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STUDY OF WATER ABSORPTION CAPACITY AND DEHULLING OF CHICKPEA SEEDS

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Abstract. Chickpea is a promising legume crop used in various sectors of the food industry. Global chickpea production has been increasing recently, with India, Australia, Pakistan, and Turkey being the leading producers. In Ukraine, 20,000–30,000 tons of chickpeas are grown annually on an area of 15,000–30,000 hectares, mainly in the Odesa, Kherson, Mykolaiv, and Dnipropetrovsk regions. Chickpea product manufacturing in Ukraine remains limited, with an estimated production of groats at 4,000–5,000 tons, flour at 1,000–2,000 tons, and flakes at a few hundred tons. The main obstacles include low demand, weak promotion, and the lack of technological standards for processing this crop. The prospects for development are associated with expanding the range of chickpea products, including instant porridges, breakfast cereals, and snack bars. The quality of chickpea seeds is regulated by DSTU 6019:2008, but there is no regulatory framework for processing, which complicates the production of chickpea-based products. Water heat treatment is an important technological process in the food industry aimed at reducing the content of anti-nutritional compounds such as protease inhibitors, phytates, tannins, and lectins. Soaking at 25–40°C for 8–24 hours facilitates the dissolution of water-soluble anti-nutritional compounds, while steaming at 100°C inactivates thermolabile components. These methods improve the organoleptic properties, digestibility of proteins and micronutrients, as well as the taste characteristics of the end products. The combination of soaking and steaming is the most effective approach. A study was conducted on the water absorption process of chickpea seeds during soaking in water at different temperatures (20°C, 40°C, 60°C). It was found that increasing the temperature accelerates water absorption through the seed coat and promotes more intensive swelling of proteins and starch. At 20°C, the water absorption process is slow, reaching 35% moisture content within 120 minutes. A temperature of 40°C ensures an optimal balance between absorption rate and saturation level (40 %). At 60°C, the highest water absorption (45%) is observed, but excessive softening may affect the grain structure. Furthermore, soaking activates enzymatic processes that contribute to reducing the content of anti-nutritional substances. The obtained results serve as a basis for optimizing technological regimes for chickpea grain preparation for further processing, particularly to decrease anti-nutritional components and enhance the nutritional value of the final products. Water-heat treatment of chickpea seeds, which involves moistening to 16%, conditioning, and steaming at a steam pressure of 0.20 MPa followed by drying to 14%, significantly enhances the efficiency of the dehulling process by intensive abrasion. This effect is explained by structural and functional changes in the seed coats and kernel: the coats become more plastic and separate evenly, while the kernel increases its mechanical strength. This contributes to a reduction in grain damage and, consequently, increases the yield of whole kernels at all stages of the process, while simultaneously reducing the formation of broken kernels and flour. Compared to dehulling untreated seeds without prior preparation, hydrothermal.

Keywords: chickpea, food industry, water heat treatment, soaking, steaming, antinutritional compounds, water absorption capacity, dehulling.

Introduction. Formulation of the problem

Chickpea seeds represent a promising leguminous crop for expanding the range of groats products in Ukraine. Due to its high nutritional value and unique composition, chickpea is widely used in the food industry both as a standalone product and increasingly as an ingredient in composite formulations. Traditionally, such formulations incorporating chickpea are utilized in the production of canned foods, bakery products, confectionery, and coffee substitutes, enriching them with valuable proteins, minerals, and other beneficial components that enhance the nutritional value of the end products. In the food sector, chickpea is used in various forms. It is processed into flour, which is blended with wheat flour to improve the nutritional quality of baked goods. The addition of chickpea flour enhances dough texture, enriches products with protein, and contributes to better organoleptic properties. Due to its unique protein composition, chickpea flour is widely applied in the confectionery industry for producing cookies, biscuits, and other products with enhanced nutritional and functional properties. Chickpea is also utilized in beverage production. Roasted chickpea is used to produce a caffeine-free coffee substitute with a pleasant taste and aroma. Chickpea milk, a plant-based alternative, serves as a substitute for cow’s milk for individuals with lactose intolerance or those following a vegan diet. In the canning industry, chickpea is used for producing protein-enriched canned meals, which can serve as an alternative to traditional meat or fish preserves. Additionally, chickpea is the key ingredient in dishes such as hummus, which has gained worldwide popularity due to its health benefits and high nutritional value. Chickpea also holds significant potential for feed applications, as its seeds serve as a high-quality protein source for livestock, poultry, and fish. The protein and amino acid content of chickpea makes it a valuable component of compound feeds, supporting improved growth and productivity in animals [1-5].

Global chickpea production continues to increase, driven by its high nutritional value, broad application potential, and adaptability to diverse climatic conditions. The majority of cultivated areas are concentrated in India, the Middle East, North Africa, as well as arid regions of Europe and the Americas. Among pulse crops, chickpea ranks third in terms of sown area, following soybean and common bean, covering approximately 100 000–120 000 km². India is the leading producer, accounting for approximately 70% of global chickpea output, amounting to around 8.1 million tons per year. The predominant variety grown in India is *desi* chickpea, characterized by small, dark seeds with a rough surface. Approximately 90–95% of India’s total chickpea production consists of the desi variety, equating to 7,3–7,7 million tons, while the kabuli variety represents only 5–10%, or roughly 0,4–0,8 million tons. Chickpea is an integral part of Indian cuisine, used in traditional dishes such as "dal" and "curry." Apart from whole seeds, a substantial portion of chickpea is processed into flour, known in India as "besan," which is widely used in baking, confectionery, and snack production. Australia is the second-largest chickpea producer, contributing 5–10% of global output, equivalent to approximately 0,6–1,2 million tons per year. Desi chickpea predominates in Australia, accounting for approximately 90% of total production, with an estimated 2,04 million tons of desi chickpea produced last year. The kabuli variety, distinguished by its larger, lighter-colored seeds with a smooth surface, comprises approximately 10% of production, or around 0,23 million tons. Most Australian chickpea is exported to India, Pakistan, and Bangladesh. Domestic consumption remains relatively low, but interest in chickpea utilization in the food industry is growing. The production of chickpea flour and other processed products is not yet substantial but is showing an upward trend. Pakistan produces approximately 4–5% of the world's chickpea, equating to about 0,3–0,4 million tons annually. The desi variety dominates production, accounting for approximately 90–95% of the total yield, which translates to around 0,27–0,38 million metric tons per year. The kabuli variety, cultivated in smaller quantities, represents about 5–10% of total production, or 0,02–0,04 million tons. Chickpea plays a crucial role in Pakistani cuisine, utilized both in whole-seed form and as flour for preparing various dishes and snacks. Turkey contributes approximately 3–4% of global chickpea production, amounting to about 0,24–0,32 million tons per year. More than 80% of Turkish production is attributed to the kabuli variety, which accounts for 0,19–0,26 million tons, while desi chickpea represents up to 20%. Chickpea is an important ingredient in Turkish cuisine, used in dishes such as hummus and falafel. A significant portion of Turkish chickpea is processed into flour, which is employed in baking and traditional food preparation. The production of chickpea flour in Turkey is estimated at tens of thousands of tons annually. Moreover, Turkey exports chickpea and its derivatives, contributing to the crop’s expansion in international markets. In Mediterranean countries such as Spain, Italy, Greece chickpea cultivation is conducted on a smaller scale, yielding 50 000–150 000 tons annually. In the United States, chickpea production reaches approximately 200 000–250 000 tons per year. Overall, global chickpea production fluctuates between 12 and 15 million metric tons annually, depending on weather conditions, cultivated area, and yield levels. [6-10]

Analysis of recent research and publications

In Ukraine, the area under chickpea cultivation typically ranges from 15000 to 30000 hectares, which is small compared to major global producers such as India or Australia. The total annual production of chickpeas in Ukraine is approximately 20000–30000 tons. The main chickpea-growing regions are Odesa, Kherson, Mykolaiv, and Dnipropetrovsk. Odesa region has around 6000–8000 hectares under chickpeas, producing approximately 12000–16000 tons. In Kherson, chickpea fields cover 5000–7000 hectares, producing 10000–14000 tons. Mykolaiv region cultivates chickpeas on 2000–3000 hectares, with producing of 4000–6000 tons, while Dnipropetrovsk has 1000–2000 hectares producing 2000–4000 tons annually.

This leguminous crop has significant potential in the international market due to its high nutritional value and the growing demand for healthy food, especially among vegetarians and vegans. Ukraine increases its production and export volumes of chickpeas every year, as favorable climatic conditions allow for large-scale cultivation. One of the key advantages of chickpeas is their economic efficiency: the cost of growing this crop is considerably lower than that of many other grains and legumes. Moreover, chickpeas exhibit high drought resistance, making them an ideal choice for regions with limited water resources. The primary importers of Ukrainian chickpeas are European Union countries, particularly Italy, Spain, and Turkey, as well as India and other Asian nations. Italy actively purchases chickpeas due to the strong demand for legumes, while India, despite being the world's largest producer, also imports them to meet domestic consumption needs.

In 2020, Ukraine became one of the leading suppliers of chickpeas to the European market, exporting several hundred thousand tons of this crop. Export volumes continue to grow, creating significant opportunities for further expansion of chickpea production in the country. Specifically, in 2020, Ukraine exported approximately 250–300 thousand tons of chickpeas, and this trend shows steady growth.

Chickpea groats production in Ukraine amounts to approximately 4000–5000 tons per year, requiring the processing of around 6000–7000 tons of raw chickpeas. The main factor affecting production volume is domestic market demand, which remains relatively low compared to crops like buckwheat or wheat. Chickpea flour production accounts for about 1% of total non-traditional flour types, equating to a few thousand tons per year, mainly used in baking and specialized food products. Chickpea flakes are produced in limited quantities, not exceeding a few hundred tons per year, due to low consumer demand since they are not a traditional product in Ukraine. Overall, domestic consumption of chickpea-based products in Ukraine is estimated at 10000–15000 tons annually, with a growing trend due to increased interest in healthy eating and alternative grain products. [11-14]

The limited presence of chickpea-based foods in Ukraine is due to several key factors. Chickpeas are not a traditional ingredient in Ukrainian cuisine, and most consumers are unfamiliar with their culinary properties. Traditional consumption patterns favor wheat, buckwheat, barley, corn, and other cereals with stable markets. Despite annual chickpea production of 20000–30000 tons, most of it is exported, while domestic processing remains underdeveloped. Estimated chickpea flour production does not exceed 1000–2000 tons annually, and chickpea flakes production is only a few hundred tons, preventing the formation of a mass market. Another major factor is the low level of marketing for chickpea products. Domestic producers primarily focus on established product categories, and chickpea-based items remain niche, difficult to find in regular supermarkets. Additionally, chickpea products are often more expensive than traditional cereal alternatives, limiting demand among mass consumers. A further constraint is the lack of established processing technologies for chickpeas in Ukraine's food industry. Unlike Turkey and India, where chickpeas are widely used in snack, bakery, and confectionery production, their use in Ukraine is mostly limited to groats and flour.

Although chickpeas remain a niche product in Ukraine, their potential in instant food, cereal breakfast, and snack bar production is significant. The most promising area is the production of instant porridge. Some Ukrainian manufacturers are already experimenting with extruded mixtures, but current volumes are small. In the next 3–5 years, chickpea-based mixes could reach several hundred tons per year. Chickpea-based breakfast cereals also have potential due to extrusion technology, which is already used for corn and oat flakes in Ukraine. Adding chickpea flour to traditional cereal blends can improve amino acid composition and increase protein content. These products are not yet widely available, but some producers are testing them, and within five years, production may exceed 1000 tons annually. Chickpea snack bars are not yet produced on a large scale but could occupy a niche among protein and energy snacks. If successfully marketed, production could reach up to 500 tons per year. [15-19]

Ukraine has a national standard regulating chickpea grain quality. The State Standard of Ukraine DSTU 6019:2008 "Chickpeas. Technical Specifications" [20] defines quality requirements for chickpea seeds intended for food, feed, and export purposes. The standard mandates that seeds must be healthy, free from self-heating signs, and have a natural color and odor characteristic of the crop. They must not contain grain pests and must meet impurity limits: mineral impurities no more than 0,1%, harmful impurities no more than 0,2%. The moisture content must not exceed 14,0%, and the protein content in dry matter must be at least 20,0%. The standard also sets maximum permissible levels for toxic elements, mycotoxins, pesticides, and radionuclides to ensure product safety for humans, animals, and the environment. Additionally, it includes quality control methods, acceptance rules, transportation, and storage requirements for chickpea seeds.

Ukraine lacks an official regulation defining technological requirements for chickpea processing into groats, flakes, and flour. The existing DSTU 6019:2008 "Chickpeas. Technical Specifications" [20] regulates raw material quality but does not cover processing standards. This creates challenges for manufacturers, as the absence of clear requirements complicates product certification and market entry. Due to the lack of regulatory frameworks, producers must rely on general processing standards for groats, flakes, and flour from other legumes or use international guidelines. Chickpea flour in Ukraine is produced according to standards developed for wheat or pea flour, despite differing technological properties. The same issue exists for flakes and other processed products, as there is no unified regulation specifying size, moisture content, thermal treatment, and nutrient composition requirements.

Legumes contain antinutritional compounds in their chemical composition, which are natural seed components serving a protective function against pests and adverse conditions. Water heat treatment of legumes is an integral part of modern technological processes in the food industry, ensuring the production of products safe for human consumption. This set of measures, including soaking, steaming, thermal treatment, and other methods, has a multifaceted impact on both the physicochemical properties of raw materials and the final quality of food products. One of the main reasons for the mandatory water heat treatment of legumes is the need to reduce the content of antinutritional substances. Water heat treatment improves the organoleptic characteristics of the end product. Soaking chickpeas softens the outer seed coat, facilitating subsequent boiling or steaming, which, in turn, ensures uniform heating and reduces thermal treatment time. This technological sequence not only enhances the digestibility of proteins and starch but also contributes to the formation of a pleasant texture, preserving the natural taste and aroma, which is crucial for consumers.

The main antinutritional compounds in chickpea seeds include protease inhibitors (trypsin and chymotrypsin inhibitors), phytates, tannins, lectins, and saponins. Trypsin and chymotrypsin inhibitors interfere with protein digestion by binding to digestive enzymes, which can reduce amino acid absorption. Phytates (salts of phytic acid) form complexes with micronutrients such as iron, calcium, magnesium, and zinc, reducing their bioavailability. Tannins can bind to proteins and carbohydrates, decreasing their solubility and digestibility. Lectins can affect the permeability of intestinal cell membranes, potentially leading to disruptions in nutrient absorption. Saponins, although having some beneficial properties, can negatively impact the mucous membrane of the digestive tract in large amounts [21-25].

Reducing antinutritional substances in chickpea-based food products is necessary to improve their nutritional value, digestibility, and organoleptic properties. Soaking and steaming are effective methods for reducing the content of antinutritional compounds such as trypsin inhibitors, tannins, and phytates. Water heat treatment of legumes is a crucial component of modern food industry technologies, ensuring the production of safe food products. This process, including soaking, steaming, and thermal treatment, significantly affects both the physicochemical properties of raw materials and the final quality of food products. The main reason for the obligatory water heat treatment of legumes is the necessity to decrease the concentration of antinutritional compounds.

Soaking seeds in water at 25–40 °C for 8–24 hours facilitates the dissolution and removal of water-soluble antinutritional components. Additionally, the process activates enzymes that break down phytic acid, reducing its negative impact on mineral absorption. Steaming (treatment with steam at 100°C for up to 30 minutes) inactivates thermolabile antinutritional substances, particularly trypsin inhibitors, which hinder protein digestion. Steam treatment also decreases tannin content, which forms insoluble complexes with proteins and micronutrients, reducing their bioavailability. The combination of soaking and steaming is the most effective method for lowering antinutritional compounds, improving the nutritional value of chickpeas without significant loss of protein and other beneficial components. Water penetration into the inner layers of chickpea seeds is a complex, multifactorial process determined by both the physicochemical properties of cell walls and the structural organization of the seed itself. The outer coat, composed mainly of cellulose, hemicellulose, and lignin, forms a dense protective barrier that limits the rapid absorption of water into the seed tissues. This layer serves as the first line of defense for the embryo against adverse external factors while simultaneously restricting the intensity of water uptake. On a chemical level, the cell walls of the inner seed layers are saturated with polymeric substances, among which phytic acid and its salts play a significant role. Phytates can form complexes with mineral ions, reducing the hydrophilicity of these structures and thereby hindering rapid dissolution and water penetration. Additionally, lipid-enriched cell membranes exhibit hydrophobic properties, further slowing the inward movement of water. Another factor to consider is the physical changes occurring during soaking. Initially, water moistens the outer seed layers, leading to their softening. However, the gradual swelling of proteins and starch inside the seed creates additional obstacles, as the expansion of internal components can reduce tissue porosity and, consequently, slow down water penetration. This swelling process is accompanied by the activation of enzymatic reactions that partially break down macromolecules but may also form temporary barriers to further water absorption [26-29].

An important aspect is the interaction between water and specific cell wall components, particularly hydroxyl groups, which form hydrogen bonds. During soaking, these bonds can create a stable network that limits the rate at which water molecules penetrate the inner seed layers. As a result, water absorption follows a gradual, saturating pattern, where rapid hydration of the outer layers occurs first, while deeper penetration slows due to both structural and physicochemical changes. Moreover, the internal seed structure, where reserve substances such as proteins, starch, and oils are located, has its own texture and density, affecting water absorption capacity. Proteins and starch, embedded in compact matrices, require additional time for softening and swelling, delaying water penetration into deeper layers. This effect is intensified by the high concentration of structural polymers, which not only physically block water penetration but also interact with it through specific chemical bonds.

Given the mandatory inclusion of water heat treatment in the technological process of chickpea groat production to ensure product safety, it is necessary to determine the impact of soaking duration on changes in seed moisture content.

Dehulling of chickpeas is one of the fundamental operations in their processing, playing a key role in determining the quality characteristics of the final product. The seed coats account for 14–16% of the seed mass and contain a significant amount of dietary fiber (up to 50–55% on a dry matter basis of the hull fraction), phenolic compounds, tannins, saponins, and other anti-nutritional components. The high levels of these substances result in the characteristic bitter taste of the hulls and negatively affect the bioavailability of nutrients, as tannins and phytates are capable of forming insoluble complexes with proteins and minerals, thereby reducing their digestibility. Additionally, the hulls contribute to the hard texture of the grain, increasing the cooking time.

The dehulling operation aims to remove the seed coats through mechanical action (impact, abrasion, etc.), which allows separation of the hulls from the endosperm without significant damage to the kernel. The removal of the hulls results in a substantial reduction in the content of insoluble fiber and phenolic compounds, which are the main carriers of undesirable organoleptic properties. Moreover, dehulling leads to a decrease in the concentration of anti-nutritional factors, particularly phytic acid–which can chelate calcium, iron, and zinc–and protease inhibitors that interfere with digestive enzyme activity. As a result, the bioavailability of chickpea proteins and mineral elements is markedly improved. During dehulling, pigmented layers of the seed coats are also partially removed, contributing to a lighter and more uniform color of the kernel, which is important in the production of flour and groats.

Dehulling affects the structural and mechanical properties of the kernel by reducing its hardness and improving water permeability. This directly shortens the cooking time by 25–40% compared to untreated chickpea seeds. Through the removal of outer seed layers, the surface contamination of the grain with microorganisms and dust particles is also reduced, which is crucial for producing safe food products. The elimination of seed coats reduces the likelihood of the presence of pathogenic microorganisms and fungal toxins that may concentrate in the outer layers of the seed, thus enhancing the microbiological safety of the final product.

Optimization of dehulling parameters is critical for achieving maximum yield of whole groats with minimal waste formation.

Research materials and methods

The subject of the research is samples of the Rozanna chickpea variety grown in the Odesa region in 2019–2021. The aim of the study is to determine the effect of soaking duration on the moisture change of chickpea seeds of the kabuli type, Rozanna variety, grown in Ukraine, when soaked in water at temperatures of 20, 40, and 60°C for different time intervals. Before the experiment, the studied grain samples were dried in a dryer to a moisture content of 11,6%.

In laboratory conditions, a technological process was carried out to study the dehulling of chickpea seeds using water-heat treatment methods based on cold and hot conditioning. The following laboratory equipment was used for the experiments:

– a laboratory dehuller USHZ-1, designed for processing the grain surface by intensive abrasion of the seed coats, during which the removal of fruit and seed coats, the aleurone layer, and partially the germ occurs. The main working parts of the machine are a disk with an abrasive surface rotating at a speed of 1500–2500 rpm and a perforated drum with an opening diameter of 2.0 mm;

– an aspiration column designed for cleaning grain from aerodynamically light and dust-like impurities and for separating the products of grain dehulling based on their aerodynamic properties. The air flow velocity is 4.5–5.0 m/s;

– a laboratory sifter RLU-1, intended for studying the separation of dehhuling products by sieving using appropriate sieve sets. The horizontal oscillation frequency is 120/200 cycles per minute, the oscillation radius is 25 mm, and the sample sieving time is 5 minutes;

– a laboratory dryer operating on the “fluidized bed” principle, consisting of a cylinder with a mesh surface where chickpeas seed, are placed for drying, an air duct with a fan, a heating unit for warming the air, and thermometers for controlling the air temperature.

The methodology of water-heat treatment consisted of the following stages:

– cold conditioning of the seed:

A sample of chickpea seeds was moistened using a water-spraying device for 15–20 seconds until the desired moisture content was reached, after which the sample was conditioned in a hermetically sealed container for a specified time. The amount of water required for moistening was calculated using the formula:

$$\text{В} = \text{З} \cdot \left(\frac{(100 - \text{А})}{(100 - \text{Б})} - 1\right), \qquad (1)$$

where

В – is the amount of water added during moistening, ml;

З – is the mass of the moistened seeds, g;

А – is the initial moisture content of the seeds, %;

Б – is the final moisture content of the seeds, %.

Hot conditioning of the seed:

Steaming of the seed was carried out in a laboratory batch-type steamer — an autoclave VK-30.

The sample was placed into a special mesh cassette and loaded into the steamer. The pressure and duration of steaming were regulated using inlet and outlet valves. After steaming, the chickpea seeds were placed in a heat-insulated container for tempering and then directed for drying.

The main characteristics of the studied grain were determined in accordance with the standards in force in Ukraine:

DSTU 6019:2008 "Chickpeas. Technical Specifications"

DSTU GOST 29144:2009 (ISO 711-85) "Grain and grain products. Moisture determination (basic control method)."

All obtained digital data were processed using Excel software from the Microsoft Office 2007 service package. Data were presented as arithmetic mean and standard error (M ± m).

Results of the research and their discussion

Chickpea seeds, like other legumes, have a specific structure that determines their properties during soaking. The study of water absorption is a key experiment for determining the soaking regime, subsequent drying, and further steaming before dehulling. Water absorption is accompanied by several physicochemical processes, the main ones being water penetration through the seed coat, swelling of internal components, activation of enzymatic processes, and changes in the structure of cell membranes.

When chickpea seeds are immersed in water, absorption initially occurs as water molecules penetrate the seed coat due to the concentration gradient between the external environment and the internal seed content. The rate of this process largely depends on water temperature, as it affects the kinetic energy of molecules. Low temperatures limit molecular movement and thus slow down water penetration, whereas higher temperatures promote rapid absorption. After the initial water penetration, the swelling process begins, during which proteins, starch, and other macromolecules in the seed's interior actively absorb water, leading to an increase in seed volume and a decrease in its density.

Additionally, soaking activates enzymatic processes that partially break down macromolecules, which may help reduce antinutritional compounds and improve the bioavailability of nutrients. The research results are graphically presented in Fig. 1

The study of chickpea water absorption demonstrates the saturation dynamics of this process. The presented graph with three curves shows changes in seed moisture content over 120 minutes of soaking at three different temperatures: 20 °C (blue line), 40 °C (red line), and 60 °C (green line).

At 20 °C (blue line), the process is slower compared to higher temperatures. In the initial stage, during the first 20 minutes, seed moisture content gradually increases from approximately 10% to 15–18%. The low temperature limits the kinetic energy of water molecules, slowing their absorption through the seed coat. In the intermediate stage (20–60 minutes), active swelling of proteins and starch occurs, leading to a gradual increase in moisture content to around 30–32%. In the final stage (60–120 minutes), the moisture content reaches approximately 35%, indicating an approach to the maximum saturation level under these conditions. Thus, at 20 °C, seed swelling is stable but slow, which may require extended soaking time to reach the optimal moisture level.

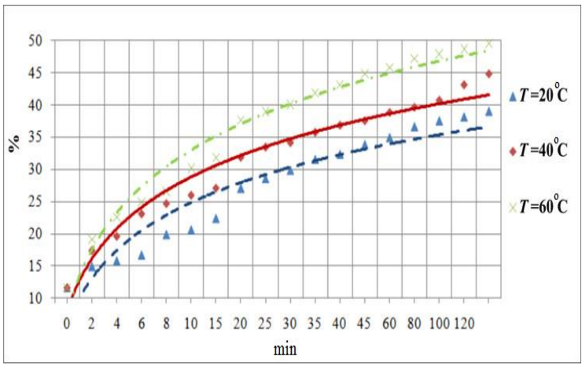

Fig. 1. Water absorption of Rozanna chickpea variety

At 40 °C (red line), the water absorption process is more dynamic. In the first 20 minutes, moisture content increases significantly – from the initial 10% to approximately 20–25%. The higher temperature facilitates faster water penetration and softens the seed coat, allowing easier water entry into the inner layers. During the intermediate stage (20–60 minutes), moisture content rises to about 30–35% as proteins and starch continue to swell more intensively. In the final stage (60–120 minutes), moisture content reaches approximately 40%, indicating that a soaking temperature of 40 °C provides an optimal balance between absorption rate and maximum saturation.

The highest water absorption is observed at 60 °C (green line). In the first 20 minutes, moisture content rapidly increases from 10% to 25–30%. The high temperature significantly increases the kinetic energy of molecules, allowing water to penetrate cell walls almost instantly and softening the seed coat, making it more permeable. In the intermediate stage (20–60 minutes), the process continues at high intensity, reaching 35–40% moisture by 60 minutes. In the final stage (60–120 minutes), moisture content gradually saturates, reaching approximately 45%. This regime demonstrates the highest final saturation, indicating the maximum water absorption potential of chickpea seeds at high soaking temperatures.

Comparing the results across different temperature regimes, several important conclusions can be drawn. First, increasing the soaking temperature accelerates water absorption due to the higher kinetic energy of water molecules and easier penetration through the seed coat. Second, the maximum moisture content that chickpeas can reach increases with temperature: about 35% at 20 °C, 40% at 40 °C, and up to 45% at 60 °C. This is crucial for optimizing technological processes since proper temperature selection can help achieve the desired moisture level while reducing antinutritional compounds and improving nutrient bioavailability.

It is also important to note that water absorption activates enzymatic processes that contribute to the partial breakdown of macromolecules and the reduction of antinutritional compounds such as phytates, protease inhibitors, tannins, and lectins. This is an additional advantage of soaking as a preliminary stage in chickpea food production, as reducing antinutritional components enhances the bioavailability of essential minerals and proteins.

In summary, the analysis of chickpea moisture absorption during soaking at different temperatures (20 °C, 40 °C, and 60 °C) allows for determining optimal technological conditions for this process. At 20 °C, seed swelling is slow and gradual, requiring extended soaking time. At 40 °C, the process combines optimal penetration speed with final saturation, making this regime the most promising for industrial applications. The highest moisture level is achieved at 60 °C; however, excessively high temperatures may cause undesirable structural changes in chickpeas, requiring careful control.

Thus, controlling the soaking temperature is a key factor affecting the efficiency of chickpea water absorption, as well as the final quality and nutritional value of food products. These findings can be effectively used to optimize soaking processes to reduce antinutritional compounds. A detailed analysis of temperature effects on the absorption rate and extent provides opportunities not only to adjust soaking to achieve optimal moisture levels but also to consider structural changes that influence the reduction of antinutritional components.

Higher soaking temperatures promote faster water penetration through cell walls, leading to more intense swelling of proteins and starch. This process is accompanied by seed coat softening and enzymatic activation, which may contribute to the partial breakdown of phytates, protease inhibitors, tannins, and other antinutritional compounds. For example, a soaking regime at 40 °C ensures sufficient water absorption speed without excessively damaging seed structural components, making it an optimal compromise for reducing antinutritional compounds.

Moreover, the study shows that each temperature regime has its own characteristics: at 20 °C, the soaking process is slower, while at 60 °C, the highest final moisture content is achieved. This can be both an advantage and a disadvantage, as excessive softening may negatively affect further technological operations. Therefore, optimizing soaking conditions based on research allows for more precise control of the technological process, considering not only moisture parameters but also the need to reduce antinutritional compounds.

Controlled soaking can serve as an effective preliminary stage in food production since optimal temperature regimes promote both maximum water absorption and partial inhibition of antinutritional compounds. This, in turn, enhances nutrient digestibility and improves the organoleptic properties of the end products.

Thus, the findings of this study are an important tool for improving the chickpea soaking process and can be successfully implemented in industrial technologies to reduce antinutritional compounds, thereby increasing the nutritional value of the final product.

At the next stage, a study was conducted to determine the effect of water-heat treatment on the yield of whole kernels, broken kernels, flour particles, and husks. Dehulling of chickpeas by the method of intensive abrasion of seed coats offers a number of significant advantages, which account for its wide application in modern technologies for processing leguminous crops. The essence of this method lies in the use of working elements with high abrasive capacity that exert multidirectional action on the seed surface, combining intensive friction with partial impact forces. This processing mode ensures highly efficient removal of the seed coat layers, even when handling chickpeas with increased hull density and uneven surface structure, which are typical morphological features of this crop.

The main advantage of this method is the high degree of kernel cleaning. Intensive abrasion allows for deeper removal of the seed coat layers compared to other methods, ensuring that the residual content of hulls is reduced to minimal levels. This is particularly important for the production of chickpea flour and polished groats, where color uniformity and the absence of hull particles are of critical importance.

Dehulling of chickpeas by intensive abrasion also contributes to the formation of a smoother kernel surface, which positively affects its culinary properties – the kernels swell more evenly and cook faster.

Another significant advantage is the possibility of combining a high degree of dehulling with minimal endosperm loss. Properly selected intensive abrasion regimes prevent deep penetration of the abrasive effect into the kernel, thus ensuring an optimal balance between cleaning and preserving the grain mass.

Dehulling by the intensive abrasion method also improves the sanitary and hygienic characteristics of the grain. Due to the deep removal of surface layers, the level of microbiological contamination and surface impurities is significantly reduced, thereby increasing the safety of the final product.

At the first stage, dehulling of chickpea seeds with an initial moisture content of 13.8 % was studied without any additional treatment. The results of the conducted study are presented in Table 1.

As evident from the results presented in Table 1, the moisture content of the initial grain at 13.8% is close to optimal for dehulling leguminous crops. At this moisture level, the seed coat has already lost excessive brittleness but has not yet become elastic, which would complicate its removal. In this state, the chickpea hull cracks under abrasive forces, while part of the protein-starch matrix of the endosperm remains intact, ensuring the formation of whole kernels. There is a clear trend of decreasing whole kernel yield with increasing dehulling time, which is typical for processes involving intensive abrasion of seed coats. After the first two minutes of treatment, the yield of whole kernels is 76.8 %, but it decreases to 69.5 % after four minutes and to 49.2 % after ten minutes. This is caused by the accumulation of microcracks and mechanical damage in the surface layers of the endosperm, leading to kernel fragmentation. Simultaneously, as the proportion of whole kernels decreases, the amounts of broken kernels and flour fractions increase proportionally: at two minutes of dehulling, broken kernels comprise only 12.1 % and flour 9.2 %, while at ten minutes these values rise to 24.3 % and 22.2 %, respectively. Meanwhile, the husk fraction increases less proportionally, reaching a maximum of 4.9 % at eight minutes, indicating that the majority of hull removal occurs at the early stages of dehulling, whereas further processing mainly causes kernel fragmentation rather than additional hull removal. Collectively, this suggests that, without water-heat treatment, the optimal dehulling time for maintaining a high yield of whole kernels is minimal (4–6 minutes), while prolonging the process significantly increases fragmentation and flour formation.

At the next stage, chickpea seeds with an initial moisture content of 13.8 % were moistened with water heated to 60 °C to reach 16% moisture, then conditioned for 6 hours before being subjected to steaming in a batch-type steamer at a steam pressure of 0.20 MPa for 5 minutes. The steamed seeds were dried in a dryer to a moisture content of 13.8–14.0%, after which they were directed to dehulling. The results of this study are presented in Table 2.

As evident from the results presented in Table 2, the treatment of chickpea seeds involving moistening to 16% moisture, followed by conditioning for 6 hours and steaming at a saturated steam pressure of 0.20 MPa for 5 minutes, led to significant changes in the structural and mechanical properties of the seed coats and the protein-starch matrix of the kernel, which directly affected the efficiency of the dehulling process. After drying to a moisture content of 14.0 %, the seeds acquired a balanced ratio of plasticity and brittleness of components: the seed coats became less rigid and brittle, which allowed them to separate more easily in whole layers under abrasive forces, while the kernel retained increased strength due to partial protein denaturation and structural densification of the endosperm induced by short-term steaming. These structural changes reduced the likelihood of deep microcrack penetration into the kernel during the initial stages of mechanical action, resulting in an increased yield of whole kernels compared to dehulling untreated seeds.

The fraction dynamics indicate that after just 2 minutes of dehulling, the yield of whole kernels was 81.1%, which is 4.3 % higher than the corresponding value for untreated seeds. With increasing processing time to 10 minutes, this value predictably decreased to 52.6 %, but remained 3.4 % higher than for untreated seeds. Simultaneously, the formation of broken kernels at early stages was reduced (8.9% compared to 12.1 % after 2 minutes of dehulling untreated seeds), indicating more effective preservation of kernel integrity during short-term treatment. The increase in broken fractions and flour over time was less intense compared to untreated seeds: for example, at 6 minutes of dehulling, the flour fraction was 14.1 %, whereas for untreated seeds it was 18.1 %.

Table 1 – Dehulling of chickpea seeds without additional treatment (initial seed moisture content 13.8%)

Fraction yield, %	Dehulling time, min				
	2	**4**	**6**	**8**	**10**
Whole kernels, % (sieve oversize 4.5×20 mm)	76,8	69,5	61,4	55,3	49,2
Broken kernels, % (sieve oversize 2.2×20 mm + sieve oversize 080)	12,1	13,9	17,1	19,6	24,3
Flour fraction, % (sieve undersize 0.80 mm)	9,2	13,7	18,1	20,2	22,2
Husk, %	1,9	2,9	3,4	4,9	4,3

Table 2 – Dehulling of chickpea seeds after moistening to 16 %, conditioning for 6 hours, and steaming at a steam pressure of 0.20 MPa for 5 minutes (initial seed moisture content after drying 14.0%)

Fraction yield, %	Dehulling time, min				
	2	**4**	**6**	**8**	**10**
Whole kernels, % (sieve oversize 4.5×20 mm)	81,1	73,9	67,8	59,8	52,6
Broken kernels, % (sieve oversize 2.2×20 mm + sieve oversize 080)	8,9	12,3	14,6	16,1	19,3
Flour fraction, % (sieve undersize 0.80 mm)	8	10,7	14,1	19,5	23,2
Husk, %	1,8	2,7	3,5	4,6	4,9

The husk was removed in similar quantities (1.8–4.9 %), but visual characteristics suggest it was separated in more uniform layers without significant fragmentation, which additionally facilitates its separation during processing.

Comparing the results of dehulling seeds with initial moisture content and seeds after water-heat treatment, it can be concluded that prior moistening and steaming increases the yield of whole kernels at all stages of dehulling, reduces the proportion of broken kernels and flour, and promotes more efficient hull separation. This is explained by the plastic softening of the seed coats and partial thermal stabilization of the protein-starch matrix, which decreases the destructive impact of abrasive-friction forces on the kernel. Thus, water-heat treatment before dehulling is a justified technological operation that not only improves the quality of the target products but also optimizes the balance between whole kernels and broken fractions

Conclusion

The soaking process of chickpea seeds is an important stage in preparation for further processing, as it affects their texture, digestibility, and the reduction of antinutritional compounds. Studies on the dynamics of water absorption at different temperatures have shown that increasing the water temperature significantly accelerates this process. At 20 °C, water absorption occurs slowly, requiring prolonged soaking. At 40 °C, there is an optimal balance between the rate of moisture saturation and the preservation of the seed structure, which promotes more effective swelling. At 60 °C, the process is the fastest but may lead to excessive softening.

The results obtained allow for determining the most suitable soaking temperature regime to reduce antinutritional compounds such as phytates, protease inhibitors, and tannins. Controlled soaking activates enzymatic processes, which improves the bioavailability of nutrients. Thus, optimizing the soaking conditions of chickpeas can be an effective method for improving the quality of the final food products, ensuring their high nutritional value and safety for consumption.

Water-heat treatment of chickpea seeds, which includes moistening to 16%, conditioning, and steaming at a steam pressure of 0.20 MPa followed by drying to 14 %, significantly enhances the technological efficiency of the dehulling process by intensive abrasion. This effect is due to structural and functional changes in both the seed coats and the kernel: the coats become more plastic and separate uniformly, while the kernel gains greater mechanical strength. This allows for reduced grain breakage and, consequently, an increased yield of whole kernels at all stages of the process, while simultaneously decreasing the formation of broken kernels and flour. Compared to dehulling untreated seeds, water-heat treatment consistently provides a higher yield of whole kernels and improved product quality.

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ДОСЛІДЖЕННЯ ВОДОПОГЛИНАЛЬНОЇ ЗДАТНОСТІ ТА ЛУЩЕННЯ НАСІННЯ НУТУ

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Анотація Нут є перспективною бобовою культурою, що використовується у різних галузях харчової промисловості. Світове виробництво нуту останнім часом зростає, лідерами по вирощуванню є Індія, Австралія, Пакистан і Туреччина. В Україні щорічно вирощують 20000–30000 тонн нуту на площі 15000–30000 га, переважно в Одеській, Херсонській, Миколаївській та Дніпропетровській областях. Виробництво нутових продуктів в Україні залишається обмеженим і складає орієнтовно: крупи – 4–5 тис. тонн, борошна – 1–2 тис. тонн, пластівців – кілька сотень тонн. Основними перешкодами є низький попит, слабке просування та відсутність технологічних стандартів на переробку даної культури. Перспективи розвитку пов’язані з розширенням асортименту нутових продуктів, зокрема каш швидкого приготування, зернових сніданків та батончиків. Якість насіння нуту регламентується ДСТУ 6019:2008, але нормативний регламент переробки відсутній, що ускладнює виробництво продукції з нього. Воднотеплова обробка для нуту є важливим технологічним процесом у харчовій промисловості, спрямованим на зменшення частки антипоживних речовин, таких як інгібітори протеаз, фітати, таніни та лектини. Замочування при 25–40°C протягом 8–24 годин сприяє розчиненню водорозчинних антипоживних сполук, а пропарювання при 100°C інактивує термолабільні компоненти. Ці методи покращують органолептичні характеристики, засвоюваність білків і мікроелементів, а також смакові характеристики готової продукції. Поєднання замочування та пропарювання є найбільш ефективним. Досліджено процес водопоглинання насіння нуту при замочуванні у воді за різних температурних режимів (20 °C, 40 °C, 60 °C). Встановлено, що підвищення температури прискорює поглинання води через оболонку насіння та сприяє інтенсивнішому набуханню білків і крохмалю. При 20 °C процес водопоглинання є повільним, досягаючи 35 % вологості за 120 хвилин. Температура 40 °C забезпечує оптимальний баланс швидкості та ступеня насичення (40 %). При 60 °C спостерігається найвище водопоглинання (45 %), але надмірне розм’якшення може впливати на структуру зерна. Крім того, замочування активує ферментативні процеси, що сприяють зниженню вмісту антипоживних речовин. Отримані результати є основою для оптимізації технологічних режимів підготовки зерна нуту до подальшої переробки, зокрема для зниження вмісту антипоживних компонентів і підвищення харчової цінності кінцевої продукції. Воднотеплова обробка насіння нуту, що передбачає зволоження до 16 %, відволоження та пропарювання при тиску пари 0,20 МПа з наступним підсушуванням до 14 %, суттєво підвищує ефективність технологічного процесу лущення інтенсивним стиранням. Такий вплив пояснюється структурно-функціональними змінами оболонок і ядра: оболонки набувають більшої пластичності та рівномірно відокремлюються, тоді як ядро посилює свою механічну міцність. Це сприяє зменшенню пошкоджень зерен і, як наслідок, збільшує вихід цілого ядра на всіх стадіях процесу, одночасно знижуючи утворення подрібненого ядра та борошенця. У порівнянні з лущенням вихідного насіння без попередньої підготовки, воднотеплова обробка забезпечує стабільно більший вихід цілого ядра і покращує якість кінцевого продукту.

Ключові слова: нут, харчова промисловість, воднотеплова обробка, замочування, пропарювання, антипоживні речовини, водопоглинальна здатність, лущення.