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MULTIDIMENSIONAL ASSESSMENT OF PHYSICOCHEMICAL PROPERTIES OF DIETARY BISCUITS

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Summary

In the paper multivariate statistical techniques in combined analysis of measurements of physicochemical properties of dietary biscuits made according to different recipes have been applied. Relationships between two groups of traits have been considered. Based on clusters and discriminant analysis, components used in biscuits responsible for similarity of final products or in a good way classifying them have been regarded.

Keywords and phrases: characteristics of dietary biscuits, multivariate assessment

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1. Introduction

Dietetic biscuits are included in the group of products intended for human consumption affected by certain diseases. Such baked bread is marketed under the designation "dietary". The composition of dietetic bread and its use depends on the type of disease. Nowadays, there has been a definite increase of interest in "a safe food", which is also classified to dietary pastry. Due to the fact that they are needed both in the prevention and treatment of certain diseases, the quality of these products is a very important issue in the scientific research.

In factories, confectionery qualities have been evaluated by organoleptic methods (sensory) and physicochemical (Mohamed et al., 1982; Sai Manohar et al., 2002). The most comprehensive assessment of quality is achieved by performing the profile analysis of texture. This analysis is widely used for the development of new food products because it allows to get a comprehensive sensory characteristics of the product taking into account the mechanical properties and geometry (Cauvain 2004; Maache-Rezzoug et al., 1998). Sponge cake is classified as confectionery products (Boobier and Baker, 2007). It is tasty and soft, and therefore is very keen consumed. Moreover, it has high nutritional value. However, sponge cakes made according to the traditional recipe, are not recommended, for example for diabetics, as they contain wheat flour, eggs and sugar.

Dietetic biscuits recipes designed for diabetics have been developed in the Department of Food Engineering and Machinery at the University of Life Sciences in Lublin. The composition of components for dietary cookies was chosen to not increase sugar level in the people blood with diabetes. For different combinations of dough ingredients, the physical properties of dietary biscuits, their sensory qualitative evaluation, and mechanical textural features using double compression test were determined in the experiment (Grzegorczyk, 2009).

The main goal of the paper is statistical analysis of the multivariate data set, characterizing physicochemical properties of dietary biscuits. Based on chosen measurable traits, discovering which ingredients in biscuits are the most important in good recognition of products and determining the similarities of dietary biscuits obtained from different recipes have been investigated.

In Section 2, material and methods are described. The result of multivariate statistical analysis are presented in Section 3. Section 4 presents the conclusions obtained in Section 3.

2. Material and methods

As ingredients in the recipe of baking biscuits three types of flour were used, namely, buckwheat flour (Bu), oat flour (Oa) and combination of wheat graham with high gluten flour (Mix). For each type of flour one of synthetic sweeteners was added: xylitol (Xyl), sorbitol (Sor), saccharin (Sacch) or salt - instead of sweetener - (Sa). Additionally, one of leavening agents was used: baking powder (Bp), baking soda (Bs), yeast (Ye), ammonia (Am) or no leavening agent (Nla). Moreover, in each type of dough white egg was also added. In this way 60 different biscuits (objects) were obtained (3 types of flour, 4 sweeteners, 5 leavening agents).

In the whole experiment many different traits on physicochemical properties of dietary biscuits were measured. Each of them was analyzed separately in Grzegorczyk (2009). Some multivariate approach in analysis of diet biscuits can be also found in Klimek (2013).

In the paper we take into account eight chosen traits, namely, hardness I [N], hardness II [N], chewiness [N], total bake [%], performance of bread [%], moisture content [%], porosity [%] and springiness [mm]. Each trait considered was measured in three replications. In order to compare dietary biscuits made according to different recipes, and regarding all traits considered, multivariate techniques has been used (Khattree and Naik, 1999, 2000; Atkinson et al., 2004). In order to compare different dietary biscuits taking into account all traits considered, multivariate techniques as principal component analysis (PCA), cluster analysis (CA), and discriminant analysis have been applied. Moreover, normality of the traits considered was also tested. Calculations presented in the paper were done in SAS Enterprise Guide 5.1.

3. Multivariate statistical analysis of properties of dietetic biscuits

In this section we compare dietetic biscuits obtained according to 60 different recipes described in Section 2 with respect to all traits considered. For this purpose we use multivariate techniques available in SAS Enterprise Guide. In the first stage we check normality of all the traits. Normality of individual traits has been verified using the Shapiro-Wilk test. For not normal traits, logarithm transformation on the measurements have been done. Testing results are enclosed in Table 1.

Table 1. Values of the Shapiro-Wilk's test for normality of individual traits and corresponding *p*-values (*p*-values confirming normality at 0.05 significant level are printed in bold)

Trait	Results for original traits		Results after taking logarithm	
	Shapiro-Wilk	*p*-value	Shapiro-Wilk	*p*-value
Hardness I	0.8377	<0.0001	0.9811	**0.4759**
Hardness II	0.8673	<0.0001	0.9801	**0.4337**
Chewiness	0.8524	<0.0001	0.9767	**0.3065**
Total bake	0.9758	**0.2765**		
Performance of bread	0.9643	**0.0762**		
Moisture content	0.9623	**0.0611**		
Porosity	0.9737	**0.2212**		
Springiness	0.9775	**0.3328**		

Results enclosed in Table 1 report that at 0.05 confidence level normality was not rejected based on measurements of five traits: total bake, performance of bread, moisture content, porosity and springiness. Measurements of the rest three traits, namely, hardness I, hardness II and chewiness, contributed to the rejection normality at 0.05 level. However, after taking the logarithm of the measurements for these three traits, normality was not rejected. For this reason, in further multivariate analysis, measurements of three traits after taking the logarithm and original measurements of five traits have been considered. In testing normality, the set of data naturally has been divided into two classes, namely, a class of traits after taking the logarithm and a class of the rest of traits. It was interested whether traits in both groups are correlated. For this purpose, the Pearson's correlations between these classes of traits have been calculated. Correlation coefficients as well as *p*-values given in brackets are given in Table 2.

Table 2. Pearson's correlations between two groups of traits and the corresponding *p*-values (significant Pearson's correlations at 0.05 level are printed in bold)

Traits	LN(Hardness I)	LN(Hardness II)	LN(Chewiness)
Total bake	0.0785 (*p*=0.5509)	0.0750 (*p*=0.5689)	0.0827 (*p*=0.5298)
Performance of bread	**-0.3290** (*p*=0.0103)	**-0.3242** (*p*=0.0115)	**-0.3295** (*p*=0.0101)
Moisture content	-0.0270 (*p*=0.8379)	-0.0358 (*p*=0.7860)	0.1123 (*p*=0.3931)
Porosity	-0.1357 (*p*=0.3011)	-0.1441 (*p*=0.2721)	-0.0691 (*p*=0.5999)
Springiness	**-0.4101** (*p*=0.0011)	**-0.4032** (*p*=0.0014)	**-0.3576** (*p*=0.0050)

Results in Table 2 reports that the class of traits after taking logarithm is significantly correlated only with the performance of bread and springiness at significance level 0.05 (printed in bold). Furthermore, all traits in the first class are negative correlated with all traits in the second class except for total bake and also except for correlation between LN(Chewiness) and moisture content which is positive. The results in Table 2 confirm the validity to study in the experiment of all the traits considered as in mostly cases (60%) they are not significantly correlated. Results in the Table 2 show that the analysis based on the canonical analysis for these two groups of traits would be little meaningful, so it has been omitted.

3.1. Principal component analysis of dietetic biscuits properties

A common technique for finding patterns in data sets of high dimension is principal component analysis (PCA). This analysis allows to reduce dimension of data sets and find combination of traits explaining the biggest impact on total variability of the original data set. Applying PCA to data on physicochemical properties of dietary biscuits, to stabilize the variation of the measurements for individual traits, values of total bake, moisture content and porosity were divided by 10, and measurements of performance of bread were divided by 100. All eight eigenvalues of the covariance matrix of the data considered and the variance explanation of the corresponding principal components are illustrated in Figure 1.

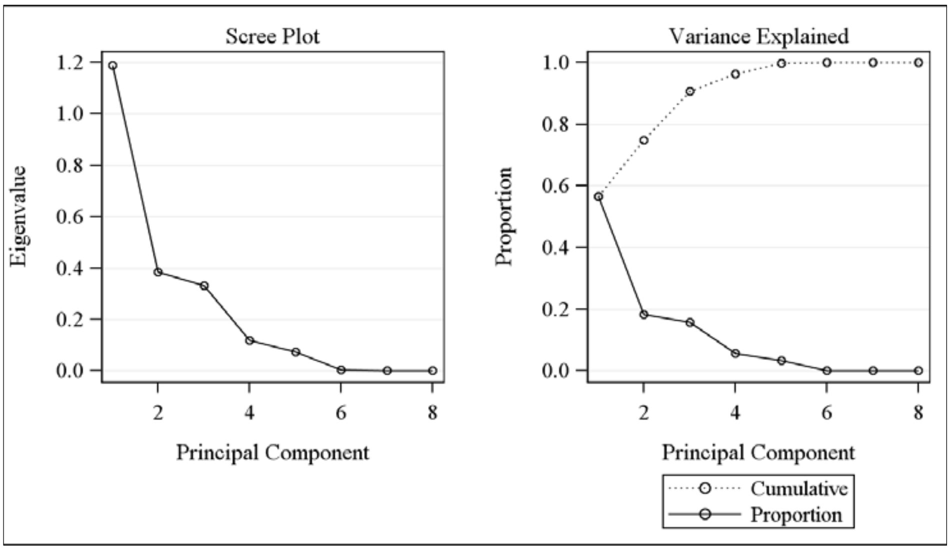

Fig. 1. Eigenvalues and principal components total variance explanation

Figure 1 shows that the last three principal components do not have significant impact on data variability and can be neglected. The first five eigenvalues of the covariance matrix for the set of traits considered and cumulative variance explanation of corresponding principal components are presented in Table 3. It can be noted that almost 57 % of the total variability is attributed to first principal component, the system of two first principal components retains almost 75 % of the total variability, and the system of the first three principal components preserves almost 91 % of the total variability.

Table 3. Eigenvalues of the covariance matrix and cumulative variance explanations of system of the principal components

Characteristic	Number of principal component				
	PC1	PC2	PC3	PC4	PC5
Corresponding eigenvalue	1.1889	0.3850	0.3328	0.1183	0.0728
Cumulative variance explanation	56.52%	74.83%	90.65%	96.28%	99.74%

Participation of the individual traits in the first five principal components, corresponding to the first five eigenvalues, is presented in Table 4.

Table 4. Share of individual features of the first five principal components

Trait	Principal components				
	PC1	PC2	PC3	PC4	PC5
LN(Hardness I)	0.5692	0.2377	0.0463	-0.0890	0.3884
LN(Hardness II)	0.5342	0.2339	0.0409	-0.0881	0.3305
LN(Chewiness)	0.4782	0.1572	0.2143	0.1791	-0.8173
0.1*Total bake	0.0352	0.0148	-0.1833	0.1310	0.1832
0.01*Performance of bread	-0.0334	0.0269	0.0130	0.9411	0.1826
0.1*Moisture content	0.0191	-0.4386	0.8689	-0.2089	-0.0514
Springiness	-0.0038	-0.0022	0.0005	0.0766	0.0463
0.1*Porosity	-0.399	0.8190	0.4019	0.0031	-0.0131

Results in Table 4 report that the main positive impact on the first principal component have hardness I, hardness II and chewiness after taking logarithm, and main negative impact has porosity. We can observe similar impact of traits on the second principal component. However, porosity has positive impact on the second and the third principal components. Moreover, moisture content has also a significant and negative effect in the second principal component and the biggest positive in the third principal component. Performance of bread has the biggest positive impact on the fourth principal component.

Correlations of individual traits with pairs of the first three principal components are presented in Figure 2. Each vector for the individual trait on the plots has coordinates being the correlations between the measurements of the trait with the corresponding principal components, respectively.

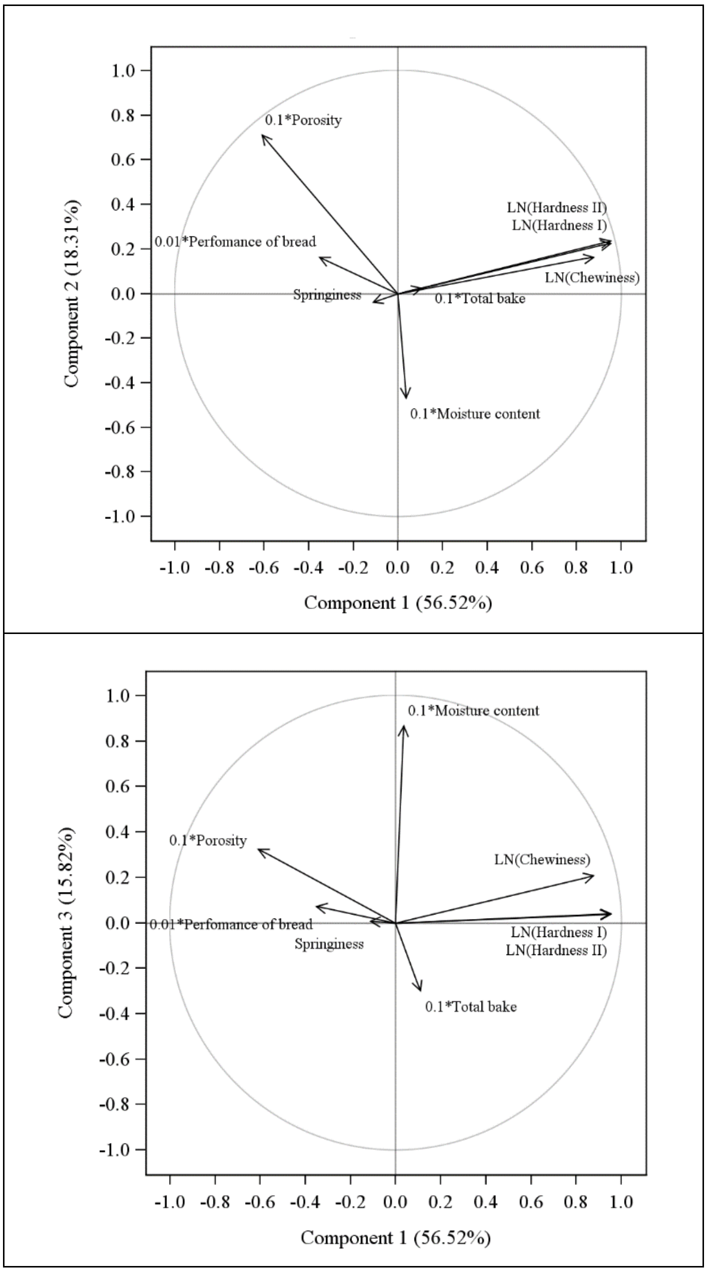

Fig. 2. Correlations of individual traits with the first three principal components

Results in Figure 2 state that the biggest positive correlations with the first principal component were noted for the hardness I and II, and the biggest but negative for porosity. The biggest positive correlation with the second principal component occurred for porosity. Moreover, we can observe in both plots in Figure 2 almost the same vectors for hardness I and II, and very similar for chewiness. The smallest correlations with the first three components are obtained for springiness.

3.2. Cluster analysis of dietetic biscuits properties

In this subsection we concentrate on finding the similarity of dietary biscuits made according to sixty combinations of different ingredients used (objects). Cluster analysis applied to all sixty objects did not allow to find out which kind of ingredient (factor) in the recipes, namely, type of flour, sweeteners or leaving agent, is the most responsible for grouping. Taking into account dietary biscuits made from buckwheat flour for all traits considered clusters obtained using the Ward's minimum-variance method are presented in Figure 3.

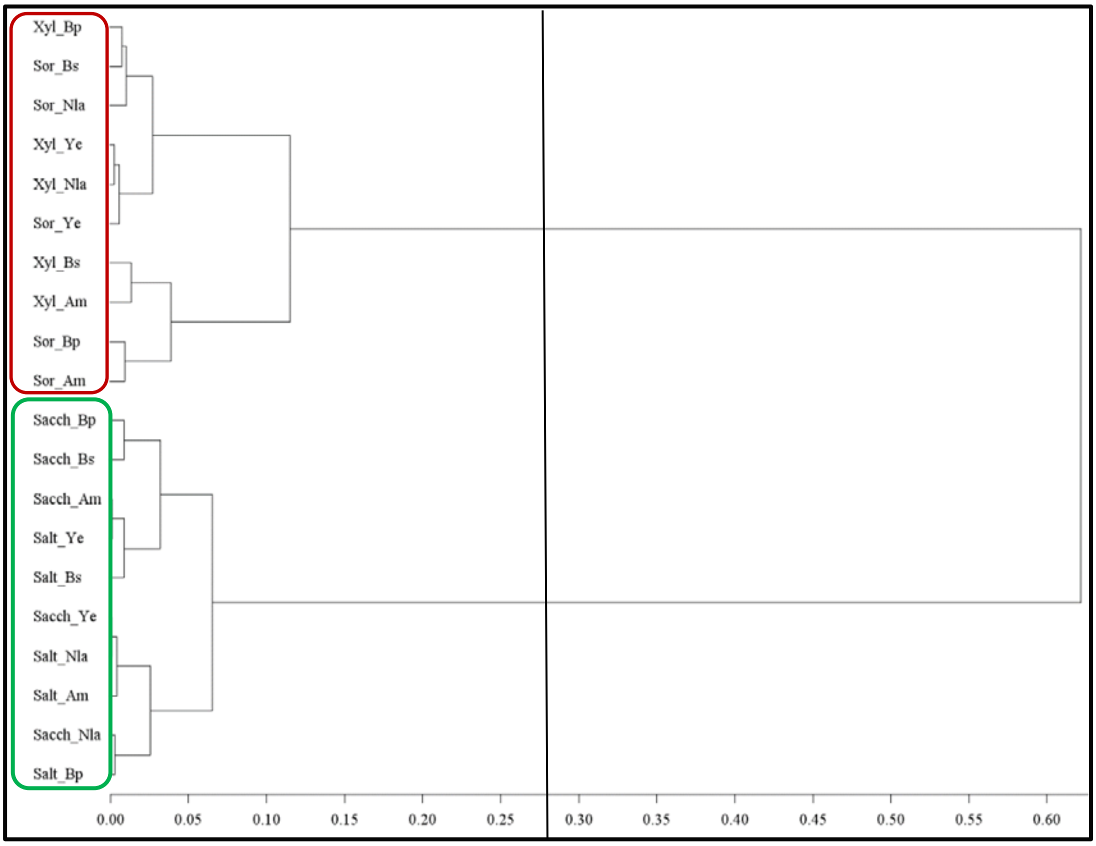

Fig. 3. Clusters for dietary biscuits made from buckwheat flour for the set of all traits considered

Results in Figure 3 report that dietary biscuits made from buckwheat flour with salt instead of sweetener or with saccharin have been grouped in the same cluster, so it means that they are very similar with respect of the set of all traits considered. The second cluster contains mixture of biscuits with xylitol and sorbitol.

3.3. Discriminant analysis of dietetic biscuits properties

To answer the question which of three factors: type of flour, sweeteners or leaving agent is the most responsible for good classification of dietary biscuits, discriminant analysis has been used. For each individual factor, based on the data set for all traits considered the results are presented in Tables 5 - 7, respectively. The results report that when flour is considered as factor, the only biscuits made from buckwheat flour are good classified in 85 %, taking into account the set of all traits considered. The worst recognized is oat flour, as the only 50 % of dietary biscuits made from this flour have been good recognized.

Table 5. Percent of good classified biscuits with respect to flour used (in bold)

	Percent classified into flour		
From flour	Buckwheat	Mix	Oat
Buckwheat	**85**	5	10
Mix	15	**65**	20
Oat	20	30	**50**

Table 6. Percent of good classified biscuits with respect to sweetener used (in bold)

	Percent classified into sweetener			
From sweetener	Sor	Sacch	Salt	Xyl
Sorbitol - Sor	**100**	0	0	0
Saccharin - Sacch	0	**93**	7	0
Salt	0	7	**93**	0
Xylitol - Xyl	20	0	0	**80**

Table 7. Percent of good classified biscuits with respect to leaving agent used (in bold)

From	Percent classified into leavening agent				
leaving agent	Am	Bp	Bs	Nla	Ye
Ammonia - Am	**58.33**	8.33	8.33	8.33	16.67
Baking powder - Bp	0.00	**58.33**	16.67	16.67	8.33
Baking soda - Bs	33.33	16.67	**25.00**	8.33	16.67
No leaving agent - Nla	0.00	0	8.33	**83.33**	8.33
Yeast - Ye	25.00	16.67	0.00	16.67	**41.67**

Results in Table 6 prove that sweeteners used in dietary biscuits have been better recognized than the type of flour. Namely, sorbitol was good classified in 100 %, salt and saccharin have been identified in 93 %, while the worst classified was xylitol in 80 %.

Results in Table 7 underline that leaving agent, similar to type of flour, is not good recognized in biscuits for the set of measurements of all traits considered. Biscuits without leaving agent have been identified the best. Biscuits with ammonia or baking powder were good classified almost in 60 % of all cases, while the worst classified were biscuits with baking soda, only in 25 % of all cases.

4. Conclusions

Using multivariate approach in the analysis of the data set of eight measurable traits for sixty different dietary biscuits enabled to learn which traits have the biggest impact on discriminant coordinates using principal component analysis. Moreover, using cluster analysis and discriminant analysis, we could show which components in recipes have the biggest impact to be in the same group of biscuits and which component is the best classified with respect of all traits considered.

Based on the set of measurements for all the traits considered the following conclusions can be formulated.

1. The set of 8 traits considered can be characterized by the only first three principal components, preserving jointly 91 % of total variability.
2. The biggest positive impact on principal components have been noted for hardness I, hardness II and chewiness after taking logarithm, and also for porosity and moisture contents.
3. Dietary biscuits made from buckwheat flour with salt instead of sweetener and saccharin were classified in the same cluster, i.e. they are very similar.
4. From the ingredients in dietary biscuits, namely, three types of flour, four synthetic sweeteners and fifth leavening agents, sweeteners have been the best factor in a good classification on dietary biscuits.

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