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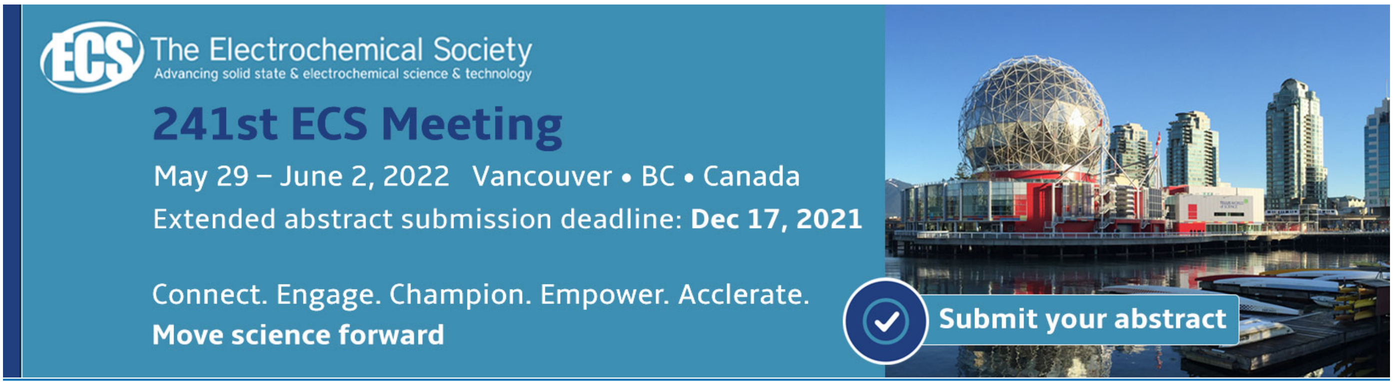

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Cellulose hydrocolloids in meat products: current status and challenges in developing functional food

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Abstract. Due to the growing health problems associated with the increased intake of saturated and *trans* fats, and the unbalanced n-6/n-3 ratio in the diet, in recent years numerous studies have focused on finding adequate substitutes for fat in meat products, while the meat industry made additional efforts to implement the obtained formulations (oleogels) in the standard production processes. Insoluble cellulose fibre in the form of microcrystalline cellulose has proven to be a promising ingredient in reduced fat, fibre-enriched functional food development, since it has been safely used as a food additive for many years with a known beneficial effect on human health. This review will discuss the recent advances of MCC application associated with alternative cellulose sources and processing technology, functional physico-chemical properties and potential as organogelator in fat mimetics. Finally, recently published data concerning its practical application in meat products as fat or starch substitutes will be presented.

1. Introduction

Daily activities, habits and diet can significantly improve health and quality of life. With the modern lifestyle, meat products have become one of the most important foods due to their nutritive value (biologically high value proteins, essential fats, soluble vitamins and minerals), convenience and taste. Therefore, they are extremely popular with consumers and the domestic meat industry produces them in a large quantity and assortment [1].

Meat products are made with high fat content and are deemed unhealthy. Some coarse and fine ground cooked products on the market, such as breakfast sausages or patties, depending on the local regulations, contain over 30% animal fat [2]. In meat products, the lipid phase is commonly present in the crystallized (solid) form, and so serves as a structure modifier, affecting the texture. The widespread consumption of *trans* and saturated fats, and unbalanced omega 6/omega 3 (n-6/n-3) ratio intake have been associated with number of adverse consequences on human health that led to higher incidence of coronary heart disease, inflammation, oxidative stress, endothelial dysfunction, several types of cancer, metabolic syndrome and obesity [3]. Thus, it is important to, ideally, replace animal fat in the meat batter with another lipid phase based on mono/polyunsaturated fats without negatively impacting processing, functionality and shelf life (stability during storage) of the product [4]. This replacement is an extremely difficult task, not only from the technological point of view but because of consumer reaction to changes in textural and sensorial characteristics of meat products. Most of the pioneer studies focused on the fundamental understanding of the structuring principles and rheological characterization of fat mimetics [5]. However, in the last two decades, this issue has encouraged the meat industry to develop some new, applicable approaches and invest a lot of resources and effort in order to produce reformulated, healthier functional meat products [6].

There has been extensive research in the field of meat processing, with significant progress in understanding the interaction between raw ingredients and processing parameters. Some innovative options in research have opened due to new ingredients available on the market and because consumers' preferences and demands have changed, in terms of less processed, organic food, with reduced cholesterol, saturated fatty acid (SFA) and sodium contents, and food enriched with fibre or biologically active components of plant origin [7].

2. Developing of reduced/low-fat meat products

The International Food Information Council Foundation reported that at the moment of purchase, 64% of consumers consider health, 67% of consumers check for saturated fat in labels and about 50% of all consumers are likely to purchase a product with a "no saturated fat" claim [8]. The meat product can be labelled as "reduced-fat" if the fat amount is decreased by 30% compared to the standard product. Nutritional organizations indicated recommendations for an optimal fatty acid intake profile where the focus is on limiting the consumption of saturated fats to under 10% of caloric intake [9]. Therefore, due to the appealing aspect, convenience and versatility, consumers are very interested in using low-fat meat products as part of the healthy diet, as long as appearance and taste of the final product is not changed above the acceptable limit [8].

Two main strategies in producing reduced/low-fat meat products are developed. The first one considers the use of low-calorie ingredients, while the second implies the replacement of the animal fat with highly unsaturated vegetable and marine oils or lipid-rich raw materials of plant origin [1]. Since fats are one of the ingredients with major flavour, mouth-feel and overall eating-pleasure capabilities in meat products, while interesterified fats are less appreciated by consumers, the approach related to oleogelation has shown to be advantageous. Moreover, approximately 50 patents concerning different fat mimetics have been filed in the last 10 years, suggesting the potential commercial value of its application in the food industry [5].

2.1. Application of oleogels

Structuring of oil media and designing of self-standing thermo-reversible viscoelastic gelator networks in the form of oleogels offers an interesting approach towards the development of nutritionally balanced meat products [10]. Incorporation of oils with oleogels in meat matrices as fat substitutes is a technological breakthrough, as this approach not only ensures the presence of polyunsaturated fatty acids (PUFA) in meat products but also the molecules that exert the gelling features could play an equally important role due to their possible direct or indirect bioactivity (e.g. dietary fibre) [3].

Dietary fibre, classified as a high-molecular weight oleogelator, is considered to be suitable for reformulated functional meat products because of the natural flavour and good water binding capabilities that prevent cooking loss [11]. Meaning, besides health benefit effects, it also provides economic profit to processors [12]. In addition to the importance of the oil phase, the nature of the gelling molecule (hydrophobicity, crystallinity, glass transition temperature) greatly affects the final oleogel's properties and efficiency [13]. Namely, the carbohydrate component determines the mechanical properties of oleogels, such as plasticity, cohesiveness and hardness (one of the most desirable characteristics of fat) [5]. Carbohydrates are especially appropriate for use in indirect dispersion methods where oil gelation is performed in the presence of water [3]. Oil-in-water emulsion stabilized by regenerated cellulose (RC) and carboxymethyl cellulose (CMC) has been shown to be extremely successful in the preparation of these oleogels [14]. Furthermore, ethyl cellulose also stands out among organogelators for meat product development because of the possibility of textural modifications similar to traditional formulations containing animal fat [15].

One of the newer promising organogelators is carboxylated nanofibre cellulose (cNF). Due to insufficient data related to the potential cytotoxicity and genotoxicity by cNF ingestion, previous research has mainly dealt with its application in edible and degradable food packaging. However, nano-size provides a high aspect ratio, specific surface area, high strength, stiffness and hydration, which is why cNF can produce a self-reassembled gel. Therefore, cNF has attracted great interest from the scientific public as a possible efficient filler for complex network matrices with high water content such as meat products [16].

3. Cellulose derived dietary fibre

The raw material of non-digestible dietary fibre is cellulose, a long chain carbohydrate polymer of glucose units linked by β-1,4-glycosidic linkages that build amorphous (paracrystalline) and crystalline regions [17]. The crystalline, rigid, linear part of the chain is of interest for the chemical, mechanical, or biological isolation of α-cellulose and production of functional ingredients that include microcrystalline cellulose (MCC), microfibrillated cellulose, nanocrystalline cellulose, nanofibrillated cellulose and bacterial cellulose [18]. CMC, methyl cellulose and hydroxyprophylmethyl cellulose (HPMC) are chemically modified cellulose. For example, CMC is obtained from alkali-cellulose after a reaction with monochloroacetic acid [18].

The most successfully commercialized form of crystalline cellulose is MCC (powder or colloid form) with well-established applications across diverse areas, especially in food and pharmaceutical industries [19]. It is estimated that the global market for the MCC, as a non-toxic, renewable and biodegradable material, will reach US$1360 million by 2024, with these two sectors as the biggest beneficiaries.

MCC has been widely investigated as a next-generation core material in various fields due to its excellent properties such as low density, high modulus, heat resistance, and transparency [20]. The physicochemical properties of MCC largely depend on its starting raw material and processing technology (extraction process) [18]. Namely, MCC that originates from non-wood sources, for example lignocellulosic materials from agricultural residues, is likely to have more impurities such as lignin, pectin and hemicellulose compared to MCC from wood and cotton sources. This indicates differences in surface area, molecular weight, particle size and shape, degree of crystallinity and polymerization, porous structure, moisture content and performance, and these are critical material attributes relevant for food applications [18,21].

3.1. The potential of MCC and CMC as hydrocolloids

Buttermilk powder, modified corn starch, wheat flour, soy protein concentrate, lupin protein and whey protein are commonly used extenders to replace meat[22]. However, many of these non meat proteins have allergen potential and this must be declared on the labels. To overcome this problem some alternative components can be used as functional ingredients to replace meat, including hydrocolloid carrageenan, xanthan, guar gum, konjac, MCC and CMC [17]. CMC and MCC have been used in many reduced-fat products as thickeners, suspendors, and gel and emulsion stabilisers, usually in combination with other gums. With the confirmed synergistic effect of these two hydrocolloids, and in order to obtain a more efficient fat substitute in the products, a commercially available product, Avicel, was formulated, which consists of co-dried MCC with about 10-15% CMC [23].

MCC and CMC are approved for use in foods as fibre additives and do not contribute to the caloric content of foods [24]. They have desirable functional physicochemical properties (gelation, water absorption, solubility, water holding capacity and pH) and can be used to improve stability and texture in particular in low-fat products [22]. Additionally, unlike soy protein, MCC use does not lead to changes in flavour. However, since a meat batter is a highly concentrated system, the functionality of novel ingredients, such as charged and uncharged fibre, largely depends on possible interactions between proteins and hydrocolloid that could lead to unexpected changes and affect quality attributes of final products [17,25].

3.2. MCC and CMC in meat products

Schuh *et al*. [17] investigated the effect of CMC and MCC at levels of 0.3-2.0% on structural/functional characteristics of emulsified sausages. They concluded that the addition of CMC (>0.7%) led to the destabilization of the sausage batter and a decrease in firmness and viscoelasticity. On the other hand, MCC was highly compatible with the meat matrix, and it improved firmness of the sausages, maintaining water-binding capacity at the level of the control sausages. Similarly, Gibis *et al*. [26] showed that replacing 10% of ground beef with a dispersion of CMC in concentrations higher then 1% led to destabilization of the microstructure, and poorer sensory quality and texture of fried beef patties. MCC could replace approximately 50% of fat in patties and improve the texture, with the best sensory scores obtained at 2% of MCC. Furthermore, these authors concluded that CMC at concentrations >0.5% is not suitable as a fat replacer in beef patties [26]. Oh *et al*. [27] investigated HPMC for the production of canola oil solidlike oleogels used as animal fat replacement in patty formulations at levels of 50 and 100%. HPMC oleogels significantly reduced cooking lost and made the texture of the patties much softer, with the highest overall acceptability at the 50% replacement level. Furthermore, HPMC oleogels showed good resistance against oxidation allowing, the formulation of healthier patties with SFA/PUFA ratio of 0.18 [27].

Recently, a new enhancement of meat product nutritional value is proposed and considers the replacement of starch with dietary fibre. Mejia *et al*. [28] evaluated the incorporation of a soluble (βG) and insoluble fibre (MCC), alone (1-3%) or in combination (1.5%), as a starch replacement in meat emulsions. They found that MCC did not change cooking loss, texture profile or colour parameters of beef emulsions, meaning that MCC or combined MCC/βG could be a good starch replacement that yields meat emulsions with fewer calories and greater insoluble fibre content.

In the United States (US), MCC has “generally recognized as safe” (GRAS) status and has gained recognition and applications within the food industry for over 40 years [18]. Regarding the constantly growing market of clean label products, meaning natural, minimally processed food, without artificial ingredients, and with ingredients that come from sustainable sources, MCC is on the list of unacceptable ingredients of major retailers. However, these chemical-sounding hydrocolloids are chemically modified polysaccharides derived from cellulose, the most abundant renewable resource in nature with a long history of safe use [5].

4. Nutritional and health benefits of insoluble dietary fibre

Mechanisms of MCC’s beneficial effects in humans are mainly indirect and include but are not limited to the control of gastric emptying and ileal brake (satiety effect), hypoglycaemic response (diabetes) and plasma cholesterol levels (cardiovascular disease) [18]. Additionally, insoluble dietary fibre defends the colonic epithelium from the harmful effects of ingested carcinogenic compounds [13,29]. It is suggested that daily intake greater than 50 g could exhibit these positive effects on human health, and this dose could be achieved by regular food or with supplements [13]. It is estimated, for example, that people in the US consume about 10 to 15 g fibre/day, while the US National Cancer Institute recommended a total daily fibre intake of 20 to 30 g/day, without exceeding 35 g/day [12]. In Europe, 3% fibre is required in a product before it can be labelled as a source of dietary fibre [26]. In any case, side effects such as flatulence, bloating, stomach pain, diarrhoea, and constipation must be considered when high amounts of fibre are included in the diet [30,31].

5. Conclusions and future work

So far, cellulosic insoluble fibre has been found to be of great importance in the production of new functional foods due to its low cost, abundant availability and effectiveness at low concentrations. In particular, cellulose fibre showed good potential in the formulation of alternatives to unhealthy fats in meat products. Nevertheless, oleogel technology has not yet been implemented in already established regular industrial processes, so extensive research is needed to provide additional insights into the structure, bioactive protection and bioactive delivery of oleogels as well as their interaction with the meat matrices and behaviour during processing, in order to standardize them and make it easier for practical applications in meat industry.

Promising results were obtained using MCC and CMC in the production of healthier cooked meat products. Therefore, further research should be directed towards the production of combinations of MCC and CMC, i.e. binary and ternary organogelator systems, and new forms of cellulose micro- or nano-structured lipid carrier. The possibility of using MCC oleogels in less minced meat products with mosaic cross section (e.g. fermented sausage), where the fermentation and ripening requires greater stability of oils in the gel structure, deserves study.

Regarding the proposed new strategies by the European Union in environmentally friendly and economically sustainable food production by 2030, further efforts should be focused on new directions in obtaining cellulose hydrocolloids and methodologies that would enable the exploitation of low-cost lignocellulosic raw materials (agricultural residues). This could be one way to reduce waste in the production chain and to limit the environmental impacts of intensive agriculture.

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