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IMPACT OF DIFFERENT SEED POWDER INCLUSION ON THE RHEOLOGICAL BEHAVIOUR OF WHEAT DOUGH

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ABSTRACT

In this study, the rheological properties of flour blends consisting of wheat flour and seed derived powder (chia, hemp, and flax) were evaluated by Farinograph and Mixolab devices.
It was found that inclusion of these alternative raw materials significantly increased water absorption (from 51.86 to 61.10%) and prolonged dough development time (from 3.00 to 6.60 min) of blends. Moreover, it was determined that blends consisting chia were presented with markedly higher C2, C3, C4, and C5 values than commercially produced wheat flour and blends including hemp and flax seed powder. The correlation analysis confirmed the existence of strong positive correlations (ranging between r = 0.896 - 0.970) among the attributes water absorption, dough development time, and dough stability measured by both Farinograph and Mixolab devices. Principal component analysis visualized data in space with 2 principal components that together explained more than 86% of total variability of the original data set and separated samples according to type of non-cereal material in the flour blends.

Keywords: flour, seed, Farinograph, Mixolab, correlation, principal component analysis

INTRODUCTION

Flours blends represent the products that occur predominantly in form of binary or ternary blends and are usually manufactured by partially replacing wheat flour with different parts of plants such as seeds, grains, tubers, roots, and leaves **(Noorfarahzilah *et al.*, 2014; Chandra *et al.*, 2015; Hasmadi *et al.* 2020)**. Primarily, there are two objectives for blending wheat flour with other plant-based raw materials, nutritional and economic **(Chandra *et al.*, 2015)**. Additionally, the use of blend flours for the production of baked goods can also help to enhance the food availability for a wider spectrum of people predominantly in the developing countries **(Dalal and Bobade, 2018; Banu *et al.*, 2021)**.
Nowadays, with increasing consumer demand for healthier cereal-based foods, incorporation of value added plant based ingredients such as chia, hemp, and flax in the powder form (milled into the flour) into bakery products can represent a useful tool for the production of nutritionally richer products **(Pejcz *et al.*, 2015; Švec and Hrušková, 2015; Wirkijowska *et al.*, 2020)**. These raw materials are considered not only as a significant sources of proteins (16 - 25% in chia, 21 - 28% in hemp and 20 - 30% in flax) and total dietary fibre (20 - 35% in flax, 30 - 34% in chia and 27 – 36% in hemp seeds), but also offer consumers a wide scale of health promoting components, for example beta-carotene B vitamins, vitamin E, calcium, magnesium, polyunsaturated fatty acids and antioxidant acting compounds, predominantly polyphenols **(Hrušková *et al.*, 2013; Švec and Hrušková, 2015; Guiotto *et al.*, 2020)**.
Rheological characteristics of dough during mixing play a significant role in flour processing. Worldwide, the most usually applied rheological instrument for dough characterization is Farinograph. By this device, the mechanical resistance of the dough during mixing is measured at the constant temperature (30°C) **(Hadnađev *et al.*, 2011; Torbica *et al.*, 2019)**. Another rheological instrument, Mixolab monitors physico-chemical properties of dough when subjected to mixing under controlled temperature (30 °C) and temperature stress (heating to 90°C followed by a cooling step to 50°C). The main advantage using of this device is that provides useful information about changes of fundamental biopolymers of flour such as proteins, starch and other flour components in a single test during heating and cooling **(Hadnađev *et al.*, 2011)**. Previously, several authors used Farinograph or Mixolab tests for evaluation of rheological behaviour of various composite flours containing non-conventional plant based raw materials such as chia, flax or hemp seeds **(Hrušková *et al.*, 2013; Švec and Hrušková, 2015; Codină and Mironeasa, 2016; Švec and Hrušková, 2017; Codină *et al.*, 2019; Guiotto *et al.*, 2020)**.
The aim of this study was to evaluate the rheological behaviour of binary flours blends containing wheat flour and different varieties of chia, hemp, and flax seed powder (5 and 10% replacement wheat flour with the studied seed powders) by above mentioned empirical rheological instruments. A further goal was to determine the strength of the relationship among rheological characteristics of flour blends obtained by Mixolab and Farinograph using correlation analysis. Finally, the measurements obtained were subjected to principal component analysis for data visualization by their projecting onto a lower-dimensional space that captures most of the variance. This statistical method was also used to identify the most significant rheological parameters of the measured data set.

MATERIAL AND METHODS

Materials

Commercially produced fine wheat flour containing 11 g of proteins, 74 g of carbohydrates, and 1.3 g of fats per 100 g (marked as control) and alternative raw materials: chia [black (CB), white (CW) and 2 types of blended variety (CM1, CM2)], flax [gold (FG) and brown (FB) variety] and hemp [(HF), non-drug variety] seeds available in local Slovak markets and markets with health nutrition were used in this study.

Table 1 Proximate composition of seeds

Proximate composition (g/100 g)	Chia seed				Flax seed		Hemp seed
	CW	CB	CM1	CM2	FB	FG	HF
Proteins	22	21.2	21	22	22	20	30
Carbohydrates	2.3	4.9	4.9	3.5	3	1	14.3
Fat	33	31.4	31	33	43	43	7.9
Total dietary fibre	40	33.7	34	33	26	31	43

Legend: CW and CB - white and black chia seed powders, CM1 and CM2 - blended chia seed powders, HF - hemp seed powder, FB and FG - brown and gold flax seed powders

Nutritional information related to these alternative raw materials located on their packages is presented in the table 1. The seeds were milled before the analysis. A grinder mill and sieves (Model 0010; Eta, Hlinsko, Czech Republic) were used to obtain seed powders with a particle size of 160 - 270 µm. Flour blends were prepared by blending wheat flour with seed powders at levels described in the table 2.

Table 2 Formulations of studied flour blends

Treatment	Component of 100 g blend flour	
	wheat	seed
Control	100	-
CW 5%	95	5
CW 10%	90	10
CB 5%	95	5
CB 10%	90	10
CM1 5%	95	5
CM1 10%	90	10
CM2 5%	95	5
CM2 10%	90	10
HF 5%	95	5
HF 10%	90	10
FB 5%	95	5
FB 10%	90	10
FG 5%	95	5
FG 10%	90	10

Legend: control - wheat flour, CW and CB - white and black chia seed powders, CM1 and CM2 - blended chia seed powders, HF - hemp seed powder, FB and FG - brown and gold flax seed powders

Rheological characteristics of dough

Mixing properties of studied flour blends were evaluated by using Farinograph (Brabender GmbH & Co. KG, Duisburg, Germany). Farinographic characteristics such as water absorption (FWA, %), dough development time (FDDT, min) and dough stability (FDS, min) were determined.

Thermo-mechanical behaviour of studied samples was analysed by Mixolab 2 device (Chopin Technologies, Villeneuvela-Garenne, France) device. Measurements were performed using the Mixolab standard Chopin + protocol according to the procedure defined by **Kuchtová *et al.* (2018)** and **Lauková *et al.* (2019)**, including a heating and cooling cycle at a constant speed of 80 rpm, tank temperature 30°C, dough weight 75.0 g, total analysis time takes 45 minutes. The parameters determined were water absorption (MWA, %), dough development time (MDDT, min), dough stability (MDS, min), C2 (protein weakening, Nm), C3 (starch gelatinization, Nm), C4 (stability of the starch gel formed, Nm) and C5 (starch retrogradation, Nm).

Statistical analysis

All rheological analyses were carried out using three independent determinations and the results were expressed as mean value ± standard deviation. Analysis of variance was used to describe the significance differences ($p < 0.05$) between the rheological parameters (measured by mixolab and farinograph) of commercial wheat flour and flour blends. A Pearson correlation analysis was applied to evaluate the correlations between the rheological properties of studied samples measured by Farinograph and Mixolab ($p < 0.05$, 0.01 and 0.001). A multivariate statistical method principal component analysis (PCA) was used to visualize the relationships between the studied samples and between the rheological attributes of the samples. Statistical analyses were performed using Statgraphic Centurion 19 software (Statsoft; Tulsa, Oklahoma, USA).

RESULTS AND DISCUSSION

Rheological properties

The mechanical and thermal properties of wheat flour and flour blends are considered important attributes that can be applied to predict the behaviour of the different raw materials in the technological process, as well as the quality parameters of the final products **(Xhabiri *et al.*, 2016)**. In this study, two empirical dough testing methods (Farinograph and Mixolab tests) were used to evaluate the effect of incorporating non-conventional raw materials into the wheat dough. The rheological properties of flour blends are presented in tables 3 (measured by Farinograph) and 4 (measured by Mixolab).

It was determined that addition of non-cereal raw materials significantly increased FWA and MWA of the blends, except for samples with CM1 5% and CM2 5%. Although the increase in WA in these 2 samples was not significant, this increase can be due to the presence of components with higher water holding capacity **(Rabail *et al.*, 2022)**. Chia seed and other alternative raw materials presented in this study contain a considerable amount of dietary fibre (Tab 1). As found in our previous studies, dietary fibre has a hygroscopic character and the incorporation of fibre-rich components can significantly increase the water absorption capacity of wheat dough **(Kohajdová *et al.*, 2014; Kohajdová *et al.*, 2018)**. **Wirkijowska *et al.* (2020)** and **Jiang *et al.* (2023)** described that this fact is predominantly caused by presence of a large number of hydroxyl groups occurring in the fibre structure, enabling more water interactions through hydrogen bonding. Results obtained in this study were in agreement with those described by **Koca and Anil (2007)**, **Pejcz *et al.* (2015)**, **Švec and Hrušková (2017)** and **Guiotto *et al.* (2020)** for hemp, flax, and chia-wheat blends.

The dough development time represents a parameter that is considered an indicator of protein quality of flours **(Göçmen and Taner, 2015)**. It was determined that the majority of blends with alternative materials (except sample CM2 5%) had a significantly prolonged dough development time (measured by both Farinograph and Mixolab) in comparison to wheat dough. This effect was observed, probably due to the partial dilution of gluten proteins and the difficulty of blending fibre-rich ingredients and wheat flour homogeneously **(Švec and Hrušková, 2017; Guiotto *et al.*, 2020)**. Furthermore, the increase in this parameter could also be attributed to the interactions between the non-wheat proteins originating from incorporated alternative ingredients and gluten, resulting in slower hydration and gluten development **(Kohajdová *et al.*, 2013)**. Previously, several authors also recorded a longer dough development time for wheat dough incorporated with different fibre reach seed powders **(Koca and Anil, 2007; Hrušková *et al.*, 2013; Pejcz *et al.*, 2015)**.

Dough stability is a parameter that is related to the dough strength and the higher values of this parameter indicate a stronger dough with greater tolerance to mixing **(Karovičová and Kohajdová, 2007; Kohajdová *et al.*, 2013)**. Inclusion of non-cereal ingredients also markedly influenced the dough stability (determined by both Farinograph and Mixolab). It was resulted that samples included 10% portion of white chia seed powder, 5-10% of black and blended chia seed powders, showed significantly longer dough stability measured by Farinograph than wheat flour. A similar increasing in dough stability was observed by other authors **(Hrušková *et al.*, 2013; Guiotto *et al.*, 2020)** for wheat dough incorporated with chia powder originated from Mexico, whole chia powder, defatted chia powder with mucilage and hemp powder produced from seeds gained as conventional planting regime commodity and bioregime conditions. On the other hand, samples containing hemp and flax at a 10% level presented with significantly shorter dough stability than the control sample. These findings agree with those determined by **Koca and Anil (2007)**, **Hrušková and Švec (2018)**, **Codină *et al.*, (2019)** who documented that the inclusion of brown and golden flax into the wheat flours and hemp in wheat-barley flour blends concluded in a significant reduction in dough stability. The authors mentioned above also postulated that this fact could be attributed to the dilution of gluten forming proteins that cause weakening of the dough.

Table 3 Farinographic parameters of wheat flour and blends of wheat flour and seed powders

	FWA (%)	FDDT (min)	FDS (min)
Control	50.98 ± 0.20	2.43 ± 0.11	8.18 ± 0.11
CW 5%	51.86 ± 0.13*	4.00 ± 0.14*	8.40 ± 0.14
CW 10%	53.85 ± 0.11*	5.65 ± 0.07*	9.35 ± 0.49*
CB 5%	52.20 ± 0.07*	4.90 ± 0.14*	8.70 ± 0.14*
CB 10%	54.15 ± 0.05*	5.90 ± 0.14*	8.90 ± 0.28*
CM1 5%	51.34 ± 0.04	4.30 ± 0.14*	9.00 ± 0.28*
CM1 10%	53.67 ± 0.14*	6.60 ± 0.14*	9.35 ± 0.21*
CM2 5%	51.20 ± 0.10	2.45 ± 0.07	8.80 ± 0.14*
CM2 10%	54.36 ± 0.07*	7.05 ± 0.21*	9.40 ± 0.14*
HF 5%	56.97 ± 0.07*	3.00 ± 0.14*	6.50 ± 0.28*
HF 10%	59.17 ± 0.02*	3.25 ± 0.11*	4.50 ± 0.14*
FB 5%	59.35 ± 0.12*	5.25 ± 0.35*	8.25 ± 0.35
FB 10%	61.05 ± 0.02*	6.50 ± 0.71*	7.50 ± 0.71*
FG 5%	59.15 ± 0.07*	5.00 ± 0.71*	7.75 ± 1.41*
FG 10%	61.10 ± 0.14*	5.25 ± 0.35*	7.50 ± 0.35*

Legend: control - wheat flour, CW and CB - white and black chia seed powders, CM1 and CM2 - blended chia seed powders, HF - hemp seed powder, FB and FG - brown and gold flax seed powders, FWA - water absorption, FDDT - dough development time and FDS - dough stability determined by Farinograph

* denotes a statistically significant differences from control sample at $p < 0.05$ level

In this study, the Mixolab parameters C2, C3, C4 and C5 were also measured. The weakening of the dough matrix during the thermo-mechanical stress can be assessed by C2 values **(Berceli *et al.*, 2022)**, while high C2 values (0.5 - 0.6 Nm) indicate good protein quality of wheat flours **(Erukainure *et al.*, 2016; Schmiele *et al.*, 2017)**. All chia blends (CB, CW, CM1, CM2) were presented with significantly higher C2 values (0.47 - 0.51) than wheat flour that pointed out a lower protein weaning. Contrariwise, samples including 10% of hemp and 5 - 10% of flax powder showed the significantly lower C2 values (0.26 - 0.37) compared to the control sample. Previously, **Mironeasa *et al.* (2017)** and **Lacko-Bartošová *et***

***al*. (2019)** reported that wheat dough with C2 values below 0.4 is less tolerant to mixing, which could also be related to the gluten dilution, thus losing some of its elasticity. Mixolab measurement C3 indicates the starch gelatinization and viscosity of the dough upon heating **(Dhaka and Khatkar, 2013)**. A significant increase in this parameter was observed for dough that included different varieties of chia seeds, which can indicate a higher gelatine capability of starch and dough viscosity, as was previously described by **Lacko-Bartošová *et al*. (2021)**. In opposite, a significant decrease in the C3 parameter was observed compared to wheat dough for dough containing hemp and flax powder. **Codină *et al*. (2019)** postulated that the decrease in C3 values alters incorporation of flax seed powder is related to starch dilution and the high content of lipid components and polysaccharides that are naturally present in the flax powder. Mixolab C4 values gives information related to amylolytic activity and hot gel stability after heating to 90°C **(Lauková *et al*., 2019)**. Previously, higher C4 values are associated with low activity of alpha amylase **(Akhlaq and Ali, 2020)**. As presented in this study, the wheat chia blends had significantly higher C4 values as control sample, which could indicate their lower amylase activity compared to tested wheat flour. On the other hand, incorporation of hemp and flax powders in wheat dough resulted a marked decrease in the C4 values of the samples. These measurements are in agreement with those determined with **Švec and Hrušková (2015)**, **Codină and Mironeasa (2016)** and **Codină *et al*. (2019)** for flour blends including hemp or flax seed powder. The authors mentioned above also reported that the presence of a higher fat content in flour blends may form an insoluble complex with amylose resulting in a decrease of the hot starch stability paste.
Mixolab C5 parameter is linked with the starch retrogradation during cooling **(Lacko-Bartošová *et al*., 2019)**. It was shown that the flour blends including 5 and 10% of various varieties of chia had the significantly higher C5 values than the control sample. **Koksel *et al*. (2009)** documented that higher C5 values mean higher levels of starch retrogradation that can indicate lower amylolytic potential of flours **(Lacko-Bartošová *et al*., 2019)**. Moreover, it was determined that the C5 values decrease markedly with an increasing amount of hemp and flax in the flour blends. **Berceli *et al*. (2022)** described that this could be reflected in decreasing retrogradation during cooling phase. It was also documented that decreased C5 values portray prolonged shelf stability and improved texture in the final products **(Ding *et al*., 2018)**.

Correlation analysis

Correlation analysis was used to assess the strength of the linear relationships between the rheological parameters of flour blends. As concluded from the table 5 and figures 1 - 3, strong positive correlations (r = 0.896 - 0.970) were observed between water absorption, dough development time and dough stability obtained by using Farinograph (FWA, FDDT, FDS) and Mixolab (MWA, MDDT, MDS). This observation was in agreement with the study of **Dabčević *et al*. (2009)** that evaluated rheological behaviour of 19 Serbian wheat samples and obtained high correlation between the FWA and MWA and between FDDT and MDDT (r = 0.982 - 0.967).
Strong positive correlations were also found between Mixolab parameters C2 and C3, C4, C5; between C3 and C4, C5; between C4 and C5; between MDS and C4, C5 and between MWA and C3 (0.577 - 0.937) and negative correlations between the water absorption measured by Farinograph (FWA) and Mixolab values C2, C3, C4, and C5 (from -0.656 to -0.873). The variability in the correlation coefficients between the Mixolab values C2, C3, C4, and C5 was found with different authors. This fact could be attributed to the different composition of studied flour blends and various origins of incorporated alternative raw materials **(Hrušková *et al*., 2013; Švec and Hrušková, 2015; Codină *et al*., 2019; Kolesárová *et al*., 2022)**.

Table 4 Mixolab parameters of wheat flour and blends of wheat flour and seed powders

	MWA (%)	MDDT (min)	MDS (min)	C2 (Nm)	C3 (Nm)	C4 (Nm)	C5 (Nm)
Control	54.80 ± 0.41	3.43 ± 0.11	8.33 ± 0.26	0.40 ± 0.02	1.76 ± 0.05	1.69 ± 0.13	2.64 ± 0.03
CW 5%	58.70 ± 0.21*	4.50 ± 0.14*	8.45 ± 0.14	0.47 ± 0.01*	1.88 ± 0.03*	1.75 ± 0.08*	2.75 ± 0.04*
CW 10%	59.80 ± 0.10*	5.95 ± 0.07*	8.70 ± 0.06*	0.48 ± 0.02*	1.91 ± 0.01*	1.84 ± 0.03*	2.86 ± 0.08*
CB 5%	58.60 ± 0,31*	4.48 ± 0.14*	8. 82 ± 0.28*	0.49 ± 0.01*	1.91 ± 0.02*	1.77 ± 0.09*	2.62 ± 0.03
CB 10%	59.80 ± 0.12*	6.00 ± 0.14*	8.93 ± 0.31*	0.50 ± 0.03*	1.94 ± 0.02*	1.75 ± 0.06*	2.75 ± 0.14*
CM1 5%	54.70 ± 0.22	4.60 ± 0.14*	8.57± 0.11	0.49 ± 0.04*	2.10 ± 0.08*	1.79 ± 0.14*	2.88 ± 0.16*
CM1 10%	56.10 ± 0.43*	6.90 ± 0.14*	8.70 ± 0.18*	0.53 ± 0.03*	1.93 ± 0.02*	1.91 ± 0.05*	2.93± 0.11*
CM2 5%	55.04 ± 0.09	3.45 ± 0.07	8.58 ± 0.23	0.48 ± 0.02*	2.13 ± 0.06*	1.86 ± 0.12*	2.94 ± 0.10*
CM2 10%	56.30 ± 0.23*	7.55 ± 0.21*	9.45 ± 0.12*	0.51 ± 0.01*	1.95 ± 0.02*	1.96 ± 0.04*	3.05± 0.13*
HF 5%	56.02 ± 0.42*	3.95 ± 0.14*	5.20 ± 0.04*	0.37 ± 0.02	1.66 ± 0.03*	1.50 ± 0.03*	2.31± 0.17*
HF 10%	58.10 ± 0.18*	4.25 ± 0.11*	4.48 ± 0.16*	0.35 ± 0.02*	1.63± 0.07*	1.32 ± 0.11*	1.98± 0.06*
FB 5%	58.45 ± 0.07*	5.25 ± 0.35*	8.41 ± 0.29	0.35 ± 0.00*	1.56 ± 0.09*	1.31 ± 0.03*	2.44 ± 0.05*
FB 10%	60.42 ± 0.14*	6.80 ± 0.71*	7.80 ± 0.07*	0.31 ± 0.01*	1.43 ± 0.02*	1.24 ± 0.14*	2.38 ± 0.57*
FG 5%	58.40 ± 0.08*	5.18 ± 0.71*	8.93 ± 0.01*	0.37 ± 0.04	1.69 ± 0.00*	1.66 ± 0.12*	2.61 ± 0.05
FG 10%	61.45 ± 0.21*	5.75 ± 0.35*	7.40 ± 0.12*	0.26 ± 0.03*	1.33 ± 0.03*	1.42 ± 0.01*	2.56 ± 0.06*

Legend: control - wheat flour, CW and CB - white and black chia seed powders, CM1 and CM2 - blended chia seed powders, HF - hemp seed powder, FB and FG - brown and gold flax seed powders, MWA - water absorption, MDDT - dough development time and MDS - dough stability determined by Mixolab, C2 - protein weakening, C3 - starch gelatinization, C4 - stability of the starch gel formed, C5 -starch retrogradation
* denotes a statistically significant differences from control sample at $p < 0.05$ level

Table 5 Correlation analysis between the rheological properties wheat flour and seed powders determined by Farinograph and Mixolab

Parameters	FWA	FDDT	FDS	MWA	MDDT	MDS	C2	C3	C4	C5
FWA	1									
FDDT	ns	1								
FDS	ns	0.567***	1							
MWA	0,964***	ns	ns	1						
MDDT	ns	0.970***	ns	ns	1					
MDS	ns	0,557***	0.896***	ns	ns	1				
C2	-0,828***	ns	0.682***	ns	ns	ns	1			
C3	-0.873***	ns	0.579***	-0,594***	ns	ns	0.937***	1		
C4	-0.822***	ns	0.676**	ns	ns	0.577*	0.899***	0.870***	1	
C5	-0,656***	ns	0.868***	ns	ns	0.794*	0.756***	0717***	0.879***	1

Legend: FWA - water absorption, FDDT - dough development time and FDS - dough stability determined by Farinograph, MWA - water absorption, MDDT - dough development time and MDS - dough stability determined by Mixolab, C2 - protein weakening, C3 - starch gelatinization, C4 - stability of the starch gel formed, C5 - starch retrogradation
*, **, *** denotes a statistically significant differences at $p < 0.05$, 0.01 and 0.001 level, ns - non-significant differences

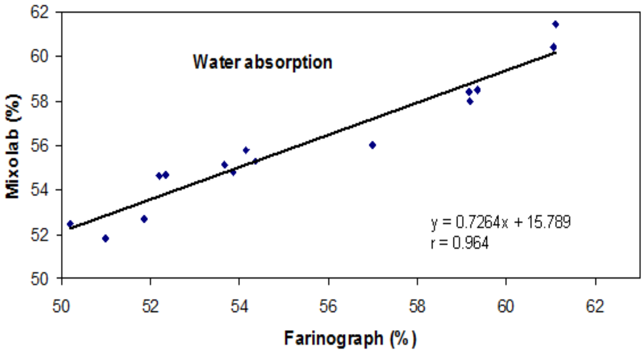

Figure 1 Correlation between water absorption determined by Farinograph and Mixolab

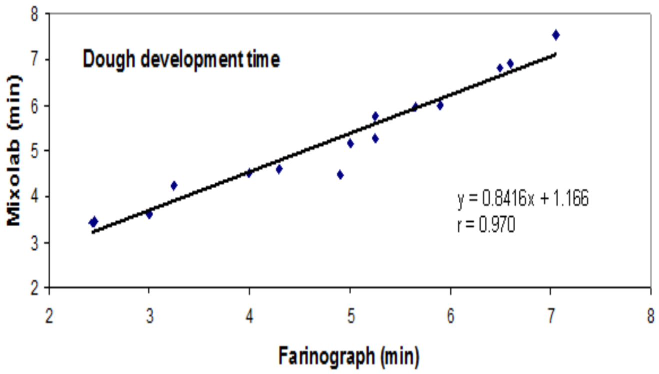

Figure 2 Correlation between dough development time determined by Farinograph and Mixolab

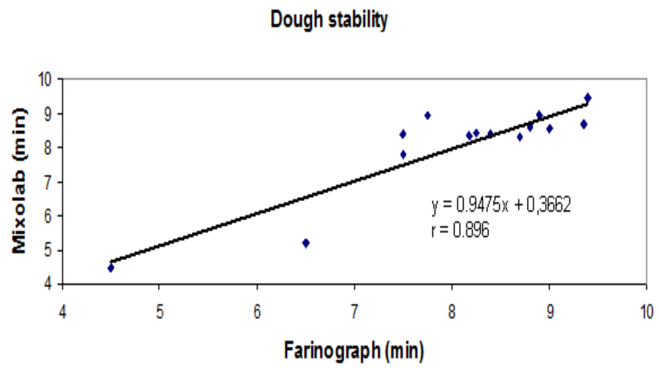

Figure 3 Correlation between dough stability determined by Farinograph and Mixolab

Principal component analysis

PCA was applied to visualize the relationships between the flour blend and their rheological parameters measured by Farinograph and Mixolab devices. The results of the PCA showed that the 2 principal components (PC) accounted together for 86.08% of the total variation were extracted. Kaiser's criterion, the technique that drops components, for which the eigenvalues are less than 1 was used for selecting the number of components (**Santos *et al.*, 2019; Michalak *et al.*, 2020**). PC1 explained 55.56% of the total variation of original data and was related to variables mixolab parameters C2, C3, C4, C5 and dough stability determined by Farinograph (FDS) and Mixolab (MDS). PC2 further explained 30.49% of the total variation and showed a close relationship between the dough development time measured by the application of different devices (FDDT and MDDT) (Fig 4). The score plot of the samples in the coordinates of PC1 and PC2 with distribution of samples in the plane of principal components is presented in the Fig 5. As concluded from this figure, PCA clearly separated wheat flour from the blends and divided these samples into the 3 groups according to the type of non-cereal raw material (chia, hemp, and flax) incorporated in the flour blend, while chia containing blends (CW, CB, CM) were characterised by the highest dough stability and C2 values, flax blends (FB, FG) by the highest water absorption capacity and hemp blend (HF) were characterised with the shortest dough development time and dough stability. In addition, PCA also identified individual groups of blend subgroups based on level of these alternative raw materials in the flour blends (5 and 10%).

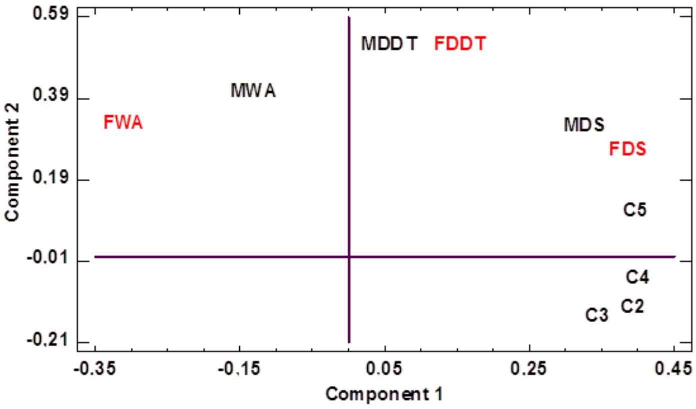

Figure 4 The plot of PC1 vs. PC2 loadings of analysed rheological parameters
Legend: FWA - water absorption, FDDT - dough development time and FDS - dough stability determined by Farinograph, MWA - water absorption, MDDT - dough development time and MDS - dough stability determined by Mixolab, C2 -protein weakening, C3 - starch gelatinization, C4 - stability of the starch gel formed, C5 - starch retrogradation

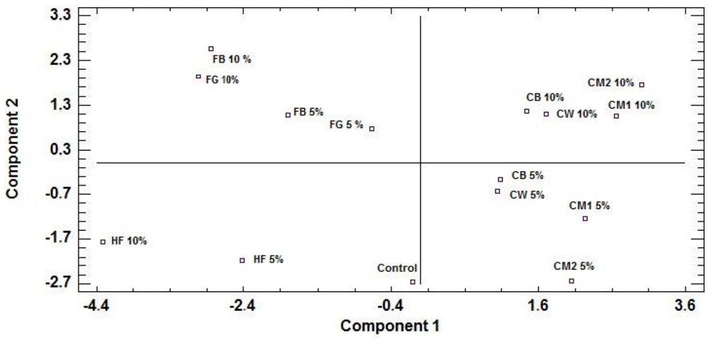

Figure 5 Scatter plot diagram of flour blends in coordinates of PC1 and PC2
Legend: control - wheat flour, CW and CB - white and black chia seed powders, CM1 and CM2 - blended chia seed powders, HF - hemp seed powder, FB and FG - brown and gold flax seed powders, 5%, 10% - content of seed powders in flour blends

CONCLUSION

In this study, the rheological characteristics of two-component based flour blends consisting of non-traditional raw materials (chia, hemp, and flax seeds) were evaluated by using a traditional (Farinograph) and modern (Mixolab) rheological tests. It was demonstrated that inclusion of these components significantly influenced not only mechanical (FWA, MWA, FDDT, MDDT, FDS, MDS) but also the thermal properties of dough (C2, C3, C4, C5). Addition of seed concluded in increased water absorption and prolonged dough development time. Furthermore, it was found that inclusion of chia seed extended dough stability, increased C2, C3, C4, C5, whereas after other seeds addition these parameters were reduced in comparison to control sample. The correlation analysis estimated the existence of strong positive correlations among water absorption, dough development time, and dough stability measured by Farinograph and Mixolab. Moreover it was documented, that Mixolab represents an innovative tool not only for monitoring the quality of protein-protease complex but also starch-amylase complex of studied flour blends.
Multivariate statistical method – PCA was also applied to reduce dimensionality of the original data and made them visible in the space represented with PC1 and PC2 that accounted together more than 86 % of the total variation of original data set and selected the most important rheological characteristics (C2, C3, C4, C5 and dough stability). Furthermore, PCA also differentiated flour blends based on type of non-cereal raw materials.

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