

## Thermoinactivation of urease in lentils in case of infrared radiation

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### Summary

The article deals with thermoinactivation of urease in lentils after high-temperature micronization with infrared rays. The empirical dependencies of degree of urease inactivation on heat treatment time and temperature were obtained. It was ascertained that the degree of urease inactivation depends on initial moisture content of the grain and the final temperature of heat treatment. A mathematical model of inactivation of undesirable substances in food was proposed, which is based on first-order equations of chemical kinetics with a reaction rate constant. The model was reworked for variable temperature processing conditions of heat treatment. Identification of model coefficients was given based on urease inactivation experiments. Model will be used to describe the thermodegradation of undesirable substances in other legumes. The moisture of lentils is 11–14 % and, under such moisture conditions, active inactivation of urease begins at a temperature of 85–90 °C and the thermal processing time is from 60 s to 90 s. Due to the sharp reduction of urease in lentils, their nutritional value improves. Lentils processed by such method can be used to increase the content of benchmark proteins and improve the essential amino acid score, which determines the nutritional value of food products.

### Keywords

infrared heat treatment; lentil; urease; urea; inactivation process; mathematical model

Lentils are among nutritionally best representatives of legumes, although many people do not eat them and many have not even tasted them because they lack information about their beneficial properties. On the shelves of shops today, lentils are presented in a whole colour palette. Depending on the variety, the composition of the seed coat and cotyledons, lentils can be yellow, orange, red, green, brown or black.

The colour of the shelled seeds is mainly related to the colour of the cotyledon. These lentils are yellow, red, or green. Whole (unhulled) seeds range in colour from green and gray to brown and black. Since the seed coat contains a variety of biologically active substances, the chemical composition of the same shelled and whole lentils will differ. Also, to a certain extent, the chemical com-

position of lentils of different varieties or grains grown in different conditions differs.

Raw red lentils are widely used in domestic kitchens as they are less coarse as whole, easier to digest and assimilate, although in some respects, unpeeled lentils are slightly more nutritious. Composition and energy content raw red lentils (per 100 g) are: energy 1 500 kJ, proteins 23.91 g, lipids 2.17 g, carbohydrates 63.1 g, water 7.82 g, ash 3 g, vitamin B3 1.5 mg, vitamin B1 0.51 mg, vitamin B6 0.4 mg, vitamin B5 0.35 mg, vitamin B2 0.11 mg, potassium 668 mg, phosphorus 294 mg, magnesium 59 mg, calcium 48 mg and iron 7.39 mg [1]. Whole lentils (as a percentage of the same seed mass) contain more fibre, potassium, calcium, iron, phosphorus and usually slightly more vitamins B6 and B2. At the same time, whole lentils

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**Tab. 1.** Nutritional value of lentils (grain).

#	Nutrient	Quantity	Norm	The norm in 100 g [%]	The norm in 419 kJ [%]	100 % normal [g]
1	Energy	1 236 kJ	7 056 kJ	73.3 %	24.7 %	2 392.5 g
2	Protein	24 g	76 g	31.6 %	10.7 %	317 g
3	Lipids	1.5 g	56 g	2.7 %	0.9 %	3733 g
4	Carbohydrates	46.3 g	219 g	21.1 %	7.2 %	473 g
5	Alimentary fibre	11.5 g	20 g	57.5 %	19.5 %	174 g
6	Water	14 g	2 273 g	0.6 %	0.2 %	16 236 g
7	Ash	2.7 g	–	–	–	–

are lower in carbohydrates and energy. But in general, the energy values do not differ so much as to change the culinary strategy for the sake of this [1]. However, green- and gray-coated lentils contain higher amounts of flavan-3-ols (catechins), proanthocyanidins and some flavonols, which largely determines the potential of lentil seeds in a health-promoting diet.

Regardless of the presence or absence of the shell, lentils are foods rich in plant proteins, especially globulins and albumins, the former of which account for more than 45 % of total seed proteins. Among two dozens of leguminous crops, lentils are in the “top 3” in terms of starch content (greater than 47 %), insoluble dietary fibre and phenols, ahead of green peas, chickpeas and mung beans in terms of the latter [2].

These seeds are considered a good source of prebiotics, as they contain prebiotic carbohydrates (12–14 g per 100 g of dry lentils), which help maintain the intestinal microbial environment and prevent gastrointestinal diseases. In addition, lentils are relatively low in fat and sodium, but high in potassium (sodium to potassium ratio is about 1 : 30) [3]. This makes lentils an excellent dietary product for obese and cardiovascular patients. Also safe for patients with cardiovascular diseases, using anticoagulants in treatment, is the low content of phylloquinone – vitamin K (5 µg per 100 g; its daily requirement in adults is approximately 80 µg).

Among other vitamins, thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), folic acid (B9),  $\alpha$ -,  $\beta$ - and  $\gamma$ -tocopherols (E) are found in lentils. Contained minerals include zinc, copper, manganese, molybdenum, selenium, and boron [3]. Tab. 1 shows the content of nutrients per 100 grams of the edible part of lentils [4].

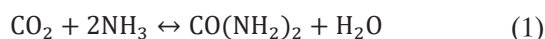
Along with many useful substances and micro-nutrients, legumes are characterized by a high content of undesirable substances [1, 5] that cause accumulation of toxins in human body, abdominal bloating, complications of food digestion

and other undesirable phenomena. Their partial inactivation is achieved by thermal treatment during the preparation process. In particular, the proteinase inhibitor should be noted, which is the product of food processing, and primarily the high activity of trypsin, which is responsible for protein absorption by the body [5]. At the same time, undesirable enzymes are also secreted, first of them being lipoxygenase, which is an enzyme that oxidizes lipids. In addition, under its action during long-term storage of legume seeds, aldehydes and ketones are formed in them, which give the beans a specific unpleasant odour and taste. As a result, the nutritional benefits of legumes are reduced. Another important deleterious enzyme is urease, a hydrolytic enzyme of the amidase group, which has the specific property of catalysing the hydrolysis of urea to carbon dioxide and ammonia. The resulting ammonia is toxic to living organisms. In raw seeds of legumes, the content of urease can reach 6 % of the amount of all proteins [6].

Since these undesirable components belong to thermolabile substances, an affordable and relatively inexpensive way to inactivate them is heat treatment [7]. The listed substances have different heat resistance. The available data show that when processing soya for 15 min, complete inactivation of lipoxygenase was observed at a temperature of 80 °C, of urease at 90 °C and of trypsin inhibitor at 100 °C. The residual activity of urease after prolonged (1 h) heat treatment is 80 % at 65 °C, 53 % at 70 °C and 0 % at 75 °C [8]. The heat resistance of the trypsin inhibitor and urease is higher and almost the same. Because the activity of urease can be determined by a much simpler method, it is often used as a marker [9]. The activity of urease is normalized in oilcakes and schroths intended for fodder production [10].

The excretion of nitrogenous substances from the body takes place mainly through urea. It is an organic substance with the chemical formula  $\text{CO}(\text{NH}_2)_2$ , an amide containing two amino ( $\text{NH}_2$ ) and one carbonyl ( $\text{CO}$ ) functional groups.

Its IUPAC name is carbonyl diamide. Urea plays an important role in the metabolism of nitrogen-containing substances in animals, is the main nitrogenous compound in mammalian urine. It is colourless, odourless and well soluble in water and a solid substance that is practically not toxic. It is neither acid nor alkali. It has a weakly expressed alkaline reaction. In the body, its synthesis occurs in the liver by the interaction of two molecules of ammonia and carbon dioxide with



The synthesized urea is excreted from the body together with urine, which ensures the release of nitrogen from the body [1].

The acidic reaction of a healthy organism should be within a slightly alkaline pH of 7.365, which is partly provided by urea. Urea is an osmotically active substance, so its excess accumulation can lead to health problems. Urea is decomposed by urease. By its action, ammonia is accumulated, which leads to poisoning of the central nervous system, changes in subcutaneous tissue and myocardial infarction as well. Therefore, it is desirable that the food product contains as little urease as possible [1].

High-temperature processing, in particular, using an infrared energy source, is an operation that is quite common in the technological processes of grain processing. This method is most often used by small enterprises producing instant cereals and flakes, and is known as high-temperature micronization [11, 12]. This method can also be successfully used to inactivate unwanted thermolabile substances in food or cereals, allowing to increase the nutritional value of legume crops.

In many scientific papers, information on processing of grain crops with infrared rays to improve various properties was published. However, practically no attention has been paid to inactivation of unwanted substances in cereal crops. Therefore, the main aims of the study were to determine the conditions for increasing the nutritional value of legume crops, red and brown lentils, by inactivating the undesirable substance contained in them, urease, and to investigate whether it is possible to use lentils processed by such a method to make compositions with traditional cereals, which will have a high content of reference protein and limited essential amino acid score.

Our scientific hypothesis was that inactivation of non-nutritive substances during processing of legumes with infrared rays is a thermally activated process, therefore, the final content of non-nutritive substances in the grain is primarily

determined by the thermal processing time and the temperature of the product. Since in conditions of thermal treatment with infrared rays, the latter two variables depend on each other and can be depicted through each other, the process of inactivation and its mathematical model can be displayed according to both the thermal processing time and the temperature of the grain. In conditions of thermal processing of the grain, the initial moisture, the distance of the radiation panel from the product, the temperature in the working zone, also have an effect on the final content of undesirable substances in the product.

## MATERIALS AND METHODS

### Samples

As research samples, we chose a very useful food product for human health, the varieties “red lentils” (Gori, Gori Region, Georgia) and “brown lentils” (Gori, Gori Region, Georgia) harvested in 2020. These products were purchased from the market in Kutaisi (Georgia). To obtain lentil grains of different moisture, we moistened the initial grains to a specified moisture. The linear dimensions of beans were determined using an electronic digital caliper VINCA DCLA-0605, 150 mm. (Neiko Tools, Lu Chu Hsiang, Taiwan). Geometrical characteristics of the grains are shown in Tab. 2.

### Equipment

High-temperature micronization (HTM) was used in this study. It is an operation of heat treatment of a product in the flux of infrared radiation heat transfer carried out in two ways: convectively from the air in the treatment zone and by infrared radiation. This can be considered a combined heat supply [12]. For experiments, a QP1 model (Elcer, Odesa, Ukraine) of a panel of 7 halogen quartz emitters was used as a source of infrared radiation. The dimensions of the panel were 247 mm × 62 mm. The length of the tube was 245 mm, tube

**Tab. 2.** Characteristics of grains.

	Variety	
	Red lentils	Brown lentils
Weight of one bean [g]	0.022 ± 0.001	0.072 ± 0.001
Geometrical parameters		
Length [mm]	4.54 ± 0.3	6.68 ± 0.5
Width [mm]	4.53 ± 0.3	6.69 ± 0.4
Thickness [mm]	2.23 ± 0.1	2.58 ± 0.2

step was 8.55 mm, rated power was 1 kW and emitter temperature was 750–800 °C.

#### Surface temperature measurement

The surface temperature of the beans sample was measured under the middle lamp of the emitter, being determined as follows: beans were placed on the pallet in a monolayer that, for a fixed amount of time (30, 60, 90 or 120 s), was placed in a heated infrared-treatment zone. Then, the pallet was quickly removed and the temperature of beans was determined using an AR360A+ infrared laser thermometer (Simzo, Long, China). The temperature was measured from –50 °C to +360 °C and the temperature measurement error was 0.5 °C due to heat loss, which could be taken as insignificant.

#### Moisture determination

The initial moisture content of lentils was determined using an electronic digital meter of grain and seed moisture (moisture meter) VSP-100 (PAtools, Kharkiv, Ukraine). Additionally, moisture loss during the infrared heating was estimated as the difference between the initial sample weight and its weight after the heat treatment. The sample weight of grain before and after the heat treatment was determined using an electronic digital analytical balance SF-400C model (Toms, Qilin, China) with a weighing accuracy of 0.01 g. The moisture content ( $W$ ) after the heat treatment was calculated based on the initial moisture content ( $W_0$ ) and mass loss ( $\Delta m$ ) according to the formula based on the standards GOST 13586.5-2015 [13] and ISO 1446:2018 [14].

#### Urease activity determination

Urease activity in lentil grains after heat treatment with infrared rays was determined according to GOST 13979.9-69 [15]. A phosphate buffer pH 7 was used as buffer A (prepared from  $\text{KH}_2\text{PO}_4$  and  $\text{K}_2\text{HPO}_4 \cdot 3\text{H}_2\text{O}$ , LenReaktiv, St. Petersburg, Russia). To prepare buffer B, 15 g of urea (LenReaktiv,  $\geq 99.8\%$ ) was dissolved in 500 ml of buffer A. The obtained buffer B was stored in a dark place for no more than 10 days. Lentil samples were ground and sifted through a 0.25 mm sieve according to GOST 13979.2-94 [16]. Amounts of  $1 \pm 0.01$  g of three samples of experimental lentils were weighed in a 150 ml volume cup. In the first glass, 50 ml of buffer A was added and placed it in a thermostat at a temperature of 30 °C. In the second and third cups, 50 ml of buffer B were added at intervals of 5 min and placed it in the same thermostat at a temperature of 30 °C. Incubation lasted 30 min, during

which time the samples were mixed with a glass bar every 5 min. After that, the liquid was drained and pH of the solutions was measured using a pH meter COM-360 (HM Digital, Redondo Beach, California, USA) equipped with a glass electrode.

Urease activity ( $UA$ ) in pH units was calculated using the formula:

$$UA = pH_1 - pH_0 \quad (2)$$

where  $pH_1$  is the pH value after processing the sample with buffer B,  $pH_0$  is the pH value after processing the sample with buffer A. The average two parallel values measurements was taken as the final.

Relative urease activity ( $UA_{\text{rel}}$ ) was calculated as

$$UA_{\text{rel}} = \frac{UA_i}{UA_0} \quad (3)$$

where  $UA_i$  is the activity of urease depending on the time of thermal processing (in pH units) and  $UA_0$  is initial activity of urease at minimum grain moisture (in pH units).

#### Statistical analysis

All experiments were conducted at least in triplicate and values of mean  $\pm$  standard deviation were calculated. Values of the reliability coefficient were calculated at  $< 0.05$ , corresponding to probability greater than 0.95, using the mathematical package MathCad 15 (Mathsoft, Cambridge, Massachusetts, USA) [17].

## RESULTS AND DISCUSSION

During the study of the dehydration process with infrared rays at high-temperature heat treatment of legume crops, the change in moisture and temperature of the grains was found to be inversely proportional to each other, determining the optimal parameters of this process. The hydrolysis of starch and the formation of dextrins are underway during heat processing, hence the nutritional value of legume crops is improved and the product becomes relatively easy to prepare. It should be assumed that the same processes take place also in other legumes at this kind of thermal processing.

#### Model of urease inactivation

To describe thermal inactivation, as a model of thermal degradation of a reagent or microflora contained in a product, a first-order differential equation is most often used in chemical kinetics and biology, which is known as the Arrhenius equation and, in its simplest form, is Eq. 4 [18]:

$$dY = -K[T(t)] \cdot Y^n dt \quad (4)$$

where  $Y$  is a quantitative measure of the reagent content (in grams),  $T$  is the absolute temperature (in degrees Kelvin);  $t$  is the time (in seconds),  $K[T(t)]$  is the reaction rate constant,  $n$  is the reaction order.

The reaction rate constant in a generalized form can be represented as Eq. 5 [6]:

$$K[T(t)] = kT^m \exp\left(-\frac{\varepsilon}{RT}\right) \quad (5)$$

where  $k$  is the proportionality coefficient (in reciprocal seconds),  $\varepsilon$  is the activation energy (in joules per mole),  $R = 8.314$  is the universal gas constant (in joules per mole per Kelvin),  $T$  is the temperature (in degrees Kelvin),  $m$  is the reaction rate constant (dimensionless).

Depending on the physical concepts of the mechanism of intermolecular interaction in the process of thermodegradation in various theories, the reaction rate constant  $m$  takes the values 0; 0.5; 1;  $-1$  [13]. For simplicity of further calculations, we put  $m = -1$ .

After substituting Eq. 5 into Eq. 4, separating the variables and integrating, we get

$$K[T(t)] = \int_{Y_0}^Y \frac{dY}{Y^n} = k \int_0^t T^m \exp\left(-\frac{\varepsilon}{RT}\right) dt \quad (6)$$

where  $Y$ ,  $Y_0$  is a quantitative measure of the reagent content at the current and initial time points (in grams).

If the temperature is constant ( $T = \text{const}$ ), the solution of Eq. 6 gives

$$F(Y) = \ln \frac{Y}{Y_0} = -kT^m \exp\left(-\frac{\varepsilon}{RT}\right) t \quad (7)$$

The dependence of the product temperature on time during infrared heating is well described by the expression in Eq. 8 [7]:

$$\Delta T(t) = \Delta T_\infty [1 - \exp(-K_t t)] \quad (8)$$

From where it follows

$$dt = d \frac{T}{[k_t(C - T)]} \quad (9)$$

$$C = T_0 + \Delta T_\infty > T \quad (10)$$

where  $t$  is time (in seconds),  $C$  is empirical coefficient,  $T$  is absolute temperature of grain (in degrees Kelvin),  $T_0$  is initial grain temperature (in degrees Kelvin),  $\Delta T_\infty$ ,  $k_t$  are coefficients.

Integrating Eq. 6, we get Eq. 11 [6]:

$$F(Y) = k[E_i(z_0) - E_i(z)] \quad (11)$$

$$z = \varepsilon_R \left( \frac{1}{C} - \frac{1}{T} \right) \quad (12)$$

$$z_0 = \varepsilon_R \left( \frac{1}{C} - \frac{1}{T_0} \right) \quad (13)$$

where  $\varepsilon_R$  is empirical coefficient (in degrees Kelvin),  $E_i$  is integral exponential function (Euler's function).

If we make the assumption that  $C$  is significantly greater than  $T$ , i.e.  $z \approx -\varepsilon_R/T$ , we use the property of the Euler function for large values of the argument, expand in a series and take into account the first term, then Eq. 11 can be represented in the following form [6]:

$$F(Y) = k \left[ T \exp\left(-\frac{\varepsilon_R}{T}\right) - T_0 \exp\left(-\frac{\varepsilon_R}{T_0}\right) \right] \quad (14)$$

As a model of the urease inactivation process, we use the dependence in Eq. 14, which is relatively simple and has only two empirical coefficients that require quantification. The determined values of these coefficients are given in Tab. 3.

In the study samples, we studied the dependence of moisture change with the dependence on heat treatment temperature and the distance of the infrared panel from the product, in the case of a fixed optimal heat treatment time (60 s) from the product.

Fig. 1 shows the dependence of the final moisture change of brown lentils on the final temperature of heat treatment. It can be seen that the moisture of the grain decreases rapidly when rising to a temperature of 100 °C and the rate of moisture reduction decreases when the temperature increases further, indicating a sharp change in biochemical parameters.

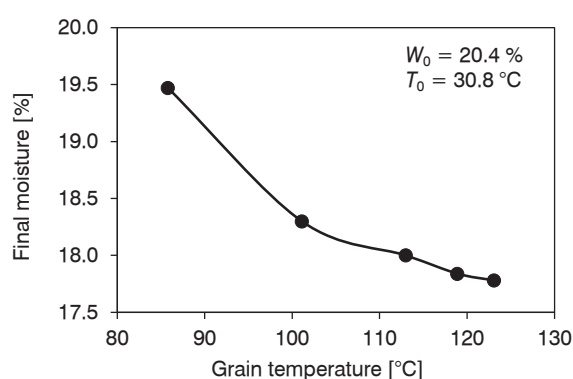
Fig. 2 shows the final temperature dependence at heat treatment of brown lentils on the distance of the infrared panel from the product. It can be seen that the temperature of the grain changes almost linearly depending on the distance of the infrared panel from the product and if the product is removed by 100 mm after 60 s, the temperature is 85.8 °C. As we have already noted, the decom-

**Tab. 3.** Values of the coefficients of Eq. 14 for coefficient  $C = \infty$  and reaction rate constant  $n = -1$ .

$W_0$ [%]	$k$ [s <sup>-1</sup> ]	$\varepsilon$ [kJ·mol <sup>-1</sup> ]	$\varepsilon_R$ [K]	$R^2$
14.1	236981	74.7	7 050	0.99
21.3	26813	51.4	6 184	0.99
30.2	16647	45.6	5 487	0.99

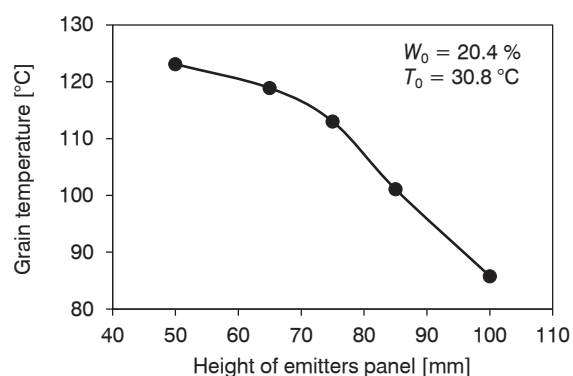
$W_0$  – initial moisture content,  $k$  – proportionality coefficient;  $\varepsilon$  – activation energy,  $\varepsilon_R$  – empirical coefficient,  $R^2$  – square of the coefficient of multiple correlation.





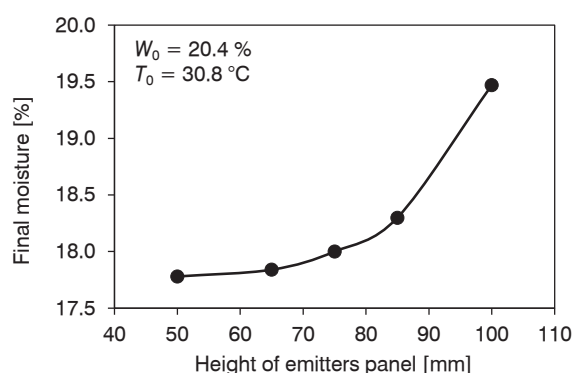
**Fig. 1.** Dependence of final moisture of brown lentils on final temperature of the grain after 60 s.

$W_0$  – initial moisture of the grain,  $T_0$  – initial temperature of the grain.



**Fig. 2.** Dependence of final temperature of brown lentils on the distance of the infrared panel from the product after 60 s.

$W_0$  – initial moisture of the grain,  $T_0$  – initial temperature of the grain.



**Fig. 3.** Dependence of final moisture of brown lentils on the distance of the infrared panel from the product after 60 s.

$W_0$  – initial moisture of the grain,  $T_0$  – initial temperature of the grain.

position of urease practically begins at a temperature of 80–90 °C.

Fig. 3 shows the final moisture dependence at heat treatment of brown lentils on the distance of the infrared panel from the product. It shows that changing the distance of the infrared panel from 100 mm to 85 mm will change the final moisture content uniformly and then the rate of moisture decrease decreases, which is proportional to the change in the temperature of the grains. The obtained results allow us to investigate the process of inactivation of unwanted substances in food in red and brown lentils.

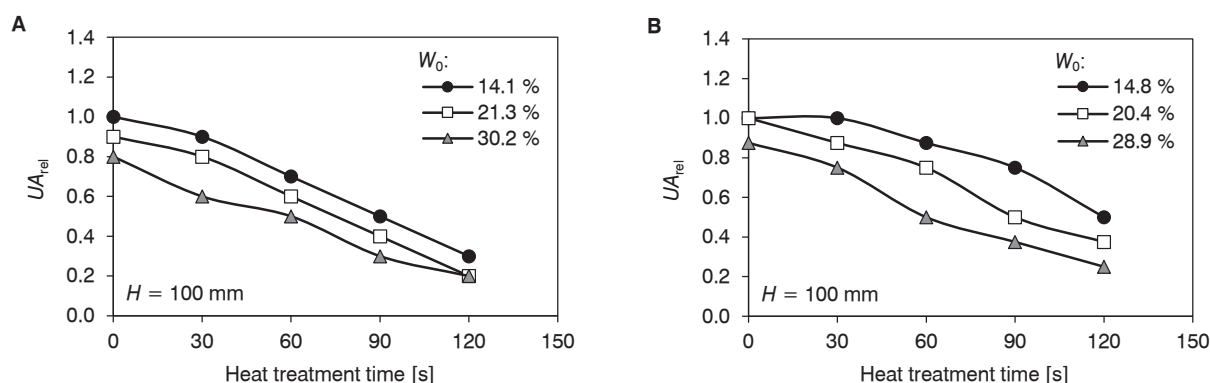
In Fig. 4–9, graphs of the empirical dependence of urease activity on the heating temperature of the grain at different initial moisture content are given.

The independent variables during infrared heating of lentils were the distance of the infrared panel to the surface of the grain monolayer, grain moisture and heat treatment time. The dependent variables were grain temperature and urease activity after heat treatment.

Fig. 4 and Fig. 5 show the empirical dependences of the urease activity of red and brown lentils on the heat treatment time when the initial moisture changes. Fixed distance of the infrared panel to the grain surface was 100 mm or 75 mm. The results are given in relative units compared to the initial activity of urease ( $UA_0$ ), i. e. before the start of infrared heat treatment and at the lowest grain moisture.

The dependence of the activity of urease red and brown lentils at the time of heat treatment turned out to be inversely proportional to their initial moisture content (Fig. 4), the higher the initial moisture content of the grain, the earlier the inactivation of urease in the grain occurs and increases after 60 s, when the distance from the infrared panel to the surface of the grain is 100 mm. In the case of a decrease in the distance from the grain surface of the infrared panel to 75 mm, active urease inactivation was observed after 40–50 s and was almost linear (Fig. 5). As we found, with a decrease in the distance to the infrared panel in the heat treatment zone, the grain surface temperature increased, that is, with an increase in the radiation intensity, the heat transfer intensity also increased, which indicated that the process of urease inactivation intensified with an increase in the heat flux intensity.

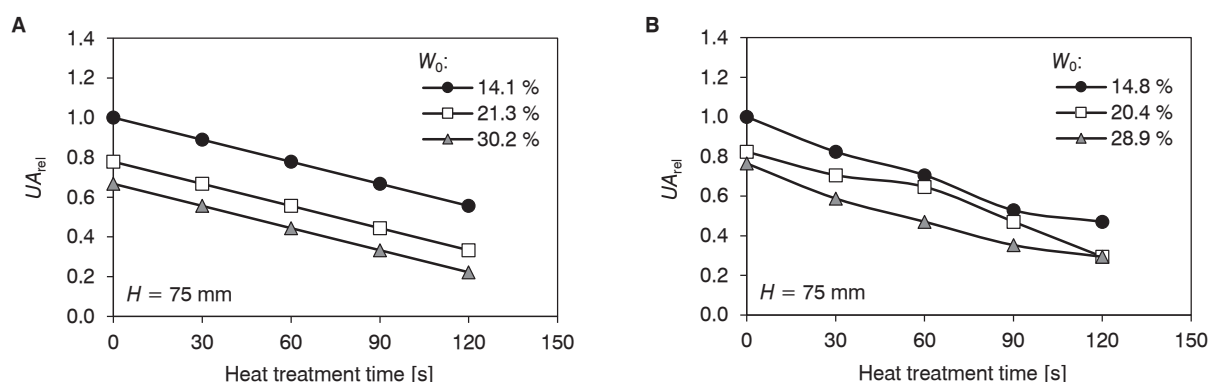
The maximum activity of urease in lentils in pH units after treatment with buffer A was 6.72, and after treatment with buffer B was 6.77. After thermal treatment of lentils with infrared rays, the urease pH rose to a neutral value of 7.0, indicat-



**Fig. 4.** Dependence of relative urease activity of lentils on heat treatment time at various initial grain moisture content and infrared panel distance of 100 mm.

A - red lentils, B - brown lentils.

$UA_{rel}$  - relative urease activity,  $W_0$  - initial moisture content,  $H$  - distance of the infrared panel to the grain surface.



**Fig. 5.** Dependence of relative urease activity of lentils on heat treatment time at various initial grain moisture content and infrared panel distance of 75 mm.

A - red lentils, B - brown lentils.

$UA_{rel}$  - relative urease activity,  $W_0$  - initial moisture content,  $H$  - distance of the infrared panel to the grain surface.

ing a decrease in urease activity. This means that complete inactivation of urease was not possible within the time period used, but its activity could be reduced to a level that will have no significant effect on urea breakdown.

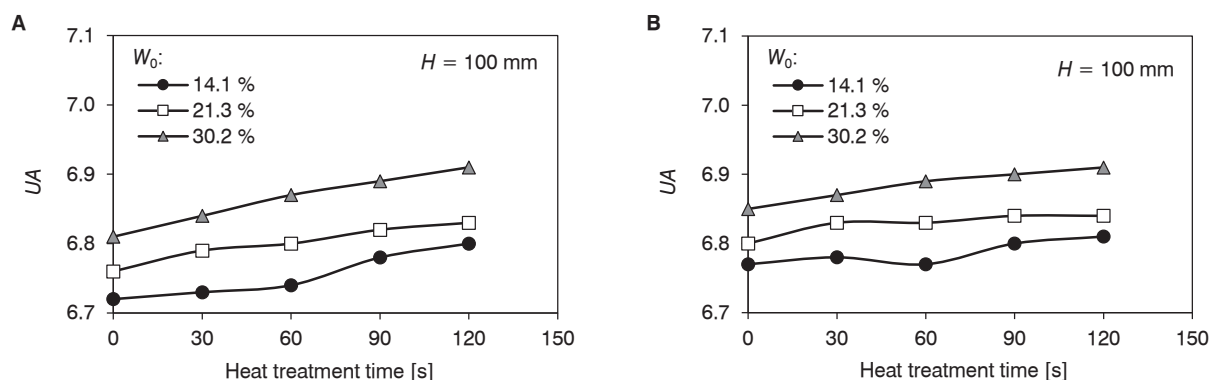
Fig. 6 show urease activity in pH units after treatment of red lentil samples with buffers A and B. As figure shows,  $pH_0$  rose rapidly after 60 s from the start of heat treatment (Fig. 6A) and  $pH_1$  also rose rapidly after 60 s (Fig. 6B). A similar picture was obtained by studying the  $pH_0$  and  $pH_1$  dependence on the heat treatment temperature (Fig. 7).

Fig. 8 and Fig. 9 show experimental data on the activity of urease as a function of the heating temperature of lentils with a change in the initial moisture. Fixed distance of the infrared panel to the grain surface was 100 mm or 75 mm. All results are given in relative units compared to the initial activity of urease ( $UA_0$ ).

If the distance of the infrared panel to the grain surface was reduced from 65 mm to 50 mm, urease inactivation was impossible, because the surface of the grain turned black (burned out) very quickly, in less than 60 s.

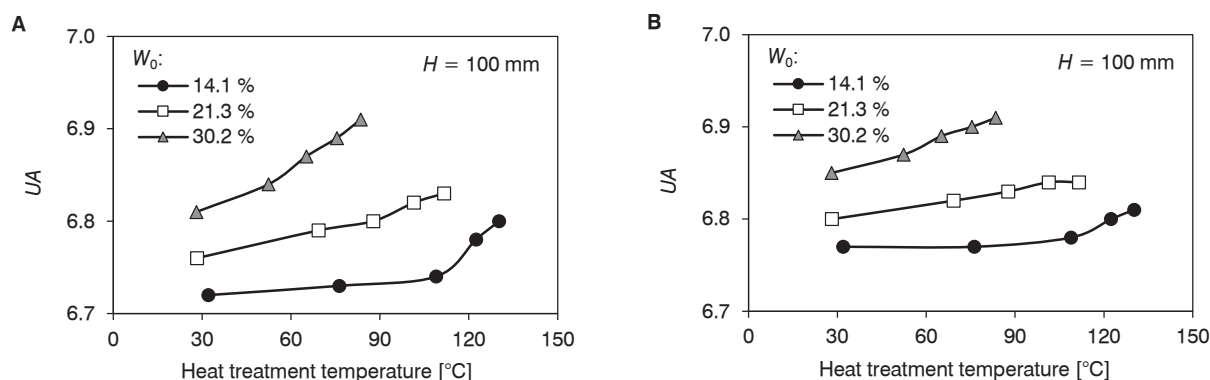
The dependence of urease activity of red and brown lentils on heat treatment temperature is also invariant to the initial moisture content of the grain (Fig. 8). Intensive inactivation of urease is observed from 70 °C with increasing  $W_0$  to 30 %, while in case of  $W_0 = 14-15$  %, intensive inactivation of urease is observed from 85 °C to 90 °C. In the case of reduction of the distance from the grain to the surface of the infrared panel to 75 mm (Fig. 9), inactivation of urease at moisture of  $W_0 = 14-15$  % takes also place at a temperature of 85 °C, while with increasing  $W_0$ , intensive inactivation of urease is also observed above 70 °C.

In the case of infrared heat treatment, the process is non-stationary, i.e. temperature is



**Fig. 6.** Dependence of urease activity of red lentils on heat treatment time at various initial grain moisture content.

A – initial urease activity (after treatment with buffer A), B – final urease activity (after treatment with buffer B).  
UA – urease activity (expressed in pH units),  $W_0$  – initial moisture content,  $H$  – distance of the infrared panel to the grain surface.



**Fig. 7.** Dependence of urease activity of red lentils on heat treatment temperature at various initial grain moisture content.

A – initial urease activity (after treatment with buffer A), B – final urease activity (after treatment with buffer B).  
UA – urease activity (expressed in pH units),  $W_0$  – initial moisture content,  $H$  – distance of the infrared panel to the grain surface.

a function of time, which, in this case, leads to non-linear dependencies. Quantification of the coefficients of such models based on experimental data is a complex task, although a number of application software packages have been developed. The higher the reliability of the estimates, the fewer the estimated parameters and the more initial information is available. Often, the values of the obtained parameters depend on the initial values, since the residual functions (in particular, the sum of least squares) can have several minima. Therefore, it is always necessary to check the obtained coefficient values for compliance with data from independent sources. For example, it is obviously necessary to abandon negative values if, for physical reasons, the value of the coefficient should be positive, etc.

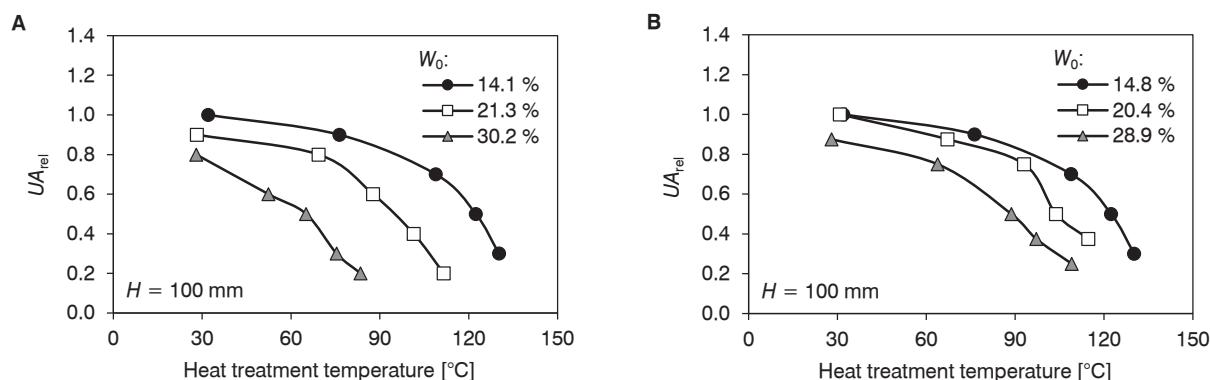
From Tab. 3, it follows that the coefficients of the model changed with the increasing moisture. The main change concerned the proportionality

coefficient  $k$ . In addition, there was a compensatory effect, as with the growth of one coefficient, the other also increased. The coefficients of Eq. 14 determined in this study for lentils were significantly different from those previously determined for soya [6]. This was probably due to the difference in the method of measuring the temperature of the grain and in the heating conditions. The shape of lentils with small thickness, relative to soya, allowed infrared radiation to penetrate and heat up their entire volume faster.

## CONCLUSIONS

Based on the obtained results, we can conclude that rapid urease inactivation takes place under intense heat micronization at a temperature of 70 °C. The inactivation process does not

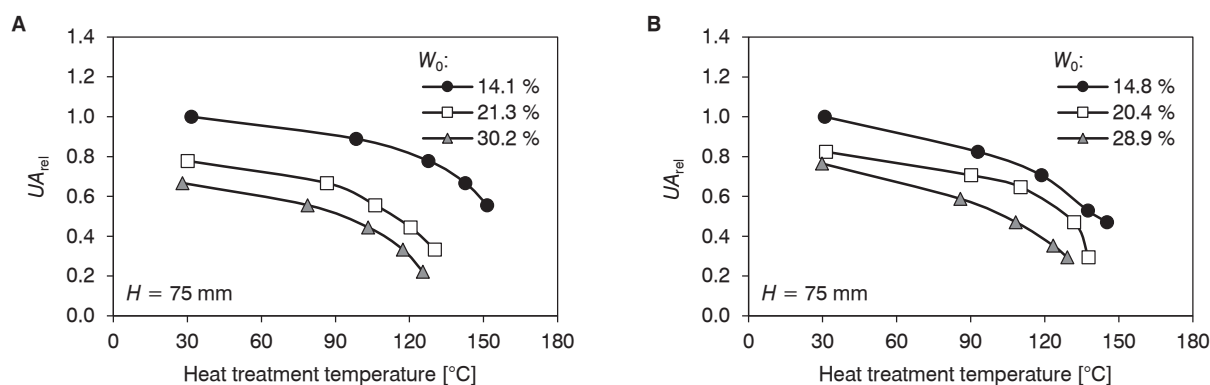




**Fig. 8.** Dependence of relative urease activity of lentils on heat treatment temperature at various initial grain moisture content and infrared panel distance of 100 mm.

A - red lentils, B - brown lentils.

$UA_{rel}$  - relative urease activity,  $W_0$  - initial moisture content,  $H$  - distance of the infrared panel to the grain surface.



**Fig. 9.** Dependence of relative urease activity of lentils on heat treatment temperature at various initial grain moisture content and infrared panel distance of 75 mm.

A - red lentils, B - brown lentils.

$UA_{rel}$  - relative urease activity,  $W_0$  - initial moisture content,  $H$  - distance of the infrared panel to the grain surface.

depend on the infrared treatment mode and depends on the initial moisture content of the grain. The gained results showed that the higher the initial moisture content of the grain, the lower the temperature at which urease inactivation begins. Urease inactivation in the product is more efficient at a smaller distance of the infrared panel, because then the temperature of the heat treatment increases. According to the results of our research, we consider the optimal distance of the infrared panel from the processed product to be 75 mm and the heat treatment time to be 60–90 s. Since the average moisture content of lentils in the market is 11–14 %, we focused the study on lentils with this moisture content and found that, under such moisture conditions, inactivation of urease began at a temperature of 85–90 °C and a heat treatment time from 60 s to 90 s. After this time, the rate of urease inactivation decreased and

any further thermal processing of grain made no sense due to energy costs. At a distance of the infrared panel to the grain surface of 50 mm, urease inactivation was not determined, since the grain surface burned in less than 60 s. During the high-temperature thermal processing of lentils with infrared rays, due to the sharp reduction of urease as an undesirable food substance, it can be considered that their nutritional value is improved. Lentils treated in this way can be used to increase the content of reference protein, which improves the score of essential amino acids and this determines the nutritional value of food products. The proposed model of urease inactivation under non-stationary temperature conditions describes the experimental results well enough. The model can also be used for processes of thermal degradation of other undesirable components of legumes, e.g. alkaloids.

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