

Predicting Bread Quality (Bread Loaf Volume and Crumb Texture)

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The objective of this study was to evaluate the predictive power of flour and dough alveograph properties in simultaneous determination of bread loaf volume and crumb texture. Ten Polish spring wheat cultivars were used in this study. Flour was determined for protein content, wet gluten content, gluten elasticity, Zeleny sedimentation volume, falling number, and ash content. Alveograph properties of the dough were strength, tenacity, extensibility, and elasticity resistance. After the straight dough bread making test, the loaf volume and breadcrumb texture were measured. Textural properties of the breadcrumbs were tested by texture profile analysis (TPA). The parameters recorded were hardness, cohesiveness, and gumminess. The results were analysed statistically to develop effective predictive models, the stepwise regression procedure and canonical analysis were applied. The results from the experimental tests indicated that among the variables, the flour protein content, the Zeleny sedimentation index, the flour falling number, and dough strength were the main factors affecting the textural properties of the breadcrumb alone and with the bread loaf volume. The results showed that a combination of several flour and dough alveograph properties could predict bread quality.

NOMENCLATURE

Flour properties: A_f – Flour ash content, %, FN – Flour falling number, s, G_f – Flour gluten content, %, GE_f – Flour gluten elasticity, mm, P_f – Flour protein content, %, Si – Zeleny sedim. index, mL. **Dough properties:** I_e – Elasticity resistance, -, L – Extensibility, mm, P – Tenacity, mm_{H₂O}, W – Strength, 10⁻⁴J. **Bread properties:** C_b – Crumb cohesiveness, -, G_b – Crumb gumminess, N, H_b – Crumb hardness, N, V_b – Loaf bread volume, cm³.

INTRODUCTION

Wheat is a principal cereal used for bread making, because of its wheat-baking properties, as well as its valuable chemical constitution. Nowadays, the quality of raw material is the most important problem for bakers. They require flour, which has the ability to produce bread with large loaf volume and good crumb texture, with good maintenance properties. Research on determining relationships between the flour properties and the characteristics of the final product remain a challenge for scientists.

Bread properties are very often influenced by flour components [Dowell *et al.*, 2008; Edwards *et al.*, 2007; Perez Borla *et al.*, 2004] and the rheological properties of the dough [Andersson *et al.*, 1994; Armero & Collar, 1997; Bloksma, 1990; Gras *et al.*, 2000; Oliver & Allen, 1992; Phan-Thien & Safari-

Ardi, 1998; Stampfli & Nersten, 1995; Tronsomo *et al.*, 2003; Wilkström & Bohlin, 1999]. Edwards *et al.* [2007] demonstrated that the hearth bread baking quality of durum wheat varied in protein composition and physical dough properties. Dowell *et al.* [2008] estimated the attributes of bread quality (loaf volume, bake mix time, bake water absorption, and crumb score) by using grain, flour, and dough quality. The importance of protein and gluten content as well as its quality and baking properties are well documented [Karolini-Skardzińska *et al.*, 2001; Færgestad *et al.*, 1999, 2000]. Some researchers showed the Zeleny sedimentation volume [Cacak-Pietrzak *et al.*, 1999; Duma, 1992] and falling number influence on bread properties [Czubaszek *et al.*, 2001]. In a majority of the mentioned studies the quality of bread was assessed by loaf volume, and the breadcrumb properties were taken into consideration only in a minority of these studies.

Several recent studies have described the relation between the rheological properties of dough and properties of breadcrumbs [Dowell *et al.*, 2008; Tronsomo *et al.*, 2003; Janssen *et al.*, 1996; Scanlon *et al.*, 2000]. The authors did not determine the relation between flour properties and alveograph parameters of the dough or the textural properties of the breadcrumb. Alveograph parameters are obligatorily used as quality indicators of wheat [Dziki & Laskowski, 2003; Laskowski & Różyło, 2004] and should be taken into consideration.

In spite of several studies that have focused on determining the relationship between the flour and dough and bread properties, there is no simple model that shows the specific flour and dough properties that have an impact on the com-

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plex bread characteristics (including bread loaf volume and texture of breadcrumb).

In consideration of this, the objective of this study was to determine the relationship between both flour components and the alveograph parameters of the dough and the loaf volume and breadcrumb texture. To develop effective predictive models, the stepwise regression procedure and canonical analysis was applied. Additionally the best and the worst cultivars to wheat bread production were characterised.

MATERIALS AND METHODS

Materials

Ten Polish spring wheat cultivars (Hezja, Kontesa, Torka, Zebra, Eta, Santa, Nawra, Jasna, Koksa, Kosma) were used in this study. The cultivars were grown in Końskowola (Agricultural Advisory Center) under the same conditions. Conditioning before milling consisted of adjusting the moisture content of the grains to 16%, followed by a 24-h rest in a closed container. The grains were milled in the CD1 Chopin laboratory mill (a simulator of industrial grinding).

Flours analysis

Flour was determined for protein content, wet gluten content, gluten elasticity, the Zeleny sedimentation volume and the falling number and ash content. The flour analyses were carried out in three replications.

Flour protein content ($N \times 5.7$) was determined according to the Kjeldahl method, wet gluten content and elasticity were determined according to the Polish Standard [PN A-74043:1994], the Zeleny sedimentation index, the falling number and ash content were determined according to International Standards [adequately ISO 5529:1992; ISO 3093:1982 and ISO 2171:1994].

Dough analysis

Alveograph properties of dough were determined four times according to ISO Standard [ISO 5530-4:2002] using a Chopin alveograph (Group Tripette and Renaud). The parameters obtained are: tenacity of the dough (P) – the maximum over pressure, extensibility of the dough (L) – the average abscissa at rupture, strength of the dough (W) – the deformation energy of 1 g of dough, elasticity resistance of the dough (Ie) – equal P_{200}/P_{max} expressed in percentage, P_{200} is the pressure measured in the bubble after having blown 200 mL of air into the dough.

Bread making and evaluation of breads

The experimental baking was a small scale straight-dough baking test according to the Berlin Institute [Jakubczyk & Haber, 1983]. The breads were prepared and baked in a laboratory oven with fermentation cabinet (Sadkiewicz Instruments, PL). Loaves of white pan bread were prepared after mixing, fermenting and proving the dough. The dough was fermented at 30°C and 75% RH for 60 min (with 1 min transfixion after 30 min) in a fermentation cabinet. Proving was performed at 30°C and 75% RH in a proving cabinet in time required for optimal dough development. The loaves were baked at 230°C for 25 min in an oven (live steam was injected

immediately after the loaves were placed in the oven). Baking tests were performed on each flour by using three replicates.

Textural properties of bread crumbs were tested by texture profile analysis (TPA) [Wang *et al.*, 2002; Steffe, 1996]. Texture analysis of the crumb was performed on three slices taken from the centre of each loaf. The bread crumb samples (20x20x20 mm) from the centre of each slice were two times compressed by a capital equipped with a 25 mm plug. Twelve replicates of bread crumb sample were analysed. The parameters recorded were hardness, cohesiveness and gumminess.

Statistical methods

Statistical analyses were done at a significance level of $\alpha=0.05$ using Statistica by Statsoft.

To develop effective predictive model the stepwise regression procedure was applied. The regression equations were recorded using the stepwise backward method which employs a combination of the procedures used in the forward entry and backward removal methods. The determination coefficient and estimation standard deviation was defined. Additionally all regression relationships were analysed and only the significant ones were presented.

Canonical correlation was an additional procedure for assessing the relationship between two sets of variables presenting simultaneously wheat and bread properties. To estimate the significance of variables the χ^2 test was applied.

RESULTS

The wheat cultivars used in this study varied in flour and dough alveograph properties, therefore bread produced differed in the loaf volume and breadcrumb texture (Table 1).

Wheat cultivar Koksa yielded the greatest volume of bread compared with the others cultivars. Also big loaf volume but significantly lower than that of Koksa was obtained when bread was produced from Jasna and Santa wheat cultivars. The smallest volume of bread was achieved when using flour from wheat cultivar Hezja. The medium loaf volume was recorded for bread produced flour from Nawra and Eta cultivars. Protein content, gluten content, gluten elasticity and the Zeleny sedimentation index of Koksa flour were 14.43%, 33.6%, 11 mm and 51.7 mL, respectively. The alveograph parameters of this wheat cultivar accounted for $P=112 \text{ mm}_{H_{2O}}$, $L=114 \text{ mm}$, $P/L=0.980$ and $W=428 \times 10^{-4} \text{ J}$. Flour protein content, flour gluten content, gluten elasticity, the Zeleny sedimentation index, the falling number and ash content of Hezja flour were 12.50%, 29.33%, 9 mm, 36 mL, 325 s and 0.568% respectively. Values of its alveograph parameters accounted for $P=62 \text{ mm}_{H_{2O}}$, $L=139$, $P/L=0.450$ and $W=215 \times 10^{-4} \text{ J}$.

In our study a multiple regression procedure indicated that there was more than one significant independent variable. The relationships between the studied parameters are given in Table 2 and the exemplary correlations between predicted and observed values are given in Figures 1a-d. The bread loaf volume was correlated with flour protein content ($R^2=0.613$) and also with flour gluten content ($R^2=0.410$) or with the Zeleny sedimentation index ($R^2=0.532$). The results indicated that good prediction could be achieved using the flour protein content and the ratio of the dough tenacity to

TABLE 1. Flour, dough alveograph and bread properties of selected wheat cultivars.

Wheat cultivar	Flour protein content (Pf)	Flour falling number (FN)	Flour gluten content (Gf)	Gluten elasticity (GEf)	Flour Zeleny sedim. index (Si)	Flour ash content (Af)	Tenacity of dough (P)	Extens. of dough (L)	Strength of dough (W)	Volume of bread loaf (Vb)	Hardness of bread crumb (Hb)	Cohesiv. of bread crumb (Cb)	Gum. of bread crumb (Gb)
Hezja	12.50 ^a	325.40 ^a	29.33 ^a	9.00 ^a	36.02 ^a	0.568 ^a	62.01 ^a	139.13 ^a	215.4 ^a	407.10 ^b	4.49 ^a	0.40 ^a	1.38 ^a
Kontesa	12.90 ^a	341.00 ^b	29.90 ^a	12.30 ^b	35.00 ^a	0.581 ^b	79.00 ^{bd}	109.00 ^b	233.75 ^b	418.44 ^b	5.22 ^b	0.43 ^{ab}	2.25 ^b
Torka	13.37 ^b	380.00 ^{cd}	31.20 ^b	7.30 ^c	41.67 ^b	0.563 ^{bc}	100.02 ^c	117.13 ^c	421.01 ^c	439.14 ^c	8.36 ^c	0.47 ^{bc}	5.04 ^c
Zebra	14.02 ^c	384.50 ^c	32.93 ^c	6.30 ^d	46.33 ^c	0.555 ^c	60.75 ^a	154.13 ^d	259.00 ^d	454.75 ^d	5.84 ^b	0.45 ^b	2.91 ^d
Eta	13.80 ^d	385.00 ^c	31.73 ^b	11.30 ^c	41.00 ^b	0.579 ^b	72.00 ^b	119.25 ^{ce}	227.00 ^{ab}	454.30 ^d	6.25 ^d	0.52 ^d	3.62 ^{ef}
Santa	14.20 ^c	378.50 ^d	31.83 ^b	12.00 ^b	47.07 ^c	0.550 ^c	82.05 ^d	107.01 ^b	259.03 ^d	473.93 ^e	5.80 ^b	0.44 ^b	2.78 ^{bd}
Nawra	15.00 ^e	388.50 ^c	34.30 ^d	5.00 ^f	56.83 ^d	0.534 ^{de}	78.00 ^b	160.20 ^d	354.00 ^e	446.22 ^{cd}	6.31 ^d	0.45 ^b	3.28 ^c
Jasna	14.47 ^{df}	388.30 ^c	32.70 ^c	8.30 ^a	48.00 ^{ee}	0.557 ^{bc}	83.09 ^d	144.02 ^a	323.03 ^e	478.49 ^{df}	8.28 ^{cc}	0.49 ^e	5.18 ^c
Koksa	14.43 ^{df}	390.20 ^c	33.57 ^c	11.00 ^c	51.66 ^c	0.540 ^c	112.02 ^e	114.03 ^c	428.01 ^c	483.54 ^f	7.57 ^c	0.49 ^e	4.55 ^f
Kosma	15.70 ^g	410.00 ^e	35.80 ^f	10.00 ^b	56.67 ^d	0.532 ^d	91.00 ^f	125.00 ^e	337.00 ^e	475.95 ^e	5.78 ^b	0.46 ^{bc}	2.90 ^d

Means with different letters in the same column are statistically different at p<0.05.

TABLE 2. Equations expressing bread properties.

Figure equation (N=120)	Estim. standard error	R-square	p-value
Bread loaf volume (V_b)			
1. $V_b = 7.59 \times P_f + 0.655 \times FN - 0.30L$	12.080	0.769	0.0000
2. $V_b = 20.539 \times P_f + 41.30 \times P/L + 137.642$	13.698	0.701	0.0000
3. $V_b = 21.497 \times P_f + 151.29$	15.519	0.613	0.0000
4. $V_b = 2.459 \times Si + 339.869$	17.070	0.532	0.0000
5. $V_b = 6.016 \times G_f + 130.660$	18.554	0.410	0.0000
6. $V_b = 7.231 \times G_f + 2.584 \times GE_f + 66.819$	17.377	0.512	0.0000
Bread crumb hardness (H_b)			
1. $H_b = 0.0148 \times W + 0.024 \times FN + 48.746 \times A_f - 34.354$	0.558	0.801	0.0000
2. $H_b = 0.0112 \times W + 0.008 \times FN - 0.0473$	0.792	0.597	0.0000
3. $H_b = 0.013 \times W + 2.541$	0.804	0.581	0.0000
4. $H_b = 1.697 \times P/L - 1.175 \times P_f + 0.064 \times FN - 2.477$	0.852	0.538	0.0000
5. $H_b = 0.1505 \times Ie - 1.77799$	0.879	0.500	0.0000
Bread crumb cohesiveness (C_b)			
1. $C_b = 0.002 \times FN + 1.462 \times A_f - 0.962$	0.023	0.606	0.0000
Bread crumb gumminess (G_b)			
1. $G_b = 0.013 \times W + 0.0299 \times FN + 50.445 \times A_f - 39.885$	0.494	0.827	0.0000
2. $G_b = 0.012 \times W - 0.339$	0.910	0.548	0.0000
3. $G_b = 0.054 \times P + 0.029 \times L - 1.481 \times P_f + 0.062 \times FN - 7.218$	0.518	0.811	0.0000
4. $G_b = 0.024 \times L + 0.064 \times P - 4.952$	0.822	0.517	0.0000

V_b – Loaf bread volume, cm³, H_b - Crumb hardness, N, C_b – Crumb cohesiveness, -, G_b – Crumb gumminess, N, A_f – Flour ash content, FN –Flour falling number, s, G_f – Flour gluten content, %, GE_f- Flour gluten elasticity, mm, P_f– Flour protein content, %, Si- Zeleny sedim. index, mL, Ie – Elasticity resistance, L- Extensibility, mm, P – Tenacity, mm_{H20}, W- Strength, 10⁻⁴J.

extensibility (R²=0.701), but the best prediction was achieved using flour protein content, the falling number, and dough extensibility (R²=0.769), (Figure 1a).

The lowest hardness of the breadcrumb was achieved when bread was produced from flour of Hezja cultivar. Also low breadcrumb hardness but significantly higher produced Kontesa and Santa cultivars. Bread produced from flour of wheat cultivar Torka was characterised by the highest breadcrumb hardness. The high breadcrumb hardness was also noted for bread made of Jasna cultivar flour. The medium breadcrumb hardness was recorded for bread produced from Eta and Zebra cultivars flour. The flour protein content, flour gluten content, gluten elasticity, the Zeleny sedimentation index, the falling number and ash content of Torka flour were 13.37%, 31.20%, 7 mm, 41.67 mL, 380 s and 0.563%. The alveograph properties of this flour were as follows: P= 100 mm_{H20}, L=117 mm, P/L=0.85 and W=421 × 10⁻⁴J.

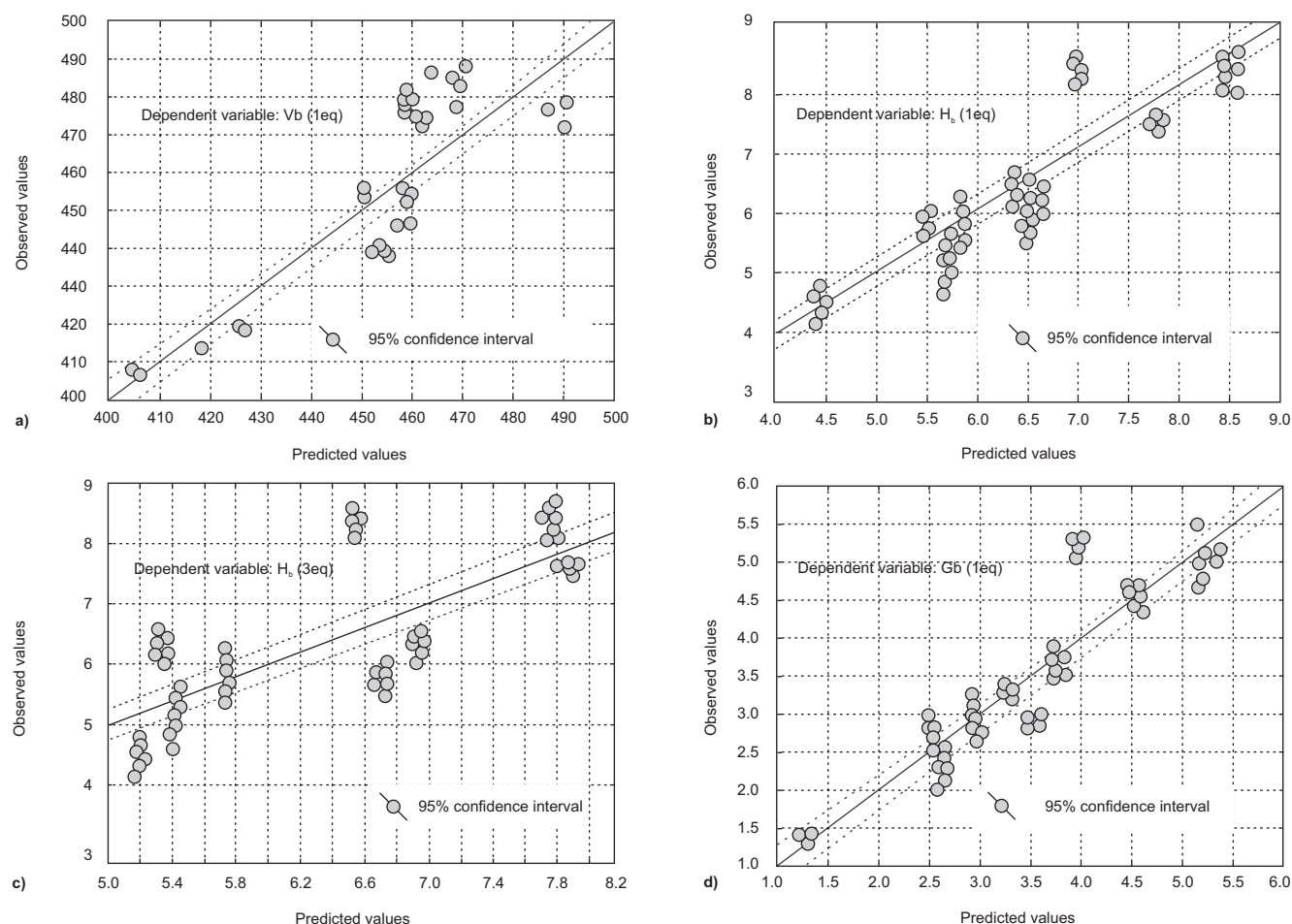


FIGURE 1. Predicted and observed values of selected equations of bread properties: a) prediction of bread volume (1 equation), b) prediction of bread crumb hardness (1 equation), c) prediction of bread crumb hardness (3 equation), and d) prediction of bread crumb gumminess (1 equation).

The predictors of breadcrumb hardness are strength of the dough, the flour falling number, and ash content (Figure 1b). The coefficient of determination (R^2) determined in our study was equal to 0.801. The R^2 value indicates that the model fits the data very well. In addition the results indicated that only the strength of the dough was a good predictor of breadcrumb hardness ($R^2=0.581$), (Figure 1c). Additionally, the stepwise regression indicated that the hardness of the breadcrumb depended significantly on the P/L alveograph, protein content, and the falling number of flour ($R^2=0.538$).

Cohesiveness of the breadcrumb was the least related to flour and dough properties; there was only one regression line predicting this feature. The results indicated that the cohesiveness of the breadcrumb depended significantly on the flour falling number and the flour ash content ($R^2=0.606$). The next parameter of the breadcrumb textural properties was breadcrumb gumminess. Bread produced from flour of wheat cultivar Hezja was characterized by the lowest value of breadcrumb gumminess, whereas that made of flours of wheat cultivars Jasna and Torka by the highest values of this parameter. The medium values of breadcrumb gumminess were recorded for bread produced from flours of Nawra and Zebra cultivars. Flour protein content, flour gluten content, gluten elasticity, the Zeleny sedimentation index, the falling number and ash content of Jasna flour were 14.47%, 32.70%,

8 mm, 48.00 mL, 388 s, and 0.557%, respectively. The alveograph properties of this flour accounted for $P=83 \text{ mm}_{H_{20}}$, $L=144 \text{ mm}$, $P/L=0.580$ and $W=323$.

In our study, the breadcrumb gumminess depended also on dough and flour properties. Breadcrumb gumminess could be described in four regression equations (Table 2). The regression equation enables the best prediction of breadcrumb gumminess, given the strength of dough, the falling number of flour, and ash content of flour ($R^2=0.827$) (Figure 1d). Consideration could also be given to the regression line for the strength of dough ($R^2=0.548$). Gumminess of the breadcrumb depended also on the tenacity and extensibility of the dough, the flour protein content, and the falling number ($R^2=0.811$).

In quality assessment of bread very important are both bread loaf volume and breadcrumb texture. The Santa cultivar gave bread with enough good volume and not too high hardness. The flour protein content, flour gluten content, gluten elasticity, the Zeleny sedimentation index, the falling number and ash content of Santa flour were 14.20%, 31.80%, 12 mm, 47.00 mL, 378 s, 0.550%, respectively. The alveograph properties of this flour were equal to $P=82 \text{ mm}_{H_{20}}$, $L=107 \text{ mm}$, $W=259$, $P/L=0.760$.

Canonical correlation was an additional procedure for assessing the relationship between the two sets of variables present-

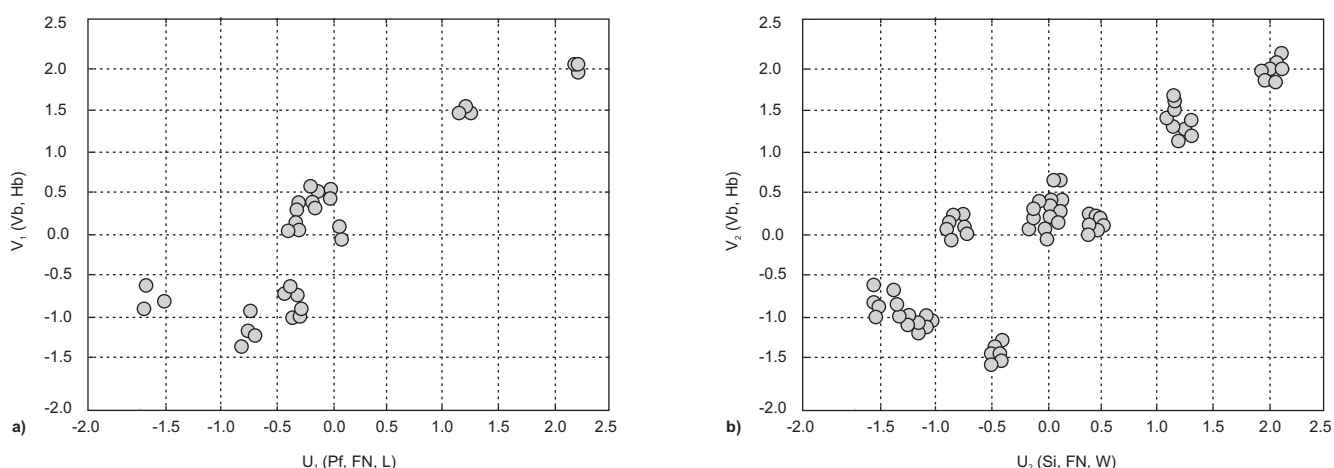


FIGURE 2. Canonical relationships between supplementary variables: a) supplementary variables U_1 and b) supplementary variables U_2 and V_2 .

ed, raw material and bread properties. The results showed that the best prediction line could be obtained for bread loaf volume and breadcrumb hardness. This analysis allowed the creation of two simple models, which could predict bread loaf volume and breadcrumb hardness simultaneously. The first model showed that the most important flour and dough properties for simultaneous prediction of bread loaf volume and crumb hardness were the Zeleny sedimentation index, the falling number, and strength of the dough. The statistically significant group of canonical variables was obtained and shown below:

$$U_1 = 0.553 \times Si - 0.942 \times FN - 0.629 \times W \quad (1)$$

$$V_1 = -0.405 \times V_b - 0.728 \times H_b \quad (2)$$

Supplementary variables U_1 and V_1 are highly canonically correlated ($R=0.875$, Figure 2a), and represent respectively flour, dough alveograph and bread properties.

The second model shows that simultaneous prediction of bread loaf volume and crumb hardness is also possible using the flour protein content, the falling number and dough extensibility:

$$U_2 = -0.238 \times P_f - 0.785 \times FN + 0.24 \times L \quad (3)$$

$$V_2 = -0.969 \times V_b - 0.057 \times H_b \quad (4)$$

Supplementary variables U_2 and V_2 are also highly canonically correlated ($R=0.877$, Figure 2b), and represent respectively flour, dough alveograph and bread properties.

DISCUSSION

In our study the stepwise regression procedure was essential to develop effective predictive models for bread loaf volume and breadcrumb texture. This method is still poorly used in the bakery field. Only Butt *et al.* [2001] used the stepwise regression procedure for assessing the significant variables contributing to bread loaf volume, total bread scores, and chapatti scores. Konopka *et al.* [2004] used the regression procedure for predicting water absorption and bread

volume. Collar *et al.* [1999] also used this statistical method for formulating dough properties by addition of a hydrocolloid. In our study, the bread loaf volume was related to the flour protein content or the Zeleny sedimentation index, but the best prediction was achieved by using the flour protein content, the falling number, and the dough extensibility. Many researches have shown a simple positive correlation between protein content and bread volume [Perez Borla *et al.*, 2004; Wilkström & Bohlin, 1999; Færgestad *et al.*, 1999] and between sedimentation index and bread volume [Duma, 1992]. It has previously been shown that alveograph properties also influence bread volume [Færgestad *et al.*, 2000; Janssen *et al.*, 1996]. In turn, Andersson *et al.* [1994] predicted loaf volume using grain, flour, and dough properties. Their prediction equation included grain and flour protein content, farinograph dough development, stability and breakdown, an extensograph area, peak height, and length. However, there is no model equation predicting a bread volume that includes both flour and alveograph properties.

There are only a few research works addressing a relation between the rheological properties of dough and the properties of the breadcrumb [Tronsomo *et al.*, 2003; Scanlon *et al.*, 2000; Janssen *et al.*, 1996]. In addition, the authors did not determine the predicting power of both the flour and the alveographic dough properties, for assessing the textural properties of the breadcrumb.

Exemplarily Tronsomo *et al.* [2003] and Janssen *et al.* [1996] described a relation between the rheological properties of the dough and breadcrumb structures. Tronsomo *et al.* [2003] affirmed that the porosity of bread was determined by the rheological properties of dough. Janssen *et al.* [1996] explained that the dough from very strong flour was more elastic and less extensible, which was a result of a very strong intermolecular interaction. Therefore, bread baked from such dough was more firm.

Only Scanlon *et al.* [2000] compared the mechanical properties (textural) of breadcrumb prepared from flours of different dough strengths. These authors noticed that breadcrumbs made from a flour possessing extra strong dough properties was stronger than breadcrumbs made from the more conventional red spring wheat flour, and there was

an indication that the extra strong flour breadcrumb specimens were more firm. Additionally, the authors did not determine the relation between alveographic parameters of dough and textural properties of breadcrumb, which could have been useful on an industrial scale.

In our study, a multiple regression procedure indicated that there was more than one significant independent variable. The results showed that the significant predictors of textural properties were both flour and alveograph dough properties.

The results of the canonical analysis allowed the creation of simple models, which showed that both flour and alveograph dough properties were important for simultaneously predicting bread loaf volume and breadcrumb hardness. The models that have been developed could be useful in industries and will make up the essential supplement of existing investigation, because the relationship between two sets of variables defining wheat and bread properties is poor. Only Butt *et al.* [2001] have characterised the group of connections between the end use quality (the bread volume, the bread, and chapatti scores) and the bio-chemical and physicochemical properties of raw material.

CONCLUSIONS

The studied wheat cultivars varied in flour and dough alveograph properties, therefore the bread produced was differentiated in the loaf volume and breadcrumb texture. High values of loaf volume were achieved for bread made of flour of Koksa, Jasna, and Santa wheat cultivars, whereas the lowest ones – for bread produced from flour of wheat cultivar Hezja. The low hardness of the breadcrumb was noted for bread produced from flour of Hezja, Kontesa and Santa cultivars, whereas the highest one for bread produced from wheat cultivar Torka. The best expected quality of bread was achieved using Santa cultivar, which gave bread with enough good volume and not too high hardness.

The results showed that the significant predictors of bread loaf volume alone and with crumb texture were the dough alveograph and flour properties. The results of the canonical analysis allowed the creation of two simple models, which could simultaneously predict bread loaf volume and breadcrumb hardness. In these models the most important flour and dough properties were the Zeleny sedimentation index, the falling number, and the strength of the dough or the flour protein content, the falling number, and the dough extensibility. This knowledge is very important to obtain the quality expected of a breadcrumb, with good loaf volume and crumb texture. The results are especially interesting for industries because flour and alveograph parameters are obligatorily used as quality indicators of wheat.

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