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STUDY OF SORPTION PROPERTIES OF QUINOA SEEDS

Abstract

The paper provides an analysis of the current state of the quinoa seed market in the world and the prospects for its production in Ukraine. The main producers of quinoa are Peru, Bolivia and Ecuador. Due to its rich chemical composition, quinoa seeds are rapidly gaining popularity. Ukrainian enterprises use quinoa grain for the production of various products and semi-finished products. Quinoa seeds are attracting increasing attention worldwide not only for their nutritional and functional properties, but also for their ability to grow in adverse climatic conditions. Increasing demand and rising global prices for quinoa is encouraging producers to adapt the crop to low altitudes and grow it in arid conditions. Breeders and scientists of different countries are actively working on the adaptation of quinoa seeds to growing in different regions, which has an important impact on food security. Quinoa grain imported to Ukraine requires long-term storage without weight loss and quality deterioration. An important influence on the state of grain mass during storage is its hygroscopicity, that is, the ability to sorb and desorb water vapor. Knowledge about the hygroscopic properties of grain is of practical importance for the scientific justification of the choice of rational modes of storage and post-harvest processing. The main characteristic of the hygroscopic properties of grain materials is the equilibrium moisture content, therefore, its determination is an important step in preserving grain quality. The equilibrium moisture content of quinoa grain was determined. The research was carried out by the generally accepted tensimetric method in the range of air temperatures ±(5...25)°C and relative air humidity 40...80%, which simulate the conditions of grain storage and correspond to long-term average data, corresponding to warm and cold seasons in Ukraine. The nature of the change in the equilibrium moisture content of quinoa grain depending on the temperature and relative humidity of the air has been established. As the relative humidity increases and the ambient temperature decreases, the equilibrium moisture content of the quinoa grain increases. Empirical coefficients were determined and an equation was proposed that describes the dependence of the equilibrium moisture content of quinoa grain on the parameters of the surrounding air, which can be used to predict its change. The obtained data are of practical importance for the selection of high-quality storage regimes for quinoa seeds.

Key words: quinoa seeds, sorption, hygroscopic properties, equilibrium moisture, storage, environment.

Introduction

Quinoa seeds are showing growing interest worldwide due to their unique nutritional value. The protein content in quinoa grains is higher than in other cereals, while essential amino acids are better distributed in it. In addition, quinoa contains a large amount of essential fatty acids, minerals, vitamins, dietary fiber and carbohydrates with a favorable hypoglycemic effect, while it does not contain gluten [1-5].

In recent decades, the production of quinoa seed began to increase steadily, and by 2013, which became the International Year of Quinoa, production and consumption of the crop increased exponentially. In fig. 1 shows changes in the indicators of cultivated area and production of quinoa in the world for 2000-2020, according to the data of the Food and Agricultural Organization of the United Nations [6, 7].

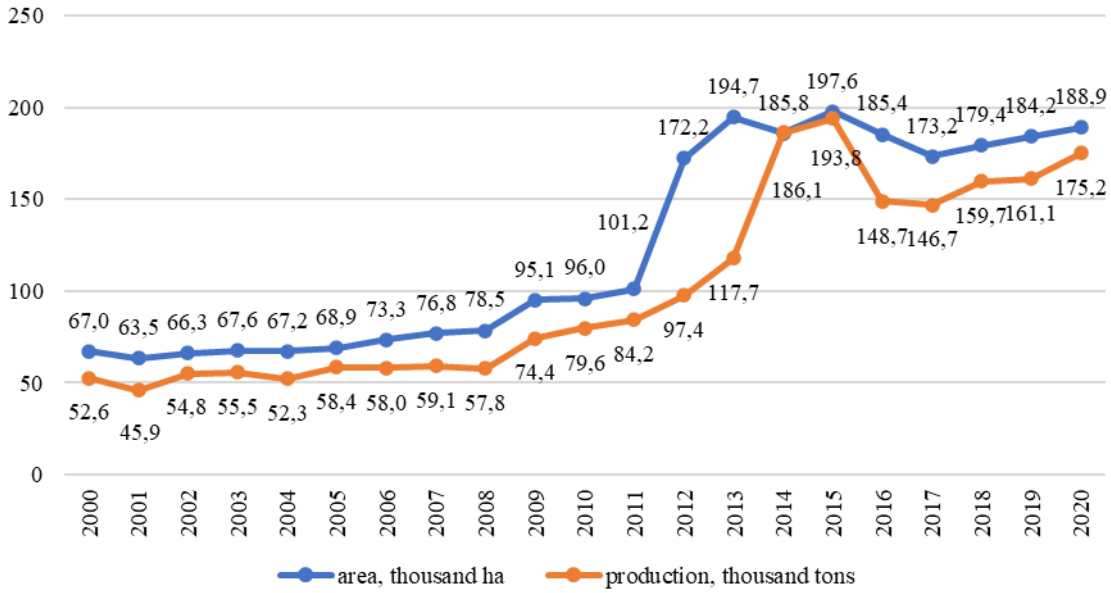
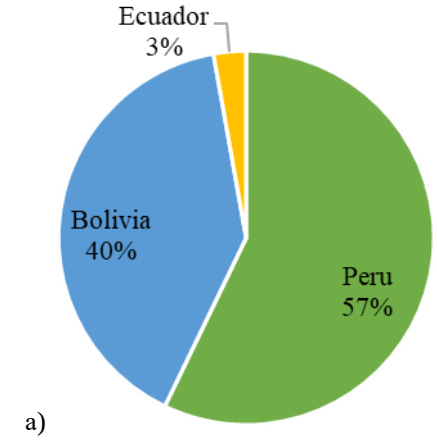


Fig. 1. World quinoa seed production

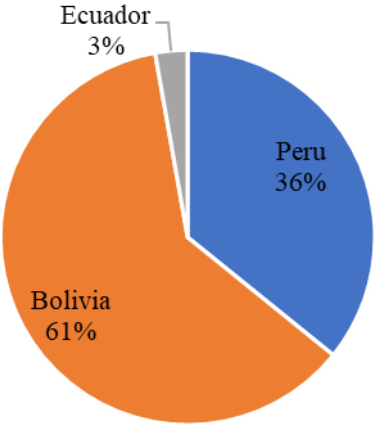
Quinoa seeds are attracting increasing attention worldwide not only for their nutritional and functional properties, but also for their ability to grow in adverse climatic conditions. Quinoa plants show resistance to frost, salinity, drought and are able to grow on infertile soils. Thus, these characteristics are very important for areas at risk of food insecurity. Recent interest in this crop has increased in recent decades due to its outstanding plasticity, which allows it to adapt to different environmental conditions.

As demand and production in other countries increase, quinoa-growing regions that are largely dependent on quinoa production for food and economic survival may suffer from this interest in negative consequences. Nevertheless, quinoa seed production can significantly improve food security due to key aspects associated with quinoa, such as its low cost of production, its ability to adapt to extreme and diverse conditions and, most importantly, its nutritional value [6].

The largest suppliers of quinoa seeds in the world are considered to be Peru, Bolivia and Ecuador. According to the Food and Agricultural Organization of the United Nations, the largest areas of quinoa seed cultivation are in Bolivia - 115.9 thousand hectares, in Peru - 67.6 thousand hectares, and in Ecuador - 5.2 thousand hectares. The leader in the production of quinoa seeds is Peru - 100.1 thousand tons, Bolivia - 70.2 thousand tons, and Ecuador - 4.9 thousand tons [7]. The structure of quinoa seed production in 2020 is shown in Fig. 2.



a)



b)

Fig. 2 – The structure of quinoa seed production in 2020: a – sown areas, b – production.

Adaptation of quinoa seeds to the climatic features of the Eurasian continent is underway. There are good results of growing quinoa in the conditions of Kyrgyzstan and the Caucasus. The only European quinoa seed selection center has been established in the Netherlands. Quinoa is already grown in France, northern Germany, Canada, the USA, Spain, England, Denmark, etc. In Ukraine, work is also underway on the selection and adaptation of quinoa seeds, and there are already successes. Scientists of the Sumy National Agrarian University developed and for the first time in Ukraine officially registered a variety of quinoa seed culture. At the same time, the areas under cultivation are still insignificant, and it is considered niche [4, 5].

The range of quinoa seed products produced by Ukrainian enterprises has also expanded recently. It is clear that 100% of quinoa seeds in Ukraine are still imported. All this grain requires long-term storage, and it is important to preserve its quality indicators.

It should be noted that for post-harvest processing and storage of grain and seeds, hygroscopic properties are of great importance. Thus, grain and seeds of all crops are able to absorb (sorb) vapors of various substances and gases from the environment. Under certain conditions, a partially or completely reversible process of release (desorption) of these substances into the environment is possible. The result of the sorption process is the acquisition of foreign odors by the grain. Sorption and desorption of water vapor characterizes the hygroscopic properties of grain. The regularities reflecting the hygroscopic properties of grain are the basis of the technology of storage, drying, active ventilation and other operations for the processing of grain masses [8-10].

Scientists pay great attention to the sorption properties of grain and oil crops, as an important factor in their post-harvest processing and storage. For many grain crops, hygroscopic properties have been studied for a long time [8-10], but work on their research continues for new crops and under different conditions. The hygroscopic properties of flax, mustard, rapeseed and chia were determined [11-13]. In these works, studies of equilibrium humidity at various environmental parameters are presented, and their dependence is established.

Research methodology

The object of research is the hygroscopic properties of quinoa seeds.

The subject of research is quinoa seeds. The initial moisture content of quinoa seeds is 9.58%.

The purpose of the study is to establish the regularities of changes in the equilibrium humidity of quinoa seeds depending on the temperature and relative humidity of the outside air, which will improve the quality and ensure its long-term guaranteed storage.

To achieve the goal, the following tasks must be completed:

− to determine the value of the equilibrium moisture content of quinoa seeds under different environmental parameters (temperature and relative air humidity);

− establish the dependence of the equilibrium moisture of quinoa seeds depending on the temperature and relative humidity of the surrounding air;

- to determine the empirical coefficients in the sorption isotherm equation for predicting the equilibrium moisture content of quinoa seeds depending on the ambient air parameters.

Research methodology. The research was carried out by the generally accepted tensimetric method in the range of air temperatures ±(5...25)°C and iota relative air humidity of 40...80%, which simulate grain storage conditions and correspond to long-term average data and correspond to warm and cold seasons in Ukraine.

For this, samples of quinoa seeds in glass boxes were placed in desiccators with a solution of sulfuric acid of a known concentration, in which the necessary parameters of relative air humidity were created artificially (with the help of a suitable solution of sulfuric acid). Each concentration of sulfuric acid corresponds to a certain air humidity [14]. Quinoa seed samples placed in desiccators were stored in a refrigerator at a temperature of plus (+5±1)°C and in a thermostat at a temperature of (+25±1)°C.

Weighing was carried out until the equilibrium humidity was established, that is, until the constant mass. Based on the change in the weight of the samples in the glass boxes at each specific moment in time, the intermediate moisture content of the grain was calculated. The initial, flow and final moisture content of the quinoa seed sample was determined according to DSTU 29144:2009 (ISO 711-85).

Research results

For the practice of grain storage, the changes that occur in the grain under different relative air humidity are of great importance. As the temperature rises, the air's ability to absorb and retain vaporous moisture increases, i.e., with an unchanged moisture content, it becomes drier and its relative humidity decreases. When the temperature decreases, the relative humidity of the air increases accordingly, because the ability to absorb moisture decreases.

A decrease in air temperature at night is always associated with growth and its relative humidity, which causes moistening of the grain, as well as the danger of moistening the grain mass during night ventilation with atmospheric air. During the day, the air warms up and becomes dry, therefore, active ventilation for grain drying can be most successfully carried out in the daytime and evening hours, and it is better to cool the grain at night and in the morning. However, in the latter case, it is mandatory to control the relative humidity of the air in order to prevent the grain from becoming wet during processing [8, 9]. In natural conditions, the relative humidity of the air changes continuously according to the daily course of temperature, as well as depending on changing weather conditions, including the seasons.

In addition to the sorption change in humidity as a result of the absorption or release of vaporous moisture through the air, direct moistening or drying of the grain is possible during the movement of droplet-liquid moisture (contact moisture exchange). These processes can occur simultaneously. In grain mass with moisture higher than its maximum hygroscopicity, moisture exchange can occur only by contact as a result of the movement of droplet-liquid moisture [8-10].

In the freshly harvested grain mass, which is characterized by a large unevenness in the moisture content of all its components, contact and sorption moisture exchange is simultaneously observed. As a result, the humidity is relatively quickly equalized, the wet fractions of impurities and unripe grain dry out significantly, and the ripe grain is noticeably moistened.

The conducted experiments showed that the duration of experiments to reach the equilibrium state of quinoa seeds was 11...14 days. After the experiments, their mathematical processing was carried out. The experimental values of current grain moisture were approximated by empirical equations for averaging sorption or desorption isotherms, in which the coefficients were determined by the method of least squares [15]. Based on the obtained sorption and desorption isotherms, the equilibrium moisture content of quinoa seeds was determined for each of the temperature and relative humidity values in the desiccators.

Next, the calculated values of the equilibrium moisture content of the quinoa seeds were compared with the final moisture content of the samples in each desiccator. The verification showed that the calculated and experimental values of the equilibrium humidity were within the error limits of the experiments. The obtained values of equilibrium humidity are given in the table. 1.

Table 1 – Equilibrium moisture content of experimental samples of quinoa seeds

Conditions of the experiment		Equilibrium moisture wp, %
Relative humidity, %	Ambient temperature, t, °C	
40	5	10,40
60	5	12,05
80	5	14,75
40	25	11,06
60	25	13,16
80	25	16,40

The terms of reaching equilibrium humidity in different conditions also vary. Thus, at a temperature of (+25±1)°C, equilibrium occurs on the 13th...14th day, and at (+5±1)°C - on the 11th...13th day of the experiment.

The most complete characteristic of hygroscopic properties is the sorption isotherm - the dependence of the equilibrium moisture content of the grain wp on the relative humidity of the air φ. It is known that grain sorption isotherms can be described quite accurately by a well-known equation of the form [11]:

$$w_p = A - B \cdot t + (C - D \cdot t)\left[\lg\left(\frac{1}{1-\varphi}\right)\right]^{0,5}$$

w_p – equilibrium grain moisture, %,
t – ambient temperature, °C;
φ – relative air humidity, %;
A, B, C, D are steels that depend on the form of the moisture connection with the dry matter of the grain

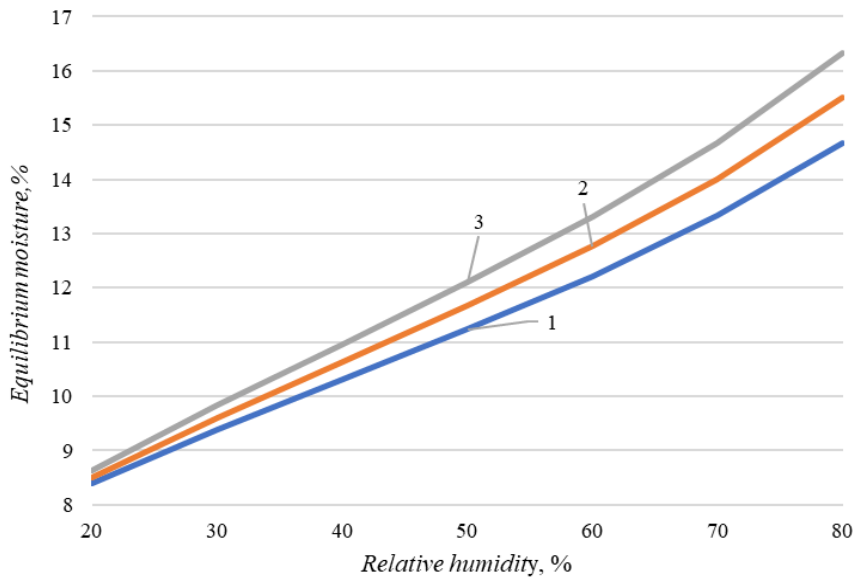


Fig. 3 – Sorption isotherms of quinoa seeds: 1 - +5°C; 2 - +15°C; 3 - +25°C

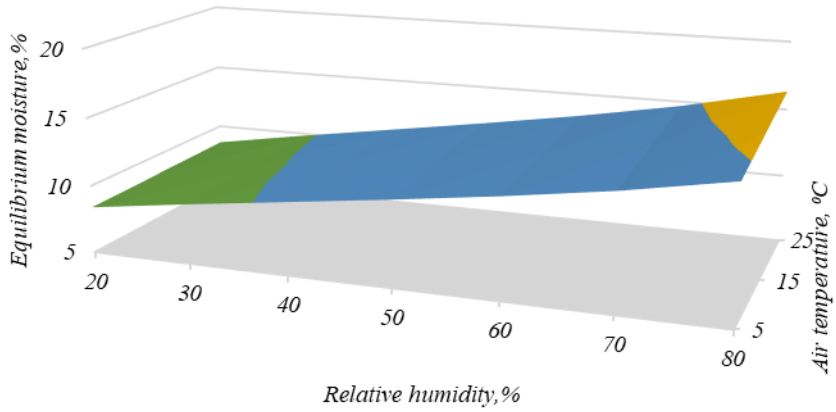


Fig. 4 – Dependence of the equilibrium moisture content of quinoa seeds on air temperature and relative humidity

and the temperature of the grain and are determined by the method of least squares based on experimental data.

We determined the values of empirical coefficients A, B, C, D for quinoa seeds: A = 4.8177, B = 0.0305, C = 11.2969 D = -0.1354

Sorption isotherms of quinoa seeds at different temperatures and ambient humidity are shown in Fig. 3.

The equilibrium moisture content of grain is affected by such factors as temperature and relative air humidity, the type of grain crop and its initial moisture content [11]. In fig. 4 shows a graphical representation of the dependence of the equilibrium moisture content of the grain on the air temperature and its relative humidity.

The determining factor that affects the amount and speed of reaching the equilibrium humidity is the value of the relative humidity of the air - the higher it is, the faster the grain absorbs moisture and the greater the equilibrium humidity. The latter also depends on the air temperature: for the same relative air humidity and a higher temperature, a lower equilibrium humidity corresponds and, conversely, a lower temperature leads to an increase in the equilibrium humidity of the grain.

Conclusions

Numerical values of the equilibrium humidity of quinoa seed samples were determined in the range of relative humidity and air temperature corresponding to environmental parameters in warm and cold seasons.

The nature of changes in the equilibrium moisture content of quinoa seeds depending on temperature and relative air humidity has been determined. As the relative humidity increases and the ambient air temperature decreases, the equilibrium moisture content of quinoa seeds increases.

Empirical coefficients were determined and an equation was proposed that describes the dependence of the equilibrium moisture content of quinoa grain on the parameters of the surrounding air - temperature and relative humidity, which can be used to predict its change.

The obtained data can be used to select drying and active ventilation modes, as well as conditions for storing quinoa seeds.

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ДОСЛІДЖЕННЯ СОРБЦІЙНИХ ВЛАСТИВОСТЕЙ НАСІННЯ КІНОА

Анотація

У роботі наведено аналіз сучасного стану ринку насіння кіноа у світі та перспективи її виробництва в Україні. Основними виробниками зерна кіноа є Перу, Болівія та Еквадор. Завдяки багатому хімічному складу, насіння кіноа набирає стрімкої популярності. Українські підприємства використовують зерно кіноа для виробництва різних продуктів та напівфабрикатів. Насіння кіноа привертає все більшу увагу в усьому світі не тільки завдяки своїм поживним та функціональним властивостям, а й завдяки здатності вирощувати її у несприятливих кліматичних умовах. Підвищення попиту і зростання світових цін на кіноа стимулює виробників адаптувати культуру до низьких висот і вирощувати її в посушливих умовах. Селекціонери та науковці різних країн проводять активну роботу з адаптації насіння кіноа до вирощування в різних регіонах, що має важливий вплив на продовольчу безпеку. Зерно кіноа, яке імпортується до України потребує тривалого зберігання без втрат в масі і погіршення якості. Важливий вплив на стан зернової маси при зберіганні має її гігроскопічність, тобто здатність до сорбції і десорбції парів води. Знання про гігроскопічні властивості зерна мають практичне значення для наукового обґрунтування вибору раціональних режимів зберігання та післязбиральної обробки. Основною характеристикою гігроскопічних властивостей зернових матеріалів є рівноважна вологість, тому її визначення є важливим кроком для збереження якості зерна. Визначено рівноважну вологість зерна кіноа. Дослідження проводили загальноприйнятим тензиметричним методом в діапазоні температур повітря ±(5...25)°С та відносної вологості повітря 40…80 %, які моделюють умови зберігання зерна і відповідні до багаторічних середніх даних, відповідають теплій і холодній порі року в Україні. Встановлено характер зміни рівноважної вологості зерна кіноа залежно від температури та відносної вологості повітря. Зі збільшенням відносної вологості та зниженні температури навколишнього середовища рівноважна вологість зерна кіноа зростає. Визначено емпіричні коефіцієнти та запропоноване рівняння, яке описує залежність рівноважної вологості зерна кіноа від параметрів навколишнього повітря, за яким можна прогнозувати його зміну. Отримані дані мають практичне значення для підбору режимів якісного зберігання насіння кіноа.

Ключові слова: насіння кіноа, сорбція, гігроскопічні властивості, рівноважна вологість, зберігання, навколишнє середовище.

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