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DETERMINATION OF THE PHYSICOCHEMICAL AND MECHANICAL PROPERTIES OF JERUSALEM ARTICHOKE TUBERS AFTER DRYING

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Abstract. Jerusalem artichoke (*Helianthus tuberosus* L.) is an important tuber crop with considerable nutritional and technological potential due to its high carbohydrate content, particularly inulin, as well as its dietary fiber, minerals, and biologically active compounds. Drying is one of the most important preservation methods used to extend the shelf life of tubers and facilitate their subsequent processing into flour, powder, extracts, and functional food ingredients. However, the drying process causes changes in moisture content, water activity, color, shrinkage, texture, density, and mechanical strength, which may influence the quality and processing behavior of the dried product. This article examines the physicochemical and mechanical properties of Jerusalem artichoke tubers after drying. The study methodology includes determination of moisture content, water activity, soluble solids, color characteristics, bulk and true density, shrinkage, rehydration capacity, and mechanical properties such as hardness, compression strength, and deformation. The analysis of the literature indicates that drying generally decreases moisture content and water activity while increasing the relative concentration of dry matter and often causing structural collapse and shrinkage. Changes in mechanical behavior depend strongly on drying temperature, drying rate, and final moisture content. Understanding these changes is essential for optimizing drying conditions and obtaining a stable product with desirable technological properties.

Keywords: Jerusalem artichoke, *Helianthus tuberosus* L., drying, physicochemical properties, mechanical properties, moisture content, shrinkage, hardness, texture.

Introduction. Jerusalem artichoke (*Helianthus tuberosus* L.), also known as topinambour or sunchoke, is a perennial plant belonging to the Asteraceae family. It is cultivated primarily for its edible underground tubers, which have attracted increasing scientific and industrial interest because of their nutritional composition and potential applications in functional foods, animal feed, pharmaceutical products, and bio-based industries.

One of the most significant characteristics of Jerusalem artichoke tubers is their relatively high content of inulin-type fructans. Inulin is a storage carbohydrate composed predominantly of fructose units and is recognized as a dietary fiber with prebiotic properties. In addition to inulin, Jerusalem artichoke tubers contain sugars, protein, minerals, dietary fiber, and phenolic compounds. Consequently, the crop has potential as a raw material for the production of functional food ingredients and value-added products.

Fresh Jerusalem artichoke tubers contain a large amount of water, making them highly susceptible to microbial deterioration, enzymatic reactions, physiological changes, and quality losses

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during storage. Drying can substantially improve their storage stability by reducing moisture content and water activity. It also decreases transportation and storage costs and makes it possible to produce shelf-stable products such as dried slices, chips, flour, and powder.

However, drying is not simply a process of removing water. The simultaneous transfer of heat and moisture can produce substantial physical, chemical, and structural changes in plant tissues. During drying, the tuber may undergo shrinkage, changes in porosity and density, browning, loss of volatile compounds, modification of carbohydrates, and changes in mechanical strength. These changes can influence milling, grinding, packaging, rehydration, and final product quality.

The relationship between drying conditions and product properties is therefore important for determining optimal processing parameters. Excessively high temperatures may accelerate moisture removal but can cause undesirable browning, structural damage, nutrient degradation, and excessive hardness. Conversely, very mild drying conditions may preserve quality but require substantially longer processing times and increase energy consumption.

The purpose of this study is to determine and analyze the physicochemical and mechanical properties of Jerusalem artichoke tubers after drying. Particular attention is given to the changes in moisture content, water activity, color, density, shrinkage, rehydration behavior, hardness, and compression characteristics. The results can contribute to the development of appropriate drying and post-processing technologies for Jerusalem artichoke products.

Analysis of literature. Jerusalem artichoke tubers are characterized by a high moisture content and a carbohydrate-rich dry matter fraction. Their principal storage carbohydrate is inulin, although the exact composition varies according to cultivar, maturity, environmental conditions, harvesting time, and storage conditions.

Inulin is particularly important from a technological and nutritional perspective. It is poorly digested in the upper gastrointestinal tract and reaches the colon, where it can be fermented by beneficial microorganisms. This characteristic has contributed to interest in Jerusalem artichoke as a potential source of prebiotic ingredients.

The tubers also contain reducing and non-reducing sugars, proteins, ash, dietary fiber, minerals, and phenolic substances. These components can influence the behavior of the tissue during drying. For example, reducing sugars can participate in non-enzymatic browning reactions, particularly at elevated temperatures.

Drying of plant materials. Drying is based on simultaneous heat and mass transfer. Heat supplied to the material increases the temperature of the product and provides the energy necessary for water evaporation. The resulting water vapor must then migrate from the interior of the material to the surface and from the surface into the surrounding air.

Drying behavior is commonly divided into a constant-rate period and one or more falling-rate periods. For many agricultural products, the falling-rate period represents the dominant stage because internal moisture diffusion becomes the principal mechanism controlling water removal.

The rate of drying is influenced by temperature, relative humidity, air velocity, material thickness, initial moisture content, and the physical structure of the product. Higher drying temperatures generally increase the drying rate by increasing vapor pressure and reducing the relative humidity of the drying environment.

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However, increasing temperature does not necessarily result in a better-quality dried product. Excessive temperature can cause surface hardening, structural collapse, discoloration, and degradation of heat-sensitive compounds.

Physicochemical changes during drying. Moisture content is one of the most important quality parameters of dried agricultural products. Reduction in moisture content decreases water activity and generally improves microbiological stability.

Water activity is particularly important because it represents the availability of water for microbial growth and chemical reactions. A product may have a relatively low moisture content but still possess sufficient water activity to support deterioration, depending on the composition and physical structure of the material.

Drying also causes changes in color. Fresh plant tissues may become darker or develop brown or yellow-brown tones during thermal processing. These changes may be caused by enzymatic browning, Maillard reactions, caramelization, pigment degradation, or structural changes that alter light scattering.

Shrinkage is another common phenomenon. As water is removed, cellular structures lose turgor and the tissue contracts. The extent of shrinkage depends on drying temperature, drying rate, moisture content, tissue composition, and the formation of internal pores. Mechanical properties describe the response of the material to external forces. Important parameters for dried plant materials include hardness, compressive strength, fracture force, deformation, Young's modulus, and energy required for fracture.

These properties are important in industrial processing because dried tubers may undergo mechanical operations such as cutting, crushing, milling, grinding, conveying, and packaging.

Fresh tubers generally have a soft and flexible cellular structure because of their high-water content. After drying, cell walls become less hydrated and the tissue becomes more rigid. Consequently, dried products may exhibit increased hardness and brittleness.

Nevertheless, mechanical behavior is not determined by moisture content alone. Drying temperature and drying rate can alter porosity, cell-wall integrity, and internal structure. Rapid drying may generate steep moisture and temperature gradients, which can contribute to cracking or case hardening.

Therefore, mechanical measurements can provide useful information for evaluating the suitability of dried Jerusalem artichoke for subsequent processing.

Research methodology. Fresh Jerusalem artichoke tubers (*Helianthus tuberosus* L.) should be obtained from a representative agricultural source. Tubers should be selected based on similar maturity, size, and absence of visible mechanical damage, disease, or decay.

Before experimentation, the samples should be washed with clean water to remove soil and foreign materials. Surface moisture should be removed using absorbent paper.

The tubers should then be cut into standardized slices of predetermined thickness. Standardizing slice thickness is essential because sample dimensions have a substantial influence on drying kinetics.

Drying procedure. The prepared samples should be weighed before drying to determine their initial mass. Drying may be performed using a laboratory hot-air dryer or convection drying oven at predetermined temperatures.

For example, experimental treatments may include:

- 50 °C;

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- 60 °C;
- 70 °C.

Samples should be placed in a single layer to ensure uniform exposure to the drying air. The samples should be weighed periodically during drying until a predetermined final moisture content or approximately constant mass is reached.

The moisture ratio can be calculated as:

$$MR=\frac{M-M_e}{M_0-M_e}$$

where:

- M= moisture content at a given drying time;
- M_0= initial moisture content;
- M_e= equilibrium moisture content.

If equilibrium moisture content is negligible compared with the initial and instantaneous moisture content, the equation may be simplified to:

$$MR=\frac{M}{M_0}$$

Moisture content should be determined using a standard gravimetric method. A representative sample is weighed before and after drying to constant mass.

Moisture content on a wet basis can be calculated as:

$$W=\frac{m_0-m_d}{m_0}\times 100$$

where:

- m_0= mass of the sample before oven drying, g;
- m_d= mass of the dry sample, g.

Moisture content on a dry basis may be calculated as:

$$W_{db}=\frac{m_0-m_d}{m_d}\times 100$$

Water activity (a_w) should be measured using a calibrated water-activity meter at a controlled temperature. Measurements should be conducted after samples reach thermal equilibrium with the measuring chamber.

The water-activity value provides an important indication of the microbiological and physicochemical stability of the dried product.

Color should be evaluated using a colorimeter based on the CIE L^* a^* b^* system.

The parameters are:

- L^* — lightness;
- a^* — red-green coordinate;
- b^* — yellow-blue coordinate.

The total color difference between fresh and dried samples can be calculated as:

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$$\Delta E=\sqrt{\left(L_0^*-L^*\right)^2+\left(a_0^*-a^*\right)^2+\left(b_0^*-b^*\right)^2}$$

where the subscript 0 represents the initial value.

The dimensions of tuber slices should be measured before and after drying. Length, width, and thickness can be recorded using a digital caliper.

Volume shrinkage can be estimated as:

$$S_v=\frac{V_0-V}{V_0}\times 100$$

where:

- V_0= initial sample volume;
- V= volume after drying.

Bulk density can be determined by measuring the mass and volume of a sample:

$$\rho=\frac{m}{V}$$

where:

- ρ= density;
- m= sample mass;
- V= sample volume.

Changes in density can provide information about structural contraction and pore formation during drying.

A predetermined mass of dried Jerusalem artichoke should be immersed in distilled water under controlled conditions. After a specified period, the samples should be removed, gently blotted, and weighed.

Rehydration ratio can be calculated as:

$$RR=\frac{m_r}{m_d}$$

where:

- m_r= mass of the rehydrated sample;
- m_d= mass of the dried sample.

A high rehydration ratio generally indicates better preservation of the original cellular structure.

Mechanical properties should be measured using a texture analyzer or universal testing machine equipped with an appropriate compression probe.

Individual dried samples should be subjected to controlled compression until fracture or a predetermined deformation is reached.

The following parameters may be recorded:

- maximum compression force;
- fracture force;
- deformation at fracture;
- compression energy;

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• hardness.

At least several replicate measurements should be performed for each drying condition to reduce experimental variability.

Statistical analysis. All measurements should be performed in multiple replicates. Results should be presented as mean ± standard deviation.

Analysis of variance (ANOVA) can be used to determine whether drying temperature produces statistically significant differences in measured parameters. Differences between means may be evaluated using an appropriate post-hoc test at a significance level of $p<0.05$.

Regression analysis can also be used to determine relationships between moisture content and mechanical or physicochemical properties.

Research discussion. The principal expected effect of drying is a substantial reduction in moisture content. As drying temperature increases, the vapor pressure difference between the sample and surrounding air becomes greater, accelerating moisture migration and evaporation.

Consequently, samples dried at higher temperatures are expected to reach the target moisture content in a shorter period than samples dried at lower temperatures.

The reduction in moisture content is technologically desirable because it reduces water activity and consequently improves storage stability. However, the final moisture content must be carefully controlled. Excessive drying can increase energy consumption and may produce a very hard and brittle product.

Water activity is expected to decrease as drying progresses. This reduction is associated with the removal of free and weakly bound water.

Lower water activity generally improves the microbiological stability of dried Jerusalem artichoke. It can also reduce the rate of certain enzymatic and chemical reactions. Nevertheless, the relationship between moisture content and water activity is not necessarily linear. The chemical composition of Jerusalem artichoke, particularly its carbohydrate and fiber fractions, influences how water is bound within the tissue.

Drying is expected to cause measurable changes in L^* , a^* , and b^* values. In general, prolonged exposure to elevated temperatures may reduce lightness and increase brownish coloration.

Color changes may result from enzymatic browning before sufficient inactivation occurs, Maillard reactions between reducing sugars and amino groups, and thermal degradation of naturally occurring pigments. Because Jerusalem artichoke contains carbohydrates and amino compounds, temperature control is particularly important when producing a dried product intended for food applications.

The mechanical response of dried Jerusalem artichoke is expected to differ substantially from that of fresh tubers. As water is removed, the material becomes less plastic and more rigid. An increase in drying temperature may therefore be associated with an increase in hardness or fracture force, although the exact relationship depends on drying kinetics and final moisture content.

At very low moisture contents, the product may become brittle and fracture readily under compression. Such behavior can be advantageous for grinding and milling but undesirable if the product is intended to be sold as whole dried slices or chips. Mechanical properties should therefore be considered together with the intended final application.

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Rehydration capacity is an indirect indicator of structural damage caused by drying. A material with relatively well-preserved cellular structure generally absorbs water more effectively than a material that has experienced severe collapse.

High drying temperatures and rapid moisture removal can cause irreversible structural changes, potentially reducing rehydration capacity.

Thus, an optimum drying regime should not be selected solely according to drying time. The final product should also satisfy requirements concerning color, texture, structural integrity, and rehydration characteristics.The physicochemical and mechanical properties of dried Jerusalem artichoke are closely interconnected.

For example, a decrease in moisture content generally increases hardness, while shrinkage can alter density and porosity. Structural collapse may simultaneously reduce rehydration capacity and change mechanical strength.

This demonstrates that optimization of the drying process requires a multidimensional approach. The shortest drying time is not necessarily associated with the highest-quality product. An appropriate drying condition should provide sufficient moisture removal for safe storage while minimizing undesirable structural and chemical changes.

Conclusion. The drying of Jerusalem artichoke tubers produces significant changes in both physicochemical and mechanical properties. Moisture content and water activity decrease during drying, resulting in improved storage stability. At the same time, removal of water causes structural contraction, shrinkage, changes in density, and modifications in mechanical strength.

Drying temperature has a major influence on these changes. Higher temperatures generally accelerate moisture removal and reduce processing time, but excessive temperature can promote undesirable color changes, structural damage, excessive hardness, and reduced rehydration capacity. The determination of moisture content, water activity, color, shrinkage, density, rehydration ratio, hardness, and compression characteristics provides a comprehensive basis for evaluating dried Jerusalem artichoke tubers.

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