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ORIGINAL RESEARCH PAPER

INFLUENCE OF HEMP FLOUR ON DOUGH RHEOLOGY AND BREAD QUALITY

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Abstract: The effect of hemp flour in a partially defatted form (HF) at levels 5, 10, 15 and 20 % on the dynamic rheological properties and wheat bread quality was analyzed. The dynamic rheological tests have shown a drop in storage modulus (*G'*) and loss modulus (*G"*) for dough samples in which HF was incorporated in wheat flour. The bread's physical parameters (loaf volume, porosity, elasticity) presented higher values than those obtained for the control sample up to a level of 10 % HF addition. The color of the bread crumbs and crust became darker with the increased level of HF addition. The bread firmness increased whereas the bread gumminess and chewiness decreased with the increased level of HF addition. Sensory, the most appreciated bread samples were those up to 5-10 % level of HF addition in the bread recipe. The PCA plot shown that, on overall acceptability, the most significant impact (p < 0.01) had the color (r = 0.855), smell (r = 0.899) and taste (r = 0.900) sensory characteristics.

Keywords: *bread-making, fundamental rheology, principal component analysis, wheat flour*

INTRODUCTION

Hemp is a multiuse, multifunctional crop that provides raw material to over 25000 products known for tradition and innovation [1, 2]. Globally, this plant has been an important source for many agro-industrial fields such as agriculture, textile, bio composite, paper-making, automotive, construction, bio-fuel, functional food, dietary oil, medicine, cosmetics, personal care, and pharmaceutical industry [3 – 7]. In the present, hemp is cultivated in at least 47 countries, Canada, China, Chile, France, and North Korea are currently the largest producers of hemp [8].

Even though hemp represents a very important industrial crop, the decline of this plant's cultivation after World War II has been unstoppable, and by the end of the 1960s it had almost disappeared from most Western European countries. A renewed interest in hemp cultivation began in the early 1990s, when the cultivation of this plant was reauthorized throughout the European Union. After more than 20 years, hemp is still a niche crop, cultivated on an area of 10,000-15,000 ha in the European Union [2]. Until 1989 Romania was the first in Europe and the third in the world in cultivating hemp and processing, possessing the most advanced spinning and weaving technology, compared to Japan and Italy.

The recent research scope all around the world is the evaluation of composite flours on basis of wheat and other cereals and nongrain seeds in the baking technology. The new baking products on the market have been driven by modern consumers' requirements, which are getting more concerned about improving diet and health. New ingredients play multiple roles as enhancing the rheological properties of dough, increasing bread quality and nutritional value [9]. One of these new ingredients are hemp seeds, which can be milled into fine flour following processes similar to other cereals. Because hemp seeds have high functional, bioactive properties and can be easily incorporated into nutritional food, in many countries it has been a recent trend to obtain food derived from hemp seeds. Recent scientific research indicates that hemp seeds are a source of valuable nutrients, so they are recognized as one of nature's perfect balanced foods [10]. Hemp seeds contain 30 % oil, 25 % proteins, 25 % starch, 16 % dietary fibers and are a source of vitamin B, vitamin E, iron, zinc, calcium and magnesium [11, 12]. For example, the consumption of 300 g bread supplemented with 20 % of hemp flour can theoretically satisfy the recommended daily intake of iron [13].

Hemp flour is high in protein (about 30 %) with prevalence of edestin (65 %) and albumin (33 %), hemp belonging to an important source of proteins compared to soybeans [14]. These two main proteins have very similar structures to proteins made by the blood, resulting in easy digestibility [15]. Hemp proteins are complete, meaning that all the essential amino acids are present in nutritionally significant amounts and have exceptionally high levels of arginine and glutamic acid [16]. The lipids in hemp seeds are very rich in poly-unsaturated fatty acids, consisting of large amounts of linoleic acid and α-linolenic acid, often in a favorable 3:1, which can decrease human cholesterol and blood pressure levels and provide immune system support [17, 18].

Hemp flour has a high nutritional value, it could be used for significantly improving the nutritional value and sensory acceptability of the gluten-free bread, while limiting the aging of the bakery products [19, 20]. Research on the use of hemp flour in bakery products has led to the recommendation to use it in proportions that should not exceed 20 % of the mixture with wheat flour or in mix with other flours. After the baking test, it

was observed that the best sensory and physico-chemical values were obtained by adding 5 % and 10 % partially defatted hemp flour in the bread making formulation, comparable to that obtained only from white flour. The quality of the bread obtained by adding 15 %, respectively 20 % flour of partially defatted hemp was like that obtained from whole wheat flour [11]. Bread with hemp flour is characterized by significantly higher protein and polyphenols content, in comparison to wheat bread. Hemp flour influenced and the color of the crumbs by increasing its browning index, and significantly inhibiting changes in the hardness of bread crumbs by reducing the bread stalling index. However, for industrial production, the share of hemp flour should not exceed 30 % [21].
The high content of insoluble fiber (10 - 15 %) may be also a reason for wheat flour fortification. Also, it was found that, by using hemp flour in baking, the finished products have flavors of hazelnut or walnut [8]. Other research shows that added hemp flour in gluten-free crackers or energy bar has much better nutritional qualities than the brown rice flour crackers in terms of higher protein, crude fiber, minerals, and essential fatty acid content [13, 20].
The aim of this study was to use defatted hemp flour to produce bread and to determine their impact on dough rheological properties and bread quality.

MATERIALS AND METHODS

Materials

A commercial wheat flour (harvest 2019) provided by S.C. Mopan S.A. (Suceava, Romania) was used. The partially defatted hemp flour provided by Marbacher Ölmühle GmbH, Germany, was used in ratios of 5, 10, 15 and 20 % on the initial wheat flour weight basis. The sample without hemp flour addition was considered the control sample (M). The flour was analyzed according to Romanian and international standards methods as follows: ash content (ICC 104/1), moisture content (ICC 110/1), fat content (ICC 136), protein content (ICC 105/2). The wheat flour was also analyzed for Falling Number (ICC 107/1), gluten deformation index (SR 90:2007) and wet gluten content (SR 90:2007).

Methods

Evaluation of rheological dough properties

The rheological properties were studied using a HAAKE MARS 40 rheometer. The doughs were prepared in a planetary mixer and left to rest before the test for 10 minutes. A plate and plate system were used with a diameter of 40 mm and once the plate was lowered, the excess dough was removed and vaseline oil was used to ensure that the dough would not dry out. The storage modulus (G') and loss modulus (G'') were determined as a function of frequency (0.00 - 20 Hz) at a constant temperature of 25 ºC. After the oscillatory frequency test, temperature sweeping test (20-100 ºC) was performed at a heating rate of 4 ºC per minute, to a constant frequency of 1 Hz and amplitude strain of 0.001.

Bread-making

Bread samples preparation was made using a single-phase method. In a Lancom spiral mixer (China) were added 1.5 % salt, 3 % yeast and 59.4 % water ratios, related to the composite flour mass. After mixing, the dough was divided, shaped and fermented for 60 minutes at temperature of 30 ºC and 85 % relative humidity (in a fermentation cabinet Piron, Italy). When the fermentation was completed, the bread was baked in an electrical bakery convection oven, Caboto PF8004D (Italy), at 180 ºC for 30 minutes.

Bread physical evaluation

The physical characteristics of the bread samples were analyzed: the loaf volume, porosity and elasticity according to the Romanian standard SR 91:2007.

Bread color evaluation

The bread color was analyzed by using a Konica Minolta CR–700 colorimeter. The color of crumbs and crust was analyzed through determining the values of L (lightness), a (greenness when negative and redness when positive) and b (blueness when negative and yellowness when positive).

Bread textural evaluation

The textural properties of bread samples were analyzed by using a Perten TVT 6700 (Sweden) texture analyzer, with which were determined the following characteristics: springiness, cohesiveness, resilience, firmness, gumminess and chewiness.

Bread sensory evaluation

The bread sensory characteristics were analyzed with the help of 25 semi-trained panelists from the "Stefan cel Mare" University, Faculty of Food Engineering. The panelists evaluated the overall acceptability, general appearance, color, flavor, texture, taste and smell by using a 9-point hedonic scale (from 1-extremely dislike to 9-extremely like).

Statistical analysis

The statistical analysis was done using a Statistical Package for Social Science (v.16, SPSS Inc., Chicago, IL, USA) and a XLSTAT statistical package (free trial version 2016, Addinsoft, Inc., Brooklyn, NY, USA).

RESULTS AND DISCUSSION

Flour characteristics

The analytical characteristics of the analyzed wheat flour indicated the following values: 0.65 % ash content, 11.23 % moisture content, 12.67 % protein content, 1.38 % fat content, 30 % wet gluten content, 6 mm gluten deformation index and 442 s Falling Number value. According to the data obtained, the wheat flour was very good for bread making with a low alpha amylase activity [22]. The partially defatted hemp flour presented 7.64 % ash content, 6.19 % moisture content, 50.41 % protein content and 8.94 % lipid content.

Influence of defatted hemp flour addition on dough rheological properties

The dough's fundamental rheological characteristics for the tests carried out on the samples with different levels of hemp flour addition were analyzed using frequency sweep and oscillatory temperature sweep tests.

Figure 1 shows the frequency sweep test results for dough samples with different levels of defatted hemp flour (HF) addition. As it may be seen from this figure, the addition of HF reduced the dough consistency as it can be noticed from the drop in G' and G'' moduli for the wheat flour dough samples in which HF was incorporated. The decrease is higher for the dough samples with low levels of hemp flour addition than for the samples in which high levels of HF were incorporated. According to Korus *et al* [18]. Such a behavior of dough rheological properties may be caused by elevated water absorption by protein present in the dough system. A strengthening effect may occur when the water from the dough system is not enough to hydrate all of its components [23]. Hemp flour contains proteins, starch which differs from that in wheat flour, non starch polysaccharides including fiber which can change water binding from the dough system, fact that influences dough rheological properties [11, 12, 24]. According to Korus *et al* [18], the addition of HF has a different effect on moduli values from a non-gluten dough. They noticed a significant decrease in the storage modulus when low levels of HF were incorporated and no statistically ones when high levels of HF were incorporated. In the case of loss modulus, they reported values comparable for all the HF levels addition and close to those obtained for the control sample [18]. All the analyzed dough samples exhibited a higher storage modulus (G') than loss modulus (G''), indicating that all of them had a more elastic behavior than the viscous one [25, 26].

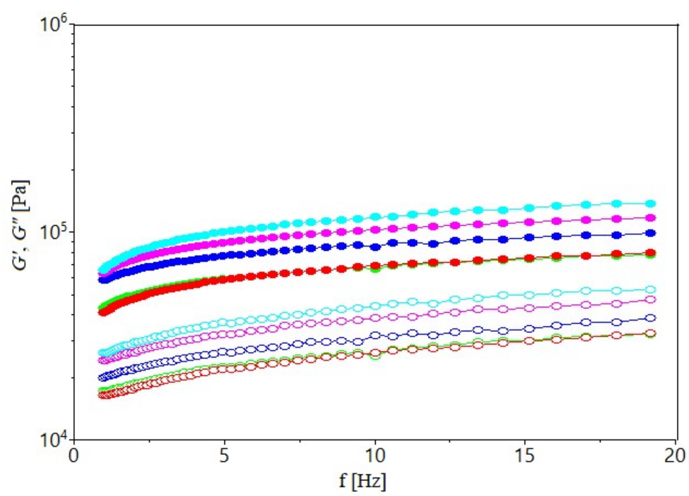

Figure 1. *Evaluation with frequency at 25 ^{0}C of G' values (represented by solid symbols) and G'' (open symbols) for samples with different levels of hemp flour addition: 0 % (●), 5 % (●), 10 % (●), 15 % (●) and 20 % (●)*

The dynamic rheological analysis of dough samples with different levels of hemp flour addition during heating are shown in Figure 2.

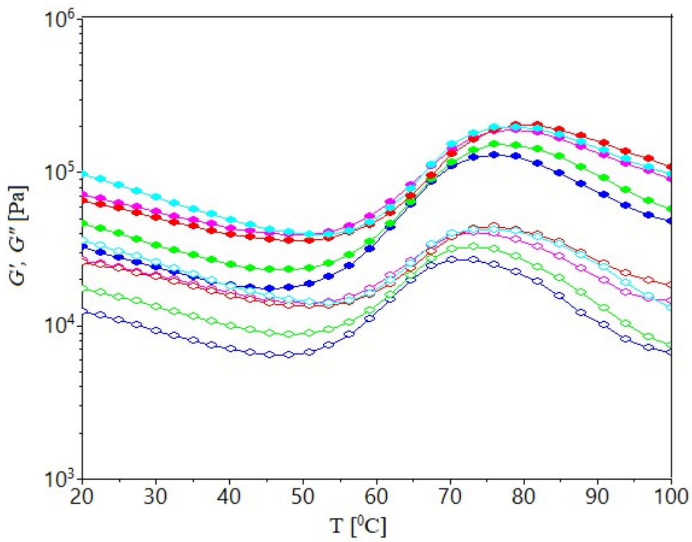

Figure 2. *Evaluation with temperature of G′ values (represented by solid symbols) and G″ (open symbols) for samples with different levels of hemp flour addition: 0 % (●), 5 % (●), 10 % (●), 15 % (●) and 20 % (●)*

The first part of the moduli behavior corresponding to the initial heating may be associated to proteins which begin to lose their capacity to retain water and begin to denaturate. By HF addition proteins become less compact, decreasing the dough consistency. As the temperature increases, the starch begins to gelatinize, fact that increases the values for G' and G'' moduli. This explains why, as temperature values increase, starch from the dough system begins to absorb water and to increase dough consistency. For the samples with hemp flour addition, the G' and G'' values are lower than those obtained for the control sample in the temperature gelatinization range due to the progressive dilution of wheat starch that leads to low pasting viscosity [27].

Influence of defatted hemp flour addition on bread physical characteristics

The bread physical characteristics are shown in Figure 3. All the bread physical characteristics increased up to a level of 10 % with hemp flour addition. However, no significant differences ($p > 0.05$) were noticed between bread samples with 10 % HF and the control sample. The decreased loaf volume, porosity and elasticity values corresponding with high levels of HF addition are probably due to the reduced amount of the gluten protein in the dough system after replacing the wheat flour with hemp flour which is non gluten flour. Also, these values may be reduced due to the increase of fiber content from the dough system by hemp flour addition, which reduces the ability to retain the gases formed during the fermentation process [28]. The results obtained are similar to those obtained by Mikulec *et al* [29], who also reported a decrease in the bread volume when high levels of hemp flour were added.

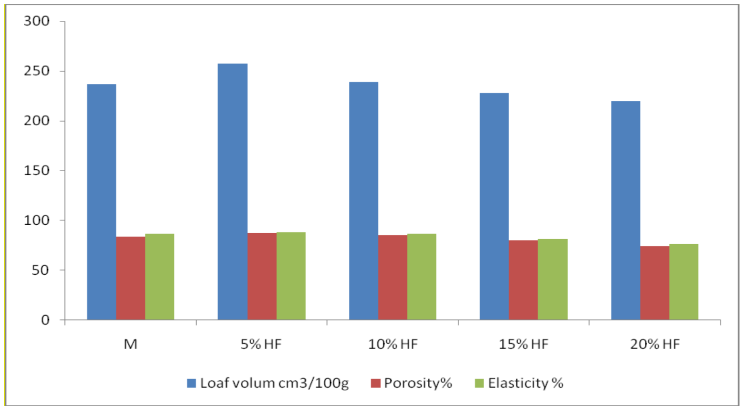

Figure 3. *Physical characteristics of bread samples*

Influence of defatted hemp flour addition on bread color characteristics

The effect of different levels of HF on bread crumbs and crust color are presented in Table 1.

Table 1. *Effect of defatted hemp flour (HF) on bread crumb and crust color*

HF (%)	Crumb			Crust		
	L^*	a^*	b^*	L*	a*	b*
0	69.22±0.03	1.37±0.01	21.73±0.02	61.89±0.02	2.67±0.03	36.33±0.02
5	53.31±0.05	1.82±0.02	20.37±0.03	55.32±0.01	3.18±0.02	33.31±0.03
10	48.70±0.02	2.43±0.02	20.12±0.01	55.39±0.02	3.32±0.02	30.01±0.01
15	41.38±0.02	2.93±0.03	18.48±0.02	51.79±0.03	3.88±0.01	27.62±0.02
20	34.24±0.02	3.77±0.04	18.12±0.02	43.87±0.02	5.72±0.03	25.23±0.02

The results obtained have shown an increase in the greenness and redness values of bread crumbs. It may be clearly noticed that L^* and b^* values decreased with the increased level of HF addition. This decrease is due to the darker color of hemp seed flour. The difference in yellowness (b) and redness (a) were statistically significant ($p < 0.05$). In the case of bread crust, it has also been noticed a decrease in L and b values compared to the control sample. The results are similar to those obtained by *Mikulec et al* [29], who also observed a decrease in lightness (brightness) and increase in the redness content (a) in the crumbs. Also, Pojic *et al* [10] and Korus *et al* [18] reported similar data, namely a decrease in the lightness and an increase in the redness of the crumbs with the increase level of HF addition.

Influence of defatted hemp flour addition on bread textural characteristics

The textural properties of the bread samples with different levels of hemp flour addition are shown in Table 2.

Table 2. *Textural parameters of breads with defatted hemp flour (HF)*

HF [%]	Springiness [%]	Cohesiveness	Resilience	Firmness [g]	Gumminess [g]	Chewiness [g]
0	87.23±0.01	0.5467±0.01	1.1535±0.02	2022±0.1	1385.77±0.01	1384.55±0.02
5	88.67±0.01	0.5762±0.01	1.1832±0.01	2134±0.1	1365.22±0.01	1364,67±0.02
10	87.31±0.02	0.5634±0.01	1.1631±0.02	2334±0.1	1277.11±0.02	1275.09±0.01
15	82.33±0.03	0.4825±0.02	0.9611±0.01	2630±0.1	1203.14±0.01	1202.67±0.01
20	78.44±0.02	0.4544±0.01	0.9403±0.01	2781±0.2	1133.12±0.01	1131.02±0.02

As it may be seen from the table above, the firmness of bread increased with the level of HF addition. Similar results have also been reported by Mikulec *et al* [29], which associated this result with bread volume because the bread with a higher volume usually presents fewer compact crumbs and, therefore, lower hardness. Taking into account that bread samples up to 10 % HF addition presented a higher loaf volume, bread values that are higher than the control sample's present higher values for firmness. These results might have other explanations with the higher protein content of hemp flour, which contributes to the reduction in the bread firmness and its water-binding capacity [30]. In breads with 5 % hemp flour addition, the values for resilience, springiness and cohesiveness increased and then decreased. For the gumminess and chewiness values, it was observed a decrease in all bread samples in which hemp flour was incorporated, as compared to the control sample. Similar results have been obtained by Mikulec *et al* [29], which reported significant decreased values for these parameters, especially when high levels of HF were incorporated in wheat flour.

Influence of defatted hemp flour addition on bread sensory characteristics

In the sensory evaluation, the best results were obtained for bread samples in which hemp flour was added up to 5 - 10 % in wheat flour as it may be seen from Figure 4. Bread with 5 % HF addition received the highest scores for general appearance and overall acceptability, whereas bread with 10 % HF addition received the highest scores for taste and texture.

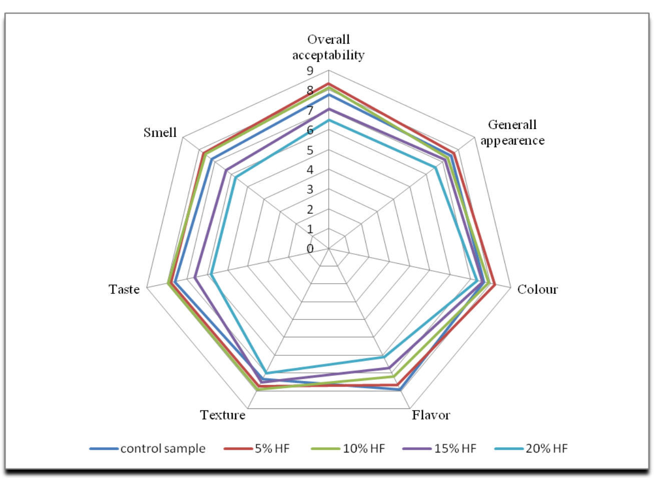

Figure 4. *Sensory characteristics of bread samples*

The color and smell were also well received for bread samples with 10 % HF additions, with scores higher than 7.5, whereas the taste and flavor were less appreciated for the bread samples in which high levels of hemp flour was incorporated into the wheat flour.

Correlation analysis of the evaluated parameters for the bread samples

The main component analysis (PCA) was performed as it may be seen in Figure 5, on bread quality characteristics, in order to test the variation between bread samples. The first two main components (PCs) make up 96.26 % of the total variance (PC1= 86.66 % and PC2 = 9.6 %). Along the PC1 component, the PCA plot shows a close association between sensory characteristics, overall acceptability and physical ones, as well as the loaf volume and porosity. Also, a good positive correlation was obtained between overall acceptability and textural characteristics cohesiveness (r = 0.995) and springiness (r = 0.954). From a sensory point of view, a positive effect on overall acceptability was presented by the texture (r = 0.687), color (r = 0.855), smell (r = 0.899) and taste (r = 0.900) characteristics, fact that reflects that these parameters presented the most significant effect on a global level in order to obtain good feedback for bread samples with different levels of HF addition. The second main component, PC2, shows a close positive association between physical characteristics: elasticity, texture, springiness, cohesiveness and resilience. The PCA plot shows along PC1 and PC2 axes a negative relationship between crumbs (CB) and crust (CT) color parameters a and values b and L. This fact is explainable since the increased levels of HF addition increase the *a* values for crumbs and crust color, whereas the values for *b* and *L* decreased.

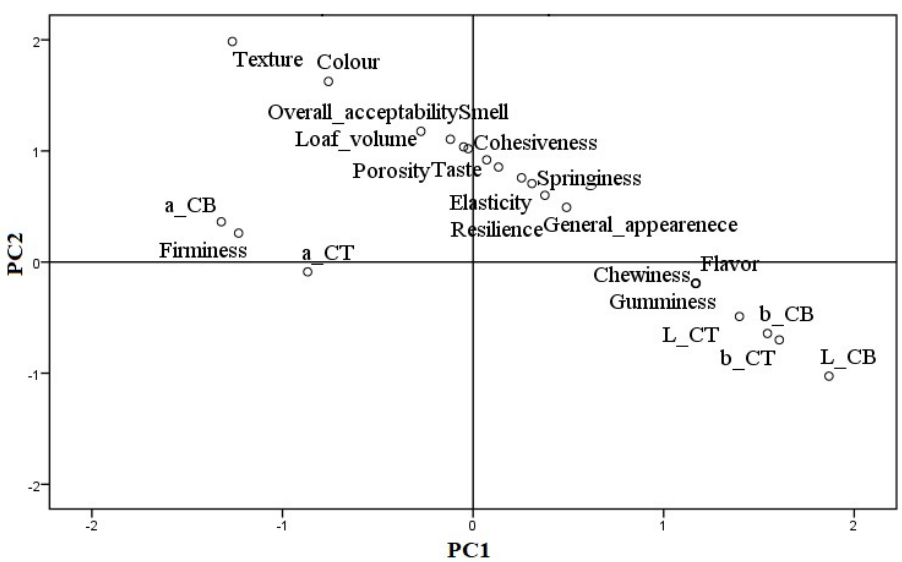

Figure 5. *Principal Component Analysis for the bread characteristics*

CONCLUSIONS

The data shows that hemp flour may be used along wheat flour to improve bread quality. The hemp flour addition affects the dough's rheological properties and bread quality from the physical, color, textural and sensorial point of view. Our studies show that HF addition reduces dough consistency in the frequency sweep at a constant temperature and in the temperature gelatinization range. According to bread quality characteristics, bread enriched up to a level of 10 % HF is one of good quality from the technological point of view. From the color point of view, the bread samples with HF addition become darker and its brightness decreased with the increased level of HF in wheat flour. The textural properties of bread samples showed that the resilience, springiness and cohesiveness increased up to 5 % HF addition and then decreased. Also, the bread firmness increased whereas the bread gumminess and chewiness decreased with the increased proportion of HF in wheat flour. According to sensory evaluation, up to 10 % HF addition the panelists appreciated very well the bread samples. The PCA analysis showed a positive correlation between the sensory characteristics, overall acceptability and loaf volume, porosity, cohesiveness, color, smell and taste.

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