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VACUUM IMPREGNATION PROCESS AS A METHOD USED TO PREPARE THE WHEAT GRAIN FOR MILLING IN FLOUR PRODUCTION

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Summary. The paper deals with research on vacuum soaking of wheat grain with various gluten contents. Grains were moisturized in soaking system in vacuum chamber at 15 °C and under pressures from 5 to 100 kPa (atmospheric pressure). Significant dependencies of final moisture content of the material on pressure in moistener chamber have been found. Furthermore, significant differences of morphological structure of grains soaked under atmospheric pressure and vacuum (5 kPa) have been observed. The achieved values of final grain moisture content confirmed the usefulness of vacuum impregnation as a method that can accelerate the long-term process of wheat preparation to many production processes (e.g. milling for flour, hulling etc.).

Key words: vacuum impregnation, wheat, milling.

INTRODUCTION

The moisturizing process is commonly used in cereal and legume grains processing. It plays an important role in preparing rye and wheat to milling. Properly performed soaking has crucial effects on flour yield and the quality of milled products [19].

A broad spectrum of devices for that process is applied in cereal industry. Their functioning consists in spraying the grains with particular water amount that is subsequently distributed over grain surface in various ways (e.g. Bühler, Vibronet systems). Grain prepared in such a way is not uniformly moisturized. However, technologically, it is a very convenient approach because it facilitates relatively precise estimation of final moisture content. On the other hand, it causes many difficulties, which is reflected in even triple moisturizing of the same raw material before milling in large processing plants. Moreover, such a concept of moisturizing process realization forces a long-term seasoning of the raw material. In the case of durum wheat, the grain may be seasoned even for 36 hrs [21].

Water in rye and wheat grains is bounded by different chemical and physical forces, and its contents varies along with changes in the surroundings. During moisturizing, namely at the initial stage, grain colloid hydration (imbibition) is the most important phenomenon that determines a great initial rate of water penetration. It is characterized by large pressure of water suction reaching even several hundreds of MPa. [16]. Parrish and Leopold [20] found that the highest grain imbibition potential was observed after 10 minutes of soaking, after coat moisturizing and releasing the absorbed gases. Air trapped in pores forming the outer part of a grain is an obstacle that delays the process of water penetration into the grain structure.

Among factors regulating the water penetration inside the grain, the following may be mentioned: type and status of fruit and grain coat, grain physicochemical properties, water temperature, or pressure under which the process is performed.

Grains with non-permeable coat (i.e. hard grains) may be found in bulk grains [3]. Grains with undamaged coat absorb water twice as fast as the unimpaired ones [2].

Small grains absorb water faster than large ones. In general, starch grains absorb water slower than protein ones. Maize grains dried at high temperatures should be soaked even two times longer to achieve 45% of moisture content than those dried at temperatures below 30 °C [12].

Moisturizing process performed at elevated temperatures makes the water amounts absorbed by grains larger [18].

Under pressures from 10.5 to 70 MPa, maize soaked for 1 h absorbs much more water than under normal pressure [10, 11, 17].

Nowadays, the vacuum processes are more commonly applied for foodstuff processing. They find the application in food packaging, loose components mixing, drying processes etc. Using vacuum, any gas and vapor may be removed from usually uneven and porous surface as well as hollows on materials, which inhibits different unfavorable processes, mainly aerobic, that occur inside food.

Works upon vacuum impregnation of animal-origin and fruit products are conducted in research centers connected to foodstuff industry [1, 4-9, 22]. The process accelerates the saturation of biological materials with liquid components.

There is no available literature data on grain vacuum moisturizing process.

MATERIAL AND METHODS

The study object was wheat grain processed in industrial practice at Flour Division, Lubella S.A. in Lublin. There were mixtures of three wheat types: low-gluten (LG) – initial moisture content – 11,9%, high-gluten (HG) – initial moisture content – 11,8%, and durum (D) – initial moisture content – 11,2%. The material was sampled from production line after purification directly before soaking.

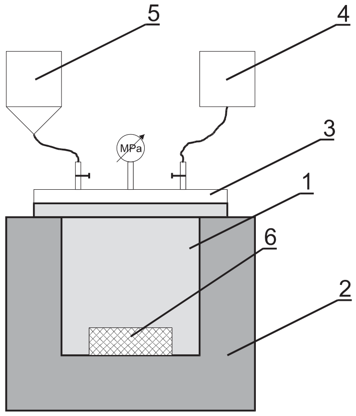

Fig. 1. Scheme of the stand for measuring the moisturizing process by means of vacuum soaking: 1 – vacuum chamber, 2 – ultra-thermostat, 3 – cover, 4 – vacuum pump, 5 – reservoir, 6 – reservoir for raw material

The moisturizing process was performed on a stand presented in Fig. 1. The temperature of moisturizing was set for 15°C after previous placing the vacuum chamber with reservoir filled with grains (about 40 g) in ultra-thermostat. Water used for moisturizing was at similar temperature as that within the chamber. The temperature differences were not larger than ± 2°C. Then, cover was sealed and pressure was set after closing the valve connected to vacuum pump. The following pressures were applied: 5, 30, 60, and 100 kPa (atmospheric pressure – control). After pressure fixing, valve connecting the chamber with vacuum pump was closed and connection with water reservoir was opened. Every sample was soaked with about 0.2 dm^3 of water portion. A slight pressure increase was observed every time the sample was soaked along with the level of chamber filling by water. Control sample was moisturized in similar way under atmospheric pressure conditions.

After grain soaking, the pressure was immediately adjusted to atmospheric one. Samples were taken directly after moisturizing (about 30-second contact with water) and in 5, 15, 30, and 60 minutes.

The excess of not-absorbed water was removed by drying the grain surface on filter paper [11, 13-15, 23]. A single layer of material was placed on double sheet of filter paper, covered with double filter paper sheet and moved for 30 sec. The procedure was repeated twice using another filter paper sheets. Then, grain moisture content was determined in accordance to norm PN-86/A-74011.

General chemical analyses used in industrial practice (protein content, gluten content, Zeleny's sedimentation test) were performed in laboratories of milling-branch producer – Lubella S.A. – using Inframatic 8600 apparatus by means of FT NIR spectroscopy. Zeleny's sedimentation test was made according to norm PN ISO 3093:1996.

Moreover, morphological changes of grain structure after the process were recorded on photos. Not moisturized, moisturized under atmospheric and 5 kPa pressure grains were observed.

All the tested raw materials were subjected to microscopic analysis. Internal structure observations of grain cross-sections were made in metallographic microscope in reflected light under 32-fold magnification. The most characteristic grains for a given material were selected during microscopic observations, then pictures on high-speed film were taken and developed in pushing process, which was ensured with high-level contrast.

Study results were statistically worked out searching for the significance influences of the tested factors (pressure, time) on the achieved effects. The analysis was carried out using Tukey's multiple confidence sections at significance level $\alpha = 0.05$. Linear regression analysis was also performed by determining the formulas describing the tested dependencies.

RESULTS

Chemical properties

Chemical analysis results of low-gluten (LG), high-gluten (HG) and durum wheat (D) are presented in Tab. 1.

Table 1. Chemical properties of the tested wheat types

L.p.	Chemical property	LG	HG	D
1	Protein content [%]	11,3	13,8	14,6
2	Gluten content [%]	22,1	30,6	32,1
3	Falling number [s]	376	316	310
4	Sedimentation test [ml]	24	48	44

Among the studied wheat types, durum one was characterized by the highest protein content (14.6%) vs. low-gluten wheat containing the lowest level of the component (11.3%). Gluten contents were recorded to show similar pattern: 32.1% in durum and 22.1% in low-gluten wheat.

Falling number reached values from 310 s in the case of durum wheat, to 376 s for low-gluten wheat. Zeleny's sedimentation test was the lowest for low-gluten (24 ml), and the highest for high-gluten wheat (48 ml).

Microscopic analysis

After soaking at low pressure (about 5 kPa), the tested grain changes its surface conformation. Water penetrated into the coat structure making it strongly moisturized due to the vacuum and sudden pressure fixing. As a result, the coat got apparently deep-yellow. Wheat grain soaked under atmospheric pressure did not change its morphology.

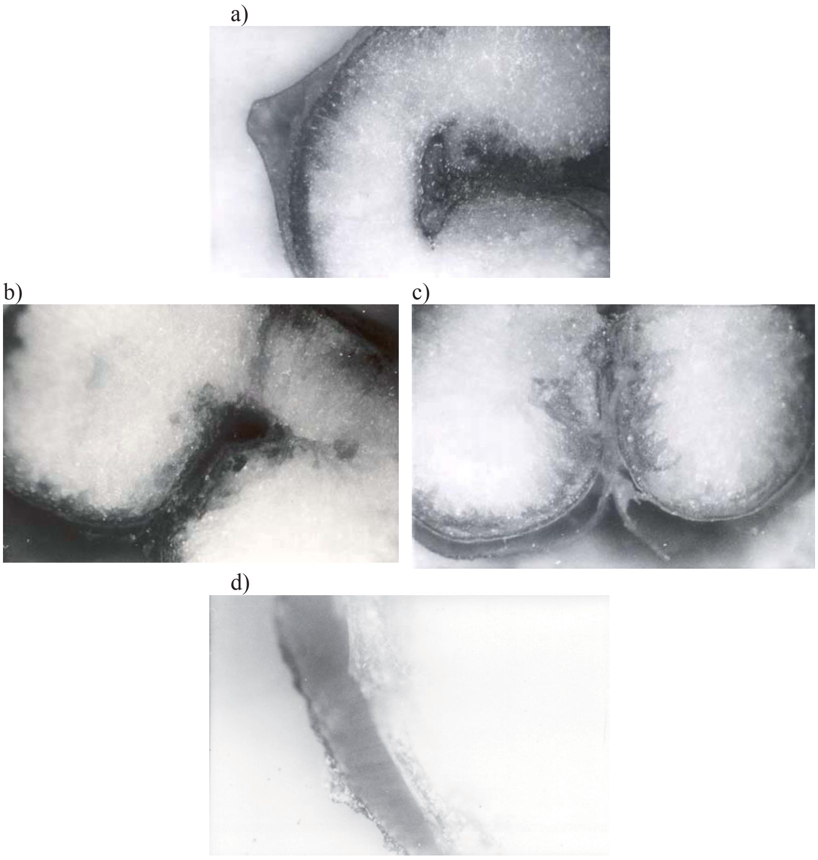

Fig. 2. Cross-sections of low-gluten wheat grain: a) not moisturized grain, b) grain moisturized under atmospheric pressure for 15 minutes, c) grain moisturized under 5 kPa for 15 minutes, d) magnification of coat fragment separating from endosperm

The microscopic analysis of wheat grain moisturizing is presented in the form of single cross-sectioned not moisturized and moisturized (under 5 kPa and atmospheric pressure) grains pictures.

The pictures are shown in Fig. 2. Low-gluten wheat grains were floury and vitreous in part. Changes of endosperm internal structure being a result of its moisturizing, were observed in a layer directly under the coat. Strongly hydrated grain fragments slightly darkened.

Moreover, a picture was taken (Fig. 2d), on which loosening of binding of coat with endosperm that was separated from it during cross-section preparation, is visible.

High-gluten wheat was characterized by semi-vitreous and vitreous endosperm, the durum one – only by vitreous cross-section. In vitreous grains, water migration observations were difficult, and stronger coat with endosperm binding was observed as well: the coat did not separate from the endosperm during cross-sections preparation. In the case of semi-vitreous grains, phenomena similar to those occurring in low-gluten wheat could be observed after longer moisturizing time.

Final moisture content of wheat grain

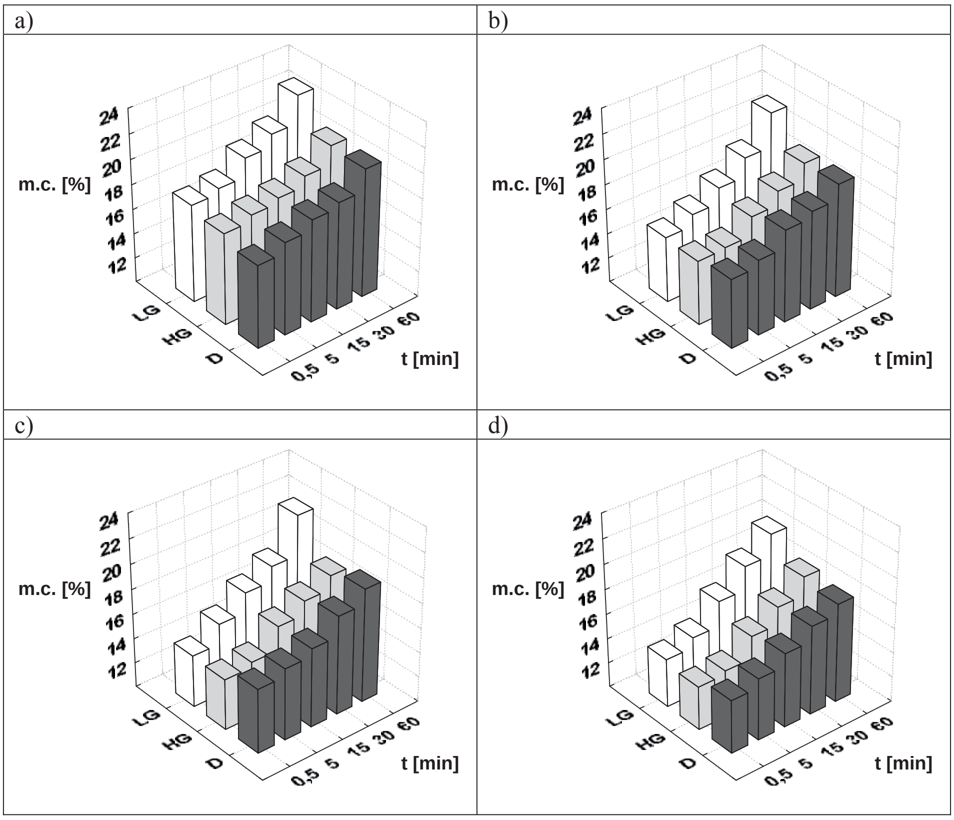

Fig. 3. Changes of final moisture contents for low-gluten (L□), high-gluten (H□) and durum wheat (D) moisturized under various pressure conditions in a function of process duration (temperature 1□ □C):
a) □k□a, b) 3□k□a, c) □□k□a, d) atmospheric pressure – 1□□k□a

□luten content was a trait that distinguished the tested wheat types. It varied from 22.1□ for low-gluten to 32.1□ for durum wheat. A comparison of the final moisture contents for three wheat types with various gluten contents vs. duration of the process performed under pressures used is presented in Fig. 3.

Low-gluten wheat grain (22.1% of gluten) moisturized both under 5 kPa and atmospheric pressure was characterized by the highest values of final moisture contents.

The lowest final moisture contents were recorded for durum wheat (32.1% of gluten). They were the lowest after moisturizing under atmospheric and 5 kPa pressures within the whole range of process duration.

Statistical analysis

The achieved results were subjected to analysis of significance influence of the tested factors (pressure, temperature, time, initial moisture content, manner of not absorbed water removal, type of moisturizing factor) on their final moisture content. The analysis was performed by means of Tukey's multiple confidence sections at the significance level $\alpha < 0.05$ (Tab. 2).

Table 2. Analysis of significance influence of selected factors on wheat final moisture content*

Factor	Value	LG	HG	D
Pressure [kPa]	5	a	a	a
	30	ab	b	ab
	60	c	bc	b
	100	d	c	c
Soaking time [min]	0,5	a	a	a
	5	b	a	b
	15	c	b	c
	30	d	c	d
	60	e	d	e

* the same letters indicate lack of significant differences

Tukey's difference significance test revealed that the studied factors (time and pressure) significantly affected the changes of final moisture contents of wheat within the tested range.

Dependencies achieved in the studies upon pressure (p) and time (τ) influence on wheat grain moisture content were subjected to multiple regression analysis, described with formulas. Determination coefficients R^2 were also evaluated. Those equations, factor variability ranges, and R^2 coefficients are presented in Tab. 3.

Table 3. Regression equations and values of determination coefficients describing the dependence between wheat grain moisture content (w) after moisturizing and time of grain's contact with water (τ), for different pressures (p) in moistener's chamber.

Raw material	Value	Form of equation	A	B	C	R^2
LG	$p\in(5\text{-}100)$ kPa $t=15^oC$ $\tau\in(0,5\text{-}60)$ min	$w=Ap+B\tau+C$	-0,029	0,103	17,23	0,90
HG	$p\in(5\text{-}100)$ kPa $t=15^oC$ $\tau\in(0,5\text{-}60)$ min	$w=Ap+B\tau+C$	-0,029	0,071	16,711	0,87
D	$p\in(5\text{-}100)$ kPa $t=15^oC$ $\tau\in(0,5\text{-}60)$ min	$w=Ap+B\tau+C$	-0,022	0,060	16,899	0,91

CONCLUSIONS

The research program provided a lot of data that after statistical working out allowed for drawing the following conclusions:

Pressure in moistener's chamber ranging from 5 kPa up to 100 kPa significantly affects the final moisture content in wheat grains. Pressure of 5 kPa causes significant changes of the final moisture contents for all the tested grain types.

Grain moisturizing time has significant effects on final moisture content of grain moisturized both under atmospheric pressure and vacuum.

Gluten content in wheat grain affects the moisture content gains achieved due to moisturizing process. Low-gluten wheat grains achieve higher final moisture contents than those containing the highest level of gluten (durum wheat).

Microscopic analysis of grain internal structure does not confirm the water penetration into the deeper layers as a result of pressure decrease in moistener chamber; water moistens only those layers adjacent to the coat. However, great loosening of the binding between coat and endosperm, namely visible in grains with floury cross-sections, was soon observed within grains moistened under 5 kPa pressure.

Final moisture contents for tested wheat types are acceptable during their preparation to milling for flour. Vacuum impregnation may find its application in industrial practice as a way to shorten long-term grain seasoning after moisturizing but before milling.

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ZASTOSOWANIE IMPREGNACJI PRÓŻNIOWEJ JAKO SPOSOBU PRZYGOTOWANIA ZIARNA PSZENICY DO PRZEMIAŁU NA MĄKĘ

Streszczenie. W pracy podjęto badania nad podciśnieniowym nawilżaniem ziarna pszenicy o różnej zawartości glutenu. Ziarna nawilżano w systemie zalewowym w komorze próżniowej, w temperaturze 15^{o}C i w ciśnieniach od 5 do 100kPa (ciśnienie atmosferyczne). Stwierdzono istotne zależności wilgotności końcowej materiału od ciśnienia panującego w komorze nawilżacza. Ponadto stwierdzono znaczące różnice w budowie morfologicznej ziaren nawilżanych w ciśnieniu atmosferycznym i w podciśnieniu rzędu 5 kPa. Uzyskiwane wartości wilgotności końcowej ziarna potwierdzają przydatność impregnacji próżniowej, jako metody przyspieszającej długotrwały proces przygotowania pszenicy do wielu procesów produkcyjnych (przemiału na mąkę, obłuskiwania itp).

Słowa kluczowe: podciśnieniowe nawilżanie, pszenica, przemiał.