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INFLUENCE OF WHEAT-MESQUITE (*Prosopis* L.) COMPOSITE FLOUR ON DOUGH RHEOLOGY AND QUALITY OF BREAD

– Research paper –

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Abstract: The purpose of this study was to evaluate the effect of wheat-mesquite composite flour on the rheology of dough and the quality of bread. The farinographic analysis showed a decrease in the development time and stability of the dough with an increase in the mixing tolerance index. The share of mesquite flour increased the value of loss and storage moduli and reduced the dough's susceptibility to stress. The mesquite flour addition increased the bread volume by about 17% and the number of large pores >5 mm. The brightness of the crumb containing mesquite flour decreased from 75.3 to 58.6 and the proportion of yellow colour increased from 19.9 to 26.4 in relation to the control bread. The bread with mesquite flour had a significantly softer crumb during storage in comparison with wheat bread, indicating a reduction in the staling. These observations were also confirmed by lowering the disintegration enthalpy of the retrograded amylopectin from 3.33 J/g for the control sample to 1.95 J/g for the bread containing 10% of mesquite flour.

Keywords: wheat bread, mesquite flour, dough rheology, quality, texture, staling

INTRODUCTION

Mesquite (*Prosopis* L.) is a plant from the Fabaceae family, which includes over 40 species. They mostly grow in the United States, Central, and South America, Africa, and the southwestern part of Asia. These melliferous plants provide edible fruits, which are a source of hydrocolloid with properties similar to acacia gum (Felker et al., 2013; Mudgil and Barak, 2020). Food processing uses pods, which, when dried and ground, can be an enrichment ingredient in various products, such as baked goods. Ground mesquite contains about 40% sugars, 15% protein, and up to 25% fibre. Despite its low-fat content, mesquite flour provides oleic acid, linoleic acid, and tocopherols. It is also rich in minerals - K, Mg, Zn, and apigenin glycoside derivatives with antioxidant properties (Felker et al., 2013; González-Montemayor et al., 2019; González-Montemayor et al., 2021). Due to the commonness of consumption, structure, properties and technological process, bread is a valuable carrier of biologically active substances that can enrich the daily human diet (Godula et al., 2019; Karigidi et al., 2021; Sikora et al., 2022). Such an enrichment ingredient for bread can also be flour from mesquite (González-Montemayor et al., 2019). The use of milled mesquite pods in wheat bread has already been the subject of several studies. Bigne et al. (2016) found that the share of mesquite flour resulted in lower dough stability and increased fermentation time. A great quantity of mesquite flour reduced the volume of the bread, increased its hardness, and decreased the springiness and cohesiveness of its crumb. In a subsequent study, Bigne et al. (2019) found that the share of mesquite flour at levels of 15 and 25% produced a dough with relatively good stability during frozen storage. On the other hand, its share at 35% already results in a weaker development of the gluten-free network and its damage during freezing. According to Gonzales-Barron et al. (2020b), the share of mesquite flour increases the content of protein, dietary fibre, and unsaturated fatty acids in bread. Moreover, the cited authors

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found that the presence of mesquite flour did not significantly affect the hardness of the crumb, but reduced its springiness and water activity, as well as staling during storage. In other studies, Gonzales-Barron et al. (2020a) observed that mesquite flour affects most of the technological characteristics of the dough due to the content of globular proteins, the fibre fraction, and galactomannans, which are factors that prevent the development of the gluten network. In another study, it has been observed that the presence of mesquite flour reduces springiness and causes an increase in dough adhesiveness, as well as lower bread volume and higher crumb hardness. However, sensory evaluation of such baked goods showed good acceptability, especially with a 25% proportion of mesquite flour (Bigne et al., 2018). Mesquite flour has also been used to enrich sweet snacks and muffins, yielding products with better nutritional value and consumer acceptability (Sciammaro et al., 2018). Although the literature indicates that it is possible to use the flour from mesquite in bakery products, the impact of this ingredient is strongly dependent on its quantity. Therefore, the purpose of this research was to test the possibility of using the flour from mesquite (*Prosopis* L.) as a factor in improving the quality and limiting the wheat bread staling.

MATERIALS AND METHODS

Materials

The materials were wheat flour (containing approx. 0.55% ash) (PZZ Krakow, Poland), lyophilised yeast (S.I. Lesaffre, France), salt, water, and mesquite flour (PureGreen, Poland) containing: 12.73% protein (Nx6.25), 2.09% fat, 4.33% ash, 40.67% total sugars, including 4.33% reducing sugars, and 41% dietary fibre, including 12.42% soluble fraction and 28.58% insoluble fraction (Latimer, 2019).

Dough preparation and bread baking

The dough was obtained from the following ingredients: wheat flour 1000 g, yeast 30 g salt 20 g, and water 613 g. The composite flour was made by mixing 900 or 950 g of wheat flour with 100 or 50 g of mesquite flour. The dough was mixed for 10 minutes in a spiral mixer (SP 12, Diosna, Germany) and then fermented at 35°C for 20 minutes. After fermentation, the dough was re-mixed for 1 minute. Portions of 250 g of dough were placed in moulds and fermented under the conditions described above. The breads were baked at 230°C for 30 minutes in the oven type CO 2 0608 (MIWE GmbH, Germany). After baking, the breads were removed from the moulds and cooled. Breads for storage tests were kept in polyethylene bags at room temperature.

Rheological properties of dough

Farinographic evaluation was performed with a Farinograph-E (Brabender, Germany) according to AACC method 54-21.02 (AACC, 2010).

The rheological properties of the dough in the range of small deformations were characterised at 25°C using a MARS II oscillating rheometer (Thermo-Haake, Germany). Rheological tests on the dough in the range of small deformations were carried out with a MARS II oscillating rheometer (Thermo-Haake, Germany) at 25°C equipped with the parallel fluted plates (35 mm in diameter, gap size 1 mm) as the measuring element. The investigated samples were placed in the rheometer for 5 minutes for their stabilisation. The spectra were recorded in the range of linear viscoelasticity at a constant strain amplitude of 0.3% in the angular frequency of 1-100 rad/s. The power law equations were used to describe the data obtained (Korus et al., 2017):

$$G'(\omega) = K' \cdot \omega^{n'} \quad (1)$$

$$G"(\omega) = K" \cdot \omega^{n"} \quad (2)$$

where: G' – storage modulus (Pa), G" – loss modulus (Pa), ω – angular frequency (rad/s), and K', K", n', n" – constants.

Both tests, creep and recovery, were carried out with constant creep strain τ_0 = 5Pa for 150 s. The recovery test was continued for 600 s. The Burgers model was used to describe the data (Witczak et al., 2017):

$$J(t) = J_0 + \frac{t}{\eta_0} + J_1 \cdot (1 - \exp^{-t/\lambda_{ret}}) \quad \text{for creep phase} \quad (3)$$

$$J(t) = \frac{t_1}{\eta_0} - J_1 \cdot (1 - \exp^{t_1/\lambda_{ret}}) \cdot \exp^{-t/\lambda_{ret}} \quad \text{for recovery phase} \quad (4)$$

where: J – compliance (Pa^{-1}), J_0 – instantaneous compliance (Pa^{-1}), J_1 – viscoelastic compliance (Pa^{-1}), η_0 –zero shear viscosity (Pa·s), λ_{ret} – retardation time (s), and t_1 – time after which the stress was removed (s).

Physical characteristics of bread

Bread volume was determined with a Volscan Profiler 600 (Stable Micro Systems, England). Crumb structure characteristics: slices of bread 2 cm thick were scanned (Plustek S-12, Plustek, Taiwan) and the results were obtained using the ImageJ program (NTH, USA) (Korus et al., 2015). CIE L*a*b* crumb colour analysis was performed according to the reflectance method with a Konica MINOLTA CM-3500d spectrometer (Konica Minolta Inc., Japan) (light source D65, observer 10°, geometry d/8).

Texture parameters of the crumb were established using a TA-XT2plus device (Stable Micro Systems, England) at a compression speed of 5 mm/s. Cylindrical crumb samples (1 cm in diameter and 2 cm in height) taken from the center of the loaf were compressed in two cycles using a P/35 aluminium cylindrical probe until 50% deformation was reached. The texturograms were analysed with Texture Exponent software (Stable Micro Systems, England). The analyses were conducted over three consecutive days.

Thermal characteristics of bread

Thermal characterisation of the crumb was performed with a Phoenix DSC 204F1 differential scanning calorimeter (Netzsch, Germany). To determine the content of freezable water in bread after baking (Ribotta and Le Bail, 2007), crumb samples (about 12 mg) were sealed in hermetic aluminium vessels and frozen to -60°C at a rate of 10°C/min. The frozen samples were held for 5 minutes at this temperature, followed by heating to 50°C at a rate indicated above. The standard was the empty aluminium dish. Temperatures (To - beginning of transformation, Tp - maximum of transformation, TE - end of transformation) and enthalpy of melting were determined using Proteus Analysis software (Netzsch, Germany). Freezable water content was expressed in g/g.

In order to evaluate the degree of staling during three-day storage, samples of bread (about 12 mg) were sealed in hermetic aluminium vessels and heated in a calorimeter to 100°C at a rate of 10°C/min. The standard was the empty aluminium vessel. The values of temperature and enthalpy of the thermal transformation were obtained from the Proteus Analysis program (Netzsch, Germany). The enthalpy values are given in J/g of dry weight.

Sensory characteristic of the bread

Sensory analysis of bread was performed in accordance with the Polish Standard PN-A-74108:1996. The 15 semi-trained panellists evaluated the following parameters: external appearance (max 5 pts); crust characteristics - colour (max 3 pts), thickness (max 4 pts), and other crust characteristics (max 4 pts); crumb characteristics - springiness (max 4 pts), porosity (max 3 pts), and other crumb characteristics (max 3 pts); taste and aroma of bread (max 6 pts).

Statistical analysis

The data were analysed by one-way analysis of variance and Duncan's post hoc test at the significance level of 0.05. A two-way analysis of variance was used to evaluate the results of the analyses taking into account storage time. The Statistica 11.0 package was used for the calculations (StatSoft Inc., USA).

RESULTS AND DISCUSSION

Dough rheology

The basic method used in the testing of wheat dough is farinographic analysis, which allows the determination of technological parameters characterising the dough during kneading. Its results can also be used to assess the influence of ingredients that modify the recipe. The introduction of mesquite flour had a significant effect on the values of farinographic parameters in relation to the control sample, although no statistically significant differences were found for the level of addition (Table 1). The dough development time was the lowest for the control sample, while the introduction of mesquite flour increased this time significantly for the dough with a 10% additive level. In contrast, the value of dough stability time was highest for the control sample. The introduction of mesquite flour lowered the values of this parameter, while the differences between addition levels were not significant. Likewise, for the other parameters, the values of which the control sample was significantly different from those for the doughs containing mesquite flour. The index of tolerance to mixing also increased significantly. Water absorption, on the other hand, was slightly, but significantly lower for dough samples containing mesquite flour. The changes in water absorption associated with the introduction of mesquite into the recipe are due to the replacement of some wheat flour, and therefore starch, with simple sugars with greater solubility and less ability to

absorb water. The results obtained in this study confirm the earlier observations of Bigne et al. (2016), who concluded on the basis of farinographic analysis that the addition of mesquite flour causes changes in water absorption. Consequently, the resulting dough is less stable compared to the wheat dough, which is caused by a weaker development of the gluten network. In turn, Gusmão et al. (2016) showed that mesquite flour has poor rheological properties, but due to its good nutritional characteristics, it is suitable for the production of cakes. In a further study, Bigne et al. (2019) found that the high share of mesquite flour in dough leads to the weakening of the gluten structure, thus weakening the dough and causing it to be less resistant to freezing.

Evaluation of the impact of recipe modification by using different additives is often performed using methods in the field of small strain rheology. Both the tangent values of the phase shift angle (in the range 0.35 - 0.45) and higher values of the storage modulus than the loss modulus ($G' > G''$) indicate the advantage of elastic characteristics over viscous ones (Figure 1b). The observed dependence of modulus values on the angular frequency and tan δ values indicate properties characteristic of weak gels. The presence of mesquite flour caused a proportional increase in the values of storage modulus and loss modulus (Figure 1a) with virtually no effect on tan δ values (Figure 1b). These observations confirm the values of the parameters of the power law models with which the mechanical spectra were described (Table 1). The values of the parameter K' indicative of the initial value of G', increased with an increase in the addition of mesquite flour, but a significant increase of this parameter was noted only with its share of 10% (Table 1). Similar changes were found for the parameter K'' indicating the starting value of G'' modulus (Table 1). On the other hand, when wheat flour was replaced by mesquite there was no significant impact on the values of parameters n' and n'', showing the dependence of moduli on angular frequency (Table 1). These results are also supported by the lack of a significant effect of the mesquite flour addition on tan δ values at $\omega = 1$ *rad/s*. Bigne et al. (2017) noted a significant increase in tan δ values of dough enriched with mesquite flour, which means a weakening of the dough, but the cited authors used much higher additions of this ingredient in the range of 15 to 35%.

Table 1. Influence of the diversified share of mesquite flour (MF) on the rheological parameters of the tested doughs

Parameter	Control	5% MF	10% MF	ANOVA - p
DT (min)	0.93±0.058^{a}	1.13±0.208^{ab}	1.37±0.153^{b}	0.037
ST (min)	7.47±0.208^{b}	5.80±0.265^{a}	5.17±0.451^{a}	<0.001
TI (BU)	25.3±3.21^{a}	35.7±2.52^{b}	40.3±1.53^{b}	<0.001
WA(%)	54.2±0.25^{b}	53.5±0.15^{a}	53.3±0.12^{a}	0.002
K' (Pa·s$^{n'}$)	5915±415.4^{a}	6675±363.2^{a}	7987±517.0^{b}	0.003
n'	0.212±0.004	0.219±0.002	0.214±0.002	0.098
R^2>	0.997	0.999	0.997	
K'' (Pa·s$^{n''}$)	2212±150.4^{a}	2448±120.0^{a}	2937±211.5^{b}	0.005
n''	0.223±0.008	0.228±0.002	0.219±0.000	0.183
R^2>	0.973	0.973	0.985	
tan δ at 1 rad·s^{-1}	0.408±0.005	0.412±0.005	0.410±0.011	0.862
$J_0 \times 10^4$ (Pa^{-1})	3.59±0.28^{b}	3.35±0.41^{ab}	2.77±0.17^{a}	0.040
$J_1 \times 10^4$ Pa^{-1})	6.55±0.68^{b}	4.14±0.72^{a}	3.77±0.61^{a}	0.004
$\eta_0 \times 10^{-6}$ (Pa·s)	0.54±0.16	0.33±0.04	0.50±0.15	0.196
λ (s)	129±23	80±25	86±21	0.075
R^2>	0.983	0.985	0.989	

DT - development time; ST - stability time; TI - tolerance index; WA - water absorption. Mean values ± standard deviation signed this same letters in particular rows are non-significant different at 0.05 level of confidence

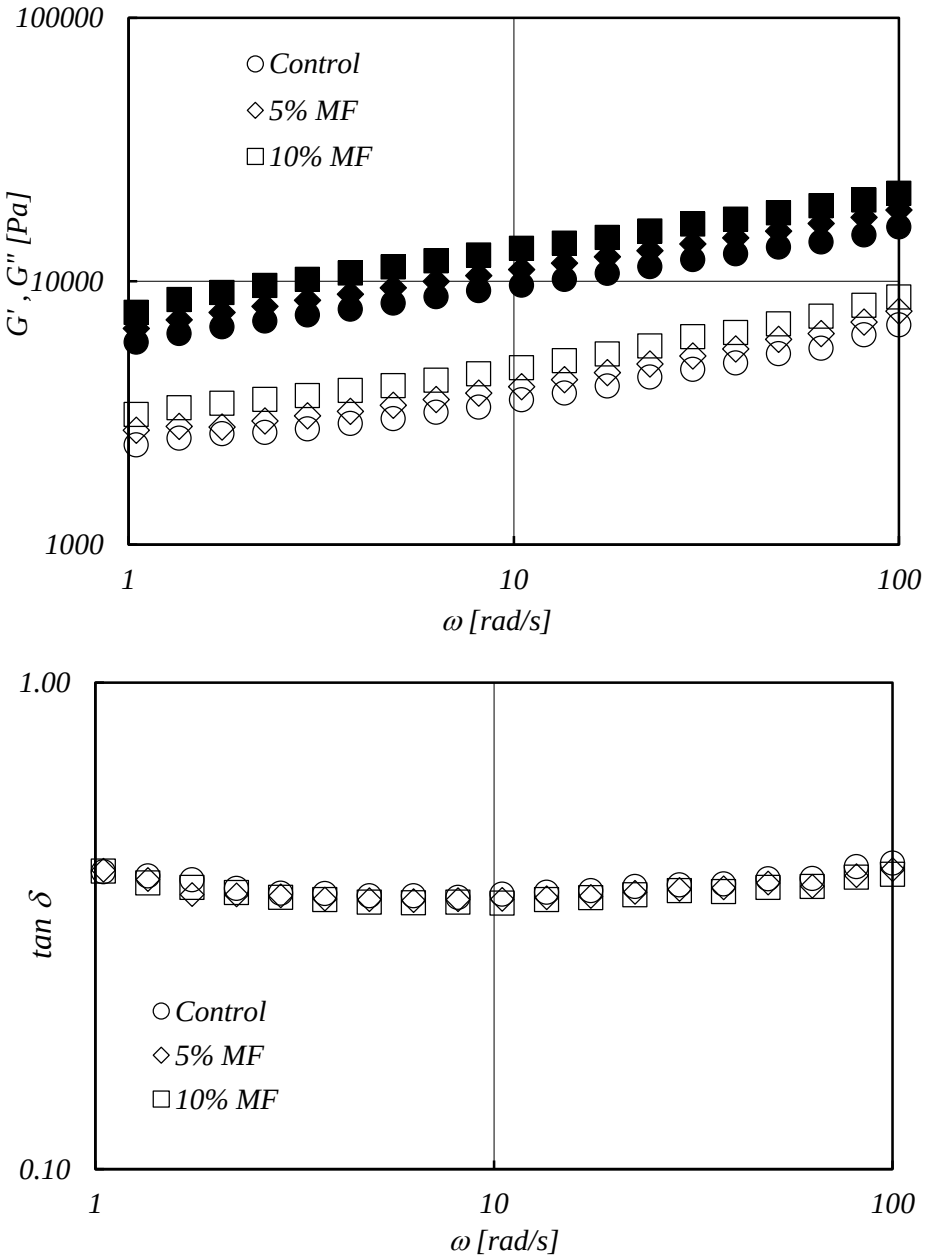

Figure 1. Mechanical spectra (a) and tangent of shift angle (tan δ = G''/ G') (b) of control dough and samples with mesquite flour (MF) addition; G' - filled symbols, G'' - empty symbols

Modification of the recipe by the introduction of mesquite flour resulted in a decrease in stress susceptibility for a 5% share and a pronounced decrease for a 10% share of this ingredient (Figure 2). Burgers model parameter values confirm these observations (Table 1). The values of the instantaneous compliance J_0 decreased with an increase in the proportion of mesquite flour. However, these were insignificant changes, with the exception of the sample containing 10% mesquite flour. On the other hand, the values of viscoelastic compliance J_1 were significantly lower for doughs with mesquite flour compared to the control sample, while the level of the addition of this ingredient itself did not have a significant effect (Table 1). Also, there was no significant effect of the addition of mesquite flour on the values of zero shear viscosity (η_0) and retardation time (λ_{ret}) (Table 1). The rheological characteristics, in terms of small deformations, of wheat dough enriched with mesquite flour allow concluding that the substitution of wheat flour in the recipe at a level of up to 10% has little effect on its characteristics. The literature data indicate that only the addition of mesquite flour at the level of 15 - 35% causes deterioration of the gluten network which demonstrates by increasing the tan δ value. This adverse effect can, however, be eliminated by the addition of transglutaminase (Bigne et al., 2017).

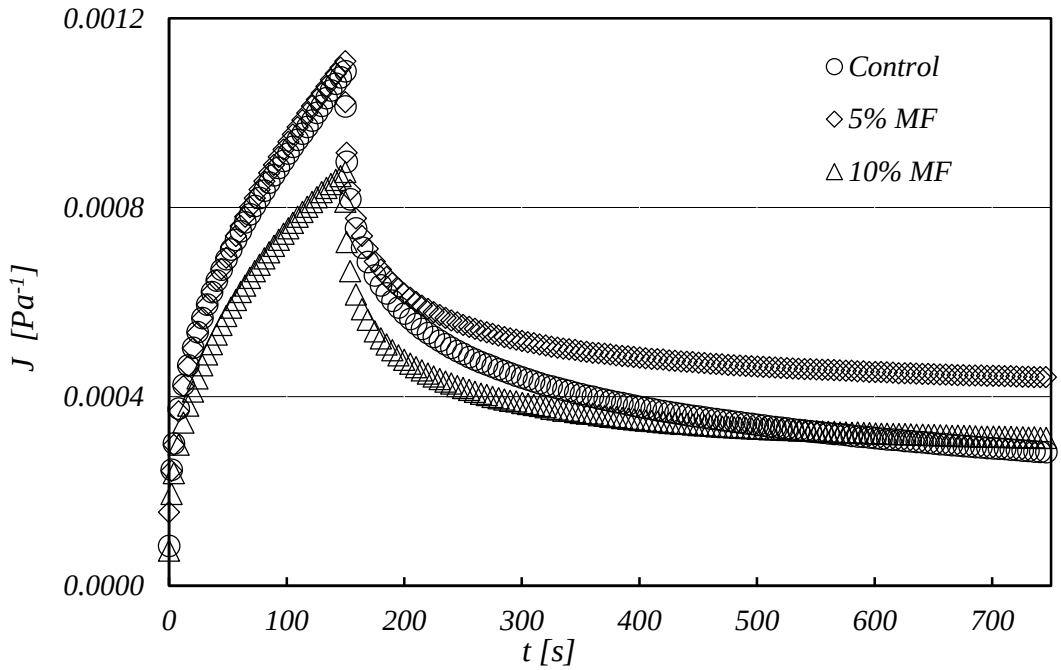

Figure 2. Creep and recovery curves of control dough and samples with mesquite flour (MF) addition.

Physical properties of the bread

The structure of the tested bread in cross-sections is shown in Figure 3. The crumb of the control wheat bread was characterised by the lightest colour, and the addition of mesquite flour clearly affected its darkening. Typical wheat bread is characterised by a relatively light colour, which can be associated by consumers with a highly processed product. Introducing mesquite flour into the recipe, which is rich in proteins, simple sugars and polyphenols, resulted in the darkening of the crumb colour. The images shown in Figure 3 present the structure of the bread crumb, which in the control wheat bread is characterised by the presence of a large number of fine pores. The introduction of the mesquite flour increased the pore size, and thus decreased their number per cm^2. These changes may be related to an increase in the amount of monosaccharides available to the yeast during fermentation, and thus an increased production of fermentation gases.

The basic parameter characterising the quality of bread and allowing the assessment of the influence of enriching ingredients are its volume and specific volume. The introduction of mesquite flour into the recipe of bread significantly increased its volume and specific volume. The changes were greater when more mesquite flour was introduced (Table 2). At a 10% share of mesquite flour, the bread volume increased by about 17% compared to the control sample. The literature indicates that the introduction of mesquite flour, especially in larger quantities, into wheat bread recipes weakens the gluten structure which results in a decrease in loaf volume (Bigne et al., 2016, 2018; González-Montemayor et al., 2021). On the other hand, Gonzales-Barron et al. (2020b) found that the presence of mesquite flour in amounts up to 10% increased the bread volume, which was also reflected in the present study.

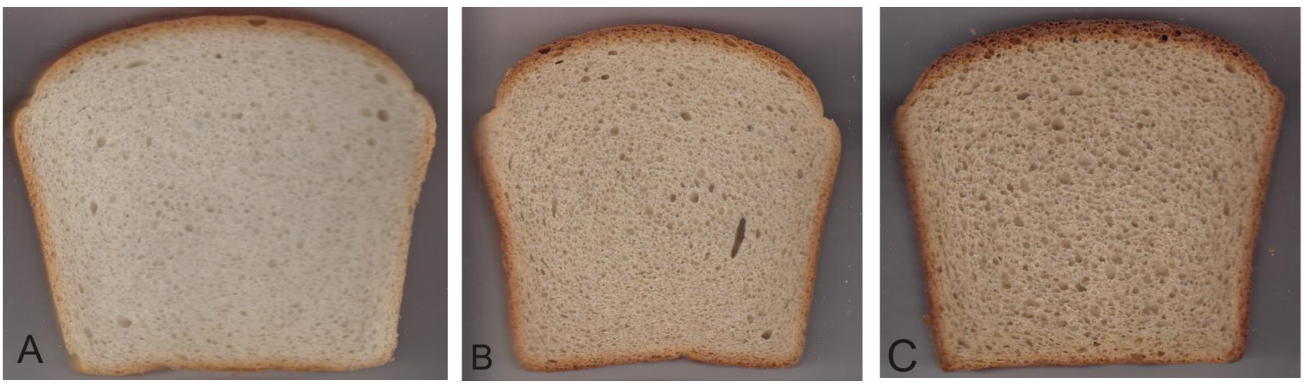

Figure 3. Cross-section images of tested breads: (A) control, (B) 5% mesquite flour, (C) 10% mesquite flour

Table 2. Physical parameters characterising the control bread and samples with different proportions of mesquite flour (MF)

Parameter	Control	5% MF	10% MF	ANOVA - p
Volume (cm^3)	654 ± 27^a	736 ± 11^b	768 ± 8^c	<0.001
Specific volume ($cm^3 \cdot g^{-1}$)	2.99 ± 0.11^a	3.39 ± 0.07^b	3.55 ± 0.02^c	<0.001
Average pore size (mm)	0.86 ± 0.03^a	0.95 ± 0.07^a	1.35 ± 0.06^b	<0.001
Porosity	0.45±0.01	0.45±0.01	0.47±0.02	0.090
Cell density (cm^{-2})	50.6 ± 1.9^b	47.6 ± 2.5^b	39.5 ± 1.6^a	<0.001
Percentage of pores > 5mm	2.68 ± 0.18^a	3.42 ± 0.44^b	6.95 ± 0.37^c	<0.001
*L**	73.5 ± 0.8^c	64.7 ± 0.3^b	58.6 ± 0.2^a	<0.001
*a**	0.94 ± 0.03^a	3.59 ± 0.07^b	5.32 ± 0.03^c	<0.001
*b**	19.9 ± 0.1^a	23.8 ± 0.1^b	26.4 ± 0.2^c	<0.001
ΔE	-	9.98	16.83	

Mean value ± standard deviation signed this same letters in particular rows are non- significant different at 0.05 level of confidence

The introduction of mesquite flour into the bread changed the parameters characterising the crumb, which were determined on the basis of digital image analysis (Table 2). Despite the fact that no significant impact of mesquite flour was observed on the porosity of the crumb itself, a significantly larger pore was found, including the pores with sizes > 5 mm, as well as a decrease in the number of pores per unit area. These results confirm observations of the crumb structure shown in Figure 3. Components of mesquite flour can modify the characteristics of the dough and the resulting bread in different ways. Simple sugars with low molecular weights can weaken the structure of the dough, but on the other hand, they hydrate more easily and are a better medium for yeast, which can stimulate their growth and production of fermentation gases. On the other hand, the proteins present in the mesquite flour and the fibre with high water absorption and swelling capacity caused the strengthening of the crumb structure as well as water and fermentation gases retention. The improvement of porosity and crumb structure of wheat bread with the addition of mesquite flour was observed by Gonzales-Barron et al. (2020a).

The crumb of the control wheat bread showed the highest value of the L* parameter, indicating the brightness of the sample (Table 2). The presence of mesquite flour significantly reduced the L* value. Simultaneously, higher values of the parameters a* and b* indicating an increase of redness and yellowness was observed, with a significant predominance of the latter. Such changes in the share of individual colour components result not only in a darker crumb colour, but also in a shift of the colour image toward brown colour, characteristic of dark bread associated with high nutritional value. The calculated values of AE (Table 2) indicate that the differences in colour between the samples with the addition of mesquite flour and the crumb of the control sample are noticeable by any observer. The change in crumb colour due to the introduction of mesquite flour is related to the presence of protein components and reducing sugars which may undergo Maillard reactions during baking, the darker colouration of the mesquite flour itself, and the presence of polyphenols in it. Also, Bigne et al. (2015) observed a favourable effect of mesquite flour on the colour of wheat bread. It should be noted that, considering the results of this research and the literature data, the replacement of wheat flour with mesquite flour up to a certain amount causes positive changes in physicochemical characteristics, and then their deterioration. It may be related to the loss of gluten occurring as a result of replacing wheat flour. This loss causes a reduction in the viscosity of the dough and, up to a certain value, improves fermentation conditions, which is further supported by the increased content of simple sugars supplied with mesquite flour. However, with a further increase in the proportion of mesquite flour, the loss of gluten is too great and the weakening of the structure associated with this leads to a deterioration of the physical characteristics of the bread by significantly weakening its structure.

The most important parameter of texture determined is the hardness of the crumb, whose values on each day of storage were highest for the control bread and ranged from 1.75 to 5.63 N (Table 3).

Table 3. Influence of storage time and different share of mesquite flour (MF) on texture parameters of tested breads

Sample	Day	Hardness (N)	Springiness	Cohesiveness	Chewiness (N)	Resilience
Control	1	1.75±0.05^{b}	0.99±0.01^{d}	0.90±0.01^{e}	1.57±0.06^{b}	0.50±0.01^{e}
	2	4.99±0.54^{e}	0.96±0.01^{bc}	0.76±0.03^{c}	3.62±0.45^{e}	0.33±0.02^{c}
	3	5.63±0.30^{f}	0.95±0.00^{ab}	0.69±0.02^{a}	3.71±0.29^{e}	0.27±0.02^{a}
5% MF	1	1.40±0.03^{ab}	0.99±0.01^{d}	0.90±0.01^{e}	1.27±0.05^{ab}	0.51±0.00^{e}
	2	3.42±0.20^{d}	0.97±0.01^{c}	0.79±0.02^{d}	2.60±0.18^{d}	0.35±0.02^{d}
	3	3.81±0.42^{d}	0.96±0.00^{bc}	0.74±0.01^{bc}	2.68±0.29^{d}	0.30±0.01^{b}
10% MF	1	1.28±0.03^{a}	0.99±0.01^{d}	0.90±0.01^{e}	1.15±0.05^{a}	0.49±0.01^{e}
	2	2.60±0.12^{c}	0.97±0.00^{bc}	0.80±0.03^{d}	2.00±0.04^{c}	0.36±0.01^{d}
	3	3.65±0.14^{d}	0.95±0.01^{a}	0.72±0.02^{ab}	2.47±0.09^{d}	0.30±0.02^{b}
Two-way ANOVA-p						
Factor A (level)		<0.001	0.080	0.012	<0.001	0.003
Factor B (time)		<0.001	0.000	0.000	<0.001	0.000
Factor A× Factor B		<0.001	0.429	0.114	<0.001	0.027

Mean values ± standard deviation signed this same letters in particular columns are non-significant different at 0.05 level of confidence

The share of mesquite flour reduced the hardness of the bread crumb, the more so, the more mesquite flour was introduced into the recipe. A two-way analysis of variance proved that both factors - the addition level and storage time, as well as their combination, have a significant effect on the change in hardness during storage. According to Gonzales-Barron et al. (2020b), the presence of Peruvian mesquite (*Prosopis pallida*) flour reduces the staling of wheat bread during storage.

Crumb springiness values decreased with storage time, however, there was no effect of the mesquite flour proportion on the values of this parameter. Bigne et al. (2015) and Gonzales-Barron et al. (2020b) observed a reduction in the springiness of the wheat bread crumb associated with the supplementation of the recipe with mesquite flour.

Cohesiveness is an important parameter for the evaluation of bread texture also from the the consumers' point of view. A decrease in its value may indicate, the tendency of the crumb to shrink, which will not be acceptable to consumers. Immediately after baking, the cohesiveness of the crumb of all samples was at a similar level but decreased during storage. The greatest decrease in cohesiveness was observed for the control bread, indicating that the share of mesquite flour reduces the occurrence of this unfavourable characteristic. An analysis of variance showed that both factors - the addition level and storage time significantly affect crumb cohesiveness.

Since chewiness is closely related to hardness, the results showed a similar trend (Table 3). The control bread had the highest chewiness on individual days of storage, while the crumb of bread with a 10% proportion of mesquite flour had the lowest. The introduction of mesquite flour into the bread recipe also had an effect on resilience (Table 3), which is a measure of the structure's ability to return after the first compression. Resilience values decreased with increasing storage time, and the highest values were recorded for the control sample. For this parameter, both the additive level and storage time, as well as the combination of both factors, significantly affected its values. Summarizing the results on the effect of mesquite flour on the crumb texture after baking and during storage, it can be concluded that the effect is favourable and concerns a reduction in the hardness and chewiness of the crumb during three days of examination, as well as a reduction in the increase in cohesiveness. The results obtained confirm previous literature data. Gonzales-Barron et al. (2020a) found that supplementation of baked goods with mesquite flour at levels up to 10% reduces crumb hardness. Bigne et al. (2018), on the other hand, indicate that higher amounts of mesuite flour increases crumb hardness and chewiness.

Thermal properties

The designated initial (T_I) of melting frozen ice crystals takes place in the temperature range from -13.8ºC for the control sample to about -16.3ºC for the sample with a 10% share of mesquite flour, the presence of which significantly lowered the value of the discussed parameter in comparison to the control sample. The determined transformation initiation temperature values are narrowly higher than those noted by Ribotta and Le Bail (2007) for

bread. The values of the transformation temperatures: onset T_O, maximum T_P, and final T_E for the control bread crumb were -9.4, 2.6, and 10.0°C, respectively. The presence of mesquite flour in the recipe lowered the values of temperatures T_O and T_P, especially in the case of its higher proportion. On the other hand, mesquite flour had no significant impact on the values of the end-of-transformation temperature (T_E). The enthalpy of ice crystals melting ranged between 77.6-78.9 J/g (Table 5). Ribotta and Le Bail (2007) report slightly higher values for this parameter. All the crumb samples tested contained about 23% freezable water (Table 4), and the presence of mesquite flour did not significantly affect its content.

When the bread crumb is heated under controlled conditions of thermal analysis, an endothermic transformation is observed associated with the melting of recrystallized amylopectin, which is responsible for the long-term retrogradation of starch (Korus et al., 2021). The temperature range for the onset of this transformation was determined to be 46.0 -56.3°C, with no significant variation between the samples studied. The maximum temperature values ranged from 62.6 to 70.8°C, and the final temperature from 73.1 to 83.3°C with no statistical variation found. The values of the enthalpy of transformation corresponding to the amount of heat required for the disintegration of the retrograded amylopectin are shown in Figure 4. The two-way analysis of variance performed showed that both factors, i.e. the addition level and storage time, as well as their combination, significantly affected the determined values. On the day of baking, the enthalpy was characterised by an upward trend corresponding to the proportion of mesquite flour, but the differences were not statistically significant. Also on the second day, there were no significant differences between the tested samples. On the last day of the research, significant differences were found between the average values of enthalpy. The highest value of enthalpy was noted in the wheat bread, and the share of mesquite flour significantly reduced the enthalpy value to a greater extent, the greater the concentration of the modifying ingredient. These observations confirm the results of crumb hardness determination and suggest that mesquite flour can effectively reduce the staling of wheat bread.

Table 4. Parameters characterising the effect of mesquite flour (MF) on the freezable water in tested breads

Parameter	Control	5% MP	10% MP	ANOVA - p
$-\Delta H$ ($J \cdot g^{-1}$)	78.4±0.3	77.6±1.0	78.9±5.5	0.924
T_I (ºC)	-13.8 ± 0.1^{c}	-14.5 ± 0.1^{b}	-16.3 ± 0.1^{a}	<0.001
T_O (ºC)	-9.4 ± 0.2^{c}	-10.2 ± 0.2^{b}	-11.5 ± 0.2^{a}	0.005
T_P (ºC)	2.6 ± 0.1^{b}	2.4 ± 0.1^{b}	2.0 ± 0.02^{a}	0.017
T_E (ºC)	10.0±0.6	9.7±0.4	9.5±0.1	0.494
FW ($g \cdot g^{-1}$)	0.235±0.001	0.232±0.003	0.236±0.016	0.924

Mean value ± standard deviation signed this same letters in particular rows are non-significant different at 0.05 level of confidence

Table 5. The results of the sensory evaluation of breads

Sample		Control	5 % MP	10 % MP	ANOVA - p
Appearance		4.8±0.4	5.0±0.0	4.9±0.3	0.154
Crust	Colour	2.8 ± 0.8^{b}	2.4 ± 0.5^{ab}	2.0 ± 0.9^{a}	0.022
	Thickness	3.9±0.4	3.9±0.4	3.8±0.4	0.853
	Other features	4.0 ± 0.0^{b}	3.6 ± 0.5^{a}	3.6 ± 0.5^{a}	0.015
Crumb	Elasticity	4.0 ± 0.0^{b}	3.7 ± 0.5^{ab}	3.6 ± 0.5^{a}	0.026
	Porosity	2.9±0.4	2.6±0.5	2.6±0.5	0.200
	Other features	2.8±0.4	2.7±0.5	2.4±0.5	0.072
Taste and aroma		5.3±1.5	5.1±1.5	4.9±2.0	0.809

Mean value of fifteen replication ± standard deviation. Mean values signed this same letters in particular rows are non-significant different at 0.05 level of confidence

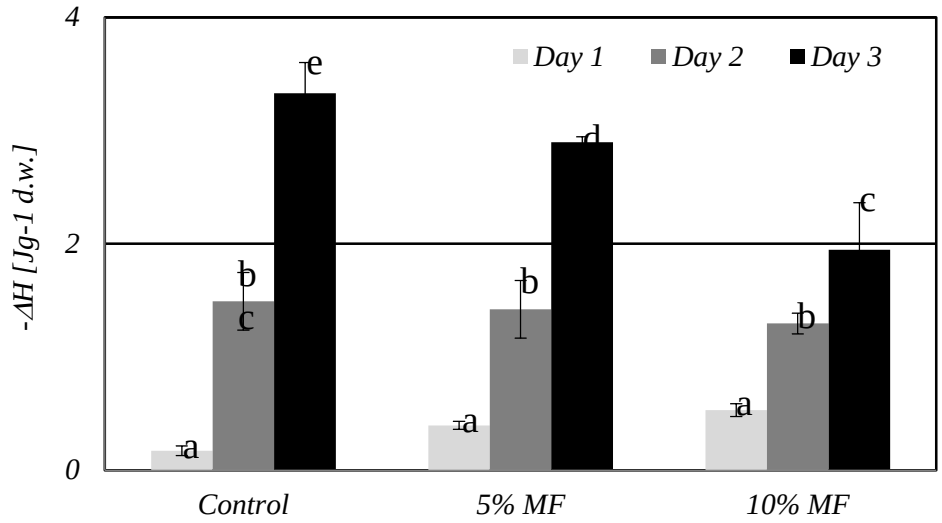

Figure 4. Effect of storage time on amylopectin melting enthalpy after retrogradation in tested breads. Mean values signed this same letters are non-significant different at 0.05 level of confidence

Sensory evaluation of bread

The overall appearance of the bread containing mesquite flour achieved acceptability at the level of the control sample (Table 1). In contrast, a decrease in the acceptability of the samples with mesquite flour was noted in the case of crust colour, which was significantly darker than in wheat bread. This fact may have lowered the acceptability of the crust because it was not characteristic of wheat bread. Acceptability of individual crumb characteristics was also slightly lower than for wheat bread, with the level of an additive having a limited effect on this (Table 3). The lower acceptability of crumb springiness and porosity may have been related to an increase in pore size and the number of large pores (>5 mm), although the porosity value itself remained constant (Table 2).

The evaluation of the acceptability of aroma and taste indicated that only a 10% share of the flour from mesquite had some, although not significant, effect on these characteristics. Summarizing the results of the sensory assessment, it can be stated that a significant reduction in the acceptability of bread characteristics was only related to the crust colour of the sample containing 10% of mesquite flour. For the other characteristics, the decrease in acceptability was small and mostly not statistically significant. Important factors affecting the sensory characteristics of bread are the high content of monosaccharides and protein in mesquite flour. These ingredients change the colour and structure of the crumb, as well as the taste of the bread. According to Bigne et al. (2018), mesquite flour can be a desirable ingredient for improving the sensory acceptability of wheat bread.

CONCLUSIONS

The conducted research allows to conclude that the wheat doughs studied were typical for weak gels, as indicated by the angular frequency-dependent storage moduli G' and loss moduli G", while the values of the phase shift angle δ = G"/G' at 1 Hz were about 0.41. The presence of mesquite in composite flour caused an increase in both the G' and G" moduli values, with the tan δ value unchanged. In addition, the presence of mesquite flour resulted in a decrease in the value of the instantaneous and viscoelastic compliance, while viscosity at zero shear changed insignificantly. The introduction of mesquite flour in the formulation increased the volume of the bread and the number of large pores > 5 mm while the pore density decreased compared to the control wheat bread. The proportion of mesquite flour decreased the brightness of the crumb and increased the share of the yellow colour. The crumb of bread containing mesquite flour was significantly softer during storage than the control wheat sample, which indicates a reduction in the staling process.The results obtained confirm that the mesquite flour added in amounts of up to 10% can be a valuable ingredient that improves the quality and extends the shelf life of wheat bread.

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