Встановлено механізм взаємодії наночастинок (НЧ) поліфунціональної харчової добавки «Магнетофуд» з функціональними групами складних білків житньо-пшеничного борошна. В основному НЧ харчової добавки «Магнетофуд» взаємодіють зі складними білками за рахунок координаційних зв'язків. Під впливом НЧ добавки «Магнетофуд» в будові складних білків відбуваються структурні зміни: виникають утворення по типу «кластерів» і електростатичні комплекси біополімеру з НЧ «Магнетофуд».

Встановлено механізм впливу НЧ харчової добавки «Магнетофуд» на зв'язок H_2O ліпо- та глюкопротеїдами житньо-пшеничного тіста. Наночастинки (НЧ) «Магнетофуд» модифікують ліпо- та глюкопротеїди, змінюють просторову будову, сприяючи посиленню процесів гідратації та водоутримання. Зокрема, під впливом НЧ «Магнетофуд» глюкопротеїди структурно змінюються, активуються, набувають додаткові реакційно здатні центри, зокрема гідрофільні. В результаті активовані білкові фрагменти житньо-пшеничного борошна, набрякаючи, обгортаються навколо вуглеводних фрагментів та утворюють стійки глюкопротеїнові комплекси. В ліпопротеїдах, завдяки наявності поляризованих НЧ «Магнетофуд» та «кластерів», а також системі водневих зв'язків між диполями H_2O, накопичення води спостерігається навколо НЧ «Магнетофуд» та в «кластерах» ланцюга ліпопротеїду. Це підвищує вологоутримуючу здатність (ВУЗ) житньо-пшеничного тіста.

Запропоновано механізм взаємодії наночастинок «Магнетофуд» із складними білками і молекулами H_2O у житньо-пшеничній тістовій системі. Накопичення води навколо НЧ «Магнетофуд» та в «кластерах» ланцюгів ліпо- та глюкопротеїдів спостерігається завдяки:

– наявності поляризованих НЧ «Магнетофуд»;

– виникненню «кластерів» у матрицях біополімерів;

– системі водневих зв'язків між диполями H_2O.

Все це сприяє підвищенню ВУЗ житньо-пшеничного тіста.

Експериментально встановлено, що харчова добавка «Магнетофуд» проявляє комплексну дію: водоутримуючу, жироутримуючу та стабілізуючу. Що призводить до поліпшення споживчих характеристик хлібобулочної продукції

Ключові слова: харчова добавка, білково-вуглеводний комплекс борошна, ліпо- та глюкопротеїди, механізм, вологоутримуюча здатність

UDC 66.075.8
DOI: 10.15587/1729-4061.2018.140048

SUBSTANTIATION OF THE INTERACTION MECHANISM BETWEEN THE LIPO- AND GLUCOPROTEIDS OF RYE-WHEAT FLOUR AND NANOPARTICLES OF THE FOOD ADDITIVE «MAGNETOFOOD»

I. Tsykhanovska
PhD, Associate Professor*
E-mail: cikhanovskaja@gmail.com

V. Evlash
Doctor of Technical Sciences, Professor
Department of Chemistry, Microbiology and Food Hygiene
Kharkiv State University of Food Technology and Trade
Klochkivska str., 333, Kharkiv, Ukraine, 61051
E-mail: evlashvv@gmail.com

A. Alexandrov
PhD, Associate Professor, Head of Department*
E-mail: alexandrov.a.v.a.v@gmail.com

T. Lazareva
Doctor of Pedagogical Sciences, Professor*
E-mail: Lazareva_T.A@ukr.net

O. Bryzytska
PhD, Associate Professor
Department of organic chemistry
National University of Pharmacy
Puschkinska str., 53, Kharkiv, Ukraine, 61002
E-mail: orgchem@nuph.edu.ua

*Department of Food and Chemical Technologies
Ukrainian Engineering Pedagogics Academy
Universitetska str., 16, Kharkiv, Ukraine, 61003

1. Introduction

At present, the bread baking industry of Ukraine is characterized by a reduction in production volumes; deterioration of the structure, the levels of quality and safety in the consumption of bakery products, as well as the competitiveness at international markets.

The share of low-quality bakery products accounts for about 20–25 % annually, since bread and bakery products often do not meet the requirements of quality standards and sanitary norms as they are made from flour with low baking properties [1]:

– flour has low gluten content;

– flour has a very poor quality of gluten – dry, weak short-torn, crusty, torn in layers or excessively stretchy;

– flour has amylo- and proteolytic enzymes with the reduced or, vice versa, increased activity [2].

It should be noted that all the drawbacks of flour are the result of improper storage of grain or its poor quality. At present, the most difficult task is to find flour of the required quality, adding which would make it possible to improve the flour, even slightly, that has insufficiently good bakery properties.

As a result, bread-making enterprises must use improvers to enhance the quality of flour and correct its deficiencies.

In addition, the improvers and components of diverse origin are used as additives to the formulation of bakery products. Their effect is multifaceted:

– increasing the shelf life, nutritional value and quality of bakery products;

– rendering medical and preventive properties;

– influencing the qualitative and quantitative composition of the human diet.

Taken together, that makes it possible to:

– expand the assortment of products;

– improve the quality and, first, the taste properties of the finished products, their originality and nutritional value;

– solve the task on prevention and treatment of various diseases associated with deficiency of certain substances [1, 2].

In addition, taking into account the desire of manufacturer to have high profits while reducing production costs, the use of technological powdered raw materials and food additives with a long shelf life appears relevant. Therefore, bread-making industry more often replaces traditional raw materials with cheaper technological powdered raw materials and nutritional supplements, which could increase the nutritional value, enrich a food product with functional ingredients and reduce caloric content. Therefore, it is an important issue to know and create functional and technological properties (FTP) of food ingredients. This would allow:

– the rational use of new types of raw materials and nutritional supplements;

– the prediction of behavior of powdered raw materials and food additives in test systems in the process of technological treatment and during storage of finished products [3].

Dough is a complex hydrophilic colloidal system, composed of the gluten frame, which is filled and surrounded by weakly swollen starch and lipids, sugars and minerals dissolved in it. It was established that lipids, carbohydrates and mineral elements reside in gluten in the chemically bound state – both in the form of adsorption complexes and partially in the form of compounds (glucolipids, lipo- and glucoproteids). At the same time, starch and shell particles are kept mechanically [4].

Properties of the raw materials, parameters of the technological process impact the state of dough masses. Neutral fats, free fatty acids, phospholipids could be included in the composition of lipoproteids. The lipids that are part of gluten affect its properties. Their effect is explained by that the unsaturated fatty acids, while oxidizing and forming peroxides and hydroperoxides, contribute to the oxidation of sulfhydryl groups –SH. As a result, disulfide bonds –S–S– are formed, which strengthen the intra-molecular structure of the protein, thereby making it denser. Disulfide bonds are formed both within a single protein molecule and between different molecules of gluten proteins. A certain part of the lipids remains non-bound to the proteins and serves a sort of lubricant between protein molecules, providing gluten with additional elasticity [4].

Moisture-retaining ability (MRA) is one of the most important functional and technological properties of food raw materials, food additives, and finished products. MRA manifests itself by monomerically retaining water via hydrophilic groups (*adsorption*). As a result, hydrated shells form around the particles of flour. In this case, the interaction between water and hydrophilic groups occurs not only at the surface of flour particles, but also inside the free adsorption water. The amount of water bound in this way is about 30 %. Then there is the so-called osmotic swelling, which occurs as a result of the diffusion of water molecules inside the particles of flour (FP). In this case, there is a consistent binding of FP of different number of H_2O layers with the participation of hydrogen bonds (*absorption*). The swelling occurs with a significant increase in the micelle volume, as the amount of water bound by this way is larger than 200 %. The capability of biopolymers (proteins, carbohydrates) to retain water in food products increases the output of finished products, prolongs shelf life and improves the texture [4, 5].

When baking bread, there are structural changes in the protein-carbohydrate complex of test systems:

– there occurs the denaturation of proteins; in this case, water is released; the proteins themselves are compacted, they lose elasticity, thereby forming a bread frame;

– the moisture released by the proteins is absorbed by starch, which firmly binds it, and at the same it is being gelatinized, thereby forming the crumb dry to the touch;

– polysaccharides are partially gelatinized and are hydrolytically cleaved to dextrins.

In addition, during storage of bakery products, moisture is eventually lost and the structure of the gluten-based frame and gelatinized starch «deteriorates» – and bread becomes stale. In order to stabilize the structure of the protein carbohydrate frame and supramolecular solvate associates of the protein-carbohydrate complex of flour, we propose applying the multifunctional food supplement «Magnetofood». «Magnetofood» is an ultra-fine ferrous oxide powder of $FeO \cdot Fe_2O_3$ with a particle size of ~78 nm [6–8].

Nanoparticles have specific properties that are determined by the presence of quantum-mechanical effects, namely: qualitatively new mechanical, magnetic, thermal and electric-conductive, optical, chemical and biological properties. The nanostructured Fe_3O_4 particles (the structure of the inverse spinel) demonstrate record magnetic properties: high magnetic moment and low magnetic permeability, which makes it possible to relate them to the superparamagnetic materials [9]. The superparamagnetic particles of Fe_3O_4 retain magnetic properties even after the action of the external magnetic field on them is terminated, which is an extremely important property for their *in vivo* application. A change in the magnetic properties of nanoparticles is a demonstration of the change in the structure of their crystal lattice. Fe_3O_4 nanoparticles have weaker magnetic properties than the iron-based ones, however, they are more resistant to oxidation [10]. At present, the most widely used in biochemistry are the Fe_3O_4 nanoparticles, due to their relatively low toxicity, high reactive and catalytic ability, and stability of magnetic characteristics [11].

NP of «Magnetofood» food supplement has high-power energy and chemical potential, and bio-relation to biopolymers, namely, proteins, carbohydrates. Therefore, they bear new functional and technological properties, for example, MRA [7, 12, 13].

In order to explain the mechanism of MRA of nanoparticles of the food supplement «Magnetofood» and the mechanism of interaction between the «Magnetofood» NP and flour lipo- and glucoproteids, it is necessary to understand the nature and power of interaction between the «Magnetofood» nanoparticles and appropriate substrates and H_2O.

2. Literature review and problem statement

An analysis of scientific literature [3, 5, 14–33] shows that bakery products are enriched with various nutritional additives-enhancers and functional ingredients to improve their quality, shelf life, and nutritional value. The course of technological processes is largely determined how FTP of raw materials is calculated. MRA is an important functional and technological property of food raw materials, dough systems and finished products. MRA characterizes the capacity of a raw material component to bind and retain water, thicken food systems in the process of technological treatment. Therefore, for the rational use of new types of raw ingredients and food supplements, their FTP should be known. And above all – water absorbing and moisture-retaining abilities, as it allows the prediction of behavior of powdered raw materials and other food ingredients in food systems in the process of technological treatment and when storing finished products.

The main components that bind water in dough are proteins and carbohydrates: 82–85 % of the total water introduced into dough is absorbed by polysaccharides and proteins. The rest of the water remains in the free state [14].

Modern raw materials market offers various food supplements for improving the water absorption capacity (WAC) of flour and the moisture-retaining ability (MRA) of dough and finished products. Mineral compounds (ammonium salts of orthophosphate acid, sodium orthophosphate, potassium) are widely used in bread making technologies [15, 16]. The disadvantages of these additives are the insufficient functionality in terms of specific volume, porosity, and shape-stability of bread.

The specialized enzymatic compositions «DSM», which were introduced to world market, are the objects of enhanced interest. They are intended for non-starchy polysaccharides of flour. The aim is to increase MRA of dough and the actual yield of bakery products [17, 18]. However, the «DSM» enzymes have a narrow orientation and do not demonstrate a comprehensive effect. In addition, the mechanism of interaction between the enzyme composite and complex flour proteins is not elucidated.

Worth considering are the biologically active substances of vegetable [19], fruit [20], and herbal supplements, which help to increase MRA of dough systems and bakery products [21]. The disadvantages of these additives are low functionality in terms of texture and physical and chemical properties of bread. And the mechanism of moisture retaining ability is not considered. At present, widespread are various nutritional supplements derived from natural ingredients: citrus fibers; hydrocolloids of vegetable origin, cellulose ethers [3, 5, 22–24]. *Citrus fiber* is a source of health-improving fiber. Their content of food fibers ranges from 88 to 93 %, including those soluble at about 20 % [3, 5, 22]. Owing to such additives, it has become possible to create low-calorie products that preserve the structural-mechanical and organoleptic characteristics of traditional analogues. However, they do not provide for the sufficient porosity of crumb. *Hydrocolloids* are the banana and apple powders; buckthorn shroud; guar and xanthan gums [3, 5, 23, 24]; polydextrose is a polysaccharide composed of glucose polymers with low molecular weight [3, 5].

Hydrocolloids are used to provide the desired viscosity or consistency, as well as to stabilize the food dispersed systems (emulsions, suspensions). Many hydrocolloids, for example, guar and xanthan gums, relate to the soluble dietary fibers. And they are the physiologically functional ingredients that can lower cholesterol level in the blood, promote normal functioning of the intestine, and demonstrate a probiotic effect. However, their influence on the technological indicators of dough semi-finished products and finished products is not significant. In addition, there are no models of interaction between the compounds and lipo- and glucoproteids of flour.

In order to enrich bakery products with high-quality protein and increase the flour MRA, it is proposed to use natural powder-like components. These ingredients are obtained by drying milk and egg products: natural yogurt, skimmed milk, natural skimmed cheese, egg yolk, etc. [3, 15, 25]. Disadvantages are the lack of polyfunctionality and the mechanism of moisture retaining ability; insufficient output of finished products.

To enhance the MRA level, the food industry has recently started to exploit various functional ingredients derived from products of secondary processing (skin, hoof, feathers [26], by-products [27], seeds, bran [28], whey [29], etc.). However, these dietary supplements are characterized by a narrow orientation; they do not demonstrate a comprehensive effect; the mechanism of interaction between complex proteins of the protein-carbohydrate complex is not considered.

In order to improve MRA of dough and bread, wheat-based bio supplements are used [30]. However, the yield and structural and mechanical indicators of finished products have not improved. There is no model of their water-retaining ability.

In addition, bio supplements of different origin have been proposed in order to increase the WAC of flour and the MRA of dough in bread-making: soybean, chick pea [31]; enzymes, microalgae, etc. [32]. The disadvantage of these additives is the lack of functionality in terms of specific volume, porosity, and shape-stability of bread. However, the model of interaction between lipo- and glucoproteids is not considered.

The bakery industry has in recent years exploited compounds of plant origin containing phenols in order to improve MRA of flour and dough [33]. The disadvantages of these bio-supplements are the inadequate yield and shelf life of the finished product.

An analysis of information sources [3, 5, 14–33] shows the lack of data on the use of nanopowdered ingredients in bread making technology and the mechanisms of interaction between nanoparticles and lipo- and glucoproteids. The multifunctional food supplement «Magnetofood» can be proposed to improve quality, prolong storage time, and create new functional and technological properties of bakery products. In food systems, «Magnetofood» demonstrates water-retaining, fat-retaining, fat-emulsifying, and stabilizing ability [6–8, 12, 13].

3. The aim and objectives of the study

The aim of this study is to substantiate the mechanism of interaction between lipo- and glucoproteids of rye-wheat flour with nanoparticles (NP) of the food supplement «Magnetofood» in order to improve the moisture-retaining ability of dough.

To achieve the goal, the following tasks were set:

– to substantiate the mechanism of interaction between nanoparticles (NP) of the food supplement «Magnetofood» and functional groups of complex proteins of rye- wheat flour;

– to establish the mechanism of influence of NP of the food supplement «Magnetofood» on the binding of moisture by lipo- and glucoproteids of rye-wheat dough;

– to substantiate the mechanism of interaction between the «Magnetofood» nanoparticles and complex proteins and H_2O molecules in the rye-wheat dough system.

4. Materials and methods to study the food supplement «Magnetofood»

4. 1. Examined materials and equipment used in the experiment

We studied the effect of NP of the polyfunctional food additive «Magnetofood» on the technological properties, namely moisture-retaining ability of rye-wheat dough.

The object of our study is the technology of the rye-wheat bread.

Subjects of the study:

– control sample 1 – rye-wheat flour in line with DSTU-P 4582:2006. The ratio of brown rye flour and wheat flour of the first grade is 60:40 according to basic formulation of the wheat bread «Darnytskyy» [34];

– sample 2 – rye-wheat flour with the polyfunctional food additive «Magnetofood» in the amount of 0.10 % to the mass of flour in a powder form [TU U 10.8-2023017824-001:2018. Food additive based on iron oxides «Magnetofood»];

– sample 3 – rye-wheat flour with the polyfunctional food additive «Magnetofood» in the amount of 0.15 % to the mass of flour mass in the form of powder;

– sample 4 – rye-wheat flour with the polyfunctional food additive «Magnetofood» in the amount of 0.20 % to the mass of flour in the form of powder;

The examined materials, equipment, and methods used in the experiment, are described in detail in paper [35].

5. Results of research into the mechanism of interaction between the food additive «Magnetofood» and lipo- and glucoproteids of rye-wheat flour

We studied effect of the multifunctional food additive «Magnetofood» on the moisture-retaining ability (MRA) of rye-wheat dough using model systems. The food additive «Magnetofood» was introduced in the form of powder when preparing the test flour samples in the amount of 0.10–0.20 % to the mass of flour [TU U 10.8-2023017824-001: 2018].

The properties of dough and bread made from it depend on the molecular structure of ingredients and the state of water contained in them; the ratio of moisture in the free and bound state. To elucidate the mechanism of influence of the additive «Magnetofood» on the components of a protein-carbohydrate complex of rye-wheat dough, we investigated the solubility, the amount of bound water, and MRA in the examined samples of rye-wheat flour.

Earlier studies [12, 13] have demonstrated that the most intensive chemical and electrostatic interaction between nanoparticles (NP) of «Magnetofood» and dipoles of H_2O and ionogenic groups of biopolymers occurs in acidic medium.

To explain the increase in moisture-retaining ability (MRA) of dough made from rye-wheat flour with NP «Magnetofood», we shall consider the mechanisms of interactions occurring between NP of the food additive «Magnetofood», H_2O and complex dough proteins.

«Magnetofood» nanoparticles (NP) modify lipo- and glucoproteids, change the spatial structure, promoting the hydration and water retention processes. In general, NP of the food additive «Magnetofood» interacts with complex proteins at the expense of coordination bonds.

The *protein substances* of flour, due to the high lability and the ability to react with various other compounds – *lipids* and especially *carbohydrates,* form *lipoproteids* and *glucoproteids.* Gluten proteins bind about half of the total amount of flour lipids. Carbohydrates and lipids, bound with gluten proteins, significantly affect its functional-technological properties and technological indicators of a dough semi-finished product. For example, gliadin can form glucoproteid, a two-component protein in which the protein (peptide) part of the molecule is covalently bound to one or several hetero-oligosaccharide groups. In glucoproteid molecules, the oligo- or polysaccharide remnants are covalently bound (by O- or N-glycoside bonds) to the polypeptide chains of the protein. Hydroxyamino acids are involved in the formation of O-glycoside carbohydrate-protein bond. There are known combinations: galactose (Gal)-hydroxylysine, galactose (Gal) or arabinose (Ara)-hydroxyproline, although more often found in the carbohydrate-protein bond are serine or threonine (Fig. 1). The addition of residues of N-acetylglucosamine (GlcNAc), mannose (Man) and galactose to serine is known; as well as Fructose (Fuc) – to threonine. However, the vast majority of such glucoproteids contain the same disaccharide fragment (the so-called Core or rod) in the carbohydrate-protein bond that consists of galactose and N-acetyl galactosamine residues (GalNAc) and has the structure Galβ1–3–GalacNAcα1. Figures denote the numbers of C atoms in the monosaccharides involved in the formation of glycoside bonds, while the Greek letters indicate the configuration of the anomeric C Core atom bound to atom O from the hydroxyl group of the remnant of serine or threonine. The structure of the carbohydrate chains of such glucoproteids also includes the remnants of N-acetylglucosamine, L-fructose, and (or) N-acetylneuraminic acid (NeuAc).

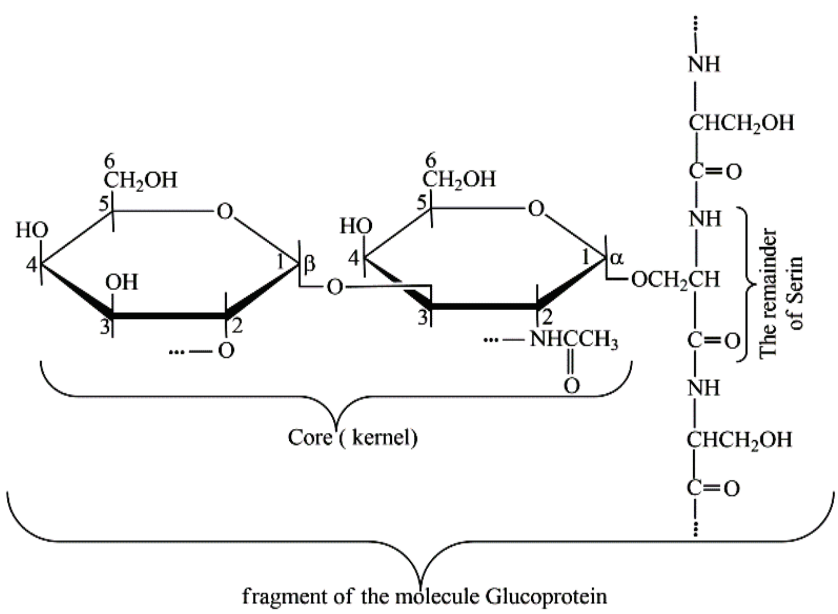

Fig. 1. Structural formula of the glucoproteid chain link that has the disaccharide fragment Galβ1–3–GalcNAcα1 (Core consists of Gal galactose remnants and N-acetyl galactosamine GalNAc)

Under the influence of NP of the food additive «Magnetofood», the structural changes occur in a glucoproteid structure, which are shown in Fig. 2.

Fig. 3 shows formation of solvatocomplexes in the «clusters» of a link of the glucoproteid chain.

An analysis of data in Fig. 3 shows that NP of «Magnetofood» are the active hydrophilic centers along with the ionogenic groups of disaccharide and protein. NP «Magnetofood» activate the formation of solvatoassociates.

The content of lipids in wheat flour is 1.6–2 %. In flour, lipids are both in the free state and in the form of complexes with proteins (lipoproteids) and carbohydrates (glycolipids). The carboxyl or oxogroups of fats are more polarized and reactive than the alcohol groups of cellulose and hemicellulose. Therefore, under the influence of NP «Magnetofood», lipoproteids and glycolipids undergo structural changes and, when hydrated, can form more stable structures. Fig. 4 shows the process of self-organization of NP from the food additive «Magnetofood» into an electrostatic complex with a lipoproteid stabilized by the electrostatic interaction between atoms and groups.

It follows from data in Fig. 4 that NP of Magnetofood form internal molecular complexes at the expense of coordination bonds with the atoms of nitrogen and oxygen from the remnants of glutamine, proline and 1-linoleyl-2-oleoylglycerol. In addition, there are partial formation of the «clusters» type that make up 30 % of the structured matrix.

Fig. 5 shows the formation of solvatocomplexes in the «clusters» of the lipoproteid chain link.

An analysis of Fig. 5 shows that due to the presence of the polarized NP of «Magnetofood» and «clusters», as well as the system of hydrogen bonds between water dipoles, the accumulation of water is observed around NP of «Magnetofood» and in the «clusters» of the lipoproteid chain, which contributes to an increase in MRA of rye-wheat dough.

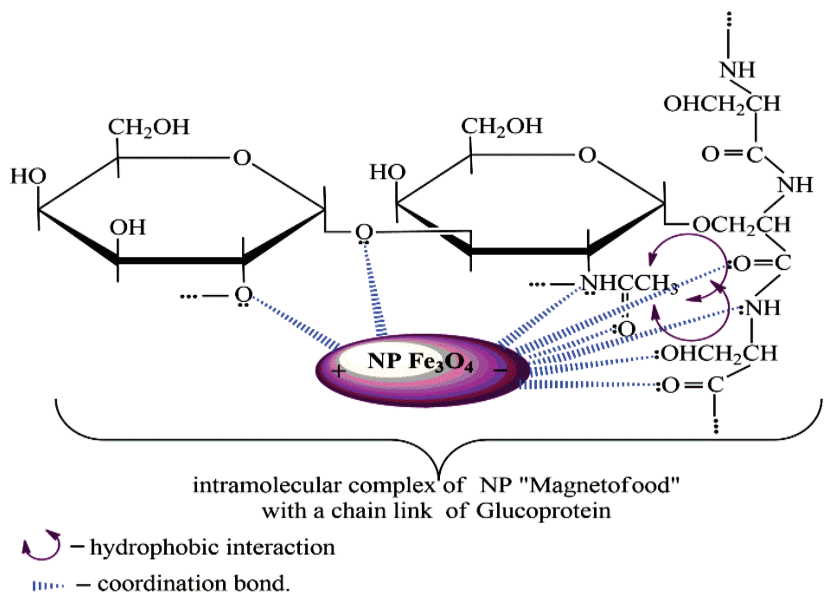

Fig. 2. Self-organization of NP of the food additive «Magnetofood» into the electrostatic complex with a link of glucoproteid chain

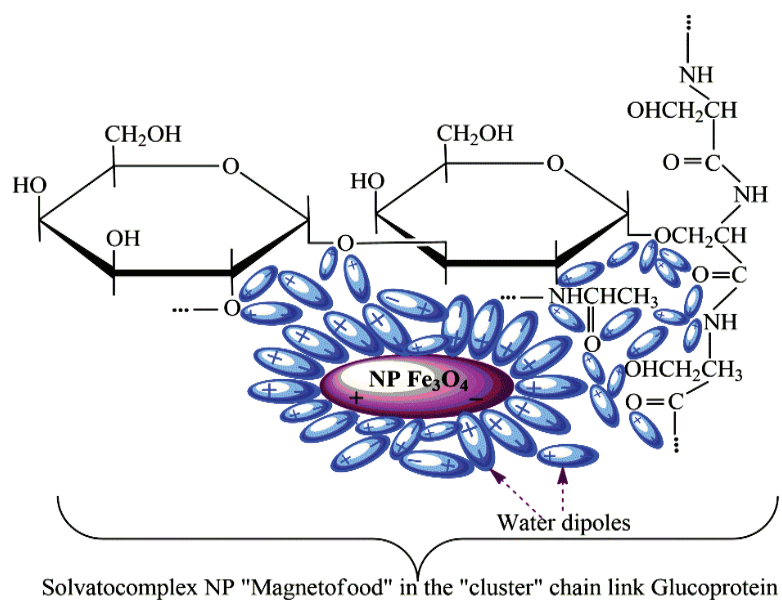

Fig. 3. Solvatocomplexes in the «clusters» of the glucoproteid chain link

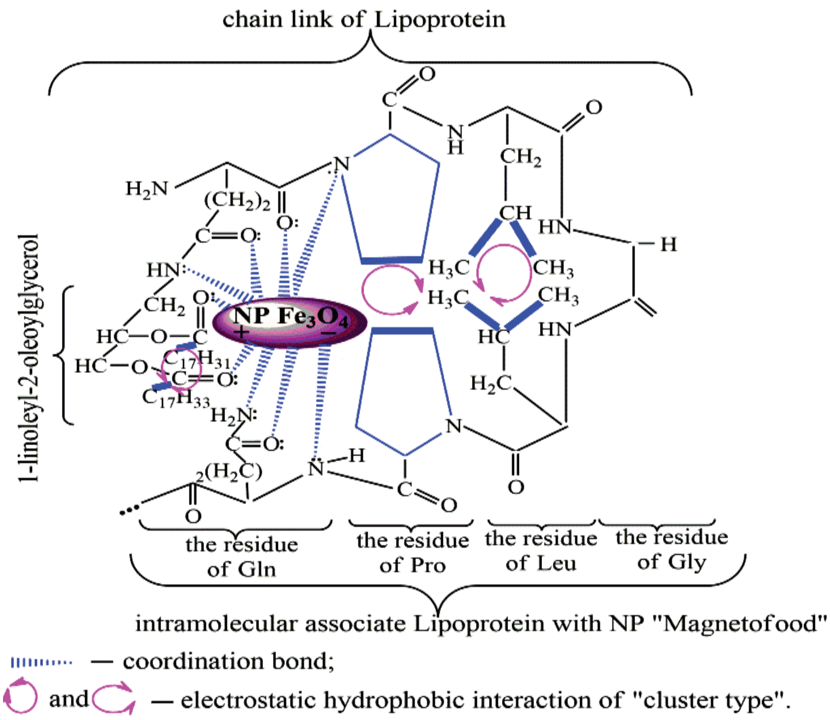

Fig. 4. Formation of the electrostatic complex of NP from the food additive «Magnetofood» with the lipoproteid chain link

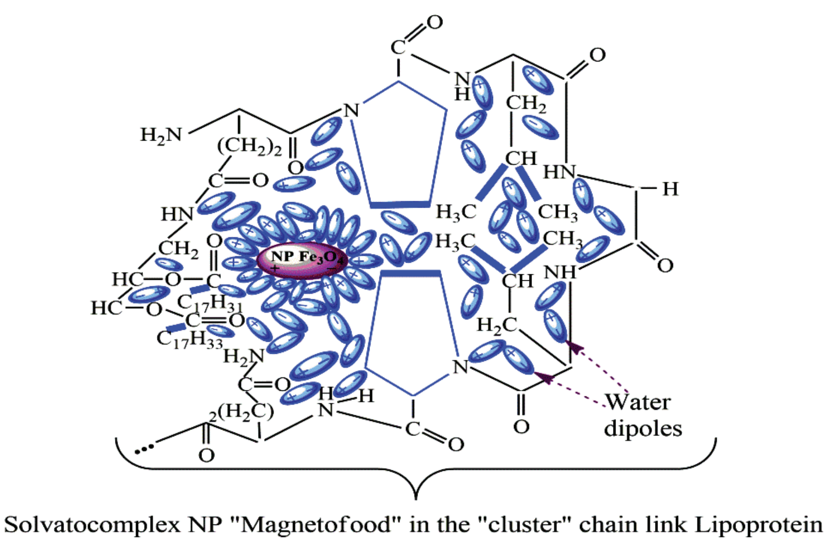

Fig. 5. Solvatocomplexes in the «clusters» of the lipoproteid chain link

It is well-known that the degree of binding H_2O to the protein is larger than that of carbohydrates due to the content of hydrophilic groups $-NH_2$, $-SH$, peptide bonds, etc. Cellulose and some hemicelluloses (specifically, glucomannan) have a linear structure. Under the influence of NP from «Magnetofood», carbohydrates and proteins change the structure, activate, acquire additional reactive centers, in particular hydrophilic.

As a result, the activated protein fragments of rye-wheat flour, when swollen, wrap around carbohydrate fragments and form strong glucoprotein complexes. That enhances the moisture-retaining ability (MRA) of rye-wheat dough.

An analysis of data in Fig. 3 shows that NP of «Magnetofood» are the active hydrophilic centers along with the ionogenic groups of disaccharide and protein. NP of «Magnetofood» activate the formation of solvatoassociates. In «clusters», there is free water and there are aqua-associates (moisture is absorbed by hydrogen bonds).

It follows from data in Fig. 4 that NP of «Magnetofood» form internal-molecular complexes at the expense of coordination links with the atoms of nitrogen and oxygen form the remnants of glutamine, proline and 1-linoleyl-2-oleoylglycerol. In addition, there are the formations of the «cluster» type through the electrostatic hydrophobic interactions between aliphatic side chains of leucine remnants and π-π-stacking interaction between aromatic fragments of proline remnants.

An analysis of Fig. 5 demonstrates that due to the presence of the polarized NP of «Magnetofood» and «clusters», as well as the system of hydrogen bonds between dipoles of H_2O, the accumulation of water is observed around NP of «Magnetofood» and in the «clusters» of the lipoproteid chain, which contributes to an increase in MRA of rye-wheat dough.

6. Discussion of results of studying the influence of the food additive «Magnetofood» on the moisture retaining ability of rye-wheat dough

An analysis of Fig. 1, 2 reveals that inside the link of the polypeptide chain of glucoproteid is the coordination interaction between NP of «Magnetofood» and the atoms of nitrogen and oxygen from the remnants of disaccharide «Cor» and serine. In addition, there occur the electrostatic hydrophobic interactions between aliphatic side chains of serine remnants and methyl groups of residues of N-acetyl galactosamine. There are the formations of the «cluster» type, as well as the electrostatic complexes of biopolymer with NP of «Magnetofood».

The «clusters» may retain the inter-micellar and intramicellar water, which is bound by the hydrogen, dipole-ion and dipole-dipole bonds with the polarized NP of «Magnetofood» and the hydrophilic groups of glucose and lipoproteids (since NP of «Magnetofood» and part of the hydrophilic groups are also contained in «clusters» and in the internal divisions of polymeric macrostructures). And, finally, water dipoles could simply participate in hydrogen bonds, without breaking their strength. In addition, lateral branches that emerged in the polymeric macrostructure promote the extension of main chains, without disrupting their «cross-linking». And this facilitates the interaction between macromolecules of biopolymers and water dipoles, and improves the hydration of complex proteins of rye-wheat flour.

The disadvantage of this study is in that the proposed mechanism of interaction between the food additive «Magnetofood» and lipo- and glucoproteids of rye-wheat flour was considered based on only one type of the dough system, specifically rye-wheat. In addition, it is not known how this additive will affect the technological indicators of dough masses with a different formulation (from other types and grades of flour).

The positive aspect is the proposed mechanism of interaction between the additive «Magnetofood» and complex proteins could be used to study the moisture-retaining ability of protein-carbohydrate complexes of other food systems (meat, milk, etc.).

7. Conclusions

1. The mechanism of interaction between nanoparticles (NP) of the food additive «Magnetofood» and functional groups of complex proteins of rye-wheat flour was established. NP from the food additive «Magnetofood» mostly interact with the complex proteins at the expense of coordination links. Under the influence of NP from the additive «Magnetofood», the structure of complex proteins undergoes structural changes: the emergence of formations of the «cluster» type, as well as the electrostatic complexes of biopolymer with NP of «Magnetofood».

2. The mechanism of influence of NP from the food additive «Magnetofood» on the binding of H_2O by the lipo- and glucoproteids of rye-wheat dough was established. NP from «Magnetofood» modify lipo- and glucoproteids, alter the spatial structure, contributing to the strengthening of hydration and water retention processes. The ionized NP of «Magnetofood» activate the formation of solvatoassociates. The «clusters» of complex proteins contain free water and there emerge the aqua-associates (H_2O is retained by means of hydrogen bonds).

3. The mechanism of interaction between the «Magnetofood» nanoparticles and complex proteins and H_2O molecules in rye-wheat dough system is proposed. Owing to the presence of the polarized NP of «Magnetofood» and «clusters», as well as the system of hydrogen bonds between the H_2O dipoles, the accumulation of water is observed around NP of «Magnetofood» and in the «clusters» of chains of lipo- and glucoproteids, which promotes the increased MRA of rye-wheat dough. The «clusters» may retain inter-micellar and intra-micellar water, which is bound by the hydrogen, dipole-ion, and dipole-dipole bonds to the polarized NP of «Magnetofood» and hydrophilic groups of gluco- and lipoproteids. And, finally, water dipoles may simply participate in hydrogen bonds, without breaking their strength. In addition, lateral branches that appear in the polymeric macrostructure contribute to the extension of main chains, without disrupting their «cross-linking». That facilitates the interaction between macromolecules of complex proteins and dipoles of H_2O and improves the hydration of lipo- and glucoproteids of rye-wheat flour.

Thus, when enriching rye-wheat flour with the food additive «Magnetofood,» its water-absorbing capacity and moisture-retaining ability both increase.

References

1. Obzor rynka hlebobulochnyh i konditerskih izdeliy Ukrainy // Hlebopekarskoe i konditerskoe Delo. 2012. Issue 3, 6.
2. Volkova S. F., Zolotuhina A. O. Sostoyanie i perspektivy razvitiya hlebopekarnoy promyshlennosti Ukrainy // Ekonomika harchovoi promyslovosti. 2012. Issue 3 (15). P. 51–55.
3. Funkcional'no-tekhnologicheskie svoystva poroshkoobraznogo syr'ya i pishchevyh dobavok v proizvodstve konditerskih izdeliy / Renzyaeva T. V., Tubol'ceva A. S., Ponkratova E. K., Lugovaya A. V., Kazanceva A. V. // Tekhnika i tekhnologiya pishchevyh proizvodstv. 2014. Issue 4. P. 43–49.
4. Auerman L. Ya. Tekhnologiya hlebopekarnogo proizvodstva: uchebnik / L. I. Puchkova (Ed.). Sankt-Peterburg: Professiya, 2003. 253 p.
5. Renzyaeva T. V., Poznyakovskiy V. M. Vodouderzhivayushchaya sposobnost' syr'ya i pishchevyh dobavok v proizvodstve muchnyh konditers'kih izdeliy // Hranenie i pererabotka sel'hozsyr'ya. 2009. Issue 8. P. 35–38.
6. The study of nanoparticles of magnitite of the lipid-magnetite suspensions by methods of photometry and electronic microscopy / Alexandrov A., Tsykhanovska I., Gontar T., Kokodiy N., Dotsenko N. // Eastern-European Journal of Enterprise Technologies. 2016. Vol. 4, Issue 11 (82). P. 51–61. doi: https://doi.org/10.15587/1729-4061.2016.76105
7. Design of technology for the rye-wheat bread «Kharkivski rodnichok» with the addition of polyfunctional food additive «Magnetofood» / Tsykhanovska I., Evlash V., Alexandrov A., Lazarieva T., Svidlo K., Gontar T. // Eastern-European Journal of Enterprise Technologies. 2017. Vol. 6, Issue 11 (90). P. 48–58. doi: https://doi.org/10.15587/1729-4061.2017.117279
8. Tekhnologiya proizvodstva i pokazateli kachestva pishchevoy dobavki na osnove magnetita / Ilyuha N. G., Barsova Z. V., Tsykhanovska I. V., Kovalenko V. A. // Eastern-European Journal of Enterprise Technologies. 2010. Vol. 6, Issue 10 (48). P. 32–35. URL: http://journals.uran.ua/eejet/article/view/5847/5271
9. Polumbryk M. O. Nanotekhnolohiyi v kharchovykh produktakh // Kharchova promyslovist. 2011. Issue 10. P. 319–322.
10. Sozer N., Kokini J. L. Nanotechnology and its applications in the food sector // Trends in Biotechnology. 2009. Vol. 27, Issue 2. P. 82–89. doi: https://doi.org/10.1016/j.tibtech.2008.10.010
11. Baranov D. A., Gubin S. P. Magnitnye nanochasticy: dostizheniya i problemy himicheskogo sinteza // Radioelektronika. Nanosistemy. Informacionnye tekhnologii. 2009. Vol. 1, Issue 1-2. P. 129–145
12. Substantiation of the mechanism of interaction between biopolymers of ryeandwheat flour and the nanoparticles of the magnetofood food additive in order to improve moistureretaining capacity of dough / Tsykhanovska I., Evlash V., Alexandrov A., Lazarieva T., Svidlo K., Gontar T. et. al. // Eastern-European Journal of Enterprise Technologies. 2018. Vol. 2, Issue 11 (92). P. 70–80. doi: https://doi.org/10.15587/1729-4061.2018.126358

13. Investigation of the moisture-retaining power of rye-wheat gluten and flour with polyfunctional food supplement «Magnetofood» / Tsykhanovska I., Evlash V., Alexandrov A., Lazareva T., Svidlo K., Gontar T. et. al. // EUREKA: Life Sciences. 2018. Issue 2. P. 67–76. doi: http://dx.doi.org/10.21303/2504-5695.2018.00611
14. Opredelenie svyazannoy vody indikatornym metodom v hlebopekarnom proizvodstve / Yurchak V. G., Berzina N. I., Shmarovoz V. M., Prishchepa M. P. // Izvestiya Vuzov. Pishchevaya tekhnologiya. 1989. Issue 4. P. 78–80.
15. Buldakov A. Pishchevye dobavki: spravochnik. 2-e izd., pererab. i dop. Moscow: SPb., 2008. 280 p.
16. Matveeva I. V., Velickaya I. G. Pishchevye dobavki i hlebopekarnye uluchshiteli v proizvodstve hleba: uchebnik. Novosibirsk: Sib. univ. izd-vo, 1998. 328 p.
17. Maforimbo E., Skurray G. R., Nguyen M. Evaluation of l-ascorbic acid oxidation on SH concentration in soy-wheat composite dough during resting period // LWT – Food Science and Technology. 2007. Vol. 40, Issue 2. P. 338–343. doi: https://doi.org/10.1016/j.lwt.2005.09.008
18. Wheat Flour Proteins as Affected by Transglutaminase and Glucose Oxidase / Rosell C. M., Wang J., Aja S., Bean S., Lookhart G. // Cereal Chemistry Journal. 2003. Vol. 80, Issue 1. P. 52–55. doi: https://doi.org/10.1094/cchem.2003.80.1.52
19. Chugunova O. V., Pastushkova E. V. Modeling of organoleptic indicators of bread with plant supplements // Bulletin of the South Ural State University. Series Food and Biotechnology. 2015. Vol. 3, Issue 4. P. 80–87. doi: https://doi.org/10.14529/food150411
20. Food supplements based on vegetable raw materials in the production of baked goods and pastries / Tamazova S. U., Lisovoy V. V., Pershakova T. V., Kasimirova M. A. // Polythematic Online Scientific Journal of Kuban State Agrarian University. 2016. Issue 122 (08). doi: https://doi.org/10.21515/1990-4665-122-076
21. Roslyakov Yu. F., Vershinina O. L., Gonchar V. V. Nauchnye razrabotki dlya hlebopekarnoy i konditerskoy otrasley // Tekhnologii pishchevoy i pererabatyvayushchey promyshlennosti APK – produkty zdorovogo pitaniya. 2016. Issue 6. P. 42–47.
22. Citrusovye volokna Herbacel AQ Plus – tip N. Specifikacii dlya pishchevyh dobavok i receptury. URL: http://specin.ru/kletchatka/109.htm
23. Gorshunova K. D., Semenova P. A., Bessonov V. V. Vzaimodeystvie gidrokolloidov i vodorastvorimyh vitaminov pri konstruirovanii obogashchennyh pishchevyh produktov // Pishchevaya promyshlennost'. 2012. Issue 11. P. 46–49.
24. Spravochnik po gidrokolloidam / A. A. Kochetkova, L. A. Sarafanova (Eds.). Sankt-Peterburg: GIORD, 2006. 536 p.
25. Drobot V. I. Ispol'zovanie netradicionnogo syr'ya v hlebopekarnoy promyshlennosti. Kyiv: Urozhay, 2008. 152 p.
26. Martins Z. E., Pinho O., Ferreira I. M. P. L. V. O. Food industry by-products used as functional ingredients of bakery products // Trends in Food Science & Technology. 2017. Vol. 67. P. 106–128. doi: https://doi.org/10.1016/j.tifs.2017.07.003
27. A review: Modified agricultural by-products for the development and fortification of food products and nutraceuticals / Lai W. T., Khong N. M. H., Lim S. S., Hee Y. Y., Sim B. I., Lau K. Y., Lai O. M. // Trends in Food Science & Technology. 2017. Vol. 59. P. 148–160. doi: https://doi.org/10.1016/j.tifs.2016.11.014
28. Current trends in the enhancement of antioxidant activity of wheat bread by the addition of plant materials rich in phenolic compounds / Dziki D., Różyło R., Gawlik-Dziki U., Świeca M. // Trends in Food Science & Technology. 2014. Vol. 40, Issue 1. P. 48–61. doi: https://doi.org/10.1016/j.tifs.2014.07.010
29. Mango seed: Functional and nutritional properties / Torres-León C., Rojas R., Contreras-Esquivel J. C., Serna-Cock L., Belmares-Cerda R. E., Aguilar C. N. // Trends in Food Science & Technology. 2016. Vol. 55. P. 109–117. doi: https://doi.org/10.1016/j.tifs.2016.06.009
30. Bharath Kumar S., Prabhasankar P. Low glycemic index ingredients and modified starches in wheat based food processing: A review // Trends in Food Science & Technology. 2014. Vol. 35, Issue 1. P. 32–41. doi: https://doi.org/10.1016/j.tifs.2013.10.007
31. Ngemakwe P. N., Le Roes-Hill M., Jideani V. Advances in gluten-free bread technology // Food Science and Technology International. 2014. Vol. 21, Issue 4. P. 256–276. doi: https://doi.org/10.1177/1082013214531425
32. Products of chickpea processing as texture improvers in gluten-free bread / Bird L. G., Pilkington C. L., Saputra A., Serventi L. // Food Science and Technology International. 2017. Vol. 23, Issue 8. P. 690–698. doi: https://doi.org/10.1177/1082013217717802
33. Effect of microalgae incorporation on physicochemical and textural properties in wheat bread formulation / García-Segovia P., Pagán-Moreno M. J., Lara I. F., Martínez-Monzó J. // Food Science and Technology International. 2017. Vol. 23, Issue 5. P. 437–447. doi: https://doi.org/10.1177/1082013217700259
34. Ershov P. S. Sbornik receptur na hleb i hlebobulochnye izdeliya. Sankt-Peterburg: Profi-inform, 2004. 190 p.
35. Investigation of the water-retaining capacity of the protein-hydrocarbon complex of rye-wheat dough with addition of polyfunctional food supplement «Magnetofood» / Tsykhanovska I., Evlash V., Alexandrov A., Lazareva T., Bryzytska O. // EUREKA: Life Sciences. 2018. Issue 4. P. 63–68. doi: http://dx.doi.org/10.21303/2504-5695.2018.00668