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Evaluation of the moisture content and drying kinetics for "cereal flakes" food products marketed in the Western Romania - indicator for quality control

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Abstract

This study aimed to evaluate the water / moisture content of "cereal flakes" products sold on the western market of the country. The moisture content was monitored by the halogen lamp drying method, respectively by evaluating the kinetic parameters of the drying process**.**

Keywords: " cereal flakes" products, moisture content, drying method, halogen lamp

1. Introduction

Cereal flakes are becoming more and more popular among Romanian consumers, especially for children. They are obtained from various cereals through boiling, drying and aeration processes, respectively heat treatments [1]. Cereal flakes are consumed especially at breakfast due to the important caloric and nutritional intake: carbohydrates (approximately 75%), proteins (6-15%) and even lipids, whose concentration varies widely depending on the type of cereals (from 1-3% in barley to 5-10% in corn and oats). In addition, they have a high fiber content (11.5% in wheat and much more, 37.7% in oats) [1]. On the other hand, they also make a significant contribution through the presence of minerals, vitamins from the B vitamins group or antioxidant vitamins (Figure 1).

Water or moisture plays an important role both in the process of obtaining cereal flakes and in the final food products, which influence their quality and acceptability [2-4]. For example, obtaining oatmeal involves steaming oat grains that must have an initial water content of 12-16%.

They are then partially dried at 100 °C to a moisture content of ~7-10%, after which the grains are flattened and pressed into roller equipment. The final drying stage follows up to a moisture below 11% [1,2].

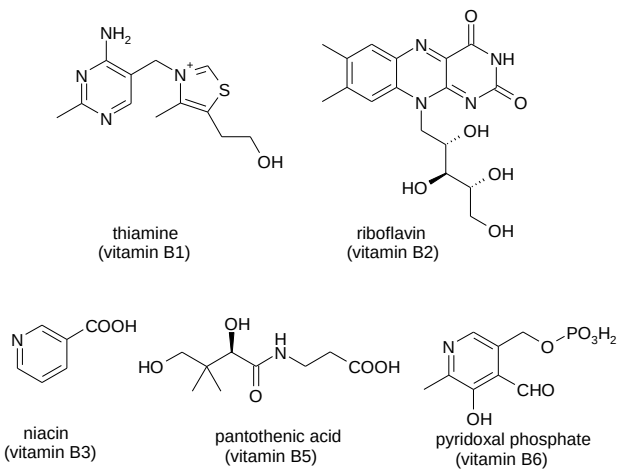

Figure 1. The main compounds of the class B vitamins existing in cereals used to obtain "cereal flakes"

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2. Materials and Method

2.1. Materials

The cereal flakes samples were purchased from supermarkets in Timişoara (Romania) and were coded as follows:
- "Gt" - wheat flakes with bran;
- "Sc" - rye flakes;
- "Ov" - oat flakes;
- "Ovc" - crispy oatmeal;
- "Gold" - barley flakes;
- "Pb" - cornflakes.

2.2. Evaluation of the moisture content of cereal flake samples by halogen lamp drying

The moisture and drying kinetics of cereal flakes were determined using a Partner WPS 210S thermo-balance with the following characteristics:
- Capacity: 210 g;
- Reading units: 0.001 g;
- 300 W halogen lamp;
- heating range: 50-160 °C;
- sensitivity to heating: 1 °C;
- maximum drying time: 10 hours.

The following parameters were set for the drying conditions of the cereal flake samples (Table 1):
- drying temperature: 120 °C;
- "strobe" interval: 30 s;
- mass of the sample: ~2 g;
- number of multiplicate samples: 2.

Table 1. Working conditions and data processing for the evaluation of moisture and drying kinetics for "cereal flakes"

Sample code	Sample Mass (mg)	Drying time (s)	Pseudolinear variation interval 1 (s)	Pseudolinear variation interval 2 (s)	Pseudolinear variation interval 3 (s)
Gt1	2079	780			400-780
Gt2	2026	600			400-600
Sc1	2006	780			400-780
Sc2	2007	720			400-720
Ov1	2006	660			400-660
Ov2	2048	600			400-600
Ovc1	2011	660	0-30	30-400	400-660
Ovc2	2010	660			400-660
Or1	2027	900			400-900
Or2	2009	660			400-660
Pb1	2028	600			400-600
Pb2	2006	660			400-660

2.3. Statistical analysis

All determinations were performed in duplicate. The average values, as well as the corresponding standard deviations have been determined (classical ANOVA statistical analysis for the following determined quantities: moisture (%), respectively average drying srates (mass unit / s)). In addition, linear regression equations $y = a \cdot x + b$ were obtained using the least squares method for moisture dependencies (% or mg) to drying time (s).

3. Results and Discussion

Studies on the moisture content of crushed (ground) samples of cereal flakes, determined using halogen lamp drying method, revealed a similar behavior for all samples, with moisture loss being a rapid process at first, followed by a continuous decrease (Figures 2 and 3) [5].

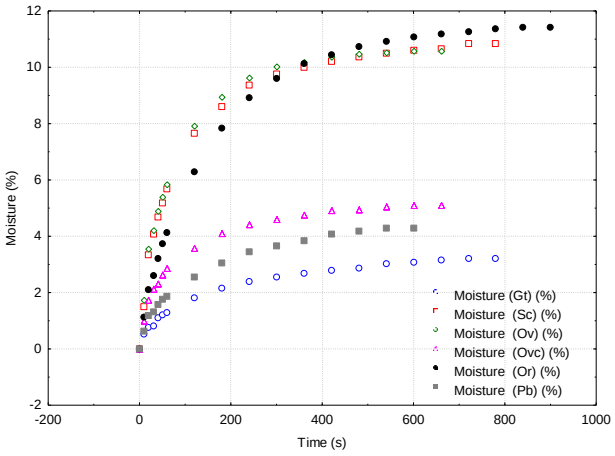

Figure 2. Variation of moisture (%) of "cereal flakes" type foods during the drying process (set "1" of duplicates)

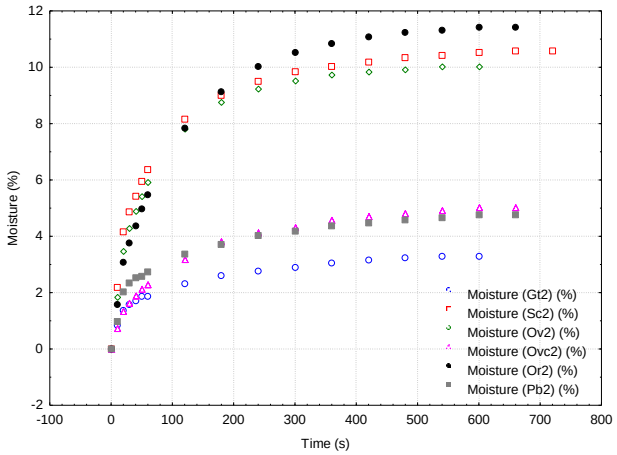

Figure 3. Variation of moisture (%) of "cereal flakes" type foods during the drying process (set "2" of duplicates)

The flattening of the weight loss variation (expressed as percentage) for the grain flake samples suggests the completion of the release of water molecules from the food matrix, which leads to the final moisture of the product. The expression by which the humidity was determined is:

$$Moisture\ (\%) = \frac{m_i - m_f}{m_i} \cdot 100$$

where: m_i - is the initial mass of the sample to be analyzed (approximately 2 g);

m_f - is the final mass of the sample after completion of drying (g)

Moisture contents of these products varied in very wide limits, from 3.26±0.06% for wheat flakes with bran, 5.06±0.06% for crispy oat flakes or 4.53±0.34% for corn flakes, up to 10.31±0.39% for oat flakes, 10.72±0.19% for rye flakes and even 11.43±0.00% for barley flakes (Table 2).

The variation in weight loss (moisture) over time indicated the use of drying kinetics to evaluate the type of waster/volatile molecules that are released from the food matrix, consisting mainly of carbohydrates, proteins and lipids.

Carbohydrates retain water molecules very well, so the proportion of "surface" and "strongly bound" water can be evaluated based on average drying rates on various intervals with approximately linear variation.

In fact, the slope of the correlation line, α, represents the average drying rate for the time interval considered:

$$v_{drying} = tg(\alpha) = \frac{\Delta moisture}{\Delta t}$$

where:

v_{drying} - represents the average drying rate of the sample over the considered time interval, which is equal to the tangent of the angle α formed between the correlation line and the abscissa (it can be expressed in units of mass,% or milligrams, related to the unit of time, s);

$\Delta_{moisture}$ – variation in mass during drying, for the period of time considered (loss of mass, expressed either as a percentage or in units of mass, as milligrams);

Δt – the time interval for which the average rate is determined (s).

Table 2. Results of the drying process of the food samples type "cereal flakes" (duplicates)

No.	Sample code	Moisture content (%)
	Gt1	3.221
	Gt2	3.302
1	**Gt ± SD**	**3.262 ± 0.057**
	Sc1	10.856
	Sc2	10.586
2	**Sc ± SD**	**10.721 ± 0.191**
	Ov1	10.583
	Ov2	10.029
3	**Ov ± SD**	**10.306 ± 0.392**
	Ovc1	5.109
	Ovc2	5.019
4	**Ovc ± SD**	**5.064 ± 0.064**
	Or1	11.428
	Or2	11.432
5	**Or ± SD**	**11.430 ± 0.003**
	Pb1	4.287
	Pb2	4.773
6	**Pb ± SD**	**4.530 ± 0.344**

The correlations over the three time intervals considered (0-30 s for "surface" water, 30-400 s for "strongly bound" water and over 400 s, the portion in which the curve is flattened) are shown in Figures 4-9 for the case of expressing the average rates in percentage units related to the unit of time (%/s), respectively in Figures 10-15 for the case of expressing the average drying rates in units of mass loss in the unit of time (mg/s). From Table 3 it can be seen that the values of the average drying rates corresponding to the "surface" water vary in the range 0.04-0.15 % / s, with maximum values for rye and oat flakes, respectively minimum values for wheat flakes with bran (where probably the gluten content allows a stronger retention of water molecules compared to other types of cereals). The rates corresponding to the "strongly bound" water are 5-10 times lower, being between 0.005-0.023 %/s (Table 3).

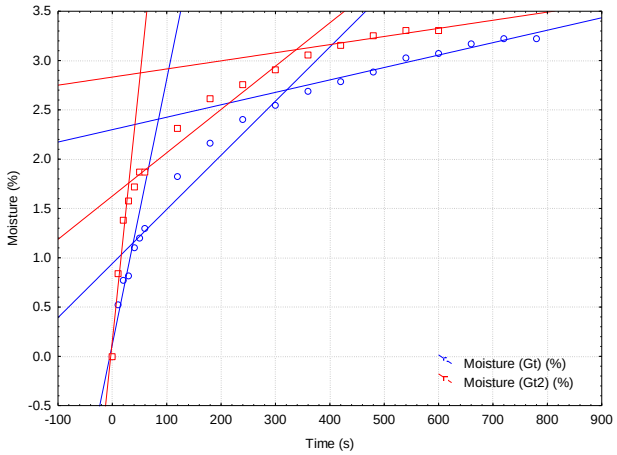

Figure 4. Variation of moisture (%) of wheat flake type products with bran ("Gt") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

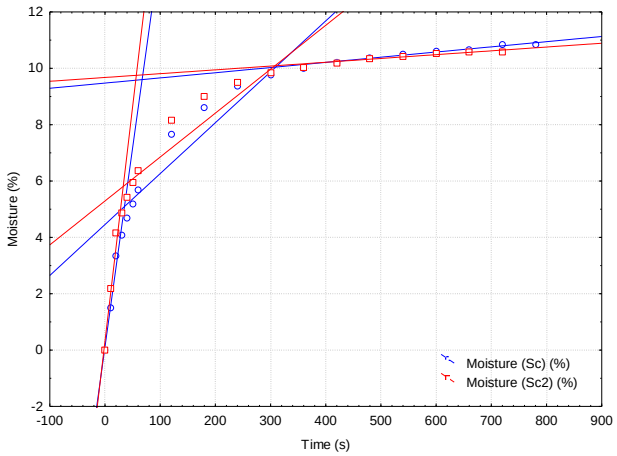

Figure 5. Variation of moisture (%) of rye flake products ("Sc") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

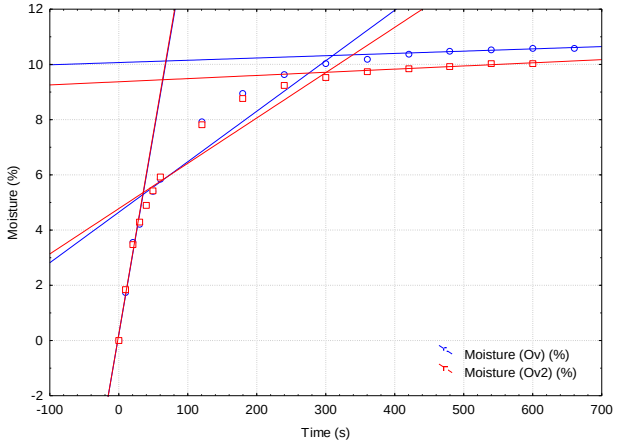

Figure 6. Variation of moisture (%) of oatmeal products ("Ov") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

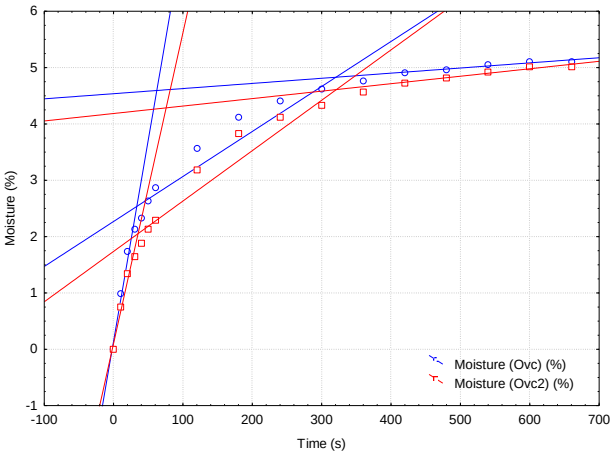

Figure 7. Variation of moisture (%) of crispy oatmeal products ("Ovc") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

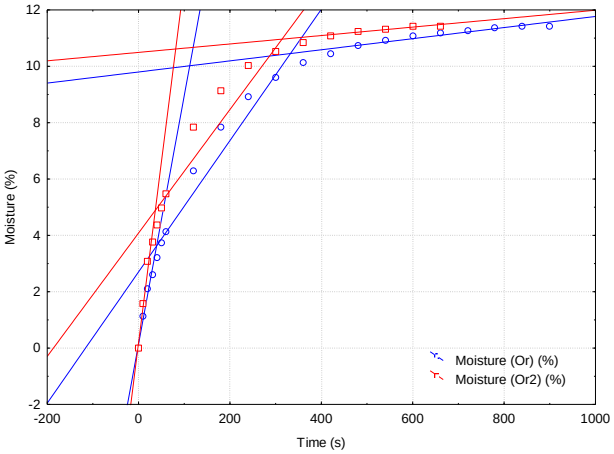

Figure 8. Variation of moisture (%) of barley flake products ("Or") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

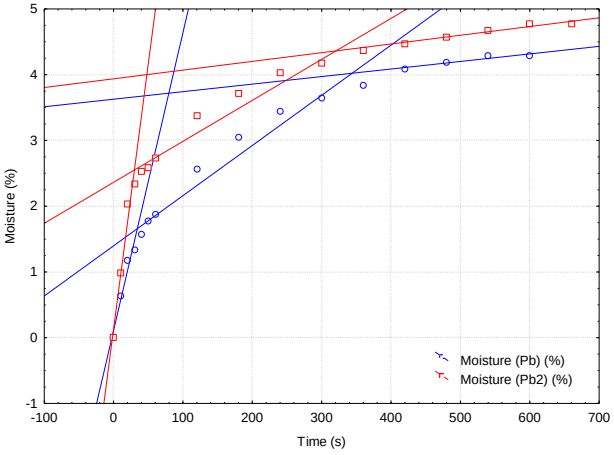

Figure 9. Variation of moisture (%) of corn flake products ("Pb") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

Table 3. Drying kinetics results for "grain flakes" food samples (drying rates expressed as % moisture loss in the unit of time over the three time intervals considered: 0-30 s, 30-400 s and > 400 s); SD - standard deviation

No	Sample codes	v_1 (%/s)	v_2 (%/s)	v_3 (%/s)
	Gt1	0.0269	0.0055	0.0013
	Gt2	0.0527	0.0044	0.0008
1	**Gt ± SD**	**0.040 ± 0.018**	**0.005 ± 0.001**	**0.001 ± 0.000**
	Sc1	0.1409	0.0181	0.0018
	Sc2	0.1660	0.0156	0.0014
2	**Sc ± SD**	**0.153 ± 0.018**	**0.017 ± 0.002**	**0.002 ± 0.000**
	Ov1	0.1444	0.0183	0.0008
	Ov2	0.1454	0.0164	0.0011
3	**Ov ± SD**	**0.145 ± 0.001**	**0.017 ± 0.001**	**0.001 ± 0.000**
	Ovc1	0.0714	0.0080	0.0009
	Ovc2	0.0552	0.0089	0.0013
4	**Ovc ± SD**	**0.063 ± 0.011**	**0.008 ± 0.001**	**0.001 ± 0.000**
	Or1	0.0881	0.0233	0.0020
	Or2	0.1282	0.0219	0.0015
5	**Or ± SD**	**0.108 ± 0.028**	**0.023 ± 0.001**	**0.002 ± 0.000**
	Pb1	0.0453	0.0076	0.0011
	Pb2	0.0806	0.0062	0.0013
6	**Pb ± SD**	**0.063 ± 0.025**	**0.007 ± 0.001**	**0.001 ± 0.000**

In the case of expressing the average drying rates as units of mass (milligrams) loss per unit of time (mg/s), the sample masses having approximately the same value (~2 g = 2000 mg), the values corresponding to the "surface" water and the "strongly retained" water are in the range of 0.814-3.079 mg/s and 0.102-0.456 mg/s, respectively (Figures 11-16 and Table 4). On the other hand, the average rates in the range corresponding to the flattening of the variation are very small and quite close (0.021-0.035 mg/s).

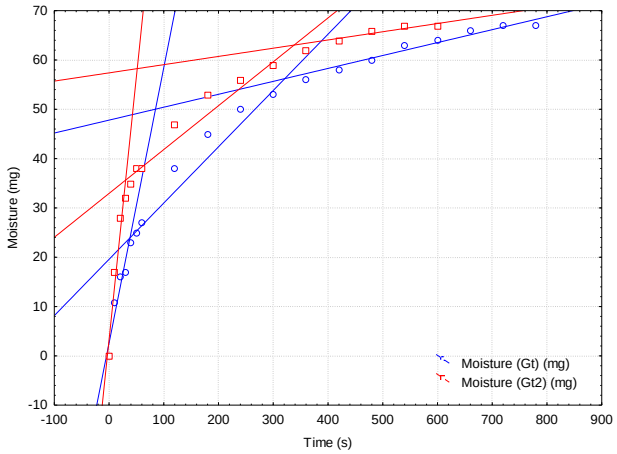

Figure 10. Variation of moisture (mass, mg) of wheat flake products with bran ("Gt") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

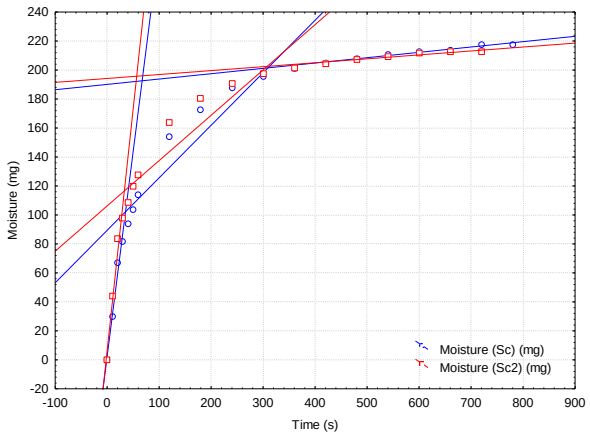

Figure 11. Variation of moisture (mass, mg) of rye flake products ("Sc") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

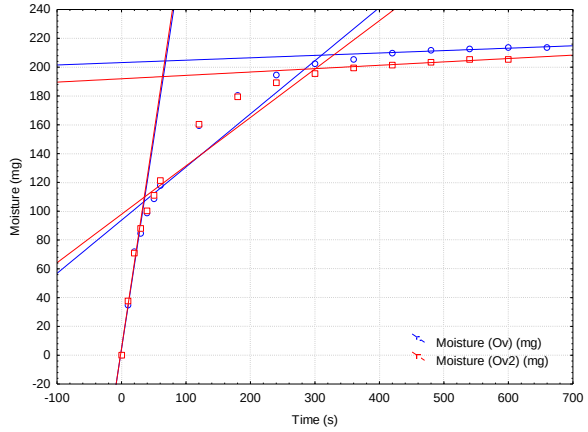

Figure 12. Variation of moisture (mass, mg) of oatmeal products ("Ov") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

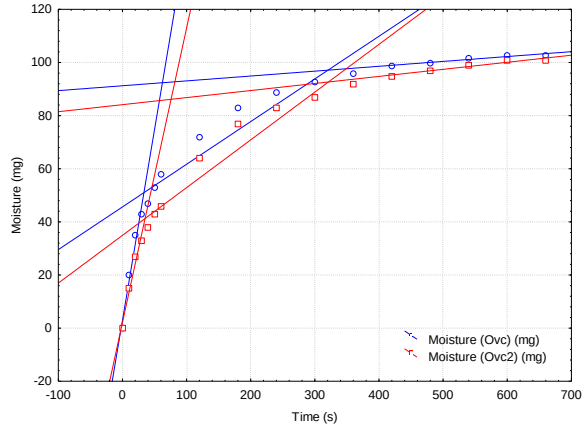

Figure 13. Variation of moisture (mass, mg) of crispy oatmeal products ("Ovc") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

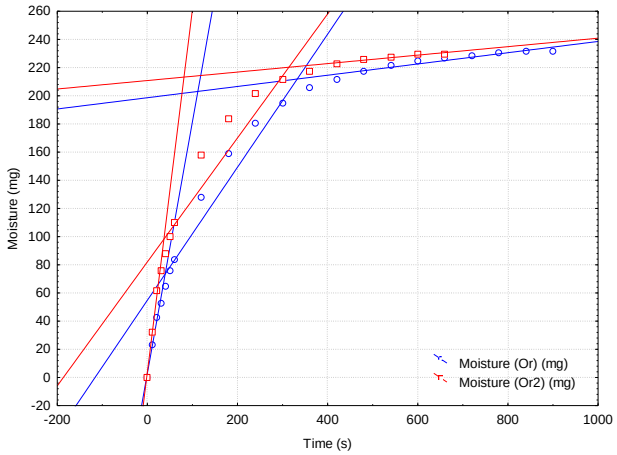

Figure 14. Variation of moisture (mass, mg) of barley flake products ("Or") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

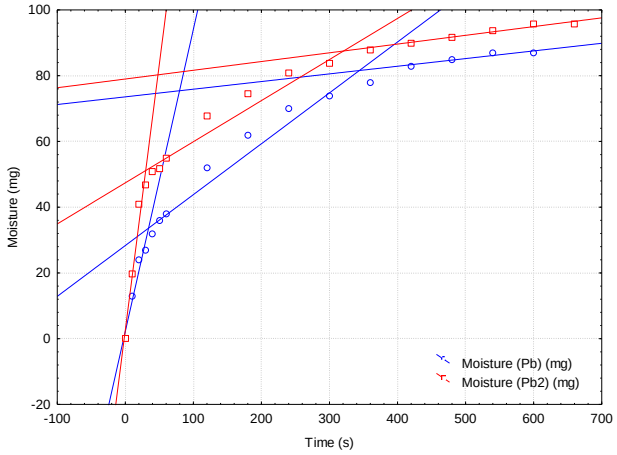

Figure 15. Variation of moisture (mass, mg) of corn flake products ("Pb") during the drying process and correlation lines for pseudolinear drying time intervals (duplicates)

4. Conclusions

Based on the results obtained regarding the moisture of the cereal flake samples sold in the Timişoara markets, as well as the drying kinetics by the halogen lamp method, it can be concluded:

- the moisture of the food products based on "flakes" type cereals varies in wide limits, respecting the maximum limit over which the microorganisms become viable;
- the lowest water content (as moisture) was obtained for the samples of wheat flakes with bran, while the maximum value was observed for barley flakes;
- the drying kinetics of the cereal flake samples allowed the highlighting of the "surface" water molecules and of the "strongly bound" ones, based on the average drying rates on significant time intervals. It was found that the lowest drying rate was obtained for wheat flake samples, where the high gluten content causes a stronger retention of water molecules in the food matrix.

Table 4. Results of the drying kinetics for the food samples type "cereal flakes" (drying rates expressed in mg moisture loss in the unit of time on the three time intervals considered: 0-30 s, 30-400 s and > 400 s); SD - standard deviation

No.	Sample	v_1 (mg/s)	v_2 (mg/s)	v_3 (mg/s)
	Gt1	0.5588	0.1142	0.0262
	Gt2	1.0683	0.0890	0.0167
1	**Gt ± SD**	**0.814 ± 0.360**	**0.102 ± 0.018**	**0.021 ± 0.007**
	Sc1	2.8269	0.3625	0.0369
	Sc2	3.3312	0.3128	0.0271
2	**Sc ± SD**	**3.079 ± 0.357**	**0.338 ± 0.035**	**0.032 ± 0.007**
	Ov1	2.8965	0.3670	0.0165
	Ov2	2.9774	0.3362	0.0234
3	**Ov ± SD**	**2.937 ± 0.057**	**0.352 ± 0.022**	**0.020 ± 0.005**
	Ovc1	1.4359	0.1607	0.0183
	Ovc2	1.1087	0.1798	0.0266
4	**Ovc ± SD**	**1.272 ± 0.231**	**0.170 ± 0.014**	**0.022 ± 0.006**
	Or1	1.7868	0.4723	0.0399
	Or2	2.5759	0.4402	0.0301
5	**Or ± SD**	**2.181 ± 0.558**	**0.456 ± 0.023**	**0.035 ± 0.007**
	Pb1	0.9191	0.1548	0.0233
	Pb2	1.6178	0.1251	0.0266
6	**Pb ± SD**	**1.268 ± 0.494**	**0.140 ± 0.021**	**0.025 ± 0.002**

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human or animal subjects (if exist) respect the specific regulation and standards.

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