Contents lists available at Canadian Scientific Journal

Canadian Scientific Journal

journal homepage: www.csjournal.ca


# Linear and nonlinear relationship of wheat storage characteristics

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ARTICLE INFO

*Article history:*

Received 20 April 2015

Received in revised form 30 April 2015

Accepted 6 May 2015

*Keywords:*

Gluten

Quality

Storage parameters

The matrix of correlation coefficients

Factors

Optimization

ABSTRACT

The article deals with the linear and nonlinear dependencies that predict performance of wheat storage at certain temperatures and storage period. Such parameters of wheat quality as gluten and gluten deformation index after cooling in the granary were determined. Indicators at different temperatures during storage of grain were compared. Experimental data have been processed in Math Cad. Experimental and theoretical values have been analyzed. We came to the conclusion that values deviations are minor, so obtained mathematical model is adequate and enables to predict grain yield depending on the storage temperature with sufficient degree of accuracy. Presented linear and curvilinear relationships between gluten and wheat gluten deformation index allow predicting the technological parameters that affect the quality of gluten. The models equations of linear and nonlinear dependence for gluten and gluten deformation index are presented. The obtained results showed that cooling used in a granary makes it possible to improve the technological parameters that define baking properties of wheat grain particularly the quantity and quality of gluten.



## 1. Introduction

Presented research shows that wheat grain storage results to a change in the quantity and quality of gluten. It does not depend on the wheat grain class but has influence on the bread-making characteristic of the flour. As it is known gluten is a protein jelly. It remains after starch and water-soluble agent cellulose washing-out of the paste. Wheat grain contains 14 to 50 percent and more of protein. Gluten (its quantity and quality) defines the class of grain. The quality of gluten includes such physical properties as extensibility, firmness, flexibility, viscidity, cohesion and the ability to keep physical properties over time. Mass fraction of protein and raw gluten as well as the quality of gluten are the main technological parameters that define baking properties of wheat grain (Fazlutdinova, Labutina, Spirin 2003).

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One of the basic directions of food processing industry growth is the development of high-performance environmentally sound technologies of food production particularly from grain with high-quality nutritional and biological value. The problems connected with the detection of reasons which cause the indicators declining of wheat quality have been under consideration more than once (Tikhonov, Belyakov 2006).

## 2. Analysis of recent research

Analysis of the storage methods developed before including the use of recycling of cereal mixtures with different ratios of dry and wet grain shows rather broad area of the research. However there are not studies related to the cooling of grain and the definition of the influence of selected storage modes on gluten quality ( Dashevskiy, Zakladnoy 1978).

Combine harvesting declines the terms of grain gathering and increases the volume of grain, but at the same time it causes the growth of grain humidity. All these require the application of new storage methods in order to ensure grain safety. Among those methods there is the storage of cooled grain. The greatest danger to stored grain is thermal heating.

This problem becomes particularly critical when the capacity of the granary is being increased. Even good thermal insulation of the granaries does not prevent grain temperature changes because of respiration (Verkholantseva, Yalpachik, Gvozdev 10.08.2012, Bul. № 15).

## 3. Statement of research objectives

For the experiment we applied cooling in two granaries (#1 and #2). The grain was not cooled in the #3 granary. The grain temperature in the #1 granary was supported at the range of 0°C to 7°C. The temperature in the #2 granary was ranged from 7°C to 14°C (Verkholantseva, Yalpachik, Gvozdev 2012, Bul. № 15; Verkholantseva, Yalpachik, Gvozdev 2012, Bul. № 16). The study was based on the DSTU 3768:2010 Ukrainian Standard of wheat specifications. The norm has defined the factors that influence on the wheat and bread quality under storage conditions. After performed research the retention period ($x_1$ factor) and the average temperature ($x_2$ factor) were considered as main factors. Linear and parabolic dependences have been obtained for wheat gluten (Y) (Rizhikov 2004; Tomashevskiy 2005).

So, it is possible to summarize #1 granary data on the base of correlation matrix according to the numerical characteristics. In conclusion wheat gluten (Y) ranges and makes up 27.62 ± 0.19, that means it is 27.43 to 27.81%.

The model equations for linear and non-linear dependence for gluten will be:

$$Y = -12{,}9+7{,}25x_1+4{,}76x_2 \quad \textit{(Linear)}$$

$$Y = -44{,}86+26{,}63x_1+1{,}69x_2-2{,}42x_1^2-3{,}1x_1x_2-0{,}99x_2^2 \quad \textit{(Curvilinear)}$$

*where*

*Y - is the gluten in units of %;*

*$x_1$ - is the storage periods in units of month;*

*$x_2$ - is the average temperature of grain in the granary, which is 0°C.*

Mathematical model of linear and curvilinear dependence gives the opportunity to obtain theoretical values for the specific conditions of grain storage. Comparing theoretical and experimental values we can conclude that value deviation is negligible, so, the mathematical model is adequate and allows, with sufficient degree of accuracy, to predict the output of first class grain depending on the storage temperature (Yalpachik, Verkholantseva 2014).

Surfaces graphs are presented (fig. 1). The received dependences make it possible to forecast the results of grain storage under cooling. When the temperature drops to 0°C gluten indicator increases to 0.5% comparing with the value at the allocation moment.

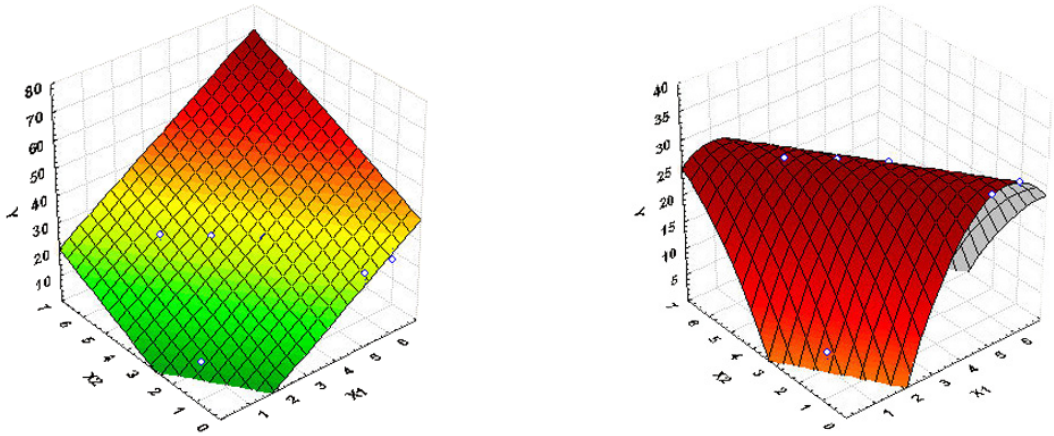


**Figure 1.** The surfaces of linear and curvilinear dependence of wheat gluten for the #1 granary (0°C to 7°C): $x_1$ is the storage period, $x_2$ is the average grain temperature in granary, Y is wheat gluten.

Thermal behavior in #2 granary was kept at 7°C to 14°C. Taking into account the #2 granary data one can conclude, according to the obtained numerical characteristics, that wheat gluten (Y) ranges and makes up 27.53 ± 0.40, which means it is 27.13 - 27.93 %. There is a strong growing relationship with the storage period ($x_1$ factor), and the tough declining relationship with the average grain temperature in granary ($x_2$ factor).

The model equations for linear and non-linear dependence for gluten will be:

$$Y = 27,5+0,15x_1-0,04x_2 \quad \textit{(Linear)}$$

$$Y = 60,54-4,7x_1-4,3x_2+0,15x_1^2+0,34x_1x_2+0,13x_2^2 \quad \textit{(Curvilinear)}$$

Surfaces graphs are given below (fig. 2).

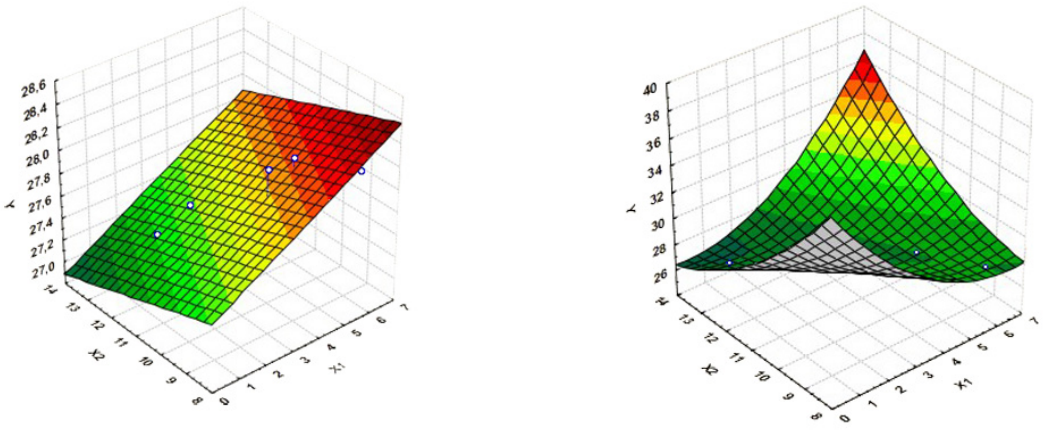


**Figure 2.** The surfaces of linear and curvilinear dependence of wheat gluten for the #2 granary (7°C to 14°C): $x_1$ is the storage period, $x_2$ is the average grain temperature in granary, Y is wheat gluten.

Gluten quality is controlled by means of IDK-1 device ('IDK' stands for Russian 'gluten deformation index'). According to the instrument readings gluten quality may be divided into three groups: good quality (I), satisfactory (II) and unsatisfactory (III). Wheat with gluten of the III group is not suitable for baking. Several factors influence on the gluten quantity and quality. They are varietal characteristics, technology of wheat cultivation (forbear, sowing terms, nitrogen nutrition), weather conditions during grain ageing and harvesting, unfavourable effect on the grain while it is growing (harmful corn-bug affection), being stored (germination and spontaneous heating) and processed (overheating when drying). Wheat can be divided into three groups according to the baking properties: strong, medium, and soft (weak) (Baum 1977).

High quality protein has a light grey or pale yellow color. Dark colors appear because of unfavourable effects on the grain during germination, processing (overheating when drying) or storage. Experimental data from #2 granary show, that wheat gluten deformation index (Y) ranges and makes 63.83% ± 3.71 i.e. 65.66 - 66.0%. There is a strong declining relationship with the storage period ($x_1$ factor) and increasing relationship with the average grain temperature ($x_2$ factor) (Yalpachik, Verkholantseva 2014).

The model equations for linear and non-linear dependence may be presented as:

$$Y = 68{,}79 - 1{,}61x_1 - 0{,}04x_2 \quad \textit{(Linear)}$$

$$Y = -45 + 38{,}5x_1 + 33{,}5x_2 - 3{,}5x_1^2 - 5{,}86x_1x_2 - 2{,}36x_2^2 \quad \textit{(Curvilinear)}$$

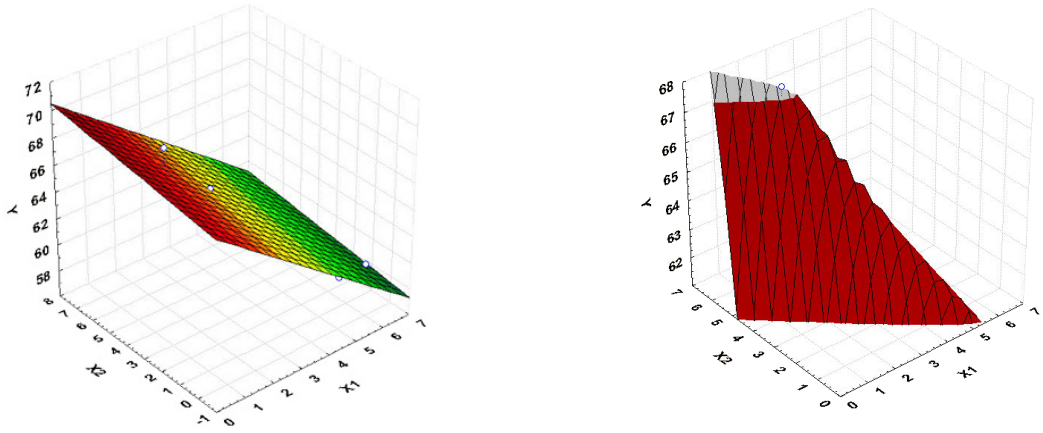


**Figure 3.** The surfaces of linear and curvilinear dependence of wheat gluten deformation index for the #1 granary: $x_1$ is the storage period, $x_2$ is the average grain temperature in granary, Y is wheat gluten deformation index.

The range of wheat gluten deformation index (Y) in the #2 granary is 71.0% ± 2.76. It makes up 68.24 - 73.76%. There is a tough declining relationship with the storage period ($x_1$ factor) and strong increasing relationship with the average grain temperature in granary ($x_2$ factor).

The mathematical model equations of linear and non-linear dependence will be:

$$Y = 64,83-0,72x_1+0,79x_2 \quad \textit{(Linear)}$$

$$Y = 57,32+1,61x_1+0,55x_2+0,0235x_1^2-0,18x_1x_2+0,067\,x_2^2 \quad \textit{(Curvilinear)}$$

Dependency graphs for the #2 granary wheat gluten deformation index are presented.

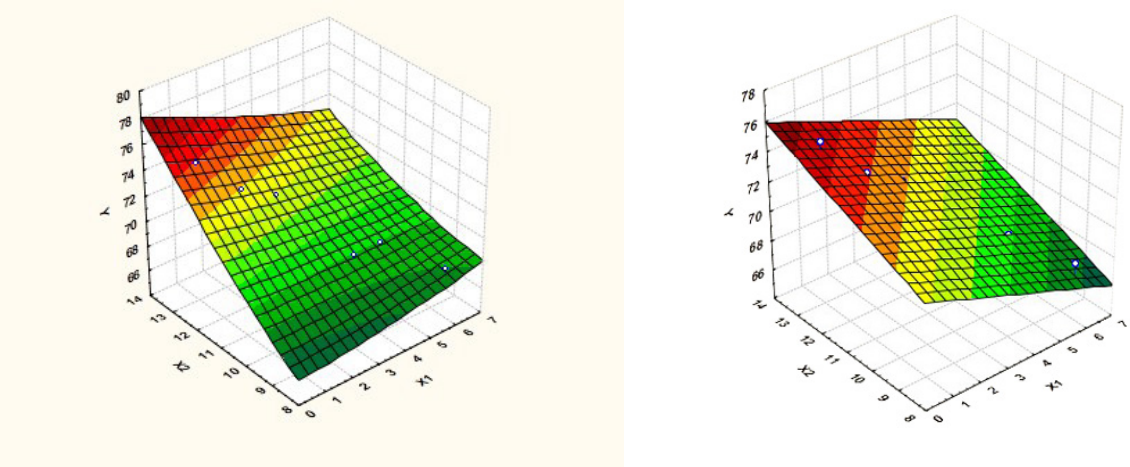


**Figure 4.** The surfaces of linear and curvilinear dependence of wheat gluten deformation index for the #2 granary: $x_1$ is the storage period, $x_2$ is the average grain temperature in granary, Y is wheat gluten deformation index.

## 4. Results

Obtained relationships allow predicting the gluten quantitative and qualitative performances, as well as recommending optimal storage options to obtain satisfactory wheat characteristics.

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