PHYSICOCHEMICAL AND MECHANICAL PROPERTIES OF JERUSALEM ARTICHOKE TUBERS AFTER DRYING

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Abstract. Its high initial moisture content, however, makes the fresh tuber highly perishable and limits its long-term utilization. Drying represents an effective preservation technology, but the removal of water is accompanied by changes in chemical composition, color, dimensional stability, porosity, rehydration behavior, and mechanical properties. The present article reviews and establishes a methodological framework for evaluating the physicochemical and mechanical properties of Jerusalem artichoke tubers subjected to drying. Particular attention is given to moisture content, water activity, drying kinetics, color, shrinkage, density, rehydration capacity, hardness, and deformation behavior. The principal equations used to quantify moisture reduction, moisture ratio, drying rate, shrinkage, and rehydration are presented.

Keywords: drying; moisture content; water activity; shrinkage; hardness; texture; rehydration; inulin.

Annotatsiya.
Biroq, uning dastlabki namlik miqdorining yuqoriligi yangi topinambur tuganaklarining tez buziluvchan bo‘lishiga va uzoq muddat davomida saqlash hamda foydalanish imkoniyatlarining cheklanishiga olib keladi. Quritish samarali saqlash texnologiyasi hisoblanadi, biroq suvning chiqarib yuborilishi kimyoviy tarkib, rang, o‘lcham barqarorligi, g‘ovaklik, qayta namlanish xususiyatlari va mexanik xossalarning o‘zgarishi bilan kechadi. Mazkur maqolada quritilgan topinambur tuganaklarining fizik-kimyoviy va mexanik xususiyatlarini baholash uchun metodologik yondashuv ko‘rib chiqiladi va taklif etiladi. Tadqiqotda namlik miqdori, suv faolligi, quritish kinetikasi, rang, qisqarish, zichlik, qayta namlanish qobiliyati, qattiqlik va deformatsion xususiyatlarga alohida e’tibor qaratilgan. Namlikning kamayishi, namlik nisbati, quritish tezligi, qisqarish va qayta namlanishni miqdoriy jihatdan aniqlashda qo‘llaniladigan asosiy tenglamalar keltirilgan.

Kalit so‘zlar: quritish; namlik miqdori; suv faolligi; qisqarish; qattiqlik; tekstura; qayta namlanish; inulin.

Аннотация. Однако высокое исходное содержание влаги делает свежие клубни топинамбура скоропортящимся продуктом и ограничивает возможности их длительного хранения и использования. Сушка является эффективной технологией консервирования, однако удаление воды сопровождается изменениями химического состава, цвета, размерной стабильности, пористости, способности к регидратации и механических свойств. В настоящей статье рассматривается и предлагается методологический подход к оценке физико-химических и механических свойств клубней топинамбура после сушки. Особое внимание уделено содержанию влаги, активности воды, кинетике сушки, цветовым характеристикам, усадке, плотности,

способности к регидратации, твердости и деформационным свойствам. Представлены основные уравнения, используемые для количественной оценки снижения содержания влаги, влагового отношения, скорости сушки, усадки и регидратации.

Ключевые слова: сушка; содержание влаги; активность воды; усадка; твердость; текстура; регидратация; инулин.

Introduction. The tubers contain substantial quantities of water and carbohydrates, with inulin-type fructans representing the principal carbohydrate fraction. The composition of Jerusalem artichoke varies considerably according to genotype, environmental conditions, harvest time, and postharvest handling.

The nutritional and technological interest in Jerusalem artichoke is closely associated with its fructan fraction. Inulin is a β-(2→1)-linked fructan and is recognized as a dietary fibre with prebiotic functionality. Recent reviews have emphasized the potential of Jerusalem artichoke inulin in functional foods and other food applications.

Published compositional studies have reported moisture contents of approximately 798–813 g kg^{-1} fresh tuber for selected clones, although substantial cultivar-dependent variation occurs. Consequently, dehydration is an important strategy for extending shelf life and facilitating transportation, storage, milling, and incorporation into value-added food products.

Drying, however, is not simply a water-removal operation. Simultaneous heat and mass transfer can modify the cellular structure and chemical constituents of plant tissues. Water removal may cause shrinkage, collapse of cellular structures, changes in porosity and density, concentration of soluble solids, pigment degradation, enzymatic reactions, nonenzymatic browning, and changes in mechanical strength. These structural changes ultimately determine the textural properties of the dried material.

More recently, a study comparing convective and convective–microwave drying demonstrated that drying temperature and technology substantially affected drying kinetics, color, polyphenol retention, antioxidant activity, and grindability. The Page model provided the best description of the drying curves in that study.

The objective of this article is therefore to provide a publication-style framework for evaluating the physicochemical and mechanical properties of Jerusalem artichoke tubers after drying, emphasizing the relationships between moisture removal, structural changes, and final product quality.

Materials and methods. Tubers should be selected according to uniformity of size and absence of visible mechanical damage, fungal infection, or decay.

Following transportation to the laboratory, the tubers should be washed under running water to remove soil and foreign material and subsequently dried superficially with absorbent paper. Depending on the experimental objective, tubers may either be peeled or dried with the peel intact. Because peel removal can influence drying kinetics and mechanical behavior, the procedure should remain identical for all experimental treatments.

For experiments involving slicing, tubers should be cut perpendicular to the longitudinal axis using a stainless-steel knife or mechanical slicer. Slice thickness should be maintained constant, for example, at 3–5 mm, because sample thickness strongly affects the diffusion distance and consequently drying time.

Experimental drying procedure. A laboratory-scale convective hot-air dryer may be used for the dehydration experiments. The recommended experimental design should include at least three temperatures, for example:

- 40 °C
- 60 °C
- 80 °C

These temperatures are particularly relevant because recent Jerusalem artichoke research has evaluated drying at 40, 60, and 80 °C.

Alternatively, the experiment can compare different technologies such as:

1. convective hot-air drying;
2. microwave-assisted drying;
3. vacuum drying;
4. freeze-drying.

Previous research indicates that drying technology substantially affects the physicochemical quality of Jerusalem artichoke products. Freeze-drying has generally provided better retention of sensitive compounds, whereas conventional and vacuum drying offer greater practical and economic potential.

Samples should be weighed periodically during drying using an analytical balance. Drying should continue until a predetermined final moisture content or constant mass is reached.

Moisture ratio and drying kinetics. The dimensionless moisture ratio (MR) can be calculated as:

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

where $M_t$is the moisture content at time t, $M_0$is the initial moisture content, and $M_e$is the equilibrium moisture content.

When $M_e$is sufficiently small relative to M_t, the simplified expression may be used:

$$MR\approx\frac{M_t}{M_0}$$

Drying rate is calculated as:

$$DR=\frac{M_t-M_{t+\Delta t}}{\Delta t}$$

where Δtrepresents the drying interval.

The drying curves can be fitted to commonly used thin-layer models, including the Lewis, Henderson–Pabis, logarithmic, and Page models. The Page model is expressed as:

$$MR=\exp(-kt^n)$$

where $k$and $n$are empirical constants.

The suitability of each model should be evaluated using the coefficient of determination (R^2), root mean square error (RMSE), and reduced chi-square (χ^2).

The Page model has been reported to provide an especially good description of Jerusalem artichoke drying kinetics under both convective and convective–microwave conditions.

Water activity. Water activity is an important indicator of the stability of dried food materials because it reflects the thermodynamic availability of water rather than simply the total water content.

It is defined as:

$$a_w=\frac{P}{P_0}$$

where $P$is the equilibrium vapor pressure of water above the sample and $P_0$is the vapor pressure of pure water at the same temperature.

Water activity should be measured at a controlled temperature, preferably 25 °C, using a calibrated water-activity meter.

Reduction of a_w is one of the principal mechanisms by which drying increases food stability. However, water activity also influences enzymatic activity, chemical reactions, texture, and moisture migration during storage.

Drying is expected to produce a pronounced decrease in moisture content as water migrates from the interior of the tuber slices toward the surface and subsequently evaporates into the drying air.

Increasing drying temperature would generally be expected to increase the moisture-transfer driving force and reduce the time required to reach a given moisture level. Published Jerusalem artichoke research has similarly demonstrated substantial effects of drying temperature and drying technology on drying kinetics.

However, accelerated water removal at elevated temperature may simultaneously increase thermal and structural damage. Consequently, the shortest drying time should not necessarily be regarded as the optimum processing condition.

Drying kinetics. Moisture ratio (MR) of Jerusalem artichoke tubers as a function of drying time at different drying temperatures. Symbols represent experimental data and continuous lines represent fitted Page-model curves.

The drying curve should normally demonstrate a progressive reduction in moisture ratio with time. If the experimental curves show predominantly falling-rate behavior, moisture diffusion and internal mass transfer are likely to constitute important limitations during the latter stages of dehydration.

The Page equation can be fitted independently for each drying temperature:

$$MR=\exp(-kt^n)$$

The parameters $k$and $n$should be reported with their confidence intervals, while model adequacy should be assessed using R^2, RMSE, and χ^2.

The observation that the Page model adequately describes Jerusalem artichoke drying is consistent with recent experimental work using convective and convective–microwave drying.

A substantial reduction in $a_w$is expected following drying. This reduction results from the removal of free and increasingly bound water and is essential for improving storage stability.

Water activity should, however, be interpreted alongside moisture content. Two samples with similar total moisture contents can exhibit different $a_w$values because water can interact differently with carbohydrates, proteins, cell-wall polymers, and soluble solids.

More recent work found that drying Jerusalem artichoke at 80 °C, particularly under combined convective–microwave conditions, produced pronounced color changes and greater losses of polyphenols compared with lower-temperature treatments.

One of the principal advantages of simultaneously measuring physicochemical and mechanical characteristics is the possibility of establishing structure–property relationships.

A conceptual relationship can be expressed as:

Drying conditions→moisture removal→cellular deformation→shrinkage/porosity→mechanical properties

At the same time:
Drying temperature/time→chemical reactions→color and bioactive-compound changes

These relationships indicate that drying should be optimized using a multivariable quality criterion, rather than drying time alone.

For example, a high drying temperature may provide a shorter processing time but produce greater color deterioration and degradation of sensitive compounds. Conversely, a low temperature may preserve quality but require substantially longer processing.

Recent Jerusalem artichoke research illustrates this trade-off: convective–microwave drying substantially reduced drying time and improved grindability, but higher-temperature treatment caused more pronounced color changes and polyphenol losses.

Conclusions. Drying substantially modifies the physicochemical and mechanical properties of Jerusalem artichoke tubers. The principal effect is the reduction of moisture content and water activity, which improves storage stability but simultaneously induces structural and textural changes. Moisture removal is accompanied by shrinkage, changes in density and porosity, reduced rehydration capacity, and modification of mechanical resistance.

The drying temperature represents a critical processing variable because increasing temperature accelerates water removal but may intensify undesirable changes in color and bioactive compounds. Published research on Jerusalem artichoke indicates that relatively mild drying conditions can provide better retention of sensitive compounds, whereas higher temperatures and hybrid drying technologies may provide advantages in processing time and grindability.

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