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Impact of Chia Flour on the Nutritional and Rheological Properties of Wheat Flour Blends and Dough

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Abstract

Aim: This study aimed to evaluate the effects of incorporating ground chia seed (chia flour, CF) in varying proportions (0/100, 5/95, 10/90, 15/85, 20/80, and 25/75 w/w chia/wheat flour) on the rheological and pasting characteristics of blends made with two types of wheat flour (types 650 and 750).

Methodology: In the analysed mixtures of wheat flour and chia flour, the total protein content was determined using the Kjeldahl method, and then the properties of starch and the activity of amylolytic enzymes were assessed using an amylograph. Additionally, the Mixolab 1 device was used to analyse the rheological properties of the dough, including its behaviour during mixing and the quality of starch and protein.

Results: Adding CF, a rich source of protein, fibre, and healthy fats, increased both total protein content and initial gelatinization temperature in the blends. However, it also extended dough development time, decreased dough stability, and reduced susceptibility to retrogradation.

Implications and recommendations: The addition of chia flour has a positive effect on the technological value of dough, therefore it is recommended to add it in amounts even greater than 10%.

Originality/value: This study provides new insights into the impact of chia flour on dough rheology, expanding current knowledge on functional ingredients in bakery applications. The findings contribute to the development of innovative, health-oriented wheat-based products enriched with high-value nutrients.

Keywords: *Salvia hispanica* L., wheat dough, rheology, Mixolab

1. Introduction

Salvia hispanica L., commonly known as chia, is a flowering plant from the mint family (*Lamiaceae*) native to regions of Central and South America, including Mexico, Guatemala, and Nicaragua. Chia seeds are used either whole, milled into flour, or extracted for their oil. The name 'chia' derives from the Nahuatl word 'chian or 'chien', meaning 'oily'. Historically, chia was staple food in ancient civilizations such as the Mayans and Aztecs, although its rise as a superfood is fairly recent (Khan et al., 2022). Just a few decades ago, chia remained a largely unknown grain with limited consumption outside local contexts (Bartkiene et al., 2023).

The rising rates of lifestyle-related diseasessuch as cardiovascular issues, type 2 diabetes, and colon cancer are closely linked to obesity, undlining the need for dietary and lifestyle changes. Epidemiological studies have highlighted that health-promoting diets tend to be high in protein, dietary fibre, and omega-3 fatty acids, while being low in saturated and trans fats and cholesterol (Ashura et al., 2021; Rubavathi et al., 2020). In response to growing concerns about health and a preference for foods with specific health-enhancing properties, there has been a heightened interest in functional foods, items integrated into the regular diet, offering physiological benefits or reducing the risk of chronic diseases beyond basic nutritional requirements (Coelho & Salas-Mellado, 2015; Kulczyński et al., 2019).

Chia seeds have attracted considerable interest for their nutrient density and health-promoting qualities, including high levels of protein, fibre, and beneficial fatty acids. They are classified as a novelty in Europe due to their unique nutritional profile (European Parliament and of the Council, 2015). Chia seeds contain a significant amount of dietary fibre, ranging from 23% to 36% (Ashura et al., 2021), with the majority being insoluble dietary fibre (IDF), which is important for digestive health. Their omega-3 and omega-6 fatty acid content, comprising up to 40% of their composition, also makes them an excellent source of polyunsaturated fatty acids (PUFAs), especially for diets deficient in α-linolenic acid (ALA) and linoleic acid (Ali et al., 2012; Oliveira-Alves et al., 2017; Oteri et al., 2023). Additionally, chia seeds contain essential minerals, proteins, and bioactive compounds such as tocopherols and phenolics, making them an exceptional protein source, surpassing conventional grains such as wheat, oats, maize, and rice (Ashura et al., 2021; Khan et al., 2022).

With increasing consumer interest in health and nutrition, researchers are challenged to create products that meet these demands. Despite their high protein and dietary fibre content, processed foods are often low in these nutrients, which are frequently lost during processing (Cena & Calder, 2020). In bakery products, refined wheat flour, lacking outer layers like bran, typically serves as the primary ingredient, though this reduces nutritional benefits. While refined flour produces desirable textures and flavours, it lacks essential nutrients, including fibre, protein, minerals, and vitamins.

Hence, there is an urgent need to replace or supplement wheat flour with plant-based ingredients beneficial to health, creating mixtures for the production of healthy and nutritious products (Bartkiene et al., 2023; Ozón et al., 2023). Chia seeds, thanks to their properties, can be an excellent enrichment of wheat flour. Despite the high nutritional value of chia seeds, their addition can also affect the rheological properties of flour mixtures, as well as the quality of the dough. Chia seed protein has a good water retention capacity and an excellent oil retention capacity, which makes it a useful ingredient in bakery products (Ashura et al., 2021). There are few studies on the development of food products enriched with *Salvia hispanica* in amounts greater than 15%. The aim of this study was to compare the effect of different amounts, from 5% to 25%, of ground chia seeds in chia flour on the rheological and gelling properties of blends obtained from two types of wheat flour.

2. Methodology

2.1. Materials

The study was conducted with wheat flour (WF) type 650 (moisture 10.9%, total protein 13.6%, wet gluten 32.3%, ash 0.62 g/100 g, fat 1.4 g/100 g, carbohydrates 74.1 g/100 g, falling number 408 s) and type 750 (moisture 10.7%, total protein 14.0%, wet gluten 33.3%, ash 0.79 g/100 g, fat 1.7 g/100 g, carbohydrates 68.4 g/100 g, falling number 322 s) (GoodMills Polska Ltd., Poland) and chia flour (CF) (*Salvia hispanica* L.) (moisture 8.8%, total protein 16.7%, fat 30.74 g/100 g, carbohydrates 7.72 g/100 g, dietary fibre 34.4%) (TAR-GROCH-FIL, Zakliczyn, Poland). Fresh pressed yeast was supplied by Lesaffre Bio-Corporation Inc. (Warsaw, Poland). Other ingredients, such as salt, were purchased from a local store.

2.1.1. Preparation of Flour Mixtures

Chia seeds were ground using a laboratory mill type WŻ-1 (Sadkiewicz Instruments, Bydgoszcz, Poland) and chia flour (CF) was obtained. The granulation of CF was below 250 µm. CF was used to prepare blends with WF type 650 and 750 in 0/100, 5/95, 10/90, 15/85, 20/80 and 25/75 w/w ratios. The control sample was 100% WF. The samples were stored in airtight containers and kept in a refrigerator (5°C) until used.

2.2. Total Protein Content in Blends

Blends were determined for total protein content – with the Kjeldahl method (ICC No. 105/2) using a Foss Tecator Kjeltec 2400 analyser (Foss, Hilleroed, Denmark) (N×5.7).

2.3. Amylographic Measurements

The properties of pastes made of the blends WF/CF were evaluated using an amylograph (Brabender, Duisburg, Germany) according to AACC Methods 22-10. The amylograms obtained were used to read out values of the initial and final gelatinization temperatures (in °C) and maximum paste viscosity in Amylographic units (AU). The measurement was performed in duplicate.

2.4. Mixolab Test

According to the AACC method 54-60.01, the Mixolab 1 device (Chopin Technologies, Paris, France) was used to assess the wheat blends' rheological properties, including the dough during mixing, as well as the quality of starch and protein. The rheological behaviour of dough was analysed in the first stage using the standard option "Chopin+" protocol. The resulting mixing curve provided information on protein development, stability and water absorption (C1), protein quality (C2), starch gelatinization (C3), stability of hot gel and amylase activity (C4), and starch retrogradation (C5). The measurement was performed in duplicate.

2.5. Statistical Analysis

The results presented are mean values ± standard deviation. The statistical analysis of results obtained for the WF/CF blends were conducted with the two-way analysis of variance (ANOVA) using Statistica 13.3 (StatSoft, Kraków, Poland). Significant differences ($p \leq 0.05$) between the mean values were determined using the Duncan's Multiple Range Test.

3. Results and Discussion

3.1. Determination of the Characteristics of the Starch-amylase Complex Using the Amylograph and Total Protein Content in Blends

Values of amylolytic determination of the analysed WF/CF blends depending on the WF type and the share of CF are shown in Figures 1 and 2, and total protein content in Figure 3.

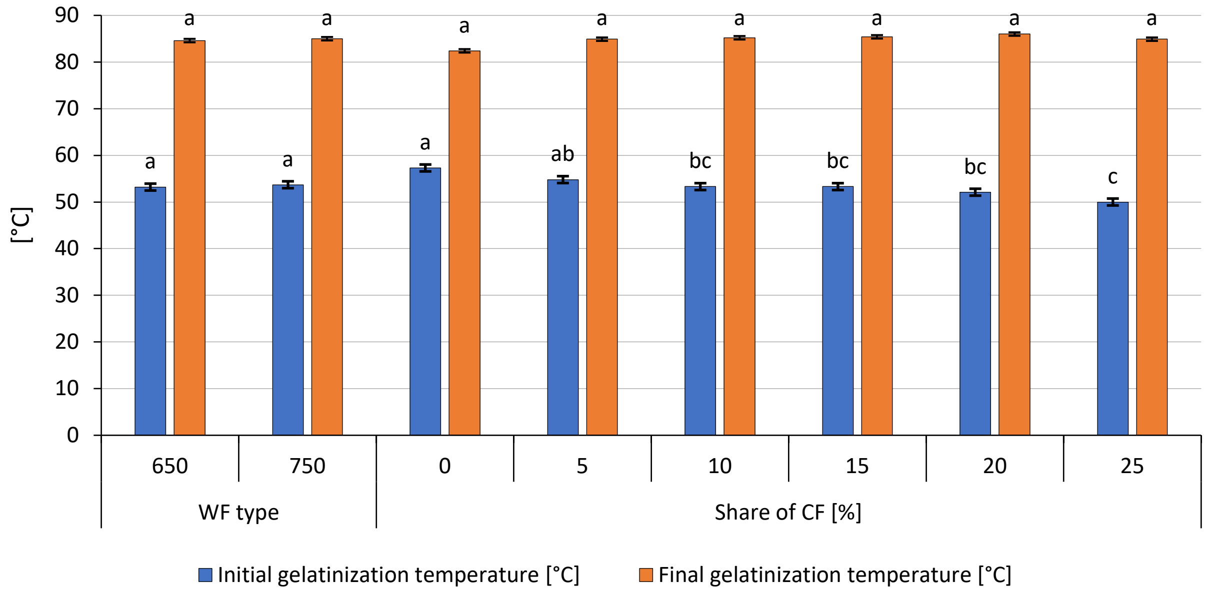


Fig. 1. Initial and final gelatinization temperature (°C) of WF/CF blends depending on the WF type and the share of CF. Small letters in the same row within one factor indicate a statistical difference (a > b > c … etc.) according to Duncan's test ($p \leq 0.05$)

Source: own research.

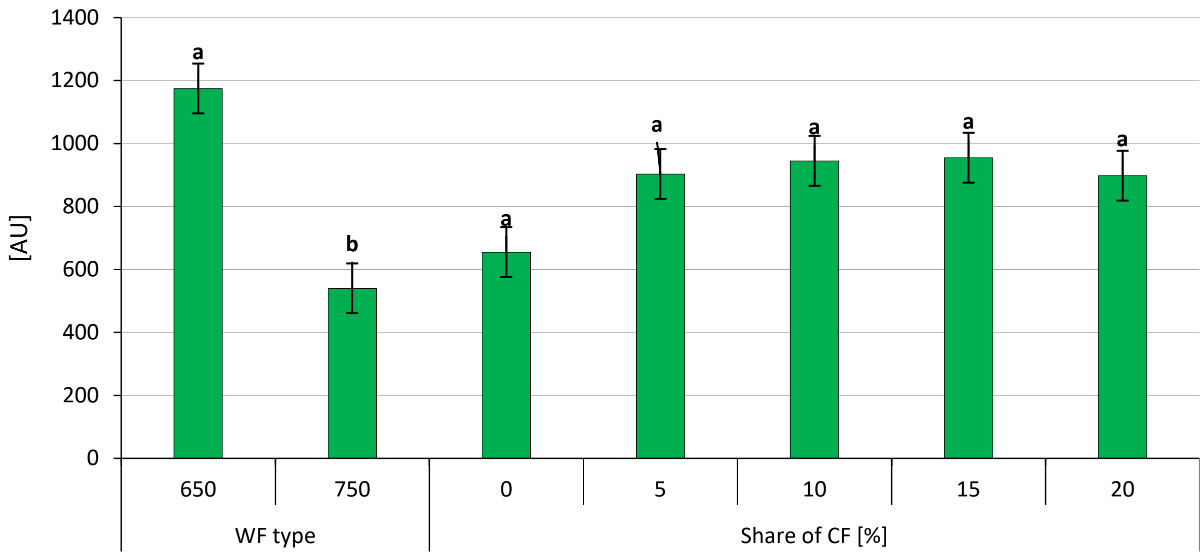


Fig. 2. Maximum viscosity (AU) of WF/CF blends depending on the WF type and the share of CF. Small letters in the same row within one factor indicate a statistical difference (a > b > c … etc.) according to Duncan's test ($p \leq 0.05$)

Source: own research.

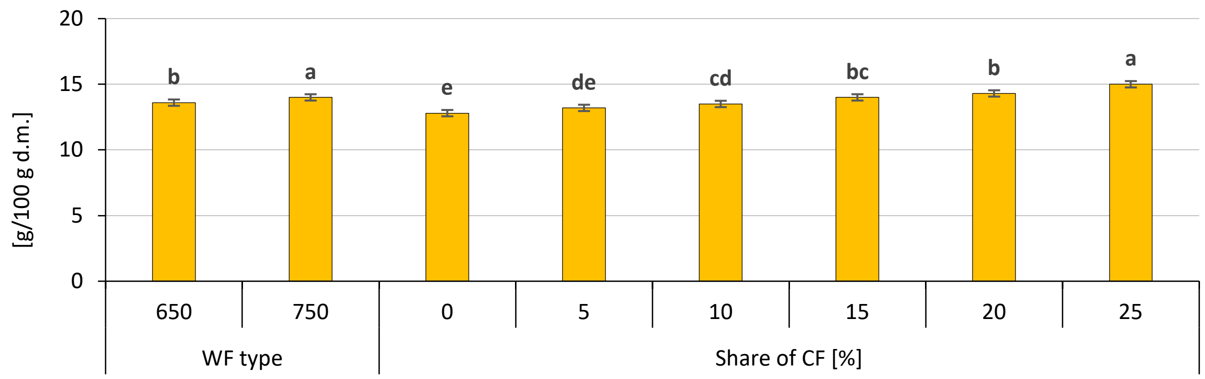


Fig. 3. Total protein content (g/100 g d.m.) of WF/CF blends depending on the WF type and the share of CF. Small letters in the same row within one factor indicate a statistical difference (a > b > c ... etc.) according to Duncan's test ($p \leq 0.05$)

Source: own research.

The type of wheat flour (WF) did not influence the rheological properties of the mixtures, including the initial and final gelatinization temperatures. Blends of WF and chia flour (CF) made with WF type 650 showed a maximum viscosity twice as high as those prepared with WF type 750, suggesting lower amylolytic activity in WF type 650. Adding CF gradually reduced the initial gelatinization temperature from 57.3°C in the control to 50.0°C in samples with 25% CF. The lipids in CF tend to inhibit starch gelatinization by forming a lipid–amylose complex, which stabilizes the starch granules and increases gelatinization enthalpy (Iglesias-Puig & Haros, 2013). The addition of CF, however, did not significantly alter other amylographic properties.

Both the WF type and CF proportion influenced the total protein content in WF/CF blends. Mixtures with WF type 750 had a higher total protein content than those with WF type 650. Adding CF increased the total protein content from 12.8 g/100 g dry matter in the control to 15.0 g/100 g dry matter in the 25% CF sample.

3.2. Mixolab Test

Mixolab provides the benefit of evaluating multiple flour characteristics of cereals in a single test, including proteins, starch, and related enzymes. Figure 4 displays the average values for hydration, Figure 5 – dough development time and stability, Figure 6 – torque C2, C3, C4, C5, and the difference between C5 and C4 for each treatment, depending on the WF type and CF proportion. Mixolab--generated graphs are presented in Figure 7.

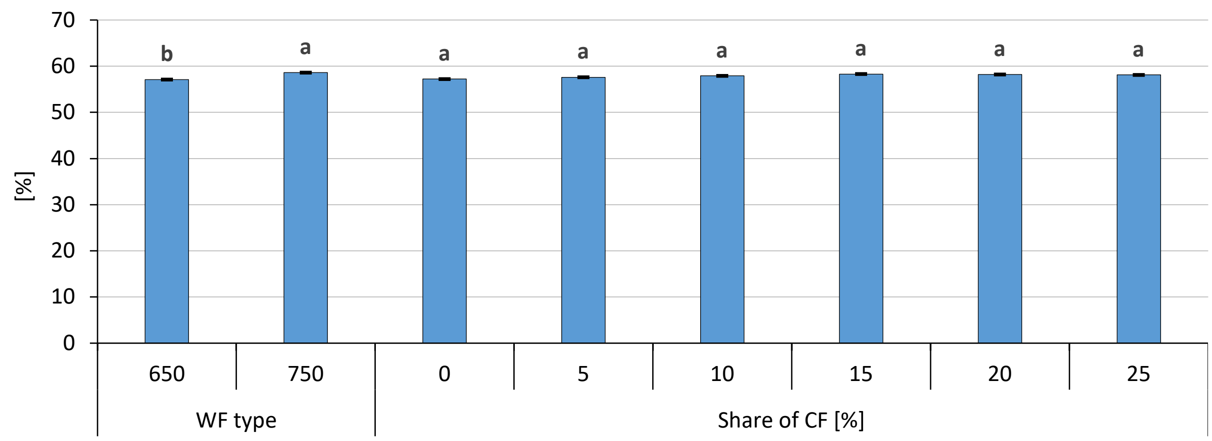


Fig. 4. Hydration (%) of WF/CF blends depending on the WF type and the share of CF. Small letters in the same row within one factor indicate a statistical difference (a > b > c ... etc.) according to Duncan's test ($p \leq 0.05$)

Source: own research.

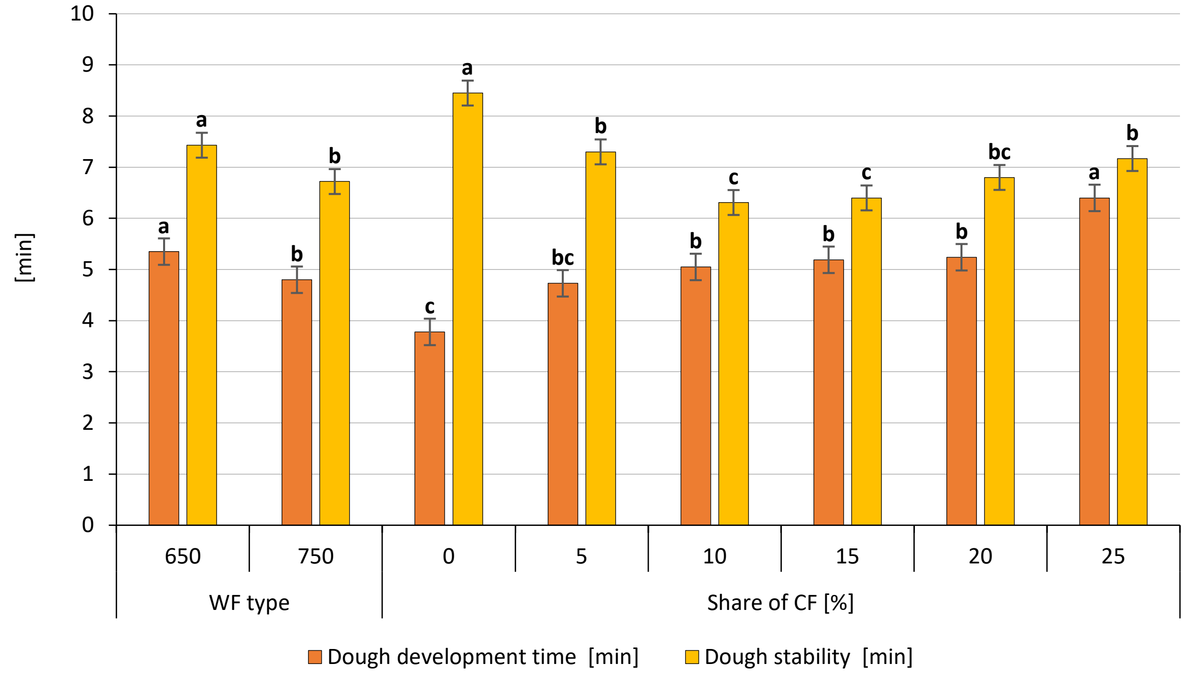


Fig. 5. Dough development time and dough stability (min) of WF/CF blends depending on the WF type and the share of CF. Small letters in the same row within one factor indicate a statistical difference (a > b > c … etc.) according to Duncan's test ($p \leq 0.05$)

Source: own research.

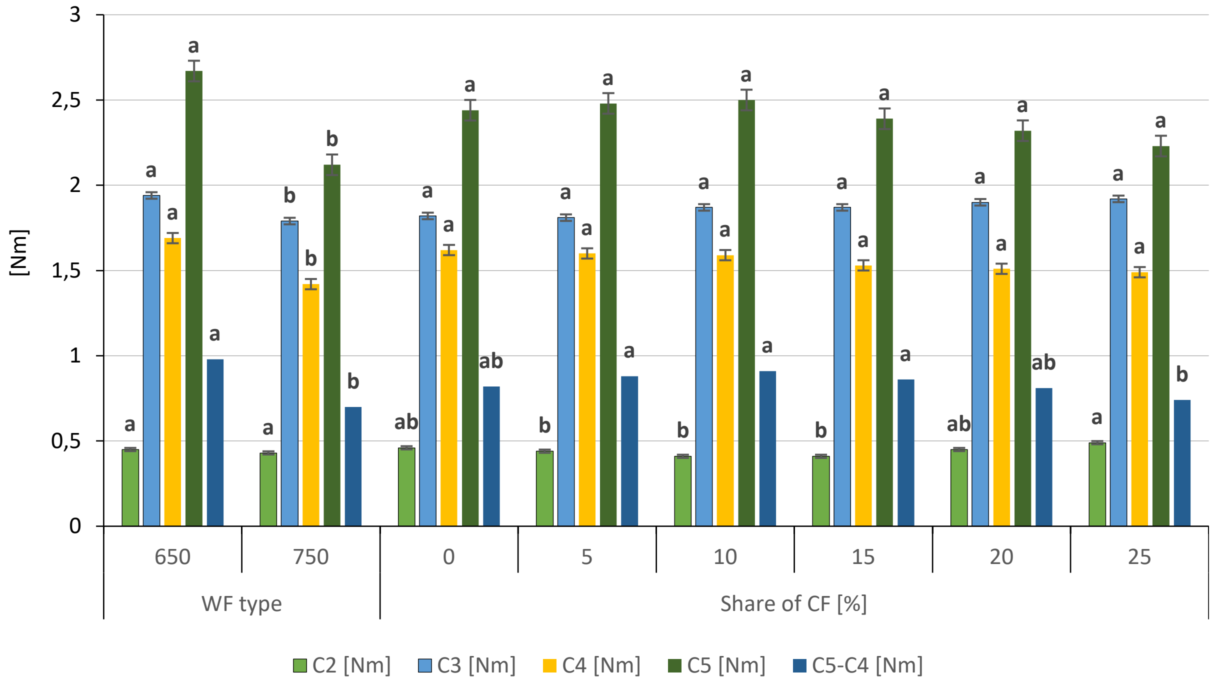
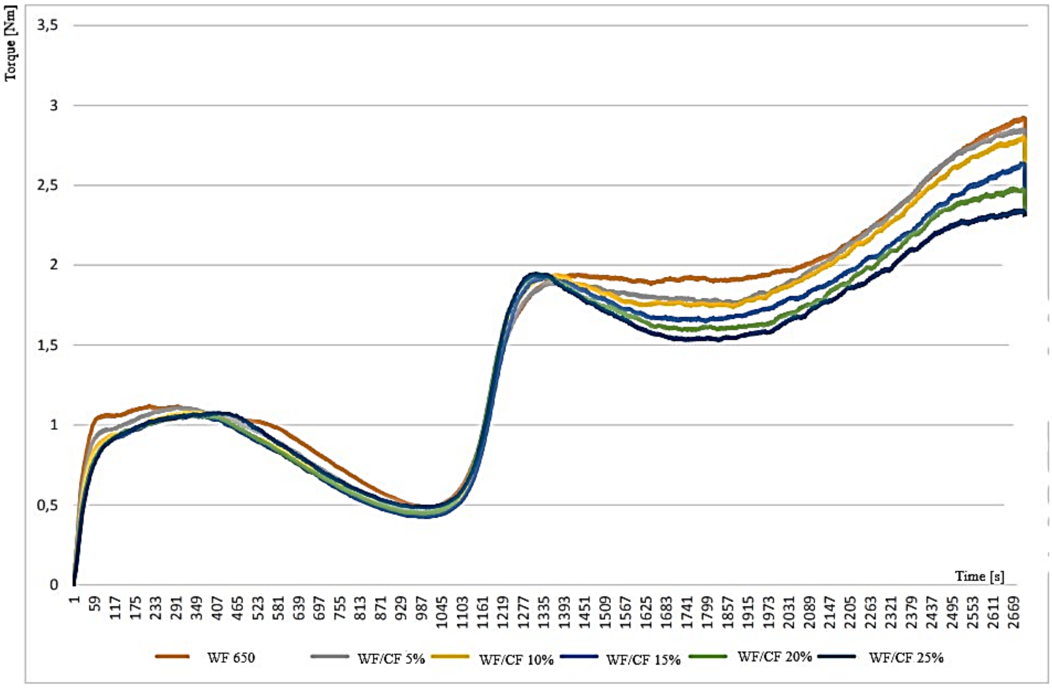
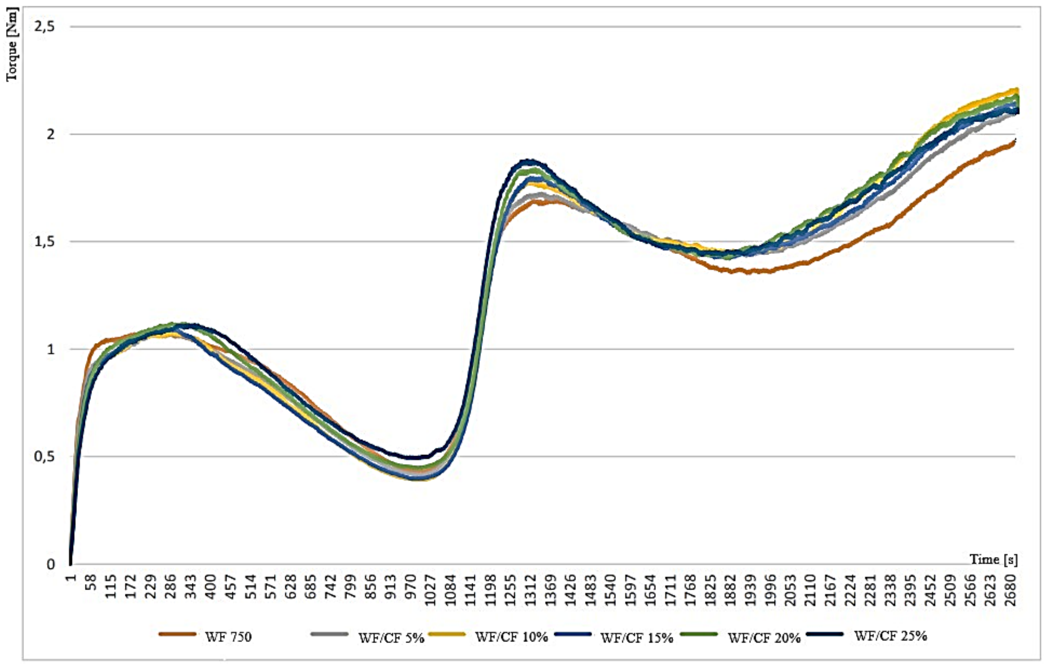


Fig. 6. Torque C2, C3, C4, C5, and the difference between C5 and C4 (Nm) of WF/CF blends depending on the WF type and the share of CF. Small letters in the same row within one factor indicate a statistical difference (a > b > c … etc.) according to Duncan's test ($p \leq 0.05$)

Source: own research.



(a)



(b)

Fig. 7. Mixolab profiles of WF and WF/CF blends. (a) WF type 650, (b) WF type 750. WF – wheat flour, CF – chia flour, WF/CF 5% – WF/CF blend with 5% share of CF. Small letters in the same row within one factor indicate a statistical difference (a > b > c … etc.) according to Duncan's test ($p \leq 0.05$)

Source: own research.

The Mixolab water absorption metric indicated the amount of water needed to achieve a dough consistency of 1.1 ± 0.05 Nm. Among the samples analysed, WF/CF blends made from WF type 750 exhibited higher hydration levels compared to those made from WF type 650, most likely due to the higher protein content. While various factors influence the rheological properties of wheat, they are primarily shaped by the quantity and composition of gluten storage proteins (glutenins and gliadins). Gluten has a high water-binding capacity (up to 300% of its own weight), along with elasticity, stickiness, and ductility (Peng et al., 2022). Notably, the addition of CF had no statistically significant impact on the water absorption of WF/CF blends. Chia seeds are gluten-free, and according to Sandoval-Oliveros and Paredes-López (2013), the main protein fraction in chia seeds is globulins (52%), which are highly water-affinitive, easily digestible, and partially or fully soluble. In a study by Iglesias-Puig and Haros (2013), the addition of 5% whole chia flour to wheat flour raised water absorption from 57.8% to 58.5%, despite a decrease in gluten content, primarily due to the high water-binding capacity of mucilage from chia's fibre content. When semi-defatted and low-fat chia flour were added, water absorption was significantly higher than with whole chia flour. Moreover, when whole chia seeds, retaining their integrity during mixing, were used, mucilage secretion into the dough was limited, reducing their water-binding ability (Iglesias-Pui & Haros, 2013). Similar results of increased water absorption were observed by Guiotto et al. (2020) when adding 5% and 10% chia flour to wheat flour.

Dough development time, which marks the point of reaching maximum torque of 1.1 Nm, reflects the flour's strength. This time was significantly longer for WF type 650 than for WF type 750, despite the latter's higher protein content. The inclusion of 25% CF nearly doubled the dough development time compared to pure WF, probably due to the increased fibre content, which requires a longer water absorption period (Pejcz & Burešová, 2022). A similar increase in dough development time was noted by Guiotto et al. (2020), who suggested this could be due to gluten dilution and challenges in evenly mixing fibre with wheat flour. Generally, longer mixing times result in stronger flour, indicating increased resistance of the dough to mixing.

The typical stability range was 4.96 to 11.42 minutes (Hoang et al., 2022). In this study, both WF type and CF proportion significantly influenced dough stability. Blends made with WF type 650 showed higher stability than those with WF type 750. Among the samples, the lowest stability was observed in WF/CF blends with 10% and 15% CF, while the highest stability appeared in the control samples without CF. In a study by Guiotto et al. (2020), dough stability increased with 5% and 10% chia flour additions, attributed to mucilage that enhanced dough stability consistently across both substitution levels. However, the results indicate that CF addition reduced dough stability in the mixtures. Chia seeds have a high fibre content, with about 85-93% in the insoluble fraction (IDF) and 7-15% in the soluble fraction (SDF) (Kulczyński et al., 2019). This high fibre content in chia dilutes gluten proteins, reducing both the gluten content in the blends and the dough stability (Coelho & Salas-Mellado, 2015).

The C2 point measures the reduction in protein strength due to mechanical work and increasing temperature. For high-quality wheat flour, a torque C2 value above 0.4 Nm is expected, with values in the 0.5 to 0.6 Nm range indicating superior protein quality, enhanced gluten heat resistance, and a stronger gluten network (Hoang et al., 2022). In this study, C2 values ranged from 0.41 to 0.49 Nm, with the highest value observed at 25% CF content, suggesting that dough with this CF level was more resistant to mixing and temperature variations. The type of WF did not affect the C2 value.

The C3 point value assesses starch gelatinization and amylolytic activity, while the C4 point reflects the stability of the hot gel. Slope γ (C3-C4) allows for calculating the rate of enzymatic degradation, and the C5 point, particularly the difference in resistance at points C5 and C4 on the graph, indicates the level of starch retrogradation during cooling (Hoang et al., 2022). The WF type significantly affected the torque C3, C4, C5, and C5-C4 (setback) values, with blends made from WF type 650 exhibiting higher values than those from WF type 750, consistent with the falling number index of the tested flours.

Codina et al. (2010) identified a positive correlation between the falling number index (FNI) and key parameters related to starch gelatinization – C3 and the difference between C3 and C2, amylolytic activity (C4), starch retrogradation (C5), and the C5-C4 difference. Their results showed that increases in these parameters correspond to increases in FNI, which this study also confirms. The amylolytic activity of WF type 650 was lower (indicated by a higher FNI) than that of WF type 750. Codina et al. (2010) also found a negative correlation between FNI and the difference between C3 and C4 (slope γ), where a higher slope value, representing the rate of enzymatic degradation from heat, decreases the FNI. This is explained by the fact that the starch degradation rate depends on starch damage and α-amylase content in flour, leading to a firmer dough consistency when amylolytic activity is lower.

Dough pasting properties, especially peak viscosity at C3 and the C5-C4 setback, correlate with bread staling kinetics (Pejcz & Burešová, 2022). The proportion of CF did not have a statistically significant impact on the gelatinization or hot gel stability of WF/CF blends. However, examining the effect of CF on starch properties in WF/CF blends revealed that samples with 25% CF showed the lowest tendency toward retrogradation, implying a lower likelihood of bread staling during storage. This is closely associated with starch gelatinization properties, particularly peak viscosity and setback (Pejcz & Burešová, 2022).

Ground chia, with its high available oil content, has the capacity to interfere with amylopectin recrystallisation and is rich in accessible mucilage, which influences dough's water balance and may inhibit retrogradation. Previous studies indicated that hydrocolloid addition to bread dough reduces retrogradation enthalpy, as hydrocolloids help stabilize water content and interact with the gluten network, affecting amylopectin recrystallisation (Correa et al., 2012; Iglesias-Puig & Haros, 2013).

4. Conclusions

Current nutritional trends focusing on healthier, nutrient-rich food products show that chia seeds and flour are becoming increasingly popular among researchers due to their rich nutritional composition, benefits for human health and impact on dough rheology. The use of chia flour in bread production can increase its nutritional value due to the content of proteins of the highest biological value, lipids with high omega acid content and dietary fibre. The addition of chia flour increased the total protein content and inhibited the kinetics of amylopectin retrogradation during storage, which is directly related to the delay of bread staling. The addition of chia flour has a positive effect on the technological value of mixtures and dough, therefore its addition in amounts even greater than 10% is recommended.

To reduce any undesirable properties of chia seeds and flour, lactic fermentation could be explored as a means to create an even more appealing and healthful ingredient – not only for cereal-based products but also for a broader range of foods.

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Wpływ mąki z nasion chia na właściwości odżywcze i reologiczne mieszanek mąki pszennej i ciasta

Streszczenie

Cel: Celem tego badania była ocena wpływu dodatku zmielonych nasion chia (mąki chia, CF) w różnych proporcjach (0/100, 5/95, 10/90, 15/85, 20/80 i 25/75) na właściwości reologiczne ciast i kleików z uzyskanych mieszanek. Zastosowano dwa typy mąki pszennej – typ 650 i typ 750.

Metodyka: W analizowanych mieszankach mąki pszennej i mąki chia dokonano oznaczenia zawartości białka ogółem metodą Kjeldahla, a następnie oceniono właściwości skrobi oraz aktywność enzymów amylolitycznych za pomocą amylografu. Dodatkowo wykorzystano urządzenie Mixolab 1 do analizy reologicznych właściwości ciasta, w tym jego zachowania podczas mieszania oraz jakości skrobi i białka.

Wyniki: Dodatek mąki chia do mieszanek mącznych spowodował wzrost zarówno zawartości białka ogółem, jak i początkowej temperatury kleikowania. Wprowadzenie mąki chia wydłużało czas rozwoju ciasta, jednocześnie skracając jego stałość oraz zmniejszając podatność mieszanek na retrogradację.

Implikacje i rekomendacje: Dodatek mąki z nasion chia ma pozytywny wpływ na wartość technologiczną ciasta, dlatego zaleca się jej stosowanie w ilościach nawet większych niż 10%. Niniejsze badanie dostarcza nowych informacji na temat wpływu mąki chia na reologię ciasta, poszerzając wiedzę na temat funkcjonalnych składników w produkcji piekarskiej. Uzyskane wyniki przyczyniają się do rozwoju innowacyjnych, prozdrowotnych produktów na bazie pszenicy wzbogaconych w cenne składniki odżywcze.

Słowa kluczowe: *Salvia hispanica* L., ciasto pszenne, reologia, Mixolab