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FUNCTIONAL PROPERTIES AND BIOLOGICAL ACTIVITIES OF BOVINE CASEIN PROTEINS AND PEPTIDES

Małgorzata Darewicz, Jerzy Dziuba, Marta Dziuba

Chair of Food Biochemistry, University of Warmia and Mazury in Olsztyn, Olsztyn

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This review is a brief description of the current state of research on the functional and bioactivite properties of caseins, their hydrolysates and peptides. The functional properties of casein and casein-originated hydrolysates and peptides reflect the natural features of their molecules and environmental characteristics. Many proteolytic enzymes are used for modifying functional and biological properties of caseins. Enzymatic modifications influence the conformation of casein molecules and, in consequence, their properties. The functional properties of caseins may improve upon partial hydrolysis. Peptides derived from casein proteins are capable of affecting the biological functions of an organism. These effects can be antihypertensive, antimicrobial, antithrombotic, immunoregulating and opioid.

INTRODUCTION

Proteins play a very important role in the food industry. The characteristics of each protein determine the functionality of this protein in foods. Different physicochemical and structural properties of proteins are expressed as functional properties. Functional properties are generally considered to be properties of a double type. These include the surface properties of proteins, such as for example foam and emulsion properties or solubility, and hydrodynamic properties, *e.g.* texture properties [Philips *et al.*, 1994; Wong *et al.*, 1996]. Surface properties are dependent on the hydrophobicity and hydrophilicity of protein domains, whereas the nature of hydrodynamic properties is determined by the size, conformation and flexibility of protein molecule structure. Functional properties reflect the natural features of protein molecules, *i.e.*, size, shape, flexibility, susceptibility to denaturation, composition and amino acid sequence, charge and its distribution, hydrophobicity/hydrophilicity, characteristics of micro-domain structures, capability of a domain or the whole molecule to adapt to environmental changes, specificity of interactions with other food components, as well as the most important environmental characteristics such as pH, temperature, pressure, ionic strength. Proteins and their hydrolysates or peptides make a complex systems with other food components. Technological processes, to which food is subjected, play quite an important role in the development of functional properties [Philips *et al.*, 1994; Wong *et al.*, 1996].

Monographs and research papers have appeared on the functional properties of casein proteins [Kinsella, 1987; Philips *et al.*, 1994; Wong *et al.*, 1996; Darewicz *et al.*, 2000a; Darewicz & Dziuba, 2005]. The design of functionality by means of enzymatic, physical or chemical methods can permit a protein to fulfill a variety of purposes in food products. Despite numerous studies, the interrelation between proteins/hydrolysates/peptides (molecular weight, conformational stability, hydrophobicity, *etc.*) and functional properties remains uncertain. It is difficult to deduce structure-function relationships due to different experimental methods and techniques that have been used and the presence of mixtures of proteins/peptides in the systems investigated. A better knowledge is in demand, since this may lead to a more efficient and wider industrial use of casein proteins.

Enzymatic hydrolysis of proteins has been also shown to produce peptides with different biological activities, such as angiotensin converting enzyme-inhibitors, opioid peptides and immunostimulating peptides [Meisel, 1997]. These peptides, which are inactive within the sequence of the precursor protein, can be released during for instance cheese ripening. Biologically active peptides are held responsible for the health- and well-being-promoting effects of food protein products. In the food industry there is a trend towards the production of functional foods and nutraceuticals containing biactive peptides.

ENZYMATIC MODIFICATIONS

Enzymatic modifications of proteins have been covered extensively [Adler-Nissen, 1986; Arai & Fujimaki, 1991; Panyam & Kilara, 1996]. They have a particularly long tradition in the food industry (*e.g.* in the production of cheese, bakery products, beer), in addition being commonly accept-

Author's address for correspondence: Prof. Dr hab. Jerzy Dziuba, Chair of Food Biochemistry, University of Warmia and Mazury in Olsztyn, Pl. Cieszyński1, 10-726 Olsztyn, Poland; e-mail: jerzy.dziuba@uwm.edu.pl

ed from the viewpoint of toxicological, physiological and sensory requirements [Visser *et al.*, 1993]. Enzymatic modifiactions have the advantage of mild reaction conditions [Arai & Fujimaki, 1991; Philips *et al.*, 1994]. Enzymatic hydrolysis of proteins has several consequences: decrease in molecular weight, increase in the number of ionizable groups, exposure of hydrophobic groups, and, consequently enhanced interactions of peptides with themselves and with the environment [Panyam & Kilara, 1996]. This implies that the solubility and the surface activity of the protein will be altered and the propensity of the hydrolysed protein to *e.g.* form and stabilise emulsions/foams may be different from that of the intact protein. In the food industry casein proteins are applied for their functionality. Food proteins not always have the functional properties that fully satisfy the requirements of producers and food consumers. Enzymatic hydrolysis can be used to alter their functional properties. The course of hydrolysis is determined by such variables as pH, temperature, time, enzyme and substrate concentrations [Adler-Nissen, 1986]. Efficient selection of their values allows to control the hydrolysis process. The choice of the enzyme used determines which peptides will be formed because of differences in enzyme specificities. As a result, hydrolysates that have been formed by various enzymes may have different functionalities. The properties of protein hydrolysates are additionally dependent upon such factors as technological treatment after the hydrolysis [Visser *et al.*, 1993].

The difference in structural properties between proteins was reported as a reason for their differences in functionality [Mulvihill Fox, 1989]. This thesis is confirmed by glaring examples of such differences, *i.e.* β-casein (β-CN), a protein with little secondary structure and no intra molecular cross-links, and β-lactoglobulin, a typically globular protein. β-Casein is considered a naturally denatured protein. It belongs to the class of the so-called reomorphic proteins [Holt & Sawyer, 1993]. The N-terminal domain of this protein is highly hydrophilic and contains five/four phosphoseryl residues, while the remainder contains many hydrophobic residues. The unique feature of these structures is their amphiphilic character [Dickinson, 1999]. At temperatures below 4°C, β-CN exists as a monomer, whereas at higher temperatures micelles are formed [Horne, 1998]. The flexible conformation of β-CN allows adsorption in a "brush"-like conformation [Dickinson, 1999]. β-Lactoglobulin is a globular protein having two disulfide bridges and a free sulfhydryl group [Hambling *et al.*, 1992]. The association behaviour of the protein depends on both pH and temperature [Kinsella, 1987]. β-Casein is thought to adsorb onto oil/water interface in a loop-and train conformation, whereas globular β-lactoglobulin has more rigid structure which can unfold in the adsorbed state [Dickinson, 1999]. It should be then expected that hydrodynamic behaviour of casein molecules will be quite different than of whey protein molecules.

SOLUBILITY

Solubility is a very important functional property of proteins since it determines their use in food processing, providing valuable information about the method for production of protein preparations, in addition influencing the emulsifying and foaming properties of proteins. Solubility is dependent on the structure and properties of a solvent, temperature and pH of an environment, concentration and charge of ions, and character of interactions with other molecules [Pearce, 1995]. The loss in solubility because of food processing in drastic conditions is often indicative of denaturation degree of a protein [Pomerantz, 1991]. In many studies the key functionality that was targeted for improvement was solubility, but enzymatic hydrolysis did not improve solubility as a rule [Panyam & Kilara, 1996; Darewicz, 2001]. This may happen because of possible interactions between peptides and between peptides and other food components. Solubility is considered the essential prerequisite for the manifestation of many functional properties. Grufferty & Fox [1988] hydrolysed micellar casein by alkaline milk proteinase. The increase in soluble nitrogen was due to the production of proteose peptones, peptides with good surface activity. Abert & Kneifel [1992] observed that an increase in the degree of acid casein hydrolysis resulted in an increase in the nitrogen solubility index.

EMULSIONS AND FOAMS

Emulsions and foams are the systems composed of two immiscible liquids, one of which is dispersed in the form of small droplets. The phenomenon of formation and stabilisation of emulsion and foam by proteins is caused by their abilities to decrease the surface tension, adsorption on the interface and formation of cohesive film around oil droplets or air bubbles [Walstra, 1993]. Solubility plays a certain role in developing the emulsifying properties [Pearce, 1995]. It has been found that hardly soluble proteins have generally poor emulsifying properties. The stability of protein film at the oil/water interface is dependent on the equilibria between protein molecules and both phases. The emulsifying properties may improve upon limited protein denaturation which does not decrease drastically the solubility but is associated with an increase in surface hydrophobicity [Walstra & De Roos, 1993].

In contrast to low molecular weight emulsifiers, the protein structure may change upon adsorption. Hydrophobic regions of the protein domains orient towards the oil phase, whereas hydrophilic ones prefer the water phase [Dalgleish, 1997]. Newly-formed interfacial surface of protein can be stabilised in two ways, either by electrostatic action (which is highly affected by, among others, pH and ionic strength), or steric action (largely dependent on the structural properties of protein molecules and their arrangement on the surface of oil droplets/air bubbles) [Darewicz *et al.*, 2000b; Darewicz, 2001].

Casein is an excellent emulsifier because it easily unfolds at the interface. This ability of casein results from its unusually flexible structure, containing not many elements of ordered secondary structure. β-Casein decreases the surface tension most efficiently. Casein's ability to lower the surface tension decreases in the following order: β-casein>α_{s1}-casein>κ-casein>β-lactoglobulin>α-lactalbu-

min>serum albumin. β-Casein is also considered to be the best emulsifying agent among caseins [Dalgleish, 1997]

Haque & Mazaffar [1992] reported an increase in the emulsion activity index and a decrease in emulsion stability after proteolysis of acid casein. Innocente *et al.* [1998] found that component 3 of proteose peptone was a good surfactant at both air/water and oil/water interfaces. Some works presented the results on specific peptides instead of mixtures of different peptides fractions, which was helpful in understanding structure-function relationships. It was found that from the viewpoint of the most favourable improvement of these properties, peptides should be composed of 15 to 35 amino acid residues, which corresponds to the degree of hydrolysis DH = 3–6% [Chobert *et al.*, 1988]. Shimizu *et al.* [1984] found that the fragment (1–23) of α_{s1}-casein had a similar emulsifying activity to that of the intact molecule. However, in another study [Shimizu *et al.*, 1986] a synergistic effect in emulsion activity between the studied (1–23) fragment and traces of coexisting peptides was observed. Lee *et al.* [1987] reported similar synergistic effects between the fragment (193–209) of β-casein and glycomacropeptide (106–169 fragment of κ-casein). These authors hypothesized that an amphiphatic structure was formed by two peptides in mixture. Turgeon *et al.* [1996] hydrolysed casein by trypsin to 5% degree of hydrolysis and obtained the following peptides possessing excellent emulsion properties: β-casein (48–63 and 129–184) and α_{s1}-casein (167–208). Darewicz *et al.* [2000b] and Darewicz [2001] in the conditions used for the hydrolysis of β-casein by plasmin, separation and purification of the hydrolysate fractions obtained β-CN peptides of different characteristics: hydrophilic (β-CN 1-28), amphiphilic (β-CN 1/29-105/107) and hydrophobic (β-CN 106/108/114-209). Their abilities to form emulsions or foams were worse, compared with β-casein. It was found that small hydrophilic peptides showed poor ability to decrease the surface tension, and low capacity for steric interactions, which implicates their unsatisfactory emulsifying and foaming properties. At pH below 9.0 the hydrophobic peptides formed emulsions that were immediately subjected to aggregation. At pH 9.0, on the other hand, the stability of their emulsions and foams was comparable with the stability of the systems formed with the contribution of β-CN. In the alkaline range of pH, an increase in the resultant charge of molecules not only prevents from their aggregation, but promotes the repulsive forces between the molecules, which is manifested by improved functional properties. A distinct separation of hydrophobic and hydrophilic areas in amphiphilic peptides together with relatively high molecular weight could be one of the reasons for their best emulsion-forming ability, as compared with β-CN and its other fragments. The improvement in these properties in the case of amphiphilic peptides may be connected with greater flexibility of their polypeptide chains with exposed hydrophobic regions and with increased electrostatic and steric interactions. The stability of emulsions formed with their contribution was not, however, equal to that formed with β-CN and the foams they formed were unstable. Lowering pH from 9.0 to 6.7 improved the ability of β-CN and its all plasmin-released peptides to form and stabilise the emulsion or foam.

A relationship between emulsion-forming and stabilising properties and the presence of secondary structure in synthetic peptides in a solution was suggested in literature [Saito *et al.*, 1995; Kang *et al.*, 1996; Sheehan *et al.*, 1998]. Based on the obtained results the authors concluded that emulsifying activity was present only in samples which showed some helical conformation in a solution. However, such a relationship has not been investigated for food proteins. To establish the structure-function relationship of β-casein, Darewicz *et al.* [2000b; 2001] investigated the secondary structure of β-CN plasmin-released peptides both in a solution and in the adsorbed state, since it is known that secondary structure can change upon adsorption [Maste, 1997]. Better emulsion-forming properties were observed for β-CN peptides, that had a higher content of α-helices.

The factors important in foam formation include, among others, surface hydrophobicity, spatial distribution of hydrophobic groups, and the presence of lipids, minerals, carbohydrates and sulfhydryl groups [Patel, 1994]. It has been found that an ideal foam-forming protein should have high surface hydrophobicity, good solubility and low total charge at the pH value of the food product, and its polypeptide chain should relatively easily unfold [Poole & Fry, 1987]. Component 3 of proteose peptone was reported to have good foam properties [Innocente *et al.*, 1998]. Patel [1994] hydrolyzed casein and identified three β-casein peptides in the mixture after hydrolysis: β-CN (101–145), (107–145) and (107–135). The decrease in foam forming ability was observed at 10% DH when compared to5 % DH. Darewicz *et al.* [2000b] and Darewicz [2001] generated hydrophilic, amphiphilic and hydrophobic peptides *via* β-casein plasmin hydrolysis. Despite very good solubility, hydrophilic peptide (1–28) was unable to form and stabilise foams. Foam forming and stalising abilities of amphiphilic peptides (1/29–105/107) were worse when compared with the intact protein. At pH 9.0 only hydrophobic peptides (106/108/114–209) formed stable foams.

BIOLOGICAL PROPERTIES

The concepts in nutrition are changing from a past emphasis on survival, then hunger satisfaction, to an emphasis on the promising use of foods to promote a state of well-being and better health, and to help reduce the risk of diseases. In evaluating the nutritional value and in determining the possible applications of protein hydrolysates, an important role is played by such factors as quantitative and qualitative composition of amino acids (*e.g.* a decreased phenylalanine content is important in the therapy of people suffering from phenylketonuria, whereas an increased content of glutamine is important in the period of physiological stress) and the presence of potentially bioactive peptides that are easily and rapidly absorbed in the human body [Meisel, 1998]. Bioactive peptides are defined as the protein fragments which are inactive in the sequences of their precursors, but after enzymatic release they can interact with body receptors and regulate the physiological functions of the organism [Meisel, 1997]. Short peptides cross the intestinal barrier more quickly than free amino acids, which affects the optimisation of water metabolism in the body,

also having the importance in designing diets for special purposes, *e.g.* for sportsmen [Siemensma, 1993]. Currently the use of bioactive peptides as nutraceuticals, in therapy, especially in the treatment of cancer, viral infections, immune, cardiac and neurological disorders, is in the area of scientists' special interest. Biologically active peptides are also recommended as functional food components [Korhonen & Pihlanto, 2003]. Biologically active peptides may be generated *in vivo*, *in vitro* and during food processing. There are two strategies for producing an increased effect of bioactive peptides in dairy products. Either bioactive peptide preparations can be added, or food proteins can undergo specific proteolysis to promote the release of encrypted bioactive sequences. In contrast to endogenous bioactive peptides, many food-derived peptides have multifunctional properties [Dziuba & Minkiewicz, 1996]. The possibility to release biologically active peptides from proteins, their structural, physiological and nutritional characteristics have been discussed in many articles [Brody, 2000; Clare & Swaisgood, 2000; Shah, 2000; Dziuba *et al.*, 1999; 2003a, b; 2004; 2005].

ANTIHYPERTENSIVE PEPTIDES

Among the different classes of bioactive peptides, the antihypertensive peptides are the best known [Yamamoto, 1997]. Among the different groups of antihypertensive peptides, angiotensin converting enzyme (ACE)-inhibitory peptides are receiving special attention due to their potential beneficial effects related to hypertension. Synthetic ACE inhibitors are known to have strong side effects [Turner & Hooper, 2002]. The food protein-derived ACE inhibitory peptides have not shown these side effects yet [FitzGerald & Meisel, 2000]. The formation of ACE-ihibitory peptides by enzymatic hydrolysis [Hernández-Ledesma *et al.*, 2005] and during cheese ripening [Gómez-Ruiz *et al.*, 2002] has been reported. ACE-inhibitory peptides after being released by food processing are able to survive gastrointestinal digestion, be adsorbed, and reach the cardiovascular system in an active form. An increase in ACE-inhibitory activity by the action of digestive enzymes on fermented casein solutions was reported [Vermeirssen *et al.*, 2003]. To evaluate milk proteins as potential precursors of antihypertensive peptides, a computer-aided analysis has been applied to screen protein sequences and compare with bioactive peptide sequences in BIOPEP database [Dziuba *et al.*, 2003b; 2005]. The results have shown that the highest relative values of the occurrence frequency of the antihypertensive fragments in milk protein chains were characteristic of bovine β- and α-caseins. Antihypertensive peptides derived from α_{s1}- and β-casein are called casokinins [Masuda *et al.*, 1996; Yamamoto *et al.*, 2003]. The following ACE inhibitory peptides arising from casein were characterised: α_{s1}-casein fragments (23–27), (24–30), (58–61), (85–93), (102–109), (109–114), (205–208); α_{s2}-casein fragment (165–170), (176–179), (195–204); and β-casein fragments (1–6), (47–51), (59–64), (80–90), (95–101), (177–183), (198–203), (199–204); and their subsets [FitzGerald & Meisel, 2000; Hernández-Ledesma *et al.*, 2005; Gómez-Ruiz *et al.*, 2002]. The structure-activity correlations of many ACE-inhibitory casein peptides, indicate that their C-terminal tri-peptide residues play a predominant role in competitive binding to the active site of ACE. Among the most favourable C-terminal amino acids there are aromatic amino acids [Gómez-Ruiz *et al.*, 2002].

ANTIMICROBIAL PEPTIDES

Compared with antihypertensive peptides, only a few reports have considered the enzymatic release of antimicrobial casein peptides. The activity of antibacterial peptides is defined as membrane-lytic activity with specificity for prokaryotic cell membranes [Floris *et al.*, 2003]. An amphiphilic, mostly α-helical conformation, and a positive net charge are recognized as dominant structural motifs determining the membrane disturbing activity [Bechinger, 2004]. However, hydrophobic α-helical peptides possessing antibacterial activity have been also studied [Epand & Vogel, 1999]. A common characteristic observed for membrane-active peptides is their ability to disturb bilayer integrity, either by disruption or pore formation [Bechinger, 1999]. Compared with antibiotics, antimicrobial peptides are able to kill target cells more rapidly and have got the activity toward some important antibiotic-resistant pathogens. There are antibacterial peptides encrypted within the sequence of casein peptides that are released upon suitable proteolysis of precursor protein. Casecidins are a group of basic, glycosylated and high molecular mass (app. 5 kDa) polypeptides released from chymosin-treated casein [Lahov & Regelson, 1996]. These peptides were shown to display bactericidal properties against several strains of *S. aureus*. Isracidin corresponds to the N-terminal part of α_{s1}-casein [Lahov & Regelson, 1996]. Isracidin exerted *in vivo* a strong protective effect against *S. aureus*, *Streptococcus pyogenes*, and *L. monocytogenes*. Casocidin-I was isolated from acidified milk and corresponds to the fragment (150–188) of α_{s2}-casein [Zucht *et al.*, 1995]. It was reported that it was a highly cationic peptide (pI=10.8) with 10 of the total 39 amino acids residues being basic. Recio & Visser [1999] isolated two highly basic peptides from α_{s2}-casein: the fragment (164–179) and the fragment (183–207). The fragment 183–207 of α_{s2}-casein showed greater antibacterial activity. The differences found in the antibacterial activities of these α_{s2}-casein fragments were attributed to differences in positioning of positive charges within the sequence. Malkoski *et al.* [2001] isolated kappacin, corresponding to nonglycosylated, phosphorylated bovine caseinmacropeptide (κ-casein 106–169). The mechanism proposed for its activity was related to the negative net charge, which prevents the adhesion of the microorganism to the receptors on the target tissue. Antibacterial activity was also reported for the fragment (184–209) of β-casein [Minervini *et al.*, 2003].

OPIOID PEPTIDES

Some milk proteins are thought to affect the gastric hormones [Hara *et al.*, 1992]. Calm, insensibilization, blood pressure depression, body temperature changes, satiety sensation, antisecretory activity, food intake regulation are the effects of opioid peptides [Tome & Ledoux, 1998]. Numer-

ous studies have focused on the presence of opioid peptide sequences in the sequence of milk proteins including caseins [Meisel, 1997]. Opioid peptides derived from bovine casein are called casomorphins or casoxins. They are also referred to as exorphins, since they exhibit nalaxone inhibition and originate from exogenous sources. Meisel & Frister [1989] reported the formation of opioid caseinopeptides during *in vivo* studies. Two components isolated from jejunal chyme were identified. The first one was identified as β-CN peptide (60–70), and the other one – as α_{s1}-CN peptide (66–74). Meisel & Schlimme [1990] concluded that κ-casein-derived peptides acted as antagonists (blocked the action of an agonist), whereas β-casein- and α_{s1}-casein--derived peptides acted as opioid agonists (molecules that bind to nalaxone receptors). Pihlanto-Leppala *et al.* [1994] studied *in vitro* formation of opioid peptides *via* proteolysis of α_{s1}-casein, β-casein-casein and κ-casein. Digestion of α_{s1}-casein yielded peptide 90–96; β-casein produced the fragment 60–66; and κ-casein yielded the fragment 33–38.

ANTITHROMBOTIC AND IMMUNOREGULATING PEPTIDES

Anticoagulative peptides originated from caseins have been reviewed recently [Rutherfund & Gill, 2000]. The amino acid sequences and functional similarities between γ-chain of fibrinogen and κ-casein were pointed out. However, they do not act in the same way in platelet function and thrombus formation. Raha *et al.* [1998] reported that the fragment (106–116) of κ-casein and its subsets *i.e.* (106–112), (112–116), (113–116), the so-called casoplatelins, acted as anti-thrombotic activity agents. Fosset & Tome [1998] found that the tetrapeptide corresponding to the fragment (39–42) of κ-casein also exhibits antithrombotic activity.

Peptides from caseins affecting the immune system have been reviewed recently [Gill *et al.*, 2000]. The vast majority of immunoregulatory peptides that have been characterized are hydrolyzate derivatives of major milk proteins. Hata *et al.* [1999] found that commercially available preparation of casein phosphopeptide comprised primarily the fragment (1–32) of α_{s2}-casein and (1–28) of β-casein, and showed immunostimulating activity in cell cultures. Monnai *et al.* [1998] studied the immunomodulating effect of κ-caseinglycopeptide (106–169) and reported its immunosuppresing activity. Also the fragment (191–193) released from β-casein and the fragment (194–199) originated from α_{s1}-casein had an impact on the development of tissues [Coste *et al.*, 1992; Britton & Kastin, 1991].

OTHER ACTIVITIES

One of the problems arising during enzymatic hydrolysis of proteins is associated with a bitter taste of released peptides. This taste results from breaking proteins down into short-chain hydrophobic peptides [Adler-Nissen, 1986]. If the average hydrophobicity is grater then 1400, the peptide will elicit a bitter taste. This author also found that peptides below molecular mass of 6000 would certainly be bitter. Caseins are a rich source of hydrophobic amino acids and therefore alteration of casein with proteases will likely result in intense bitterness. Many methods have been developed to annihilate or mask the peptide bitterness, including the use of cyclodextrins, starches, margarine, creaming powder, vegetable oil, fatty substances, acidic amino acids, and enzymes (exopeptidases) [Tamura *et al.*, 1990].

Proteins are allergens and therefore it is possible that products derived after enzymatic modification of proteins may also be allergens. The antigenicity of α_{s1}-casein and some peptides derived from its C-terminal part was studied [Otani & Hosono, 1989]. It was found that α_{s1}-casein has at least two antigenic fragments: (136–199) and (165–179). Otani *et al.* [1988] reported on antigenic sites for β-casein. The authors concluded that the most likely location of the antigenic sites was in the following fragments: (1–25), (26–60), (61–93), (94–102), (103–109), (110–144) and (157–185). In some studies hydrolysis was attempted to reduce allergenicity and improve digestibility of proteins. Depending upon enzyme specificity and the extent of hydrolysis, allergenicity of milk proteins can be decreased if not eliminated. Mahmoud *et al.* [1992] studied the effect of the degree of hydrolysis on the antigenicity of casein. A significant decrease in antigenicity was observed during the first 10% of hydrolysis duration. It should be kept in mind that while the antigenic reactivity of the protein hydrolysate is a crucial factor in the production of hypallergenic infant formulas, the functional properties, particularly surface--active properties, are also very important while preparing a stable formula (as pointed out in the previous sections).

FINAL REMARKS

1. The principal reason for differences in the functional properties between proteins are their different structural properties.

2. A limited degree of casein hydrolysis can improve the functional properties. Minimum molecular weight of thus obtained peptides should not be lower than 2/5kDa.

3. The development of the functional properties of hydrolysates/peptides obtained from casein is determined by the specificity of enzymes used for hydrolysis, and the conditions of the process.

4. The distinguishing features of good emulsifying properties of casein peptides are clustering of hydrophilic and hydrophobic residues in distinct zones, together with certain minimum molecular mass enabling such a distribution of these regions, as well as high surface-load of peptides on the interface.

5. There is a relationship between the induction of alfa--helix structure and the emulsion-forming ability of casein peptides.

6. Some casein peptides are thought to affect the biological functions of an organism. These effects can be: antihypertensive, antimicrobial, antithrombotic, immunoregulating and opioid.

7. Casein hydrolysis can reduce its allergenicity and improve digestibility.

8. Many bioactive peptides and peptides that are released after casein hydrolysis are likely to be bitter.

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WŁAŚCIWOŚCI FUNKCJONALNE I AKTYWNOŚĆ BIOLOGICZNA KAZEINY I JEJ PEPTYDÓW

Małgorzata Darewicz, Jerzy Dziuba, Marta Dziuba

Katedra Biochemii Żywności, Uniwersytet Warmińsko-Mazurski w Olsztynie, Olsztyn

Niniejszy przegląd jest krótkim omówieniem obecnego stanu wiedzy na temat funkcjonalnych i bioaktywnych właściwości kazeiny, jej hydrolizatów i peptydów. Właściwości funkcjonalne kazeiny i pochodzących z niej hydrolizatów oraz peptydów są odzwierciedleniem naturalnych cech ich cząsteczek oraz cech środowiskowych. Wiele enzymów proteolitycznych można wykorzystać do modyfikacji cech funkcjonalnych i biologicznych kazeiny. Modyfikacje enzymatyczne wpływają na konformację cząsteczek kazeiny i w konsekwencji na ich właściwości. W efekcie ograniczonej hydrolizy kazeiny poprawie mogą ulec jej właściwości funkcjonalne. Peptydy uwolnione z kazeiny wykazują zdolności wpływania na funkcje biologiczne organizmów. Wykazują one aktywność: przeciwnadciśnieniową, antybakteryjną, antykoagulacyjną, immunoregulacyjną i opioidową.