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PATTERNS OF REDISTRIBUTION OF MACRO- AND MICROELEMENTS DURING WHEAT PROCESSING INTO FLOUR AND ASSESSMENT OF FACTORS AFFECTING THEIR RETENTION

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Abstract

This paper examines patterns of changes in the elemental composition of wheat during its processing into flour. The study is aimed at identifying the transformations of chemical elements occurring at various stages of grain processing. The dynamics of changes in the content of macro- and microelements is analyzed, which allows us to determine the impact of technological processes on the quality characteristics of the final product. The methodological basis of the study includes spectral analysis, X-ray fluorescence spectrometry and other modern methods that ensure high accuracy in determining the elemental composition. The use of these methods allows us to obtain a detailed picture of the redistribution of chemical elements and to identify the factors that contribute to their preservation or loss. The purpose of the work is to assess the impact of various stages of grain processing on the elemental composition of finished products, as well as to develop recommendations for minimizing the loss of biologically significant elements. The results obtained can be used in the flour-milling industry to optimize technological processes and increase the nutritional value of flour. The practical significance of the study lies in the development of recommendations for improving technological processes for processing wheat, which will preserve the maximum amount of useful elements in the final product. The conclusions reached during the work can be used to improve flour quality control methods and develop new standards for its production.

Keywords: Flour and bread rheology, flour fortification, food additive, element deficiency, agriculture.

Introduction

Flour fortification with iron is a widely adopted strategy in many countries, but its impact on iron status and anaemia remains controversial. A systematic review identified 1881 papers, from which 13 studies covering 26 subgroups (14 subgroups of children under 15 years and 12 subgroups of women of reproductive age) were identified.

The results of the analysis showed that statistically significant reductions in the prevalence of anemia were observed in only 4 of 13 subgroups of children and 4 of 12 subgroups of women of reproductive age. In addition, among the subgroups with available ferritin data, significant reductions in low ferritin were observed in only 1 of 6 subgroups of children, but in all 3 subgroups of women of reproductive age.

Thus, the evidence on the effectiveness of flour fortification in reducing the prevalence of anaemia remains limited and heterogeneous. However, the impact of fortification on improving iron status, particularly in terms of ferritin levels in women of reproductive age, appears to be more consistent. This may indicate a need to reconsider approaches to flour fortification and take into account factors influencing iron bioavailability, such as the forms of iron used, co-nutrients and dietary patterns of the population (Pachon et al., 2015).

Food fortification is an important and cost-effective strategy to combat micronutrient deficiencies such as iron, zinc and vitamin A, particularly in low- and middle-income countries. Despite ongoing debate about its effectiveness and safety, the approach brings significant benefits to health, the economy and society as a whole.

Various fortification methods, including large-scale fortification, biofortification and on-site fortification, help reduce the prevalence of nutrient deficiencies and provide long-term economic benefits. Experience

with fortification programmes in several countries shows that the greatest success is achieved when public and private organizations and other stakeholders collaborate. Effective partnerships in advocacy, management, capacity building, implementation and monitoring can enhance the impact of these programmes.

Thus, sustainable success of food fortification depends on an integrated approach that includes evidence-based strategies, cross-sectoral collaboration and effective monitoring and regulatory mechanisms (Olson et al., 2021).

Large-scale food fortification (LSFF) is an effective strategy to increase micronutrient status and improve population health in low- and middle-income countries (LMICs). Data analysis has shown that LSFF contributes to significant reductions in the prevalence of anaemia (by 34%), goiter (by 74%) and neural tube defects (by 41%), and can prevent vitamin A deficiency in nearly 3 million children annually.

However, the effectiveness of fortification programs varies by age and level of fortified food consumption: women over 18 years of age benefit more than children, who may consume insufficient amounts of fortified foods. In addition, the success of LSFF is determined not only by its biological effectiveness, but also by programmatic and implementation factors, such as the availability of fortified foods, consumption behavior, and the quality of monitoring.

Thus, LSFF has the potential to significantly improve micronutrient status and population health in LMICs, but its long-term sustainability and effectiveness require further study, taking into account local context and implementation factors (Keaty et al., 2019).

Micronutrient deficiencies, especially zinc (Zn) and iron (Fe), are a major problem in global food systems, particularly in the Global South. These 'hidden hungers' are linked to soil and crop conditions that limit micronutrient intake.

Various strategies exist to increase Zn and Fe levels in the diet, including supplementation, food fortification, dietary diversification, and crop biofortification using breeding techniques and fertilizers. Estimates suggest that Zn deficiency may be more common than Fe deficiency, particularly in sub-Saharan Africa. However, there are significant knowledge gaps, particularly regarding biomarkers needed to accurately diagnose the micronutrient status of populations.

Modern analytical technologies, such as the use of stable isotopes of Zn and Fe, offer new perspectives for studying micronutrient pathways in food systems. Their application may contribute to a more accurate understanding of the extent of 'hidden hunger' and the development of more effective strategies to overcome it, which will ultimately help reduce the negative impacts of micronutrient deficiencies on public health (Gregory et al., 2017).

A global transformation of food systems is needed to address the interrelated challenges of undernutrition, obesity and climate change. An analysis of existing policies and interventions has shown that the most effective are multi-component approaches, such as sustainable agriculture and school feeding programmes that can simultaneously improve nutrition, reduce inequalities and enhance environmental sustainability.

Dual-tax approaches, including labelling, reformulation, nudges and fiscal measures, have been shown to be effective in improving diets and reducing socioeconomic disparities. However, some, such as labelling, appear to be more effective among women and wealthier groups, requiring additional consideration in policy development.

Despite the benefits identified, there is a lack of data on the impact of food policies on environmental sustainability and women's empowerment. There is also a lack of high-quality evidence on the effectiveness of interventions in food supply chains.

Thus, to build more sustainable food systems, there is a need for more research to address knowledge gaps and for integrated policies that take into account both food and environmental security (Burgaz et al., 2023).

Mandatory wheat flour fortification in urban areas of Cameroon resulted in significant improvements in micronutrient status among women and children. Following fortification, there was a reduction in the prevalence of anaemia in women, an increase in mean plasma ferritin, zinc, folate and vitamin B-12 concentrations, and a reduction in the prevalence of zinc and folate deficiency. Particularly pronounced improvements were seen for folate status, where concentrations increased by over 250% and the prevalence of deficiency decreased to less than 1%.

Despite the positive impact of fortification on micronutrient levels, mean haemoglobin concentrations and prevalence of anaemia in children did not change, indicating the need for further research and possible revision of fortification approaches. In addition, as the study is based on comparison of pre- and post-intervention data, causal relationships require further confirmation.

Overall, the results demonstrate the effectiveness of mandatory wheat flour fortification in improving micronutrient status among the urban population of Cameroon, particularly iron, zinc, folate and vitamin B-12. However, further research is needed to assess the long-term impact and optimize the fortification program (Reina et al., 2017).

The study found that foliar biofortification effectively increased zinc content and bioavailability in whole grain flour of the old wheat variety, but had no significant effect on iron concentrations in either variety studied. However, the old wheat variety had higher iron levels and bioavailability than the modern variety.

Milling grains significantly affects the micronutrient content: whole grain flour contains more iron, zinc and health-promoting compounds than white flour. The bread-baking process slightly changes the concentration of iron and zinc, but significantly increases their bioavailability, making the finished product more valuable from a nutritional point of view.

The obtained results confirm the prospects of developing a production chain for the production of functional bread enriched with microelements. Such bread can play an important role in the prevention of chronic cardiovascular diseases, improving the nutrition and health of consumers (Ciccolini et al., 2017).

The results of this study show that consumption of zinc- biofortified wheat flour in rural Pakistan resulted in a modest increase in zinc and iron intake among adolescent girls. However, despite a 21% increase in zinc intake, no significant change was observed in plasma zinc concentrations (PZC). However, a significant reduction in the prevalence of iron deficiency was observed, suggesting the potential benefit of biofortified flour in improving iron status.

These data highlight the need for further research to more accurately determine the impact of biofortification on zinc status, as well as the development of more sensitive biomarkers to adequately assess changes in zinc levels. Overall, wheat biofortification remains a promising strategy for increasing zinc intake, but its effectiveness requires further evidence (Gupta et al., 2022).

The study showed that the addition of oat fiber (WOF) and the use of different types of flour have a significant effect on the rheological properties of the dough and the quality of the finished bread. The highest instantaneous yield was noted in the whole grain flour samples, while the samples with the addition of 6% WOF demonstrated the lowest yield. The specific volume analysis revealed that the control white bread had the highest volume, while the whole grain bread had the lowest.

White bread also showed the fastest moisture loss, while bread moisture content depended on the flour type and storage time. Whole grain bread showed the greatest hardness during storage, and the smallest pores were recorded in the 12% WOF sample. In water extraction, white bread and the 12% WOF sample showed similar results, while no significant differences were found between spelt and whole grain bread.

Overall, bread with 12% WOF demonstrated an optimal balance between health benefits and technological characteristics, making it a promising product for fortified baking (Kurek et al., 2017).

Micronization of wheat bran resulted in significant changes in their functional properties. A decrease in the average particle size (D_{50}) from 362.3 ± 20.5 μm to 60.4 ± 10.1 μm (medium bran) and 11.3 ± 2.6 μm (ultrafine bran) was accompanied by an increase in the specific surface area and destruction of the aleurone layers. Micronization resulted in an increase in the soluble dietary fiber content, ferulic acid release, and antioxidant properties (total polyphenol content, $ABTS•^{+}$ and DPPH• scavenging activity), but a decrease in the water-holding capacity and insoluble dietary fiber content.

The rheological properties of the dough also changed: the dough with ultrafine bran had a higher water absorption capacity, gelatinization temperature, peak and final viscosity, and lag value. However, it demonstrated a shorter stability time, tensile strength, and extensibility compared to the dough with coarse bran. In addition, the dough with ultrafine bran was characterized by higher hardness, which was reflected in a decrease in the loss moduli and frequency dependence (n'). Thus, micronization of bran improves their antioxidant properties and solubility of dietary fiber, but significantly affects the rheology of the dough, which must be taken into account when developing functional bakery products (Lin et al., 2021).

The addition of natural calcium sources such as egg and oyster shell powder and skim milk powder had a significant effect on the rheological, nutritional and sensory properties of the bread. Fortification with egg and oyster shell resulted in increased water absorption, dough development time and stability, heat of transition and rebound viscosity, while reducing the weakening index. Bread with the addition of skim milk contained the least amount of carbohydrates and had the lowest energy value, while bread enriched with oyster shell demonstrated the highest content of protein, ash, fibre and carbohydrates.

Sensory evaluation showed that bread with egg and oyster shells had lower odor and overall acceptability scores compared to the control sample and bread enriched with skim milk. At the same time, the tested samples had higher mineral and amino acid content, with the exception of proline. Overall, the results of the study confirm that the use of natural calcium sources in bread baking can improve its technological and nutritional characteristics, but a possible decrease in organoleptic properties should be taken into account (Alsuhaibani, 2018).

The addition of cross-linked (CL) rice starch to wheat flour resulted in a decrease in dough strength and extensibility, which is associated with a decrease in gluten formation. However, it significantly increased the total dietary fiber content of the steamed bun, reaching a maximum value with the addition of 30% CL starch. The inclusion of 15% CL starch increased the fiber content, while minimally affecting the sensory properties and appearance of the product. Thus, 15% CL rice starch is a promising ingredient for enriching steamed buns with fiber, providing their nutritional value while maintaining organoleptic characteristics (Farah et al., 2017).

Fortification of wheat flour with iron and zinc results in high bioavailability of these micronutrients in the products. Iron absorption from flour fortified with iron alone was 15.9 ± 6.8%. However, addition of zinc sulfate decreased iron absorption to 11.5 ± 4.9% ($P < 0.05$), whereas addition of zinc oxide had no significant effect (14.0 ± 8.9%). Zinc absorption did not differ between the supplementation forms: 24.1 ± 8.2% for zinc oxide and 23.7 ± 11.2% for zinc sulfate ($P = 0.87$). These results indicate that zinc oxide is the preferred form for co-fortification of flour, as it does not reduce iron absorption (Susilowati et al., 2002).

Fortification of wheat flour with iron and zinc is an effective strategy to reduce micronutrient deficiencies, especially in developing countries. The review addresses key aspects including the prevalence of micronutrient deficiencies, consequences, choice of fortifiers and their levels, shelf stability, bioavailability and acceptability of fortified flour. The importance of comparing fortification with other intervention strategies, environmental aspects and successful examples of fortification programmes are also highlighted. Simple addition of micronutrients to flour is a promising solution to meet the nutritional needs of vulnerable populations (Akhtar et al., 2011).

Materials and Methods

ALVEO – Determination of rheological properties of dough was carried out using an alveograph from the Chopin company according to GOST R 51415-99. The method is based on the preparation of dough samples of standard thickness after kneading and testing at constant humidity, inflating air bubbles from them and plotting graphs of pressure changes inside the bubble over time. The properties of the dough were assessed based on the appearance of the obtained diagrams. Alveograms of the results of studying the consistency of wheat flour are presented in the appendices. The study of the rheological properties of dough is of great importance for understanding the changes that occur at the stages of holding, kneading and shaping the dough, as well as for managing the quality of bakery products.

The rheological properties of dough depend on the state of the protein-proteinase complex and determine the quality indicators of bread products. Using an alveograph, we determined the ability of wheat flour proteins to form an elastic hydrated gel, which significantly affects the structural and mechanical properties of the dough. Using the alveograph device, we determined the following parameters of dough properties: maximum air pressure (P, mm), corresponding to the elastic deformation of the dough; total deformation of the dough (L, mm); the amount of energy (W, 10-4 J) and the P/L ratio spent on inflating the dough bubble (ball) until it bursts.

Conducting the test: A dough sample (water + salt + flour) is inflated into a bubble under excess air pressure. This process simulates dough deformation under the action of gases released by yeast cultures or chemical leavening agents. A flour sample is mixed in a dough mixer, rolled out, placed in a proofing chamber (20 min), and inflated with air in the ALVEOGRAPH itself. The process of dough ball formation and its rupture is recorded by the ALVEOLINK NG in the form of curves and numerical values of rheological parameters, which are displayed on the screen of the display included in the system and printed on a laser printer.

The consistographic analysis method is based on measuring the pressure applied to the dough in a mixing bowl. A double mixing knife creates pressure on the dough and presses the dough against a pressure sensor. In analyses at a constant moisture level, the maximum pressure in the bowl (Prmax) is recorded, which directly depends on the adsorption potential of the flour.

Results and Discussion

Flour is the main raw material for the production of bakery products, therefore the characteristics of the dough and the quality of baked goods largely depend on it. The main factor determining the ‘strength’ of flour is its gluten content and its quality, as well as the rheological properties of the dough. In order to assess the rheological properties of locally produced wheat flour, the rheological properties of the dough were studied. Wheat flour of the highest, first and second grades was taken as objects of study.

In recent years, Uzbek flour producers have paid special attention to the quality of finished products, especially their rheological properties, since before producing finished products, they determine the structure, deformation properties, elasticity, flexibility and other parameters of the dough.

The results of the curves of the rheological properties of dough from premium, first and second grade wheat flour, obtained by the alveography method, are presented in Table 2. The use of premium flour when kneading dough leads to an increase in elasticity, a decrease in its extensibility, an increase in the ratio of elasticity to elongation and an increase in the deformation energy of the dough.

Table 1 Flour quality indicators determined using the alveograph apparatus

Indicator name	High level	First class	Second grade	Enriched flour
Deformation energy of the test W, EA	250	324	76	163
Maximum excess pressure P, mm	205	162	84	136
Average abscissa in tear L, mm	27	48	54	33
Curve shape indicator, P / L	7.59	3.38	1.56	4.12
Elasticity index G, cm	11.5	15.4	16.3	12.8

Enriched flour demonstrates intermediate rheological characteristics between the first class and the second grade. Let’s consider its indicators in comparison with other samples. Dough deformation energy (W, EA): Enriched flour has 163 EA, which is higher than the second grade (76 EA), but significantly lower than the first class (324 EA).

This means that dough made from enriched flour has moderate strength, but is not as elastic and durable as dough made from first-class flour. Maximum excess pressure (P, mm): The pressure is 136 mm, which is higher than that of the second grade (84 mm), but lower than that of the first grade (162 mm). This indicates an average gas-retaining capacity of the dough, which can affect the porosity and fluffiness of baked goods. Average abscissa in a tear (L, mm): The value is 33 mm, which is closer to the high level (27 mm), but lower than that of the first (48 mm) and second grades (54 mm). This indicates a balanced extensibility of the dough: it does not tear too much, but does not spread too much. Curve shape indicator (P/L): Enriched flour has 4.12, which is higher than that of the second grade (1.56), but lower than that of the first grade (3.38). This indicates a better balance of elasticity and extensibility compared to the second grade. Elasticity index (G, cm): Enriched flour shows 12.8 cm, which is closer to the high level (11.5 cm), but lower than the second grade (16.3 cm). This indicates the average elasticity of the dough, which can have a positive effect on its stability during fermentation.

The following conclusions were made based on the Table 1: Enriched flour occupies an average position between the first class and the second grade in its properties. It has sufficient elasticity and flexibility, but is inferior to the first class in these indicators. Its use can be optimal for improving the nutritional value without significantly deteriorating the baked goods.

Table 2 Flour quality indicators

Flour quality indicators	High class	First class	Second grade	Enriched flour
Humidity	11	9	13	24
1. Quantity and quality of raw gluten 2. IDK	29 68	32 72	30 110	24 74
Description of raw gluten (manual method)	homogeneous, slightly crumbly, sticky			
Number of those who dropped out in TSC-3	400	380	510	480
Damaged Starch Index: USD AACC	25.7 7.90	25.4 7.82	18.4 5.90	23.0 6.70

Particular attention was paid to determining the composition and quality of raw gluten. The raw gluten content in all samples exceeded the minimum limit of 28%. The largest amount of raw gluten was found in the first grade flour sample (32%). A study of the elastic properties of gluten showed that two samples had the first gluten quality group, and one had the second group.

The Table 2 contains data on the quality of different grades of flour: high class, first class, second grade and enriched flour. Below is a comparative analysis of the key parameters: Humidity: The lowest is in the first class - 9%. The highest is in the second grade - 13%, which may indicate a greater ability to absorb moisture. Quantity and quality of wet gluten: The highest gluten content is in the first class (32%), which indicates better baking value. The minimum value is in enriched flour (24%), which can be explained by the addition of microelements affecting the gluten framework. Gluten deformation index (GDI): The lowest value is in the high class (68), which indicates a more elastic and stable gluten. The highest value is in the second grade (110), which indicates weak and less elastic gluten. Enriched flour has an IDK of 74, which is closer to the first class, but higher than that of high-class flour. Description of raw gluten: In all samples, the gluten is uniform, but with varying degrees of stickiness and friability. The number of dropped outs in TSK-3 (an index of enzymatic activity). The second grade has the maximum value (510), which indicates high enzymatic activity and, possibly, greater amylase activity. The first class has the minimum value (380), which indicates better quality flour for baking. Damaged starch index (USD): The greatest starch damage is in high-class flour (25.7), which may indicate more intensive grinding of grain. The lowest is in the second grade (18.4), which corresponds to a coarser grind. Enriched flour (23.0) occupies an intermediate position.

AACC (water absorption capacity): The highest value is for premium flour (7.90), indicating its high ability to absorb moisture. The lowest value is for second-grade flour (5.90), indicating lower protein quality. Enriched flour has an index of 6.70, which is higher than that of the second grade, but lower than that of the first grade. The following conclusions can be drawn from the Table 2: First-grade flour has better baking properties due to its high gluten content, low WAC, and good water absorption capacity. Second-grade flour is less valuable in baking, as it has a high WAC, low starch damage, and high enzymatic activity. Enriched flour occupies an intermediate position in its properties, closer to first-grade flour, but with a lower gluten content. The addition of iron and zinc could affect the gluten framework and the ability of the dough to retain gas.

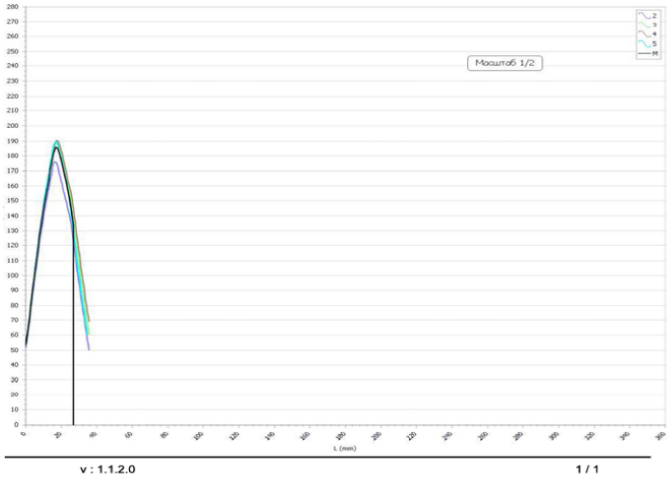

Figure 1 Description of the rheological curve of premium flour

The presented rheological curve in the Figure 1 shows the change in the resistance force of the dough during its stretching. The main characteristics of the curve: The maximum resistance of the dough is about 190-200 EA, which indicates high elasticity and strength of the gluten framework. The steep rise of the curve in the initial phase of stretching indicates good water absorption capacity of the flour, as well as high content and quality of gluten. The rapid fall of the curve after reaching the peak indicates a relatively low extensibility of the dough. This is typical for premium flour, which contains less bran and more protein fractions, contributing to the formation of elastic dough. The close location of the curves of different samples indicates the stability of the rheological properties among the samples studied.

Thus, this premium flour is characterized by high dough elasticity, which makes it suitable for baking products with a well-developed structure and volume.

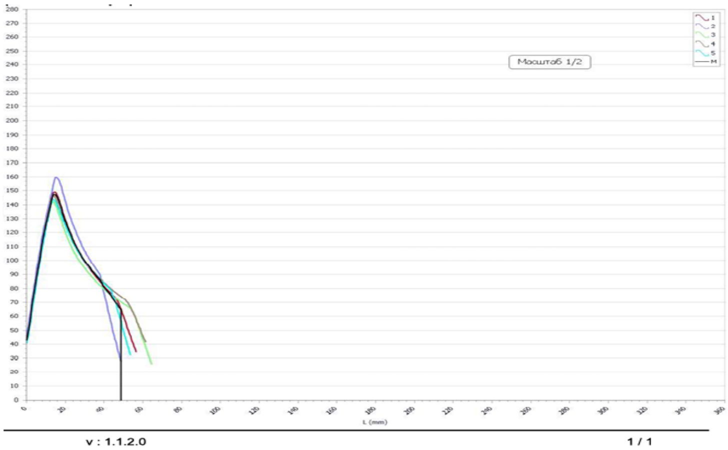

Figure 2 Description of the rheological curve of first grade flour

The Figure 2 shows the rheological characteristics of the dough made from first-grade flour. The main parameters of the curve allow us to evaluate the quality of gluten and the plasticity of the dough: The maximum resistance of the dough is about 160-170 EA, which is slightly lower compared to premium flour. This indicates less elasticity of the dough and a softer consistency. A more gradual rise in the curve indicates a slightly lower water absorption capacity of the dough compared to the premium grade, which is due to the presence of grain shell particles. A more extended descending part of the curve indicates increased dough extensibility, which is a positive property when molding products. A more pronounced divergence of the curves of different samples may indicate variability in the characteristics of first-grade flour depending on the composition and grinding. Thus, first-grade flour is characterized by good elasticity and extensibility of the dough, which makes it suitable for the production of various bakery products with a soft and porous crumb.

The main parameters of the curve indicate reduced strength properties of the gluten framework and high dough plasticity: The maximum dough resistance is about 75-80 EA, which is significantly lower compared to premium and first grade flour. This indicates weak gluten and low dough elasticity. A steep rise in the curve with a rapid decline indicates insufficient water absorption capacity and a weak dough structure, which is associated with a high content of bran particles. A short descending part of the curve indicates low dough extensibility, which can complicate the molding of products.

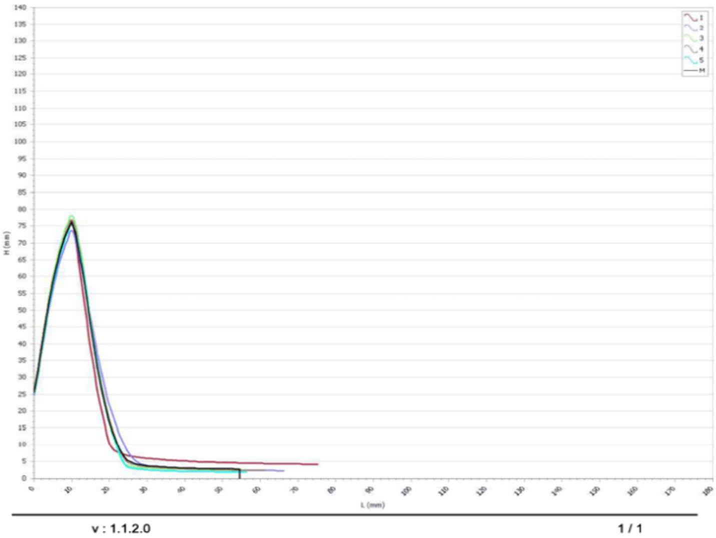

Figure 3 The figure shows the rheological characteristics of dough made from second-grade flour

The Figure 3 shows minimal variability of the curves of different samples indicates the stability of the second-grade flour indicators, but at the same time confirms its weak baking properties. Thus, second-grade flour has low elasticity and weak gluten, which limits its use in the baking industry. It is more suitable for the manufacture of products that do not require high gas-retaining capacity of the dough, such as rye and bran breads.

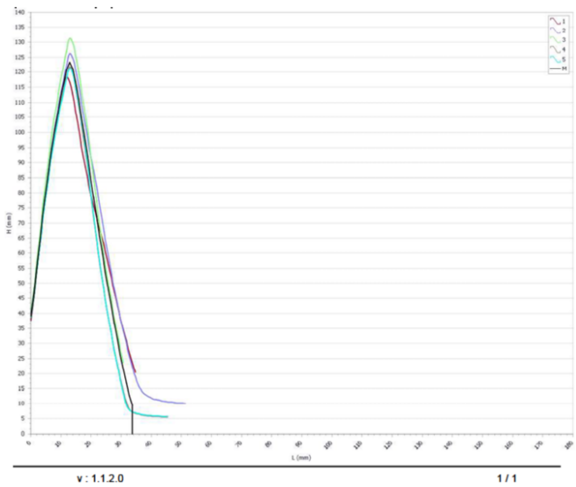

Figure 4 Description of the rheological curve of flour with the addition of its own iron and zinc

The Figure 4 shows the rheological curve of dough prepared from flour with added iron and zinc microelements. Key characteristics: Maximum dough resistance is about 125-130 EA, which is higher than that of second-grade flour, but lower than that of premium flour. This indicates some strengthening of the gluten framework due to the added microelements. A sharp rise in the curve and a high peak indicate a strengthening of the dough structure, improved elasticity and water absorption capacity. A smoother descending section compared to dough from ordinary flour indicates a slower loss of strength and extensibility, which may be due to the interaction of iron and zinc with flour proteins. Low final values after the curve decline indicate reduced dough extensibility, which may affect its gas-retaining capacity. The addition of iron and zinc affects the rheological properties of the dough, increasing its strength, but at the same time slightly reducing elasticity. This can affect the baking properties of the flour, making it more suitable for the production of baked goods with high dimensional stability.

Conclusions

This study confirmed that enrichment of wheat flour with microelements such as iron and zinc, as well as the use of bran micronization and the addition of natural calcium sources have a significant effect on its physicochemical and rheological properties.

1. Comparative analysis showed that premium flour has the highest elasticity, as well as a higher dough deformation energy (250-324 EA) compared to first and second grade flour.
2. A study of the gluten quality revealed that first grade flour samples contain more raw gluten (32%), providing a better dough structure.

Particular attention is paid to the effect of processing methods on the bioavailability of micronutrients. It is shown that biofortification of wheat significantly increases the zinc and iron content in flour, but the efficiency of iron absorption varies depending on the form of the micronutrient.

3. Micronization of bran improves the antioxidant properties of flour and increases the content of soluble dietary fiber, which makes it a promising component for functional bakery products.

Thus, the results of the study confirm the feasibility of introducing new technologies for processing and enriching flour to increase its nutritional value. A promising direction for further research is to study the effect of various forms of trace elements on the bioavailability of nutrients, as well as the development of optimal process parameters for the production of high-quality fortified flour.

4. In the course of the study, patterns of change in the elemental composition of wheat during its processing into flour were identified. Analysis of the obtained data, presented in comparative tables and rheological graphs, showed that grain processing is accompanied by a redistribution of macro- and microelements between different fractions. It was found that when milling wheat, a significant part of micro- and macroelements is concentrated in the bran, while premium flour is characterized by a lower content of elements such as Fe, Zn, Mg and P. This is due to the fact that the bulk of minerals are concentrated in the grain shell, which is removed during processing.

The comparative tables confirm that the higher the flour grade, the lower its ash content and the content of elements included in the bran. Thus, the greatest number of useful substances is preserved in second-grade flour.

5. The graphs show that different flour grades have different characteristics during dough formation. Thus, premium flour demonstrates lower deformation energy, a lower elasticity index and altered parameters of the curve shape, which indicates its weaker baking properties compared to first- and second-grade flour. Enriched flour, containing additional amounts of iron and zinc, shows improved characteristics compared to premium flour, but does not reach the level of first-grade flour in dough elasticity. Nevertheless, its deformation energy and damaged starch index indicators make it a promising product for improving the nutritional value of bakery products.

- For the first time, a comprehensive study was conducted on the redistribution of mineral substances depending on the type of flour and the processing method used.
- The patterns of change in the rheological properties of dough when using different types of flour, including enriched flour, were determined.
- The influence of the content of microelements (iron and zinc) on the quality of the dough and its structural and mechanical properties was revealed.

Thus, the results of the study have practical significance for the baking and flour-milling industries, and also open up prospects for the development of new types of functional flour with increased nutritional value.

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