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ANALYSIS OF THE CHANGES IN THE MOISTURE OF POTATO CHIPS DURING STORAGE USING THE LOGISTIC REGRESSION MODEL

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Abstract. The aim of the work was the comparison of the changes in the moisture of potato chips in standard storage conditions (temperature 20°C, (RH) relative humidity of 40-50%) and in a climatic chamber (temperature 45°C, RH 80%), as well as stating the relationship between the length of storage and the conditions mentioned above. The changes in the moisture of potato chips under storage are two-stage in character and can be described by logistic curves. Regardless of the storage conditions, water absorption by chips undergoes the same dynamics. The moisture of chips stored in a climatic chamber featured doubly higher values than that of traditionally stored chips. The rate of water absorption by stored potato chips also depends on the product's properties – the thickness of the potato slices and the kind of flavorings added. A relationship exits between the increase in the moisture of chips stored in the standard manner and those undergoing accelerated test conditions. Short-time storage in a climatic chamber can be useful in determining the changes in chip moisture for several months of storage under standard conditions.

Keywords: moisture, potato chips, storage

INTRODUCTION

Potato chips, widely available on the market are a most popular snack product. One of the properties of such ready-to-eat products is their characteristic crispy texture, resulting from the appropriate choice of both the raw materials and technological parameters. The condition which must be fulfilled in order to obtain a crispy texture in potato chips is a low water content (up to 2.5%) [6]. Because of their high hygroscopicity, such ready-to-eat products are immediately foil-wrapped in order to facilitate storage for several months. The packing materials employed involve different types of metal foil laminates. Metalization significantly lowers the permeability of the foil regarding both oxygen and water vapor (at least by one or, more often, by two orders of magnitude). Since packaging acts as a barrier to water vapor, it has a direct impact on the product's moisture content in the course of storage [1,2]. As for imposing expiry dates, the moisture content of the product constitutes one of the main criteria.

To determine the expiry date, a storage experiment is usually carried out in standard conditions, according to the norms for particular kinds of products. If the keeping quality of raw materials or ready made products is counted in months, there is a need to introduce quick storage tests which enable the expiry date to be rapidly determined. Such tests are carried out under extreme conditions usually at higher temperatures and air humidity, thus accelerating the rate of any changes.

The aim of the work was a comparison of the changes in the moisture content of the potato chip under standard storage conditions (temperature 20°C, (RH) relative humidity of 40-50%) and in a climatic chamber (temperature 45°C, RH 80%), as well as stating the relations between the length of storage and the above-mentioned conditions.

MATERIALS AND METHODS

Materials

The subject of this investigation was potato chips produced in a production plant. The chips underwent the same technological conditions but differed in the following factors:

- potato slice thickness (normal and x-cut)
- the kind of flavor enhancer used (salt, cheese-onion, onion, red pepper and bacon)

The chips were packaged into 100g aluminum foil packets having the facility to be thermally welded.

Experiment

The chips were stored under standard conditions (temperature 20°C, RH of 40-50%) for 36 weeks and in a climatic chamber (temperature 45°C, RH 80%) for 9 weeks. It was assumed that one week's storage in a climatic chamber would represent four weeks storage under standard conditions.

Analyses were performed every four weeks (standard conditions) and weekly (climatic chamber); 3 packages from each chip variety serving as the subject. Their content was mixed in order to obtain unified investigation material. Analysis involved the determining of moisture according to the gravimetric method [8].

Statistical methods

Exploratory analysis of the experimental data and the specificity of the storage process for the different groups of chips under examination give sufficient grounds for using the logistic regression model. We assume that the moisture of chips *(y)* is a function of the time *(t)* with accuracy to the random error in the form

$$f(t) = \frac{a}{1 + be^{-ct}} \quad \text{or} \quad f(t) = \frac{a}{1 + be^{-ct^d}}, \tag{1}$$

where: *a, b, c, d* are unknown parameters of function *y*, the so-called logistic function. It is one of the most versatile and useful models for describing two-phase phenomena and fitting distinct sigmoidal responses – e.g. the growth process – to the characteristic inflexion point but lacks a maximum or a minimum. Also considered in the paper is the process of the absorption of moisture by the chips while being stored which has exactly the same dynamics. The intensive growth of moisture appears at moment: $t_{inf} = ln(b)/c$ (or $t_{inf} = [ln(b)/c]^\wedge(1/d)$), i.e. at the inflexion point of the function $f(t)$). Moisture grows to critical value *a*, being a horizontal asymptotic of the logistic curve. The unknown parameters *a, b, c* have been estimated on the basis of the observations of the moisture content of chips y_1, $y_2, \ldots, y_n$ and the time moments t_i with a four-week time interval. In accordance with the minimum square method, the estimates of parameters *a, b* and *c* minimize the loss function defined by

$$S(a,b,c) = \sum_{i=1}^{n} (y_i - \frac{a}{1+be^{-ct_i}})^2 . \tag{2}$$

The estimates of the model parameters can be obtained by numerical methods using quasi-Newton's methods or Marquardt's method (for details see [3], [4] and also [10]). To decrease the final value of the loss function and thus improve the logistic regression model for the experimental data used to describe the standard chip storage process, a model with four parameters was used assuming that parameter d = 1.5. This was dictated by some practical considerations and numerical reasons – we continually have the three-parameter model. Next, in order to compare the dynamics of the changes for the two moisture absorption processes by those chips stored in a climatic chamber and those under standard conditions, we calculated the ratios of derivatives of the estimated logistic functions in successive time moments. It is clear that we can thus determine the rate of change in one process by referring to the second process.

RESULTS AND DISCUSSION

The changes in the moisture of 6 groups of potato chips stored under standard conditions and in a climatic chamber were described with the use of logistic models (tab. 1) and are presented in figures 1a-1b. For all estimated models (except for group gr2cl) the determination coefficient R^2 achieves high values near or above 95%. This means that the participation of the variation of the response variable (the moisture) is explained by the proposed logistic model which is high and essentially statistical (small error in estimation). This proves a very good fit for the experimental data curves and indicates the usefulness of the model.

Table 1. Equations of the logistic regression model describing the changes in the moisture content of potato chips stored in a climatic chamber and under normal conditions

Variety of potato chip	Flavoring / enhancer	Model	Regression coefficients			Determining Coefficient
			a	b	C	R^2 (%)
1 ch *	cheese-onion		5.586	2.536	0.114	96.64
2 ch *	Pepper		4.801	2.358	0.093	96.03
3 ch *		$f(t) = \frac{a}{1 + be^{-ct}}$	6.633	3.236	0.086	94.82
4 ch *	cheese-onion		8.904	3.426	0.069	92.12
5 ch *	Onion		5.423	3.464	0.127	99.44
6 ch *	Bacon		4.505	2.900	0.109	96.58
1 cl **	cheese-onion		3.556	1.326	0.010	94.58
2 cl **	Pepper		3.522	1.377	0.010	83.03
3 cl **		$f(t) = \frac{a}{1 + be^{-ct^d}}$	3.182	1.108	0.015	94.15
4 cl **	cheese-onion		3.782	1.262	0.012	98.00
5 cl **	Onion		3.155	1.682	0.021	97.16
6 cl **	Bacon		2.405	1.094	0.014	95.51

* ch - climatic chamber,
** cl – under normal conditions.

The rate of water absorption by the potato chips was different for different storage periods and conditions. Moisture in the chips increased faster in the first weeks of storage than it did in the final weeks. That phenomenon proved that maximum water absorption had been reached within the time period under investigation. Regardless of the storage conditions, a stabilization of the moisture in the stored products took place after 28 weeks' storage. The higher relative air humidity as well as the higher temperatures in the climatic chamber affected the stored products' moisture absorption rate. Data regarding the moisture in the chips differed significantly in the two places where the chips had been stored as mentioned earlier. Assuming that one week of storage in the climatic chamber represents four weeks of storage under standard conditions, the figures recorded for the climatic chamber were doubly higher than those for keeping the chips in standard conditions. Within a period of 36 weeks, moisture in the chips under standard conditions increased from 1.5% to about 3%, while those chips stored in the climatic chamber showed moisture ranging 4.5-7% after 9 weeks of storage.

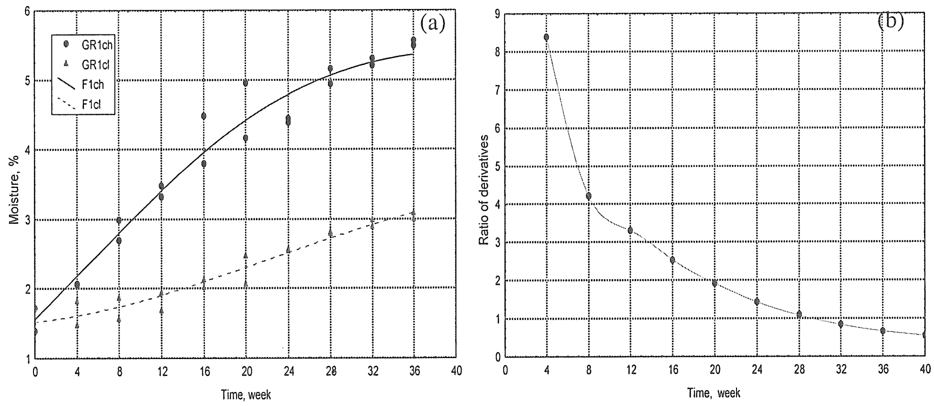

Fig. 1. Changes in the moisture in cheese-onion chips (group 1) during storage in the climatic chamber (ch) and under normal conditions (cl). a. logistic curves with experimental data (F) b. ratio of derivatives of the moisture function

In order to find the relation between the moisture of chips stored in the climatic chamber and of those kept in standard conditions, a quotient of gradients was determined for the estimated logistic function. Functions determined in this way are presented in figures 1b-6b. Despite the similar shape of the logistic curves determined for particular groups of chips, the rate of water absorption, presented in terms of the quotients of gradients, was different. Cheese-onion and pepper chips (fig. 1, 2) featured similar rates of water absorption – within the first weeks of storage in the climatic chamber. The chips absorbed water several times more quickly than did those under the standard conditions. In their twenty eight week storage, the rate of water absorption evened itself out and in the subsequent weeks it showed a decrease for the chips in the climatic chamber in comparison to those stored under standard conditions. The curve for bacon chips – the group 6 function (fig. 6) – proved similar; however, the rate of water absorption by climatic chamber chips throughout the storage period was higher than that for chips stored under the standard conditions.

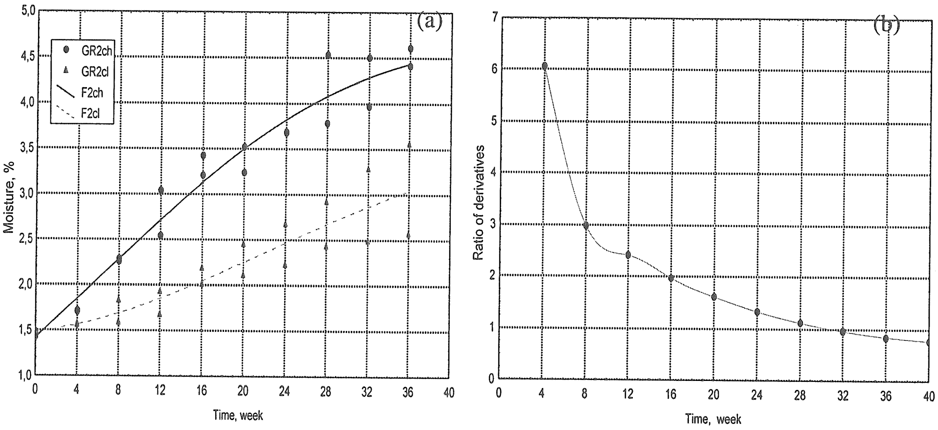

Fig. 2. Changes in the moisture of pepper chips (group 2) during storage in the climatic chamber (ch) and under normal conditions (cl). a . logistic curves with experimental data (F)
b. ratio of derivatives of the moisture function

A slightly different picture was obtained for the rate of water absorption by the chips in group 3 – x-cut ready-salted and 4 – x-cut cheese onion (fig. 3, 4) which featured the highest moisture growth when stored in the climatic chamber. The rate of water absorption by the chips in the climatic chamber was several times higher than that for those stored under standard conditions. Over the subsequent weeks of storage, the rate decreased and then increased again.

Such a situation points to the fact that the rate of water absorption by those chips in the climatic chamber was affected not only by the storage conditions, but also by the properties of the products. Investigations [5,6,7,8] carried out proved that with standard storage, the factors affecting the rate of water absorption by the chips were both the kind of chips (x-cut or traditional) and the kind of flavor enhancers added.

X-cut chips (groups 3 and 4) were characterized by their higher moisture content than were the traditional chips, the difference being evident throughout the 36-week period of storage under standard conditions and throughout the 9-week-period for the chips in the climatic chamber. These results were also confirmed by the previous investigation regarding the changes of properties in the stored chips made of potato slices of different thicknesses [6,7]. X-cut chips were characterized by their lower fat content than normal chips, because of which, water absorption during storage was higher. The lower rate of water absorption recorded in the traditional chips was reflected by the milder course of the logistic curves determined (figs. 1a, 2a, 5a, 6a).

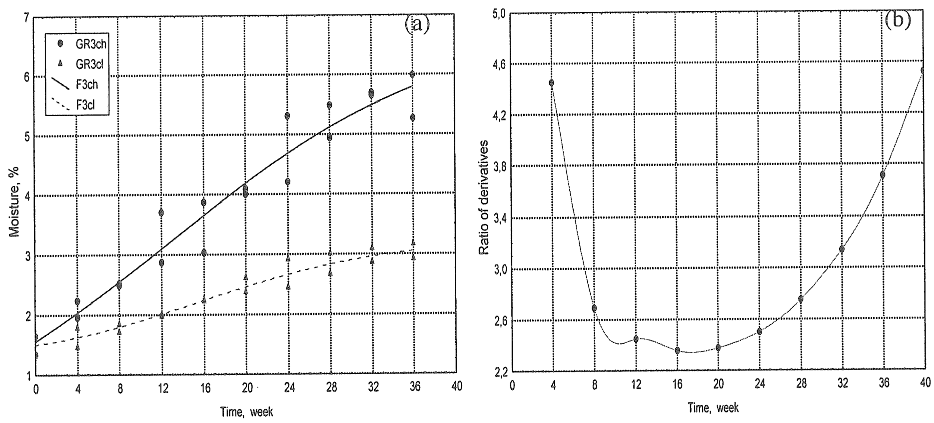

Fig. 3. Changes of the moisture of x-cut ready salted chips (group 3) during storage in the climatic chamber (ch) and under normal conditions (cl). a. logistic curves with experimental data (F)
b. ratio of derivatives of the moisture function

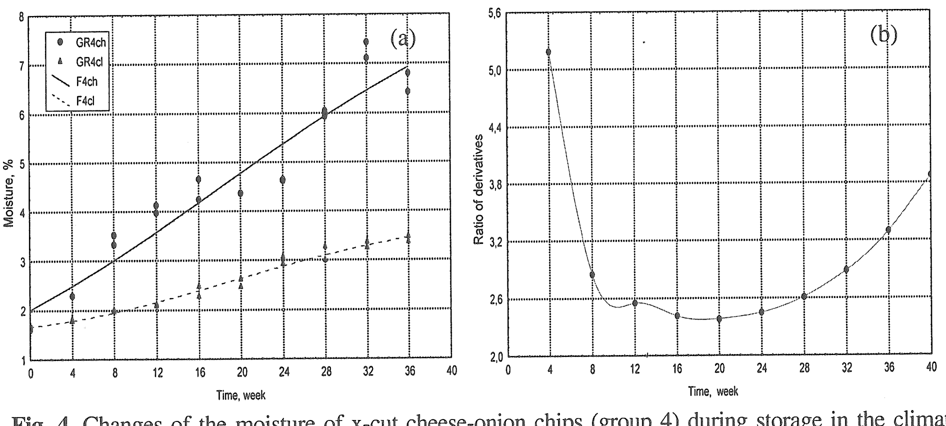

Fig. 4. Changes of the moisture of x-cut cheese-onion chips (group 4) during storage in the climatic chamber (ch) and under normal conditions (cl). a. logistic curves with experimental data (F)
b. ratio of derivatives of the moisture function

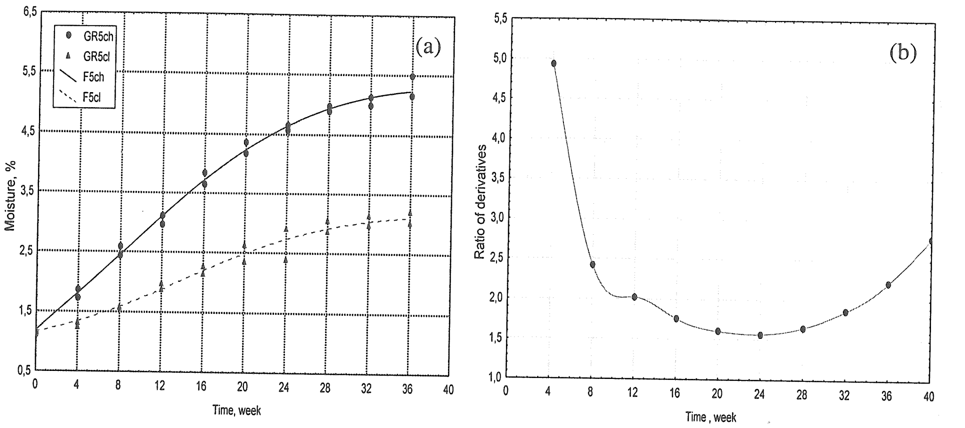

Fig. 5. Changes of the moisture of onion chips (group 5) during storage in the climatic chamber (ch) and under normal conditions (cl). a. logistic curves with experimental data (F) b. ratio of derivatives of the moisture function

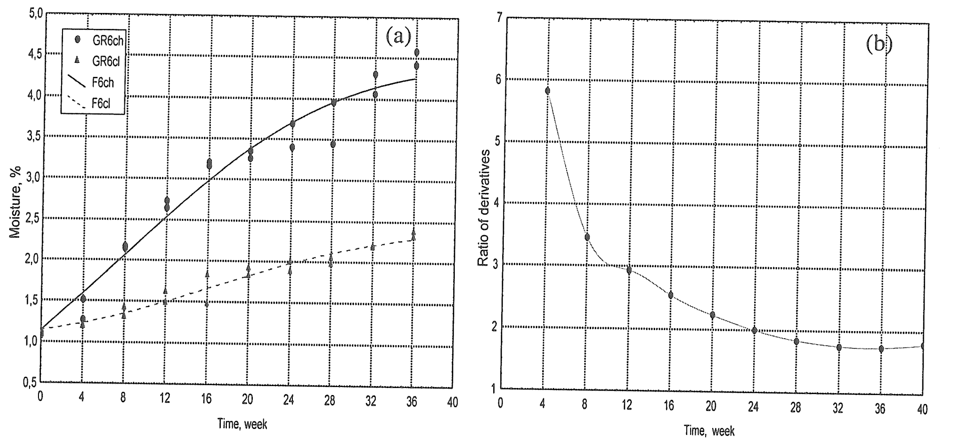

Fig. 6. Changes of the moisture of bacon chips (group 6) during storage in the climatic chamber (ch) and under normal conditions (cl). a. logistic curves with experimental data (F) b. ratio of derivatives of the moisture function

The addition of various flavorings gave rise to differences in the chips, not only as far as their taste was concerned, but also in respect of their rate of water absorption. The cheese-onion flavored chips (group 1) and the onion (group 5) featured a higher rate of water absorption in comparison to the pepper flavored chips (group 2) and the bacon. (group 6). Similar relations have been stated in previous investigations, where the lowest moisture noted within the 28-week-period of storage under standard conditions was represented by the bacon chips [7].

The application of the quick storage test using the climatic chamber resulted in an approximately doubly higher increase in chip moisture in comparison to standard storage practices. The changes in chip moisture in the subsequent weeks of storage followed different rate patterns - as represented by logistic curves. When comparing chip properties over subsequent weeks of storage one should take into account the different rates of water absorption by the products which is related to the two-stage character of the process as well as to considerations of the raw materials.

CONCLUSIONS

1. The changes in potato chip moisture as a result of the storage process are two-stage in character and can be described by logistic curves.
2. Regardless of storage conditions, water absorption by chips undergoes the same dynamics.
3. The moisture of chips stored in a climatic chamber is twice that of the moisture in traditionally stored chips.
4. The rate of water absorption by the stored potato chips also depends on the product's properties viz: the thickness of the potato slices and the kinds of flavor enhancers added.
5. A relation exists between the increase in the moisture of the standard stored chips and those undergoing accelerated test conditions. Short-time storage in a climatic chamber can be useful in determining the changes in chip moisture for lengthier storage periods under standard conditions.

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PORÓWNANIE ZMIAN WILGOTNOŚCI CZIPSÓW ZIEMNIACZANYCH PODCZAS PRZECHOWYWANIA Z UŻYCIEM LOGISTYCZNEGO MODELU REGRESJI

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Streszczenie. Celem pracy było porównanie zmian wilgotności czipsów ziemniaczanych przechowywanych standardowo (temperatura 20°C, wilgotność względna 40-50%) i w szafie klimatyzacyjnej (temperatura 45°C, wilgotność względna powietrza 80%) oraz określenie zależności między długością okresu przechowywania w wymienionych warunkach. Zmiany wilgotności czipsów ziemniaczanych podczas przechowywania zachodzą dwufazowo i można je opisać krzywymi logistycznymi. Niezależnie od warunków przechowywania absorpcja wody przez czipsy zachodzi z taką sama dynamiką. Wilgotność czipsów przechowywanych w szafie klimatyzacyjnej była dwukrotnie wyższa niż czipsów przechowywanych tradycyjnie. Tempo chłonięcia wody przez czipsy ziemniaczane podczas przechowywania uzależnione jest również od właściwości produktów – grubości plasterków ziemniaka i rodzaju dodanej przyprawy. Istnieje zależność pomiędzy wzrostem wilgotności czipsów przechowywanych standardowo i w warunkach przyspieszonego testu. Krótkie przechowywanie w szafie klimatyzacyjnej może służyć do wyznaczania zmian wilgotności czipsów podczas kilkumiesięcznego przechowywania w warunkach klasycznych.

Słowa kluczowe: wilgotność, czipsy ziemniaczane, przechowywanie