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INFLUENCE OF TWO VARIETIES OF FLAXSEED FLOUR ADDITION ON WHEAT FLOUR DOUGH RHEOLOGICAL PROPERTIES

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The aim of this study was to evaluate the effect of golden and brown flaxseed addition in wheat flour at the level of 0g/100g, 5 g/100g, 10 g/100g, 15 g/100g and 20 g/100g on dough rheological properties. The empirical and dynamic rheological properties of the dough substituted with flaxseed flour were recorded by the Alveograph and Haake MARS Rheometer. The results showed that regardless of variety, the addition of flaxseed to the white wheat flour resulted in the decrease of dough extensibility, weakening effect and decrease of dough consistency, as indicated by the drop of G' and G'' moduli. As the temperature increased, the wheat flour sample without flaxseed flour addition presented higher viscoelastic moduli values than the flaxseed-wheat flour blends. The addition of flaxseed to wheat flour changed all the dough rheological properties, the best results being obtained up to 10% flaxseed addition. Higher levels of flaxseed addition have conducted to dough with too high tenacity, extensibility and less elasticity.

Keywords: brown flaxseed, golden flaxseed, wheat flour, rheological properties

Introduction

Flax (*Linum usitatissimum*) is an oilseed containing about 40-50% oil, 23-34% protein, 5% mucilage and 4% ash (Toure and Xueming, 2010). It is a functional food being the leading source of the alpha-linolenic acid (ALA) (Cameron and Hosseinian, 2013) and of lignans which consist especially of phenolic compounds (Oomah, 2001). Besides the high content of omega 3-fatty acid (53% of total lipid content) flaxseed oil also contains 19% oleic acid, 17% linoleic acid (LA), 5% palmitic acid and 3% stearic acid (Bernacchia *et al.*, 2014). The 0.3:1(n-6: n-3) fatty acid ratio makes flaxseed a valuable lipid source which can lead to significant reductions in blood lipids that will improve the cholesterol and triglyceride level (Oomah, 2001). Moreover, the flaxseed oil may prevent the colon carcinogenesis in multiple intestinal neoplasia (Min) mice (Oikarinen *et al*., 2005). During the thermal process, the ALA acids from the food in which flaxseed is incorporated remained stable and its bioavailability is not affected (Chen *et al*., 1992).The lignan components of flaxseed present anti-oxidant properties and may have beneficial effects on breast and prostate cancer, type 2 diabetes, inflammatory bowel disease, reduction of cholesterol and blood glucose level (Dugani *et al.,* 2008).Regarding the protein composition of the flaxseed globulins, it represents 18.6% while albumins represent 17.7% of the total protein content (Chung *et al*., 2005).The amino acid composition of flaxseed is similar to those of soy, being rich in tryphtophan, valine and lysine (Kaur, 2017).The flaxseed mucilage is located in the outermost layer of the seed hull, being composed of 50–80% of carbohydrates, 4-20% of proteins and 3 to 9% of ashes (Cui, 2001). The predominant flax mucilage compound consists of a mixture of neutral arabinoxylans and acidic rhamnose-containing polysaccharides (Cui *et al.*, 1994). The flaxseed mucilage can be considered as a food hydrocolloid according to the data of its chemical composition (Ziolkovska, 2012). It may be used as a stabilizer, thickener, water-holding capacity (Kaewmanee *et al*., 2014). Flaxseed is also rich in some macro minerals such as Mg, K and Na and micro elements such as Zn, Mn, Cu and Fe (Kaur *et al.*, 2017).

The golden and the brown flaxseeds are two varieties of flaxseed that are known nowadays. There are no significant differences between these varieties in terms of their chemical composition, total antioxidant capacity and total phenolic compounds of seeds (Barroso *et al.*, 2014), the colour of the flaxseeds being given by the amount of pigment they contain (Ganokar and Jain 2013). Of the two varieties, the golden flaxseed has been more extensively explored than the brown one (Giada, 2010) despite the fact that the brown flaxseeds are usually easier to find than the golden ones. Due to their color difference, golden flaxseeds are easier to be introduced in bread recipe, whereas the brown flaxseed has a more marked taste as compared to the golden one and, therefore, it has high potential of being used as an ingredient in backery products.

Dough rheological properties of wheat flour with different levels of flaxseed addition were previously studied (Pourabedin *et al.*, 2017; Codină and Mironeasa, 2016; Koca and Anil, 2007; Xu *et. al.,* 2014; Roozegar *et al.*, 2015; Meral and Dogan, 2013). Some studies showed that water absorption increased with the increase of flaxseed addition level in wheat flour dough (Pourabedin *et al.*, 2017; Marpalle et al., 2014; Xu *et. al.*, 2014; Koca and Anil 2007), while others found no significant changes of this parameter (Najla, 2015). Moreover, some researchers have noticed a decrease of water absorption with the increase of flaxseed addition level (Codină and Mironeasa, 2016; Roozegar *et. al*. 2015). These different results regarding water absorption tendency with the increase of flaxseed addition level are probably due to the flaxseed particle size used in the studies (Codină and Mironeasa, 2016). Dough stability decreased as the proportion of flaxseed increased according to different studies (Pourabedin *et al.*, 2017; Codină and Mironeasa, 2016; Koca and Anil, 2007; Xu *et. al.*, 2014) or may increase if low levels are added (Meral and Dogan, 2013; Roozegar *et al.*, 2015). Dough development time also may increase (Pourabedin *et al.*, 2017) or decrease (Codină and Mironeasa, 2016) with flaxseed flour addition probably due to the level of water that exists in wheat flour dough. The extensibility of wheat flour dough with flaxseed addition decreased whereas the resistance to extension increased with the increase of flaxseed addition level (Koca and Anil, 2007; Pourabedin *et al.*, 2017). According to Pourabedin *et al.*, 2017, the interaction of some compounds from flaxseed flour with wheat flour gluten may conduct to the increase of dough resistance to extension. Regarding dough gelatinisation process, some studies have shown that flaxseed addition delayed the swelling of the starch granules, by inhibiting this process (Codină and Mironeasa, 2016).

The aim of the present work was to determine the wheat flour dough rheological properties by using two varieties (golden and brown) of flaxseed flour addition at a level of 0 g/100g, 5 g/100g, 10 g/100g, 15 g/100g and 20 g/100g in wheat flour. Since there are no official recommendations for a daily intake of flaxseed, the levels have been chosen according to our previous studies (Codină *et al*., 2016; Codină *et al*. 2016) which point out that the best bread quality characteristics were obtained up to a level of 10-15% flaxseed flour addition. For this purpose, the empirical and dynamic dough rheological properties were investigated by using an Alveograph device and a dynamic HAAKE MARS Rheometer. To our knowledge, no study has been made yet to compare the effect of the two flaxseed varieties in wheat flour addition on both dynamic and empirical dough rheological properties.

Materials and methods

Basic ingredients

The research has been carried on wheat flour type 650 (harvest 2015) purchased from S.C. MOPAN S.A. (Suceava, Romania). The brown and golden flaxseed varieties used were purchased from the local market (Cluj-Napoca, Romania). The flaxseed grains were ground in a domestic blender and incorporated in wheat flour at different substitution levels. The physico-chemical analyses of wheat and flaxseed flours were analyzed according to the following Romanian standards: protein content (SR EN ISO 20483:2014), moisture content (M) - (SR EN ISO 712:2010), fat content (SR ISO 7302:2002), ash (A) - (SR EN ISO 2171:2010), alpha-amylase activity by Falling Number method (SR EN ISO 3093:2010), wet gluten and gluten deformation index (SR 90:2007).

Wheat flour is considered very good for bread making, having 14.5 g/100g moisture content, 12.60 g/100g protein content 1.5 g/100g fat content, 0.65 g/100g ash content, 8 mm gluten deformation index and a falling number of 380 s.

The brown flaxseed presents 6.2 g/100g moisture content, 19.74 g/100g protein content 42.25 g/100g fat content, 3.5 g/100g ash content whereas the golden flaxseed presents 5.6 g/100g moisture content, 20.85 g/100g protein content, 41.12 g/100g fat content and 3.41g/100g ash content.

Empirical dough rheological properties

The empirical dough rheological properties were obtained using an Alveograph device (Chopin Technologies, France) according to SR EN ISO 27971:2015. The following characteristics were determined: dough extensibility (mm) indicated by length (L) of the alveogram curve, maximum pressure (P) representing the peak height (mm), baking strength (W), index of swelling (G) and configuration ratio of the Alveograph curve (P/L).

Fundamental dough rheological properties

The dynamic rheological properties were established with a HAAKE MARS 40 rheometer with parallel plate geometry (40 mm diameter) and with 2 mm gap. The dough sample was placed between plates and the excess of dough was removed. In order to prevent the drying of the samples during testing, a thin layer of vaseline was applied. Before measurement, the sample was let to rest for 10 min to allow relaxation. Frequency sweep tests were carried out from 1 to 20 Hz in the linear viscoelastic region (LVR) previously established. The storage modulus (G'), loss modulus (G'') and loss tangent (tan δ) were determined at a constant stress at 25^{0}C and during heating (25-90^{0}C) at the rate of 4ºC per min.

Statistical analysis

The statistical analysis was made using Microsoft Excel 2007 and Unscrambler X 10.1 software system (Camo, Norway).

Results and discussion

The effect of golden and brown flaxseed level on the chemical composition of wheat flour

The changes in the chemical composition and falling number values of wheat flour with different levels of flaxseed addition (brown and golden variety) are shown in Table 1 and Table 2.

Table 1. The effect of golden flaxseed addition on the chemical composition of wheat flour (g/ 100g) and falling number value (s)

Constituents (g/ 100g)	Control	5 (g/100 g)	10 (g/100 g)	15 (g/ 100 g)	20 (g/100 g)
Moisture	13.9±0.02	13.48±0.01	13.07±0.01	12.65±0.02	12.24±0.01
Ash	0.65±0.01	0.78±0.01	0.92±0.01	1.06±0.01	1.20±0.01
Fat	1.5±0.01	3.47±0.01	5.46±0.01	7.43±0.01	9.42±0.01
Protein	12.6±0.02	13.01±0.03	13.42±0.03	13.83±0.02	14.25±0.02
FN (s)	445±2.65	450±2.63	455±1.87	475±1.02	522±2.22

Table 2. The effect of brown flaxseed addition on the chemical composition of wheat flour (g/ 100g) and falling number value (s)

Constituents (g/ 100g)	Control	5 (g/100 g)	10 (g/100 g)	15 (g/ 100 g)	20 (g/100 g)
Moisture	13.9±0.02	13.51±0.01	13.13±0.02	12.74±0.01	12.36±0.01
Ash	0.65±0.01	0.78±0.01	0.93±0.01	1.07±0.01	1.22±0.01
Fat	1.5±0.01	3.53±0.01	5.57±0.01	7.60±0.01	9.65±0.02
Protein	12.6±0.02	12.95±0.03	13.31±0.02	13.67±0.03	14.02±0.02
FN (s)	445±2.65	517±2.03	525±1.97	544±1.68	558±2.15

For both varieties of flaxseed addition in wheat flour, it may be seen a positive linear increase in ash (A), fat and protein content with the increase level of flaxseed addition. This may be due to the higher ash, fat and protein content in flaxseed as compared to the wheat flour, having in view the data provided by the basic ingredients characteristics. A similar trend for these chemical characteristics was also reported by Marpalle *et al.* (2014). The falling number (FN) value decreased with the increase level of flaxseed addition for both types of flaxseed varieties.

Empirical dough rheological properties

The Alveograph data are shown in Table 3 and Table 4. According to the results obtained, a similar trend was noticed for all the Alveograph characteristics of golden or brown flaxseed-wheat flour blends.

Table 3. The Alveograph characteristics of golden flaxseed-wheat flour blends

Parameters	Control	5 (g/100 g)	10 (g/100 g)	15 (g/ 100 g)	20 (g/100 g)
P (mm)	104±0.02	96±0.01	101±0.02	115±0.01	122±0.01
L (mm)	68±0.01	58±0.01	55±0.01	36±0.01	27±0.01
G (mm)	18.4±0.01	17.0±0.01	16.5±0.01	13.4±0.01	11.6±0.01
W (10^{-4}J)	257±0.02	193±0.02	180±0.01	154±0.03	136±0.02
P/L	1.53±0.01	1.66±0.01	1.84±0.01	3.19±0.01	4.52±0.01

Table 4. The Alveograph characteristics of brown flaxseed-wheat flour blends

Parameters	Control	5 (g/100 g)	10 (g/100 g)	15 (g/ 100 g)	20 (g/100 g)
P (mm)	104±0.02	105±0.01	104±0.01	109±0.02	119±0.02
L (mm)	68±0.01	54±0.01	40±0.01	31±0.01	23±0.01
G (mm)	18.4±0.01	16.4±0.01	14.1±0.01	12.4±0.01	10.7±0.01
W (10^{-4}J)	257±0.02	210±0.02	163±0.03	141±0.02	120±0.02
P/L	1.53±0.01	1.94±0.01	2.60±0.01	3.52±0.01	5.17±0.01

It can be observed a decrease of dough extensibility, index of swelling and baking stretched with the increased level of flaxseed addition probably due to the gluten dilution effect, even if the amount of proteins in the dough increases with the increased level of flaxseed addition. Thus, at the maximum level of 20% flaxseed flour added in wheat flour, the value of dough extensibility is 2.51 times lower than in the case of golden flaxseed addition and 2.95 times lower than in the case of brown flaxseed added flour as compared to the blank sample. As for the index of swelling and baking stretch, it decreased by 1.58 times and 1.88 times respectively in the case of golden flaxseed addition and by 1.71 and 2.14 times in the case of brown flaxseed for a 20% addition in wheat flour as compared to the control sample. Koca and Anil (2007) had also reported a decrease in extensibility in all samples with flaxseed flour at the same addition level. Pourabedin *et al.* (2017) concluded that the lowest extensibility was obtained for the sample with the highest flaxseed addition. As regards the maximum pressure, this value increases at high levels of flaxseed addition, being in accordance with the results obtained by Pourabedin *et al.* (2017). These researchers have found an increase in the resistance to extension with the increase of flaxseed level added, probably due to the presence of mucilage gum in flaxseed which may lead to an increase of dough tenacity. However, at low levels of golden flaxseed addition, the Alveograph P parameter presents lower values as compared to the control sample and similar ones when brown flaxseed was incorporated. This may be due to the fact that at the Alveograph the rheological properties of flaxseed-wheat flour blends were determined at constant hydration. According to our previous study (Codină and Mironeasa, 2016), on the increased level of falxseed addition in wheat flour, water absorption decreased. By adding approximatively the same amount of water in the Alveograph mixer where flaxseed and wheat flours were mixed, it is possible for the dough to have a slight water excess which can lead to a lower dough resistance (Kieffer and Stein, 1999) and therefore, to a lower value of Alveograph dough tenacity. However, when high levels of flaxseed are incoroporated in the wheat flour dough, a clear increase of dough tenacity was noticed, probably due to the higher amount of gum from flaxseed-wheat flour which can lead to a more uniform and dense dough.

Fundamental dough rheological properties

The dynamic rheological properties evaluated for wheat flour dough with different levels of flaxseed addition are shown in Figure 1 and Figure 2. Figure 1 (A-D) shows the frequency sweep results for golden and brown flaxseed-wheat flour blends. The measurements were performed in the linear viscoelastic region of the wheat flour dough, as described by Georgopoulos *et al.* (2004) and Mohammed *et al.* (2011). Figure 2 (A-D) presents the evolution with temperature of G', G'' and *tan* δ for wheat flour with different levels of golden and brown flaxseed addition.

As it is obvious in Figure 1, the addition of flaxseed caused a lowering of dough consistency as it can be seen from the drop in G' and G'' for the flaxseed-wheat flour blends as compared to the control sample. The decrease is more prominent for the samples with low levels of flaxseed addition than for those in which high levels were incorporated. The loss modulus (G'') presents lower values than the storage modulus (G') in the whole range of frequencies, suggesting a solid elastic-like behavior of all flaxseed-wheat flour dough samples. Moreover, both modules increased with the increase of frequency.

Loss tangent is the ratio of viscous and elastic component of the dough which was tested (Singh and Singh, 2013). For all dough samples the value is lower than 1. Similar observations on wheat flour dough dynamic rheological studies were also reported by Ronda *et al*. (2013); Mariotti and Alamprese (2012). The dough from control sample showed higher *tan* δ values as compared to the dough with 15% and 20% flaxseed addition for both flax varieties added, indicating the fact that the control sample presents a more viscous structure than those with higher levels of flaxseed addition. Dough samples with 5% and 10% golden flaxseed addition presented less elastic characteristics than the control sample and higher ones in the case of brown flaxseed flour addition.

Figure 2 presents the changes in G', G'' and tan δ values as the temperature rises. The decreases in the moduli values as the temperature increases are probably due to the protein denaturations which lose their capacity to retain water. It begins to be retained gradually by starch granules which gelatinise, increasing the dough visco-elastic properties. This increase depends on the content of the α-amylase from wheat flour, a higher content of amylase will cause a lower increase (Codină *et al.*, 2012). As we can see from both types of flaxseed addition in wheat flour, the control sample presented the higher values of the *G′* and *G″* moduli and the lower value of *tan δ* which may be correlated with the falling number value, the control sample had the lowest value of all the dough samples (see Table 1 and Table 2). Once the temperature gets higher, starch granules absorb the water available in the dough and increase dough viscosity (Haros *et al.*, 2006). In the temperature gelatinization range, the *G′* and *G″* values are lower for dough samples with flaxseed addition probably due to the high content of fat from flaxseed and due to starch dilution (Codină and Mironeasa, 2016).

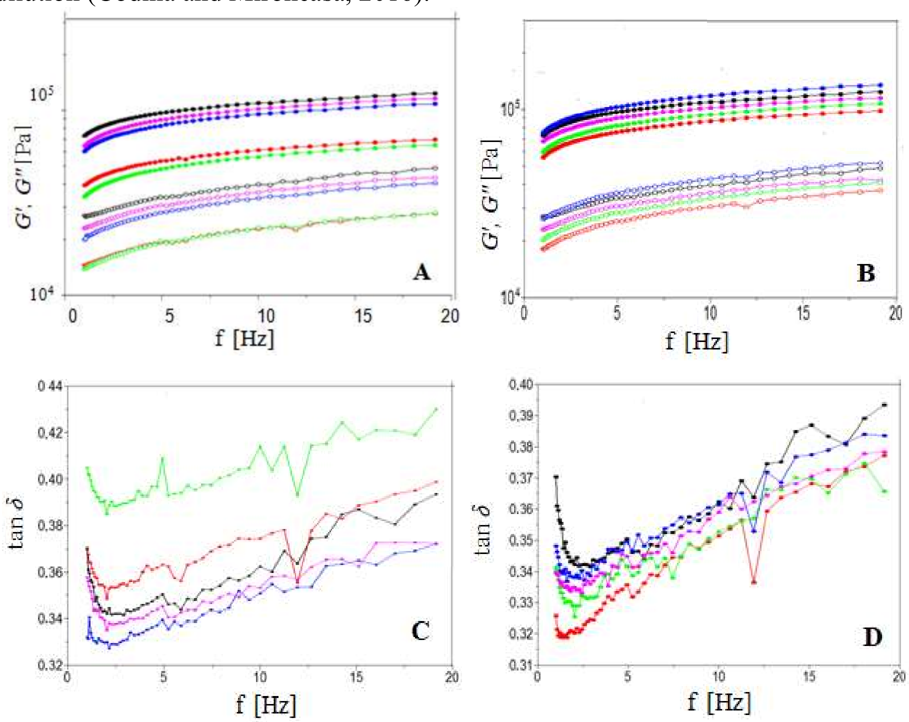

Figure 1. Frequency dependent evolution of *G′* (represented by solid symbols), *G″* (open symbols) - (Figure A, B) and tan *δ* – (Figure C, D), at 20⁰C, for samples with different levels (-●-0%; -●-5%; -●-10%; -●-15%; -●-20%) of golden flaxseed (GSF) (left) and brown flaxseed (right) addition

The relationship between flaxseed-wheat flour blend characteristics, Alveograph curve parameters and dynamic rheological characteristics

The principal component analysis was conducted in order to achieve the influence of golden flaxseed and brown flaxseed on dough physico-chemical and rheological parameters. The first two principal components explained 93% of the total variance (PC1 explained 65% and PC2 explained 28%, respectively). The principal component scores and loadings are shown in Figures 3 and 4.

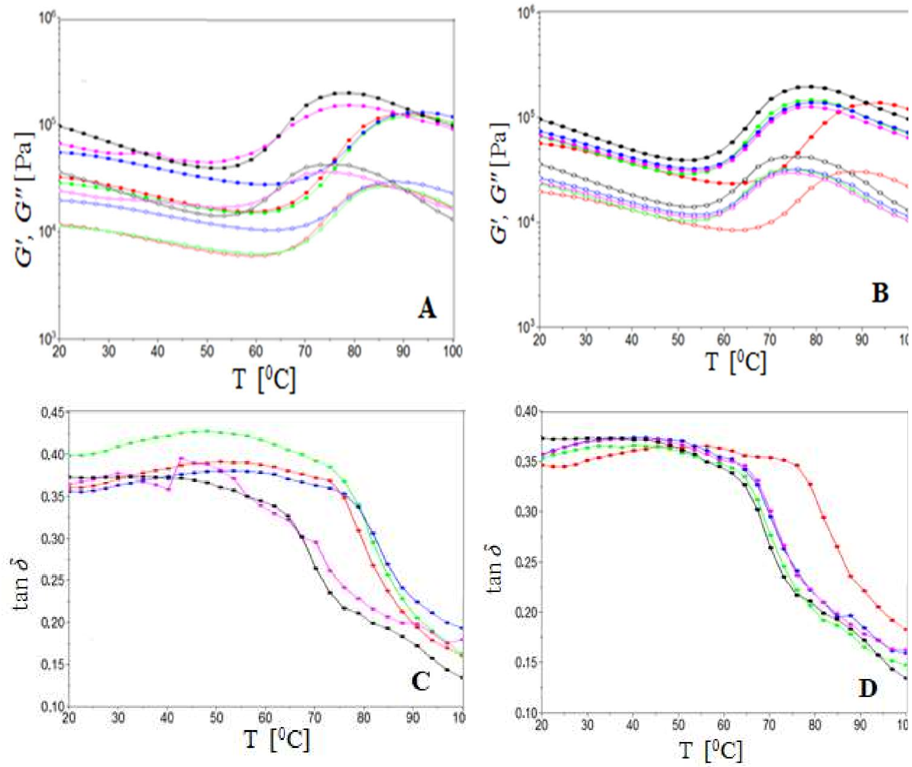

Figure 2. Temperature dependent evolution of *G′* (represented by solid symbols), *G″* (open symbols) – (Figure A, B) and tan *δ* - (Figure C, D) for samples with different levels (-●-0%; -●-5%; -●-10%; -●-15%; -●-20%) of golden flaxseed (GSF) (left) and brown flaxseed (right) addition

As we can see in Figure 3, the control sample (C) is placed in a different quadrant from the other samples. A very good correlation can be observed between the samples with 10% golden flaxseed, 5% golden flaxseed and 5% brown flaxseed and 20% golden flaxseed with 20% brown flaxseed.

The parameters placed in the inner ellipse of Figure 4 have not influenced the PCA scores. *G′*, *G″*, *tan δ*, protein content, moisture content (M), FN, P, L, G and W have the highest influence on the PCA scores. Regarding the correlations obtained, highly negative ones can be observed between moisture and Alveograph parameters L (r=0.698*), G (0.757*) and W (0.674*). This may be due to the specific method of dough preparion by means of Alveograph where the amount of saline solution addition is related to the flour moisture (Popa *et al.* 2009). The ash content is correlated positively with fat (r=0.869**), protein (r=0.671*) probably due to the fact that flaxseed presents a higher amount in these compounds than wheat flour and by its addition in wheat flour it will proportionally increase these values.

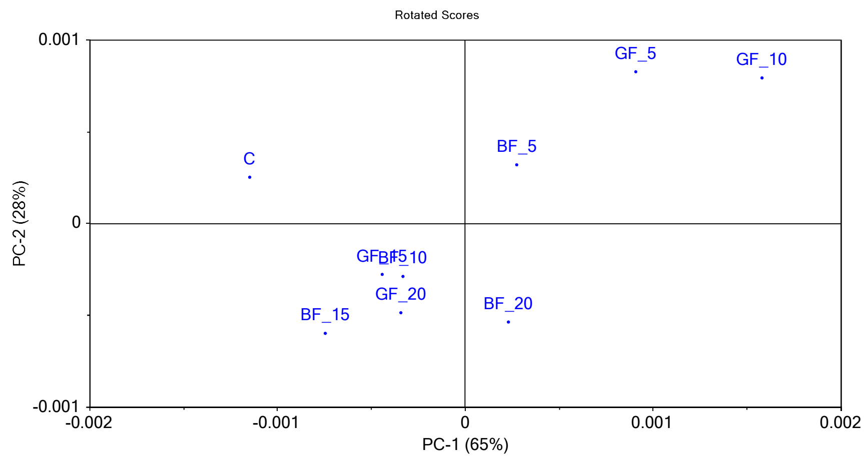

Figure 3. Principal component analysis scores: C-control sample, BF – brown flaxseed, GF – golden flaxseed

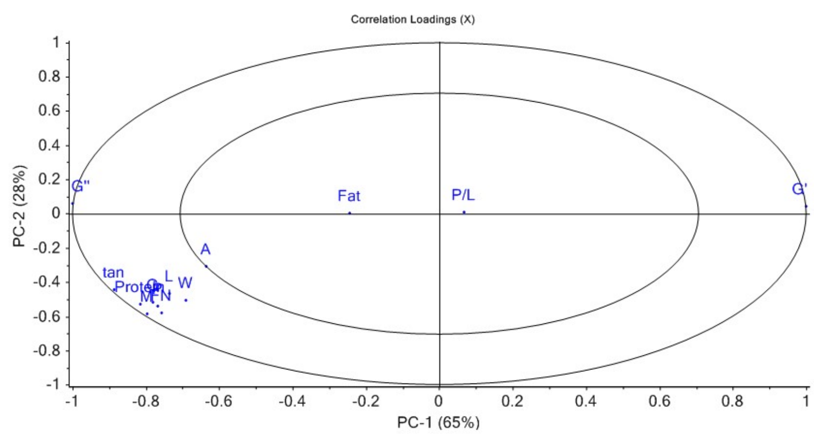

Figure 4. Principal component correlation loadings between flaxseed-wheat flour blends characteristics, Alveograph curve parameters and dynamic rheological characteristics

Regarding the correlations obtained with Alveograph values, positive ones were obtained with P (0.867**) and P/L (0.896**) and negative ones with L (r=-0.865**) and W (r=-0.777*). The protein content is positively correlated with P/L (r=0.825**) and negatively with L (r=-0.811**), G(r=-0.820**) and W (r=-0.875**). Similar correlations between protein content and Alveograph parameters were also reported by Popa *et al.* (2009). The FN is negatively correlated with L (r=-0.804**), G (r=-0.809**) and W (r=-0.674*) similar inverse correlations being also found by Codină *et al.* (2010). The *G′* is negatively correlated with *tan δ*(r=-0.713*), this fact being predictable, the less elastic the characteristics of the samples are, the higher *tan δ* is.

Conclusions

From the point of view of the analysis of the results of the empirical rheological properties, it is obvious that the increased level of flaxseed addition decreases the dough baking strength and increases the P/L ratio value. From the point of view of the dynamic rheological properties, dough with flaxseed addition presents distinctive solid state characteristics, showing acceptable dynamic rheological properties. The decrease of G' and G'' moduli with frequency at 20^0C was more prominent for the samples with low levels of flaxseed addition than for those in which high levels were incorporated. As the temperature got higher, the control sample presented higher values for the G' and G'' and lower ones of $\tan\delta$ than for the dough samples with flaxseed addition. In order to obtain good rheological properties, dough samples should not exceed a 10% flaxseed addition in wheat flour dough due to the fact that at high levels flaxseed-wheat flour dough presented less elastic characteristics, too high tenacity and values for extensibility and baking strength similar to the control sample.

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