

AN INFLUENCE OF HEATING USING IR RADIATION ON PEA SEEDS MOISTURIZING PROCESS

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Summary. The paper presents changes of humidity and compressive force values in pea seeds moisturized and subjected to thermal processing using IR radiation vs. thermally unprocessed ones. Seeds were heated in a device designed for IR processing. The material prepared in such a way was moisturized at different temperatures. During moisturizing, the humidity and compression force were recorded. The achieved data revealed a considerable impact of IR heating on the pea seeds moisturizing process. The preliminarily heated by IR radiation peas absorbed water faster during moisturizing and were characterized by lower resistance to compression.

Key words: compression strength, IR radiation, moisture content, pea seeds.

INTRODUCTION

A quick development of foodstuff markets that are adapted to increasing requirements and variable needs of a modern consumer has been lately observed. Economical, social, and cultural transformations have resulted in the change of a modern man's lifestyle through, among others, improvement of an awareness of a rational diet. It manifests in a wider and wider usage of plant-origin protein preparations as well as whole plants which is, in turn, associated with consuming products of lower animal-origin, highly calorific fats content. High-protein plants such as pea, soybean and other leguminous may be a raw material for such products. These plants' seeds play an important role in feeding, because they may supplement, and even replace animal-origin nutrients. Plant-origin materials – as primary – are much cheaper to produce than animal ones, and their resources may be quickly increased.

An increase of women's professional activity along with good material situation of many families have caused an increase of consumer demand for industrially prepared, ready-to-eat, ready-to-heat, or ready-to-cook food – so-called convenience food. To produce that type of products, the raw material must be subjected to specific technologies improving its sensory and functional traits with no loss of valuable nutrients. In industrial practice, these operations consist in thermal (often helped by a pressure – barometric or water – hydrothermal) treatment of the processed materials. Thermal processes made under appropriate conditions guarantee:

- Inactivation of anti-nutrient factors;
- Digestibility improvement;
- Positive changes in amino acid profile;

- Microorganisms' damage;
- Tastiness improvement.

That type of processing invokes a variety of changes in nutritive and functional features of raw materials, which depend on their natural properties, and on the other hand, the way and conditions in which the thermal process is conducted. Thermal processing in foodstuff industry should be made under elevated temperature, elevated or decreased humidity, and the heating time reduced to a minimum, namely at temperatures above 100°C [Andrejko 2005], because such conditions reduce vitamin and protein decomposition. During the thermal processing, heat is most often transferred from heating medium (hot air, water, oil, heating surface, etc.) to the material. However, many raw materials may be heated by supplying the energy in a form of electromagnetic field. The method is based on a material's ability to absorb electromagnetic waves and then to convert them onto the heat. During IR processing, the temperature of a raw material quickly increases, therefore the time of the process gets shortened, which increases its efficiency. Effects of the thermal process depend on the working parameters of the applied devices and qualitative traits of the processed materials. Up to date, these issues have not been fully solved and they require further intensified studies. Thus, the paper presents an influence of pea seeds heating with IR radiation on moisturizing process taking into account changes of humidity and compression strength.

MATERIAL AND METHODS

Material

Pea seeds of Pomorska cv. were the material for study. They are characterized by beige-olive color with violet dots; 1000-grain weight is about 230 g. The uniform material, referring to the variety, originated from 2006 harvest. Seed moisture content was about 10.0%.

Experimental

Pea seeds were heated using IR radiation at 180°C for 20 sec. Directly after that, seeds were moisturized at various temperatures: 20°C, 50°C, and 70°C. IR thermally processed and preliminarily unprocessed seeds were moisturized. During the moisturizing process, water content (in accordance to AACC Method 44-15A) and compression strength were determined for pea seeds.

IR radiator

Ceramic radiator ECS-1 of 400 W (Elcer) was chosen as IR emission source. It is a temperature radiator supplied with electricity (230 V) having a fraction of per cent of visible radiation in its spectrum (dark radiator), heating all surface points in a uniform way (plane radiator). Mean temperature of filament is about 500°C at wavelength $\lambda = 2.5\text{-}3.0 \mu\text{m}$.

Stand for IR processing of loose plant-origin materials

The process of pea seeds IR heating was performed in a device designed and constructed by the author (Fig. 1). The main elements of the stand are: frame (1), belt conveyor and heating system with continuous temperature regulation. Material is fed to a gated feeder (3), then supplied on the conveyor (single layer). Material on band passes to heating zone (8), where it is treated with IR radiation. Thermally processed material can be directed to a cooler or cylindrical crusher. Belt conveyor is supplied by a DC motor equipped with voltage regulator that makes it possible to continuously regulate belt velocity within range of $5 \cdot 10^{-3} \text{m} \cdot \text{s}^{-1}$ to $7 \cdot 10^{-2} \text{m} \cdot \text{s}^{-1}$ (time the seeds remain in heating zone is from 15 to 200 sec, respectively). The belt of the conveyor (6) is characterized

by great resistance to high temperatures (up to 250°C) and slight permeability for IR radiation (only about 10%). The device is equipped with two heating heads (with 4 ECS-1 radiators in each): the upper one mounted over and the lower one placed under the belt of the conveyor. Only the upper heating head can be used to process fine seeds. When heating large seeds, e.g. white lupine, it is recommended to turn on also the lower heating head. In that case, the belt should be replaced with a net made of copper wire ($\varphi = 0.1$ mm) with square perforation (1 mm length). Over 90% IR radiation passes through such a net.

Depending on processing time and material type, the device's efficiency can be adjusted within wide range. For pea seeds (assuming that the weight of 1 m² single-layer seeds is about 4 kg), the efficiency is from 4.5 kg·h⁻¹ (processing time 200 sec) to 60 kg·h⁻¹ (processing time 15 sec).

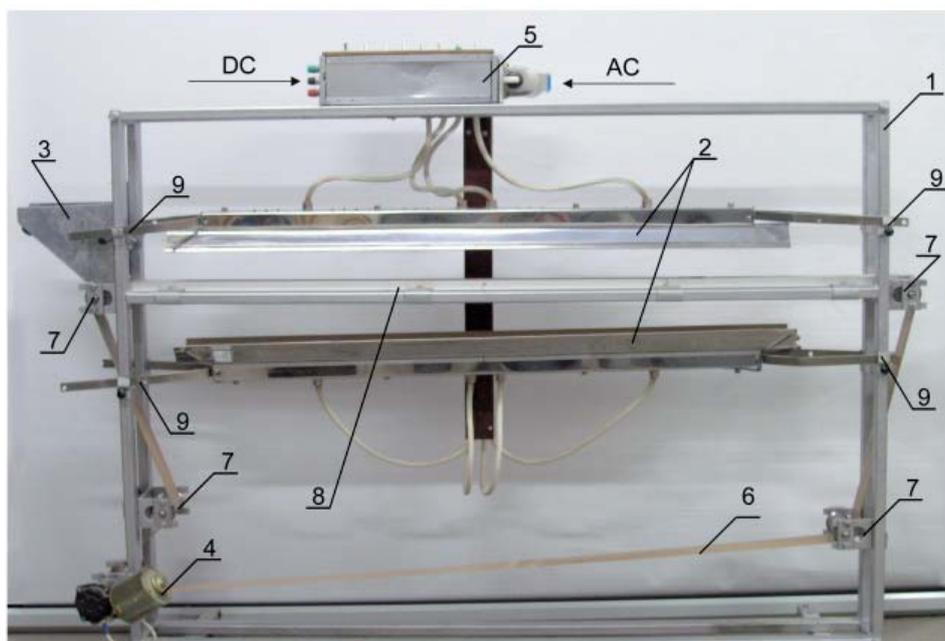


Fig. 1. Laboratory stand for IR thermal processing of loose plant-origin materials: 1 – frame, 2 – head with four independently supplied radiators, 3 – feeder, 4 – DC motor, 5 – operating block, 6 – belt conveyor, 7 – rolls, 8 – heating zone, 9 – head adjustment

The device is equipped with two heating heads under and over the belt (or net). Both elements guarantee continuous regulation of the distance between them and belt from 40 to 200 mm (distance from radiators to conveyor). It is very important at estimating the processing temperature. Depending on the number of working radiators and their distance, temperature values on the belt (net) surface varied.

Water absorption measurements

Pea seeds with known water content were placed in a special basket and immersed in distilled water of a content temperature (20°C, 50°C, or 70°C). After assumed time intervals (5, 10, 15, 20, 25, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, and 360 minutes), about 10-gram samples

were taken out, dried on a filter paper, and then their humidity was determined. Single seeds were subjected to compression test.

Compression test

Most often, studies upon the compression strength of single seeds are based on compressing between two parallel plates. However, two study variants can be distinguished: the first one refers to load application till permanent deformation or sample damage – exceeding the elasticity limit for a given material. Rheological model is the second attempt. No elasticity limit is exceeded in that type of study, instead, the phenomena occurring within biological materials subjected to loads at plasticity limits and after removal of those loads are focused on. The present experiments involve the first model.

The applied method consisted in axial compression test of single pea seeds between two parallel plates in strength-testing device Instron 4302. Velocity of moving plate was constant ($10 \text{ mm}\cdot\text{min}^{-1}$). Single pea seeds were placed on immobilized plate and then compressed using the moving one. The axis of the force passed through diameter of the transverse section of a seed. Measurement was continued till the seed broke by registering compression force F , at which it happened. Arithmetic mean from 10 replications was the final result.

RESULTS AND DISCUSSION

Humidity changes during moisturizing of seeds preliminarily heated with IR and of unheated ones

Literature data revealed that both processing parameters (e.g. temperature, pressure), and physical and chemical properties of raw materials themselves determine the course of water absorption. An influence of temperature during soaking process on the rate and amount of the absorbed water is presented in Figures 2-4: the rate of water absorption by pea seeds increased along with the temperature growth (from 20°C to 70°C). The process was in particular apparent at the first stage, i.e. for about 60 minutes.

The phenomena associated with the temperature's influence on water absorption rate were studied by Maskan [2002] and Turhan et al. [2002]. The univocally achieved results determined the role of temperature (6°C to 100°C) in the moisturizing process. An increased temperature caused an acceleration of water absorption rate by wheat, lupine, soybean, and horse bean seeds. The pressure, under which the process was conducted, was another factor intensifying the process. Both the elevated [Gunasekaran 1992, Gunasekaran and Farkas 1988, Muthukumarappan and Gunasekaran 1992], and lowered pressure [Grochowicz and Rydzak 2002] increased the water absorption rate.

Besides outer factors, also physical and chemical features of the raw material play an important role during the water absorption process. Sopade and Obekpa [1990] as well as Tang et al. [1994] reported that small seeds absorbed water faster. It was associated with larger specific surface area, thus easier and faster absorption. Moreover, permeability of seed coatings, seed viability [Grzesiuk and Kulka 1981], and their chemical composition determine both the rate and amount of the absorbed water. Desphande and Cheryan [1986] as well as Sopade et al. [1992] found that protein is the main constituent that absorbs water, although other components such as cellulose, starch, and pectins also contribute to the process. Also Pilosof et al. [1985] reported on a significant role of proteins in water absorption. Lewicki [1998] found that the level of seed injuries (changes in the structure and composition) due to drying should be taken into account during re-hydration process.

Permanent changes of chemical composition, structure, and metabolic processes occur in pea seeds due to IR processing. Therefore, differences of water absorption rates presented in Figures 2-4 and referring to seeds preliminarily heated using IR radiation and unheated ones may result from these changes. Regardless of the applied water temperature, preliminarily IR heated seeds absorbed water during soaking.

From the point of view of processing engineering, not only the rate of water absorption, but also its impact on the main parameters [Verma and Prasad 1999], as well as how to predict the soaking time under given conditions [Abu-Ghannam and McKenna 1997, Bhattacharya 1995, Taiwo et al. 1998] should be known. Therefore, in many laboratories, studies upon the mathematical description of water absorption by grainy plant-origin materials have been conducted. Process of moisturizing by some cereal grains – i.e. wheat or rice – has been well recognized and several models were built, which were based on Fick's diffusion law [Becker 1960, Hsu 1983a, 1983b, Singh and Kulshrestha 1987, Yi Zang et al. 1984]. However, diffusion laws are complex and numerous functions and parameters are required to describe them, thus they become difficult in practical calculations for majority of examples. In consequence, Peleg [1988] proposed bi-parametric, non-exponential, empirical formula to model water absorption process in raw materials and foodstuff:

$$u(\tau) = u_o \pm \frac{\tau}{K_1 + K_2 \cdot \tau}, \quad (1)$$

where:

$u(\tau)$ – humidity at time τ , %,

u_o – initial humidity, %,

K_1 – constant value, $h \cdot \%^{-1}$,

K_2 – constant value, $\%^{-1}$.

There is sign „ \pm ” in formula (1). Sign „ $+$ ” is used for model water absorption, and „ $-$ ” for drying process.

The main trait of that formula is its simplicity as compared to other ones [Maskan 2002]. It was positively verified for several cereals and legumes [Abu-Ghannam and McKenna 1997, Hung et al. 1993, Peleg 1988, Sopade and Obekpa 1990, Sopade et al. 1992].

Curves of water absorption for soaked pea seeds presented in Figures 2-4 served for mathematical description of the process. To do this, non-linear estimation of the achieved experimental data was used. The calculated values of coefficients K_1 and K_2 are presented in Table 1.

Value of constant K_1 informs on the mass transfer rate during moisturizing process, i.e. the lower K_1 , the higher rate of water absorption [Abu-Ghannam and McKenna 1997, Hung et al. 1993, Sayar et al. 2001, Turhan et al. 2002]. Such conclusion is consistent with the achieved results. The untreated with thermal processing prior to soaking pea seeds absorbed water much slower than those subjected to IR radiation, thus the value of constant K_1 was much lower than in the case of the thermally processed seeds.

Although coefficient K_1 has been quite well defined in numerous publications, there is great divergence referring to the importance of constant K_2 . Maskan [2002], who studied water absorption by wheat products found that constant K_2 is related to maximum water absorption capacity, i.e. at lower K_2 values, a material's ability to absorb water increases. Abu-Ghannam and McKenna [1997] as well as Sayar et al. [2001] drew similar conclusions. However, others [Hung et al. 1993, Maharaj and Sankat 2000, Sopade and Obekpa 1990, Sopade et al. 1992] did not confirm these reports. An analysis of the data presented in Figures 2-4 and Table 1 did not show univocal dependencies between maximum water absorption capacity by pea seeds and constant K_2 .

In general, the formula proposed by Peleg well describes water absorption process at pea seeds – both raw and preliminarily IR processed ones. However, as it results from the cited literature references and own observations, importance of constant K_2 during soaking of loose plant-origin materials is not univocal. In our opinion, value of K_2 coefficient and its variability range for different process parameters may be related only to particular type of plant material. Thus, this issue requires further detailed studies.

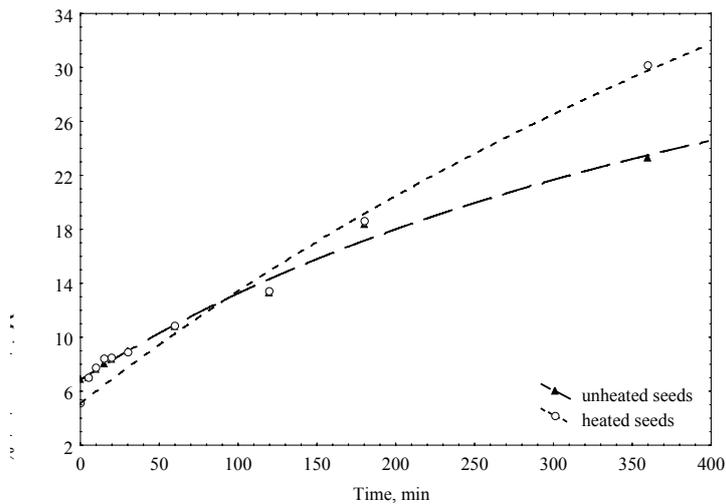


Fig. 2. Comparison of 20°C water absorption by pea seeds that were preliminarily IR processed at 180°C for 120 sec with the untreated ones

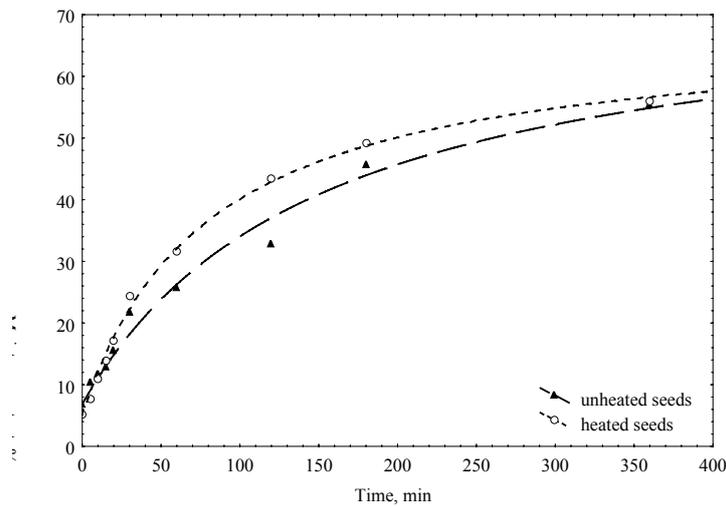


Fig. 3. Comparison of 50°C water absorption by pea seeds that were preliminarily IR processed at 180°C for 120 sec with the untreated ones

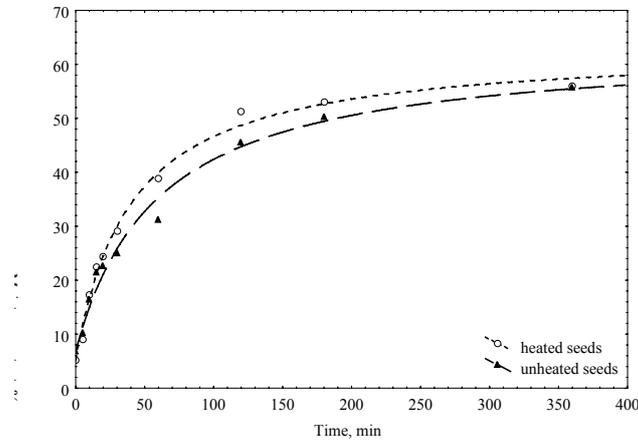


Fig. 4. Comparison of 70°C water absorption by pea seeds that were preliminarily IR processed at 180°C for 120 sec with the untreated ones

Table 1. Mathematical description (Peleg's model) of humidity changes at pea seeds during soaking

Soaking temperature, oC	Preliminarily heated seeds		Thermally untreated seeds	
	Formula	R2	Formula	R2
20	$w(\tau) = 5,11 + \frac{\tau}{11,037 + 0,009 \cdot \tau}$	0.984	$w(\tau) + 6,84 + \frac{\tau}{13,271 + 0,023 \cdot \tau}$	0.995
50	$w(\tau) = 5,11 + \frac{\tau}{1,270 + 0,016 \cdot \tau}$	0.998	$w(\tau) = 6,84 + \frac{\tau}{2,207 + 0,015 \cdot \tau}$	0.992
70	$w(\tau) = 5,11 + \frac{\tau}{0,688 + 0,017 \cdot \tau}$	0.997	$w(\tau) = 6,84 + \frac{\tau}{1,048 + 0,018 \cdot \tau}$	0.993

Changes of compression force during moisturizing preliminarily IR heated and untreated pea seeds

Seed's compression strength plays an important role in many technological processes. Thus an attempt to evaluate the range of compression force during moisturizing preliminarily IR processed and the untreated pea seeds was undertaken. The results presented in Figures 5-7 reveal that thermal interaction of IR radiation was a reason of decreasing the compression force measured during the seed soaking. That phenomenon was particularly apparent during the soaking performed at 20°C, while at 50°C and 70°C it could be observed at the first stage of the process. In general, processing the seeds using IR radiation, which causes numerous structural and physicochemical changes, was the reason for decreasing the compression force measured during seed moisturizing. The attempt to express those changes using regression equations was undertaken (equations 2-7). However, despite the high values of determination coefficients R^2 that prove a good fitting of the mathematical description to experimental data, the presented formulae seem to be too complex and they do not fully express the phenomenon essence. Details of mathematical description of the presented phenomena should be the subject of further investigations.

The role of IR radiation in shaping the compression force was confirmed in earlier studies. They revealed that values of compression force that causes destruction of white lupine seeds (cv. Wat) [Andrejko, Rydzak 2000] and rye grains (cv. Warko) [Andrejko, Grochowicz 2001] were lower

after IR treatment. Similar conclusions were drawn by Fasina et al. [2001], who recorded a decrease of forces damaging seed structure after thermal processing of bean, pea and lentils, but those values were different for particular materials, although processed under the same conditions.

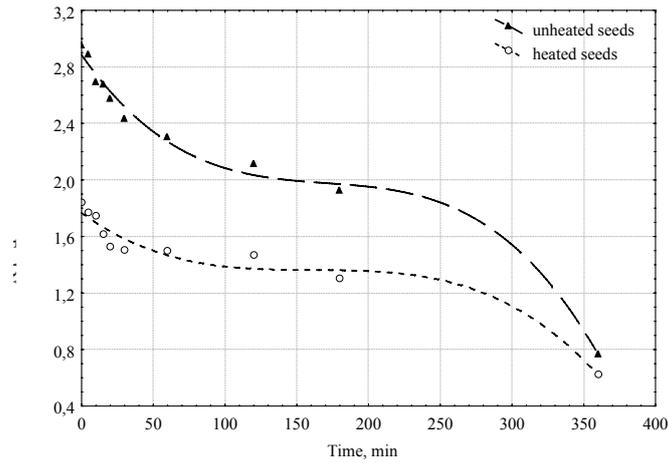


Fig. 5. Comparison of compression force changes (F_s) during moisturizing preliminarily IR heated and untreated pea seeds. Temperature of water during moisturizing 20°C

$$\text{Unheated seeds} - F_s(\tau) = -2E-07 \cdot \tau^3 + 8E-05 \cdot \tau^2 - 0,0145 \cdot \tau + 2,885, \quad (2)$$

$$R^2 = 0,9911.$$

$$\text{Heated seeds} - F_s(\tau) = -9E-08 \cdot \tau^3 + 5E-05 \cdot \tau^2 - 0,0074 \cdot \tau + 1,7662, \quad (3)$$

$$R^2 = 0,959.$$

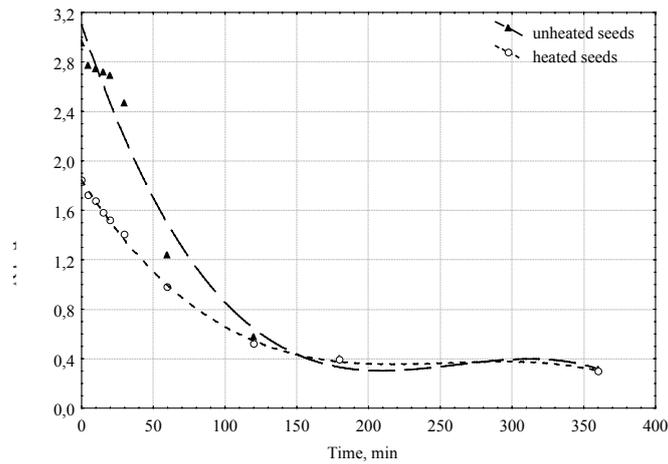


Fig. 6. Comparison of compression force changes (F_s) during moisturizing preliminarily IR heated and untreated pea seeds. Temperature of water during moisturizing 50°C

$$\text{Unheated seeds} - F_s(\tau) = -2E - 07 \cdot \tau^3 + 0,0001 \cdot \tau^2 - 0,0344 \cdot \tau + 3,099, \quad (4)$$

$$R^2 = 0,9764.$$

$$\text{Heated seeds} - F_s(\tau) = -9E - 08 \cdot \tau^3 + 7E - 05 \cdot \tau^2 - 0,0182 \cdot \tau + 1,843, \quad (5)$$

$$R^2 = 0,9987.$$

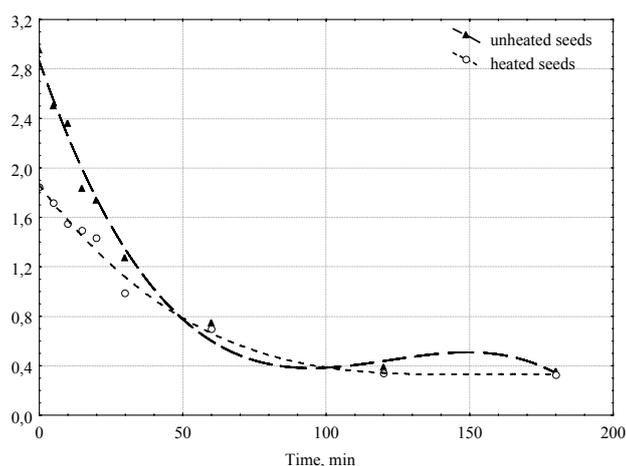


Fig. 7. Comparison of compression force changes (F_s) during moisturizing preliminarily IR heated and untreated pea seeds. Temperature of water during moisturizing 70°C

$$\text{Unheated seeds} - F_s(\tau) = -2E - 06 \cdot \tau^3 + 0,0006 \cdot \tau^2 - 0,066 \cdot \tau + 2,859, \quad (6)$$

$$R^2 = 0,9892.$$

$$\text{Heated seeds} - F_s(\tau) = -5E - 07 \cdot \tau^3 + 0,0002 \cdot \tau^2 - 0,0312 \cdot \tau + 1,878, \quad (7)$$

$$R^2 = 0,9874.$$

CONCLUSIONS

1. Pea seeds subjected to IR thermal processing absorb water faster than preliminarily unheated ones.
2. Peleg's model can be sufficiently used for mathematical description of water absorption by pea seeds with various levels of processing.
3. Thermal influence of IR radiation causes a decrease of compression force values during moisturizing pea seeds. The phenomenon is particularly apparent at moisturizing pea seeds at 20°C. Variations of compression force during moisturizing process can be described – with great precision – using third-order equations.

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