air Convection	Simple, inexpensive, suitable for large volumes	May negatively affect seed quality, not energy-efficient
Infrared	Energy-saving, preserves nutrients, fast drying	High energy consumption, requires specialized equipment
Vacuum	Best quality preservation, minimal nutrient loss	Expensive, requires complex equipment
Microwave	Very fast, excellent nutrient preservation	High energy consumption, requires precise control
Infrared + Vacuum	Energy-efficient, maximizes nutrient preservation	Technologically complex, expensive equipment
Microwave + Infrared	Ensures uniform moisture evaporation within the product, high final quality	Complex control system, requires advanced technological coordination

The choice of drying method and technology for sunflower seeds is critical for preserving seed quality and enhancing energy efficiency. Each method has its unique advantages and disadvantages. While air convection dryers

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are simple and cost-effective, microwave dryers are highly efficient and ensure excellent nutrient preservation. Vacuum and infrared drying technologies offer the highest quality retention. According to recent studies, **combined drying technologies** are significantly more effective than traditional methods, allowing for better energy savings and improved product quality.

Conclusion. Improving the efficiency of air convection dryers by addressing their drawbacks can lead to substantial economic benefits and better product quality. To minimize the negative effects of high temperatures, it is necessary to utilize low-temperature drying technologies or implement systems that precisely control the airflow. Establishing optimized drying parameters and incorporating **automated monitoring systems** not only reduces energy consumption but also enhances the final product quality. Combining **air convection drying** with **infrared** or **vacuum technologies** can result in more efficient drying while preserving the nutritional content of sunflower seeds.

Through such **integrated technologies,** energy efficiency can be improved, product quality enhanced, and production processes optimized. Therefore, the use of combined drying methods proves to be more effective than conventional techniques and contributes to achieving high-quality results across various industrial sectors.

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