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Mini Review

A review on application of hydrocolloids in meat and poultry products

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Abstract

Hydrocolloids are used in meat products to improve functional properties and compensate undesirable effects of fat reduction, salt reduction and freeze/thaw process. In poultry products, such as nugget, hydrocolloids are added to coating batter to reduce oil adsorption and increase moisture retention during frying. In this review, application of different hydrocolloids (starch, gum and fiber) in meat products (especially sausage, freeze/thawed sausage, and low salt sausage) and poultry products (chicken breast, chicken sausage and nugget) are discussed.

Introduction

Today's tendency in utilization of food products with reduced or low fat content and food containing functional ingredients is more critical than before. Traditional meat products have approximately 20–30% fat content which increases risk of obesity and some types of cancer, and saturated fat is closely related to high blood cholesterol and coronary heart diseases (Gök *et al*., 2011). Sausages as processed meat products are used in different cultures around the world. A number of various ingredients in the appropriate amount are needed to produce a desired quality and safe product which is cost effective. Two factors that are essential to obtain a desirable product are abilities to form a strong and coherent matrix and water holding capacity (WHC) (Savadkoohi *et al*., 2014).

Fat has a major effect on texture, juiciness, mouth feeling and flavor of the meat products. Fat interacts with other components present in meat systems. It improves consumer acceptability and overall flavor (Tobin *et al*., 2013). Meat proteins are emulsifying agent in meat systems. For production a stable meat emulsion, meat proteins must surround the finely chopped fat particles before cooking. Myosin is the major structural protein for fat emulsification and WHC. The non-polar amino acid residues of the myosin tail would be assosiated with the fat cell surface, as the same time polar amino acid residues of the myosin head would be attached to the water phase. Thus fat is a vital component for formulation of meat products (Sorapukdee *et al*., 2013). Fat reduction can be lead to undesirable texture (rubbery and dry texture), unpleased flavor, unsuitable sensory properties and appearance of final product, also increases cooking time and decreases tenderness and juiciness.

The main salt used in meat products is NaCl that has functional properties, such as binding to water and fat, preservative effect, increasing shelf life by controlling aw, and significant effects on the textural properties of meat products. Salt reduction increases cooking loss, decreases shelf life and has an undesirable effect on texture, but because of direct relationship between salt intake and hypertension, it is necessary to reduce salt content in meat products. To compensate negative effects of salt reduction, other ingredients should be added to improve textural parameters and water binding properties of meat products (Madril and Sofos, 1985; Ruusunen *et al*., 2003a and b; McGregor, 2007). Also freezing and thawing negatively influence texture and binding properties of bologna type sausage especially low fat one. It is related to ice crystal formation affecting on internal structure during freezing (Colmenero *et al*.,

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1995).

To offset the detrimental effects of fat reduction, salt reduction and freezing and thawing, several investigations have been done to understand the effects of using non-meat ingredient such as hydrocolloids on emulsion stability, texture, appearance and sensory properties of low fat meat products (Barbut and Mittal, 1992; Brewer *et al*., 1992; Kumar and Sharma, 2004; Gök *et al*., 2011).

Also increased demand for consumption of poultry meat products in many countries caused in development of several valuable products such as chicken nugget. During deep fat frying of nugget, heat transfers from surrounding oil to the food's interior, thus the structural properties of coating batter plays an important function in oil uptake. Hydrocolloids are used in batter systems as functional components to improve adhesive batter performance and reduce oil uptake. (Saguy and Pinthus, 1995; Xue and Ngadi, 2006; Yogesh *et al*., 2013). Hydrocolloids are proteins or polysaccharides in some cases with functional properties such as thickening, gelling, stabilizing, film forming, dispersing and texture modifying that are successfully used in food products (Funami, 2011). In this article, the effects of different types of hydrocolloids (starch, gum, and fiber) as fat replacers in meat and poultry products will be reviewed.

Effects of hydrocolloids on gelling characteristics of meat proteins

Myofibrillar protein (MP), mostly consisting of myosin and actin, plays an essential role in producing the desirable texture and WHC of comminuted meat products, such as sausages. It is related to its ability to produce 3-dimensional gels upon heating and following cooling. Gelation of muscle protein involves partial denaturation and subsequent permanent aggregation of myosin heads during formation of disulfide bonds and helix-coil transitions of the tail part of the molecules, resulting in a 3-dimensional cross-linked network formation. Formation of 3-dimentional gels are influenced by different factors, such as pH, salt concentration and non-protein polymer ingredients (Sun *et al*., 2011; Sun and Holley, 2011).

Non-meat ingredients by interacting with meat proteins or changing the physical state affect on thermal denaturation of meat proteins and finally modify physical quality of cooked meat products such as texture and juiciness (DeFreitas *et al*., 1997a). Hydrocolloids have some effects on formation of protein gel matrix; therefore, by understanding protein performance in presence of hydrocolloids we can predict influence of hydrocolloids on meat products.

Carrageenan is a linear anionic sulfated polymer of galactose and anhydrogalactose, which is extracted from red seaweeds; three main carrageenan fractions are kappa (thermo reversible brittle gel formation), iota (thermo reversible elastic gel formation) and lambda (thickener, non-gelling). They are widely used in the food industries such as canned meat, reduced fat products (frankfurters) for its gelling characteristic, thickening and water binding properties (Giese, 1992; Therkelsen, 1993; Candogan and Kolsarici, 2003a and b; Bixler and Porse, 2011).

Addition of up to 2% carrageenan (CGN) to myofibrillar protein was not significantly effective on thermal transition temperature (thermal denaturation temperature) and caused in negligible changes in thermal stability, suggesting that no interaction occurred between CGN and protein, but presence of 2% salt by changing ion strength, influenced the peak of proteins transition (DeFreitas *et al.*, 1997a). Thus, CGN effects were ion strength-dependent. Also it was demonstrated with chicken meat proteins. Thermal stability of meat proteins from thigh (red meat) and chicken breast (white meat) muscle in presence of CGN and CGN/NaCl was investigated. Different types of carrageenan indicated very slight effect on chicken muscle proteins by itself. However, in presence of salt (2.5%), CGNs significantly affected protein stability. This effect varied about red and white meat, probably due to their structural and physicochemical differences (Amako and Xiong, 2001).

To understand CGN performance in meat protein systems, effect of carrageenan on salt soluble meat protein (SSMP) were examined in a model system. Kappa and iota-carrageenan improved gel strength and moisture retention of SSMP. Evaluation of carrageenan performance in presence of stabilizer/destabilizer reagents and microstructure properties indicated no molecular interaction; and improved water retention might be attributed to carrageenan by itself (DeFreitas *et al*., 1997a). In other study, carrageenan effect on gelation of salt soluble meat protein was evaluated and it was reported that increase in gel strength and WHC was not related to CGN-protein interaction. Gel network was formed by protein without CGN participation. CGN was presented in interstitial spaces of meat protein network and it bound to water and formed gel upon cooling (Verbeken *et al*., 2005). Ultimately, according to several studies it could be concluded that effect of carrageenan in meat protein systems was not related to CGN-protein interaction.

Alginate is a polyuranan obtained from cell wall of some of brown alga and bacteria (Stokke *et al.*, 2000). Alginates are mostly the alkali or alkaline earth salts of alginic acid; the sodium salt being the most extensively used in food products. The only other derivative of alginic acid that is used in the food manufacturing is propylene glycol alginate or PGA (Bixler and Porse, 2011). It produces thermoreversible gel that does not melt on heating (Saha and Bhattacharya, 2010). Evaluation of thermal stability of protein-alginate mixture demonstrated that alginate decreased thermal transition temperature when was added to beef crude myofibrillar, sarcoplasmic and connective tissue proteins. It was suggested that alginate changed physical state of protein and it affected the texture of meat products (Ensor *et al.*, 1991).

Flaxseed gum (FG) is a heterogeneous polysaccharide of xylose, arabinose, glucose, galactose, galacturonic acid, rhamnose and fructose which is obtained from by-product of oil industry (Chen *et al.*, 2006). It is an anionic polysaccharide with good WHC and exhibits weak gel-like properties and forms the thermo-reversible gel (Zhao *et al.*, 2014). FG influenced thermal stability, dynamic rheological characteristic and texture of meat proteins and salt soluble meat proteins (SSMP). Chen *et al.* (2007) reported that addition of 2% FG to meat or SSMP (obtained from pork) increased thermal transition temperature and improved emulsion stability. In addition, FG improved gel strength and water retention and increased storage modulus (indicating improvement in gel strength) of gel. Finally, results of this experiment confirmed that an interaction occurred between meat proteins and FG.

Dietary fibers such as rice bran fiber have been used in meat products. Study the effect of rice bran fiber (0.1, 0.5, and 1%) on heat induced gelation of meat protein in a model system revealed that rice bran influenced the WHC, color and texture of salt soluble meat protein gel and solubility of myofibrillar protein. Study on apparent viscosity showed that rice bran fiber (0.1, 0.5, and 1%) increased maximum value of viscosity (apparent viscosity is associated with emulsion stability). Results indicated that effect of this ingredient was related only with rice bran and probably there was no interaction between protein and rice bran fiber (Choi *et al.*, 2011).

Barley β-glucan (BG) is a non-starchy polysaccharide that is mainly consisted of the linear polysaccharide (1→3), (1→4)-β-D-glucan. It could be used as fat replacer because of its very viscous nature, water binding properties and potential to be as a foam stabilizer and emulsion (Temelli, 1997). DSC (differential scanning calorimetry) measurement was used to study the effect of carboxymethyl cellulose (CMC) and BG on meat protein system. It was demonstrated that 0.8% BG increased the amount of required energy for protein denaturation. Scanning electron microscopy (SEM) showed that BG did not interfere in protein matrix formation but CMC inhibited strong protein matrix formation, so it increased cooking loss in meat products. However, CMC increased WHC and 0.8% BG decreased it. This indicated that CMC was effective at binding water at colder temperatures and it might interfere with protein–fat interactions in a heated protein matrix (Morin *et al.*, 2004).

Meat products

Cooked sausage

Starch

Several types of starch are commonly added to emulsion style meat products for their functional properties (adhesion, binding, gelling, emulsion stabilization, moisture retention) and economic benefits (Pietrasik, 1999). Starches are obtained from different botanical sources such as grain (wheat, corn), tubers (potatoes) and root (tapioca) (Skrede, 1989). Modified potato and corn starch were successfully used to control emulsion stability and water retention of bologna sausage with sheep tail fat. Potato starch was better in control jelly/fat separation than corn starch due to better hydration/binding properties and higher amount of amylopectin which had stabilizing effect (Aktaş and Genccelep, 2006). Modified potato starch (distarch phosphate) with different fat and protein level, influenced on the properties of scalded sausages. Addition of starch did not compensate negative effect of fat reduction on cohesiveness, gumminess and chewiness, but it significantly affected on WHC, cooking yield and hardness of sausage. In general, modified starch was not suitable to improve textural parameters (Pietrasik, 1999). Inclusion of modified waxy maize starch in beef sausage improved WHC, cooking yield and decreased purge loss; also it resulted in a low caloric sausage that was more acceptable than control sausages (Mohammadi and Oghabi, 2012). Other types of modified starch such as modified broken rice starch (extruded and phosphorylated) was added to low fat sausage (55% fat reduction) which decreased energy value and improved textural and sensory acceptance of sausage (Limberger *et al.*, 2011). As well, a type of modified potato starch (MPS) in low fat sausage affected on color, texture, and produced a tender and low caloric sausage. Thus production of a low caloric sausage by adding MPS was possible (Liu *et al.*, 2008).

Gums

Ayadi *et al.* (2009) reported that increasing carrageenan concentration from 0.2 to 1.5% in turkey meat sausage caused reduction of emulsion stability, because of interfacial tension reduction between dispersed and continues phase in presence of carrageenan, and increased WHC. The effect of carrageenan on emulsion stability was different to that reported by Candogan and Kolsarici (2003a) who showed that addition of carrageenan to low fat frankfurter would increase emulsion stability. Low concentration (lower than 0.5%) of carrageenan increased elasticity of gel. Higher concentration (0.5 to 1.5%) increased hardness. The effect of carrageenan on WHC, hardness and elasticity was related to presence of carrageenan in interstitial space of protein gel network in low concentration and forming an additional carrageenan gel network in high concentration, as discussed previously.

Studies on the influence of carrageenan on sensory properties of sausages indicated that it could improve sensory scores in beef sausages (Xiong *et al.*, 1999). It caused better texture in low fat frankfurter, but not similar to high fat (He and Sebranek, 1996). Iota-carrageenan also successfully incorporated to low fat sausage because of texture and flavor close to ordinary sausage (Solheim and Ellekjær, 1993). Results of study reported by Barbut and Mittal (1992) indicated that addition of 0.5% kappa-CGN caused better moisture retention than iota-CGN and Xanthan gum. Also tenderness of product containing kappa-CGN was better than others, and resulted in a more acceptable sausage than high fat control.

In several studies effect of carrageenan was evaluated in combination of other gums. The effect of carrageenan (0.3 to 0.7%) and carrageenan (0.3 to 0.7%)/pectin (20%) in low fat beef frankfurter (<3.0% fat) in comparison of high fat frankfurter (17% fat) was studied. Samples containing carrageenan showed higher WHC and cooking yield and lower purge loss than low fat one. These effects improved by increasing carrageenan concentration. Low fat frankfurter showed cholesterol content lower than high fat frankfurter. Addition of pectin gum did not improve sensory scores of frankfurter containing carrageenan and carrageenan was more effective on characteristic of low fat frankfurter than pectin (Candogan and Kolsarici, 2003a). During 49 days refrigerated storage bacterial growth was higher in low fat frankfurter with added hydrocolloids because of higher water activity than high fat (17% fat) one resulted from extra water addition. High fat frankfurter showed higher TBA value than low fat frankfurters containing carrageenan or carrageenan and pectin (Candogan and Kolsarici, 2003b).

Mixture of carrageenan/gellan/flaxseed gum was added to starch free emulsion type sausage which indicated that interaction between gums affected the properties of sausage. Increasing carrageenan level in mixture negatively affected the expressible fluid, cohesiveness and springiness. But gellan gum showed a positive effect on texture, and flaxseed gum improved emulsion stability, hardness and springiness. In general, according to results of interaction between gums; making a product with higher WHC, better texture and color was possible. It was concluded that gum combination could be used as suitable starch replacer (Zhou *et al.*, 2010).

Konjac glucomannan is a neutral polysaccharide extracted from the tuber of Amorphophallus konjac (González Canga *et al.*, 2004). Konjac flour is a low caloric ingredient. It produced a thermally stable gel when dissolved in alkaline coagulant (such as calcium hydroxide) (Colmenero *et al.*, 2013). It's important technological properties are water retention capacity, gelling and thickening characteristic. Usually konjac blend (KB) was used as multi-ingredient fat replacer in meat products; it was a combination of konjac with starch, with or without carrageenan (Tye, 1991). Incorporation of konjac blend in two forms (dry and prehydrated) in low fat bologna model system indicated that it increased hardness, gumminess, chewiness and cohesiveness of product in prehydrated form more than dry form. Using of 1% KB in low fat bologna was recommended because it produced a product texturally similar to high fat one. Increased WHC, more stable gel matrix and desirable texture of product with KB was caused by interaction between carrageenan, konjac flour and starch (Chin *et al.*, 1998a). In another study, the effect of different konjac blends (konjac flour/starch, konjac flour/starch/carrageenan) on low fat bologna was compared. Combination of starch, carrageenan and konjac flour gave a product with higher cooking yield and more acceptable texture (Chin *et al.*, 1998b). Production of low fat frankfurter (18% fat) in presence of konjac/gellan mixture demonstrated that these additives improved sensory properties of low fat products similar to high fat products (28% fat). It decreased the storage time compared to high fat one, but it was rational (6-9 week) (Lin and Huang, 2003). Usually, konjac by itself decreased the firmness of meat products when used at high level. So addition of other ingredients such as starch or carrageenan, could compensate this negative effect

(Yang *et al*., 2001). Also konjac gel which degraded with ultrasonic could be used in low fat Chinese-style sausages. Increasing konjac concentration caused in increasing hardness, springiness and gel stability at same molecular weight. Different molecular weight affected the viscoelasticity of product at the same konjac concentration. Finally, konjac gel by different molecular weight resulted in acceptable sensory and textural characteristics similar to high fat sausage (Lin and Huang, 2008). Triki *et al*. (2013) studied the effect of konjac gel and konjac gel/olive oil on the properties of fresh sausage (merguez). Reformulation of sausage did not affect on the shelf life and biogenic amines of merguez sausage during refrigerated storage. Konjac gel did not change the sensorial properties of sausage and decreased caloric value of sausage.

Curdlan, a microbial polysaccharide, is a linear homopolymer of D-glucose with β-(1, 3) glucosidic linkages. Curdlan gel formation depends on heating temperature. Heating at 60°C, curdlan forms a thermo-reversible gel and heating to 80°C, it forms an irreversible gel (Harada *et al*., 1996). Use of curdlan in non-fat pork sausage resulted in a product similar to high fat (20% fat) one. Also in low fat sausage, it formed a thermo-reversible gel that improved meat protein system (Funami *et al*., 1998a and b).

Locust bean gum (LBG) or carob gum, a galactomannan vegetable gum, was used as thickener and gelling agent in food products. It is less soluble and has lower viscosity than guar gum. It requires heating to dissolve and it is soluble in hot water. Because of non-anionic nature, LBG is not affected by ionic strength or pH. It is used in canned meat formulations because of its heat stability. Xanthan gum is a non-linear anionic polysaccharide obtained from *Xanthomonas campestris.* It has been used as a viscosifier in the meat industry for marinades. It is a long chain polysaccharide composed of the glucose, mannose, and glucuronic acid. The unique property of xanthan is ability to increase viscosity of liquid considerably at very small concentrations. These two types of non-starch hydrocolloids (LBG and Xanthan) are non-gelling hydrocolloids (Rodríguez-Hernández and Tecante, 1999; Lamkey, 2009). Incorporation of LBG/Xanthan combination in low fat frankfurter (12 and 10% fat) and frankfurter contained olive oil instead of pork fat gave an acceptable product such as high fat control. Low fat frankfurter with added LBG/Xanthan, had higher cooking yield, better emulsion stability and texture and overall acceptability similar to high fat control. Replacing pork fat with olive oil decreased firmness, gumminess and chewiness and increased adhesiveness of product, while did not change sensory acceptability (Lurueña-Martínez *et al*., 2004). In other study addition of 0.5% Xanthan gum to low fat breakfast sausage increased fat and moisture retention, but it negatively affected the textural and sensory properties (Barbut and Mittal, 1992). It was similar to results reported by Solheim and Ellekjær (1993) who mentioned that Xanthan gum by itself decreased firmness, elasticity and made off odor in low fat sausage. Thus it could be concluded that addition of Xanthan gum by itself was not suitable for using in meat product, but use of Xanthan gum in combination of other hydrocolloids gave better results.

Marchetti *et al*. (2013) studied the effect of different binders on the properties of low lipid meat emulsions formulated with fish oil. Different binders (milk proteins concentrate, whey protein concentrate, thermally treated whey protein concentrate, ovalbumin, hydroxypropylmethylcellulose, methylcellulose, mixtures of kappa/iota carrageenans or xanthan/locust bean gums) did not change the overall microstructure pattern of systems, but principally affected the level of interactions between macromolecular constituents. Xanthan/locust bean gums and mix of kappa and iota carrageenans caused the highest hardness, similar to control formulation with fat.

Amini Sarteshnizi *et al.* (2014) optimized the prebiotic sausage formulation by using of BG and resistant starch (RS) by D-optimal mixture design approach. Results indicated that RS decreasd cooking yield, while BG increased it. Resistant starch increased hardness and RS/BG combination showed antagonistic effect on hardness. The sensory evaluation of color and texture were correlated to instrumental color and texture analysis.This results indicated that softer texture and higher a^* was more acceptable.

İn another study, Petersson *et al*. (2014b) compared the effect of rye bran, oat bran and barley fiber on low fat sausage. Rye bran consists chiefly of insoluble arabinoxylans and cellulose, while oat bran includes a higher proportion of soluble dietary fiber, mainly BG. Oat BG have a higher molecular weight than barley BG. Sausages with oat bran showed low process and frying loss and high firmness and acceptability. Sausages containing barley bran, with highest level of BG, showed high process and frying loss as the addition of rye bran, and lowest firmness. Oat bran was suitable for using in sausage.

Also Álvarez and Barbut (2013) studied the effect of BG, inulin and their mixture on the emulsion stability, color and textural properties of low fat cooked meat batters. Fat reduction showed undesirable effect on emulsion stability and decreased hardness and lightness. BG caused stickiness by itself and inulin powder caused excessive hardness. Use of BG and inulin combination was most effective. Their combination compensated undesirable effect of fat reduction and undesirable effect of BG and inulin by themselves.

Fibers

Dietary fiber has been added to sausage to counteract the problems caused by fat reduction. Many studies have been done on low fat meat products with fat partially replaced by dietary fiber that helps to develop rheological properties and stability. Effects of different fibers in sausages are summarized in Table 1.

Table1. Effect of fibers on cooked sausage

Meat product	Type of hydrocolloid	Impact on product	Reference
Low-fat frankfurters	Peach dietary fiber	Reduced textural properties at high level (29%) of fiber and low level of fat	Grigelmo-Miguel *et al.* (1999)
Bologna sausages	Albedo (raw and cooked)	Reduced residual nitrite, sensory properties was similar to ordinary sausage	Fernández-Ginés *et al.* (2004)
Frankfurter	Citrus fiber (CF)	Lowered taste score, affected on texture and color	Cengiz and Gokoglu (2007)
Low fat pork sausages	Hydrated oatmeal and tofu	Oatmeal caused higher WHC, cooking yield and softer texture. 15% oatmeal and tofu addition resulted in greatest acceptability	Yang *et al.* (2007)
Reduced-fat frankfurters	Vegetable oils/rice bran fiber	Cholesterol and energy value reduction	Choi *et al.* (2010)
Bologna sausages	Orange dietary fiber/oregano essential oil	Increase shelf life due to antimicrobial compounds in fiber	Viuda-Martos *et al.* (2010)
Low fat sausages	Heat-treated homogenized potato pulp	Increased firmness, decreased frying loss and juiciness	Bengtsson *et al.* (2011)
Low fat frankfurters	Pig skin/wheat fiber	Increased moisture and protein content, decreased cooking loss and improved emulsion stability, increased hardness	Choe *et al.* (2013)
Reduced fat frankfurters	A mix of sunflower seed	Improved physicochemical,	Choi *et al.* (2013)

Freeze/thawed cooked sausage

Starch

Modified waxy maize starch enhanced freeze-thaw stability by cryoprotectant effect, resistance to retrogradation and increasing WHC (Lee *et al.*, 1992; Colmenero *et al.*, 1996). Dexter *et al.* (1993) indicated that using of 2% modified waxy maize starch in turkey bologna decreased purge loss after freeze/thawing. similar results obtained by using it in low fat frankfurter (10% fat) stored at 0°C for 4 week (Yang *et al.*, 2001). Comparison of corn starch, modified potato starch, potato flour, wheat and tapioca starch on properties of freeze/thawed meat sausage showed that modified potato starch was suitable for frozen and not frozen sausage but corn starch showed poor freeze/thaw stability (Skrede, 1989).

Freeze/thaw stability of native starch, enzyme-modified carboxymethyl starch (ECMS) and enzyme modified starch (ES) as fat replacers in meat product was assessed. ECMS showed the greater freeze thaw stability than native starch and enzyme modified starch (ES) because of presence of negatively charged functional group. Decreasing freeze-thaw stability in presence of ES probably was due to low molecular weight and less stability of ES. Finally, it was suggested that ECMS could be used in meat product to prevent water separation and extending shelf life. As well, properties of sausage such as WHC, emulsion stability, sensory quality and textural parameters were acceptable in presence of ECMS (Luo and Xu, 2011). Study the effect of tapioca starch on freeze/thaw stability of fish sausage was investigated. Results showed that Tapioca starch increased WHC, cooking yield, hardness and chewiness of fish sausage. It was effective in increasing freeze/thaw stability at a freeze/thaw cycle. The result of experiment was correlated to tapioca starch concentration (Prabpree and Pongsawatmanit, 2011).

Gums

Study the effect of carrageenan (CGN) on freeze/thaw stability showed that addition of kappa and iota carrageenan decreased purge loss and increased hardness in presence of NaCl, but addition of KCl decreased the functional properties of k and iota-carrageenan and caused a softer texture than CGN-NaCl (DeFreitas *et al.*, 1997b). It was probably because of negative effect of interaction between kappa and iota-CGN with KCl (Trius *et al*., 1994a and b). Lambda carrageenan caused a softer texture than control in presence of KCl and NaCl. Thus, combination of k or iota- CGN with NaCl was recommended for increasing freeze/thaw stability of pork sausage, and this effect could be improved by addition of sodium tripolyphosphate (STPP) (DeFreitas *et al*., 1997b). Also Bater *et al.* (1993) reported that k-CGN reduced freeze/thaw purge loss in cured turkey meat.

Low salt cooked sausage

Modified tapioca starch was used in low salt (less than 1.5%), phosphate free frankfurter. It reduced frying loss (optimum amount: 2%), caused better water and fat binding properties (Ruusunen *et al.*, 2003b). Addition of carrageenan, sodium citrate and CMC in low salt (<1.4%) bologna sausage indicated that these additives improved frying yield, firmness and saltiness of product. CMC caused in a less juicy and lower flavor intensity product, while CGN and sodium citrate enhanced flavor intensity (Ruusunen *et al.*, 2003a). Other studies showed that carrageenan

Table2. Effect of hydrocolloids on other meat products

Meat product	Type of hydrocolloid	Impact on product	Reference
Low fat beef burgers	Tapioca starch (TS) Oat fiber (OF) Whey protein (WP)	TS: more acceptable tenderness, juiciness and textural properties OF: increased WHC and juiciness WP: only affected Kramer shear forces	Desmond *et al.* (1998a)
Low fat beef burger	Alginate/calcium lactate Pectin, MCC, oat fiber, carrageenan tapioca starch, modified waxy maize starch	Alginate/calcium lactate: lowest cooking loss, acceptable textural properties Pectin, MCC, oat fiber, carrageenan: desirable flavor and overall quality	Desmond *et al.* (1998b)
Light pork burgers	Soy protein (with 0.7% konjac/gellan mix)	Up to 2% improved textural parameters, and sensory scores, higher than 2% decreased textural parameters	Akesowan (2010)
Pork model burgers	Chitosan (high molecular weight) chitosan (low molecular weight)	High molecular weight: improved cooking yield, better antioxidant activity. Low molecular weight: extended shelf life, increased redness of product	Sayas-Barberá *et al.* (2011)
Pork buegers	Albedo-fiber powder obtained from passion fruit	İmproved nutritional value, cooking yield, moisture and fat retention. Decreased TBA value and aerobic mesophilic bacteria and enterobacteria	López-Vargas *et al.* (2014)
Low fat ground beef patties	WPC	Increased chewiness, better fat and water retention, 4% WPC was resulted the greatest overall acceptability	El Magoli *et al.* (1996)
Precooked ground beef patties	Carrageenan/sodium alginate	Cooking loss and textural characteristic was similar to high fat patty	Lin and Keeton (1998)
Restructured Ham with PSE	Modified food starch kappa-carrageenan soy protein isolate	Modified starch increased moisture retention, k-CGN and SPI was not acceptable due to lower moisture retention.	Motzer *et al.* (1998)
Dry fermented sausages	Cereal(wheat, oat), fruit (peach, apple, orange dietary fibers) (DF)	3% DF increased hardness and cohesiveness, 1.5% DF particularly orange fiber resulted in more acceptable sausage	Garcıa *et al.* (2002)
Dry-cured sausages	Orange fiber	Reduced residual nitrite, protected lipid from oxidation	Fernández-López *et al.* (2007)
Dry fermented sausage	Carrot dietary fiber	3% fiber addition gave sensory quality similar to conventional sausage 3%< fiber addition affected fermentation process and textural quality	Eim *et al.* (2008)
Spanish dry-fermented sausage	Orange fiber	Decreased nitrosamine formation by decrease residual nitrite and favored micrococcus growth	Fernández-López *et al.* (2008)
Low fat fermented sausages	κ ,i carrageenan/olive oil	ι –CGN up to 2% had better effect to prevent lipid oxidation	Koutsopoulos *et al.* (2008)
Fermented sausage	Amorphous cellulose	By replacing up to 50% of fat by Amorphous cellulose produced an acceptable sausage	Campagnol *et al.* (2012)
Dry fermented sausages	Konjac gel	Fat reduction increased hardness and chewiness and decreased cohesiveness. Product was sensory acceptable	Ruiz-Capillas *et al.* (2012)
Turkish dry-fermented sausage (sucuk)	Orange fiber	Reduced residual nitrite, increased TBA value, increased cooking yield, improved lactic acid bacterial growth	Yalınkılıç *et al.* (2012)
Dry fermented sausage	Healthy oil combination stabilized in a konjac matrix	Decreased saturated fatty acids content and increased polyunsaturated fatty	Colmenero *et al.* (2013)
Low fat beef patties	Modified corn starch/water	Improved moisture retention and textural properties, up to 75% fat could be replaced by this combination	Khalil (2000)
Meat based Patties	Oat Gum and Oatrim	Moisture content reduced by increasing additives concentration, sensory quality was acceptable	Dawkins *et al.* (2001)
Low fat ostrich meat patties	Modified starch/soy protein isolate	Sensory properties was similar to high fat patties	Hoffman and Mellett (2003)
Low fat ground pork patties	Carrageenan	0.5% carrageenan resulted in desirable texture and sensory quality, without significant effect on microbial growth during storage	Kumar and Sharma (2004)
Low fat beef patties	Oat's β-glucan (13.45%)	Higher fat and moisture retention, increased juiciness significantly, no adverse effect on microbiological quality during frozen storage	Pinero *et al.* (2008)
Low salt, low fat beef patties	Wakame/olive oil	İmproved binding properties and cooking retention values of moisture, fat and fatty acides, decresed caloric value.	López-López *et al.* (2011)
Beef patties	Flaxseed flour (FS) and tomato paste (TP)	FS: decreased a* and L*, decreased cooking loss TP: increased a* and L*, increased cooking loss FS and TP showed negative effect on sensory characteristics	Valenzuela Melendres *et al.* (2014)
Ham	Kappa-Carrageenan Modified Corn Starch	Kappa-Carrageenan: increased cooking yield, reduced juiciness Modified Corn Starch: decreased cooking yield but resulted in juicer	Prabhu and Sebranek (1997)
Emulsified meatballs	Konjac, agar, curdlan gum, k-carrageenan	Konjac/curdlan interaction increased chewiness and gumminess, konjac/CGN decreased cooking loss	Hsu and Chung (2000)
Emulsified pork meatballs	Rice bran	Lower concentration (<10%) and smaller bran particles resulted in better texture and sensory acceptability than higher concentration (15%)	Huang *et al.* (2005)
Low fat meatballs	Carrageenan and guar gum	Carrageenan showed better effect on textural peoperties	Ulu (2006)
Meatball	Xanthan, guar, carrageenan and locust bean gum	Gums decreased moisture content and increased ash and texture values, gums produced a lighter-colored product. Consumer acceptability of meatball conaining 1% locust bean gum was higher than others.	Demirci *et al.* (2014)

improved cooking yield and hardness and binding strength of sausage containing 1% salt (Xiong *et al.*, 1999), and increased flavor intensity of sausage in 1.5% salt (Matulis *et al.*, 1995).

Also alginate and locust bean gum reduced cooking loss in pork sausage. It was attributed to formation of hydrogen binding with water, but use of these gums, resulted in a softer, crumbly and slippery texture. So these gums were undesirable for use in low fat (4%), low salt (1%) pork sausages (Xiong *et al.*, 1999). García-García and Totosaus (2008) studied the effect of potato starch, LBG and k-CGN on low fat sodium reduced sausage. Sodium was replaced by potassium and calcium chloride. Starch, k-carrageenan and LBG increased cooking yield. Starch increased expressible moisture and decreased cohesiveness, probably due to difference in temperature of starch granule gelatinization and meat protein denaturation. Addition of combination of LBG and carrageenan improved texture of sausage, because other ions (potassium and $CaCL_2$) enhanced functional properties of k-CGN and better interaction with LBG occurred.

Sea spaghetti with health benefits is recommended for utilization in meat products, but it makes a dry product and less acceptable sensory quality. Konjac gel was a recommended hydrocolloid for limiting undesirable effects in meat products. Sea spaghetti/konjac gel was used in low fat (1.7% fat) and reduced fat (10.5% fat) frankfurter with 1% salt. The properties of product were affected by konjac gel concentration significantly. Sea spaghetti/ konjac gel decreased cooking yield and emulsion stability, changed color parameters, and made more heterogeneous microstructure. In general, production of sensory acceptable low salt frankfurter with added sea spaghetti in presence of konjac gel was feasible (Colmenero *et al*., 2010). As well, production of a functional dry fermented sausage by reduction of salt content, inclusion of inulin and olive oil emulsified in alginate was examined. 58% NaCl replaced by KCl and $CaCl_2$. Inclusion of 6% inulin and emulsified olive oil gave an acceptable product (Beriain *et al*., 2011).

Inclusion of carrot fiber (CF) and potato starch (PS) to low salt (1.2%) pork sausage with high pressure treatment was examined. Dietary fiber improved water binding capacity (WBC), emulsion stability, and also increased lightness of product. Textural properties were improved in presence of CF and PS, but no synergistic effect on textural properties was detected when CF/PS combination was used. In addition, PS produced more acceptable sausage than CF. Ultimately; it was possible to produce low salt sausage by addition of hydrocolloids such as dietary fiber (Grossi *et al*., 2012).

Other meat products

Various gums and starch have also been added to other meat products such as burgers, patties, ham, fermented sausages and meatballs. Meatballs and burger are produced mainly from ground meat (beef and/or lamb), fat (beef fat and/or lamb tallow fat) and have several spices and/or moistened bread (Serdaroğlu and Değırmencioğlu, 2004). Patties are popular cooked meat products which raises some health concerns due to their high animal fat (around 30%) and energy contents (around 350 kcal/100 g) (Delgado-Pando *et al*., 2012). Also fermented sausages have a high level of animal fat. The fat content, which at first ranges between 10% and 20%, raises to values more than 30% of the final product related to the dehydration that occurs throughout the manufacturing process (Campagnol *et al*., 2012). So fat reduction of these products is essential. One way to offset detrimental effects of fat reduction is using of non-meat ingredients that improve WHC and textural parameters. Hydrocolloids are succesfully used for this purpose. Effect of hydrocolloids on these products is summarized in Table 2.

Poultry product

Chicken sausages and chicken breast

Properties of low fat chicken sausage formulated with chicken breast, WPC, Xanthan/guar gum (ratio 3:7) was assessed. Increasing WPC and gum concentration affected textural properties (by decreasing hardness), color (by altering lightness and redness) and microstructure (by increasing cohesiveness and decreasing granular matrix). In general, low fat sausage was sensory acceptable and concluded that added ingredients improved functional properties of sausage (Andrès *et al*., 2006b). As well, evaluation of stress relaxation behavior of product indicated that reduction of fat content affected on viscoelastic properties. Higher fat content caused in higher elastic modulus, while WPC and gums was not effective (Andrés *et al*., 2008). Color and pH was not affected by storage time, but some textural parameters changed. Throughout 50 days of refrigerated storage, no coliforms were noted confirming successful heat treatment for the duration of sausage production (Andrés *et al*., 2006a).

Low salt without phosphate chicken breast meat with added BG was processed under high pressure (HPP). HPP increased L^* and decreased a^* colorimetric parameters. Processing salt which was added breast by pressure/temperature combination, increased lipid oxidation. Formation of radicals as initiators of lipid oxidation occurred under HPP. However, adding BG was effective in decreasing lipid oxidation with no effect on color. These results demonstrated antioxidant properties of BG. BG also improved the gel hardness in low salt breast to be similar breast with 2.5% salt. Finally, it was suggested that production of a reduced salt chicken breast by inclusion of BG and using of high pressure was feasible (Omana *et al*., 2011a and b; Bolumar *et al*., 2012). Antioxidant strength of BG was demonstrated by Thondre *et al.* (2011), who concluded that barley BG samples (Glucagel, Barley balance and barley fiber rich fraction) had antioxidant activity and barley fiber rich fraction was notably better than others. Antioxidant properties of BG is related to phenolic compounds which are presented in cereal grains in free and bound form as conjugates with sugars, fatty acids or proteins.

Chicken breast was injected by low methoxyl pectin (LMP) and amidated low methoxyl pectin (LMP-A) and compared with breast containing NaCl and Sodium tripolyphosphate (STPP). LMP improved cooking yield and moisture retention was higher than control with no additives, but these properties were not as good as those got by adding NaCl/STPP to breast (Detienne *et al*., 2000). Combined effect of chitosan and modified atmosphere packaging on the shelf life of chicken breast fillets was evaluated. Chitosan and MAP increased the shelf life of breast fillet 6 and 7 days, respectively. MAP/chitosan treatment was more effective and extended the shelf life 9 days. The effect of chitosan was related to antioxidant and antimicrobial activity (Latou *et al*., 2014).

Nugget

Batter or breadcrumb-coated products are highly desirable foods. Chicken nugget is one of this breaded fast food which is produced by using of deep fat frying process (Soorgi *et al*., 2012). Batter coatings (coating) are usually used in deep fat frying since they improve appearance, flavor and texture by reduction of dehydration, aiding browning and giving a crisp texture to the fried parts (Suderman *et al.*, 1981), also provide nutrition and desired color to the fried products by protecting the natural food juices from the effects of freezing or reheating. These coatings act as a barrier against loss of moisture. Thus, final product is tender and juicy on the inside and crisp on the outside (Fiszman and Salvador, 2003; Dogan *et al*., 2005). Adhesive batters provide an adhesive layer between a product (so-called substrate) and an outer breading layer (Xue and Ngadi, 2007).

Improved public awareness of the necessity of fat reduction in their diets is increased. Intensive research has been prompted on ways to decrease the amount of fat absorbed during frying. Methods that increase water holding capacity or enable oil barrier films to form can reduce oil uptake. Use of additives such as gums, proteins, cellulose derivates, modified starch, and alginates is the most convenient method to decrease oil uptake (Chen *et al*., 2008). The use of hydrocolloids in battered food has been found to be effective (Adedeji *et al.*, 2009). Their higher water-binding capacity resulted in developing viscosity and consistency in batter systems, helped to trap gas released by fast action of leavening agent. Therefore, higher volume and improved texture was resulted (Altunakar *et al*., 2004; Sahin *et al*., 2005). Starch and gums have been used as hydrocolloids in nugget batter formulations to decrease oil uptake in deep-fat fried products in various studies.

Starch

Starch and modified starches have been used as batter ingredients to develop batter texture (Fiszman and Salvador, 2003). Devadason *et al.* (2010) compared the effect of corn starch, tapioca starch, wheat semolina and wheat flour on the properties of buffalo meat nugget. These starches used as binders. The results indicated that corn and tapioca starch had significantly increased the stability of emulsion, but corn starch gave better emulsion stability and product yield when compared to wheat flour, tapioca starch, and wheat semolina. It was the superior quality binder for developing emulsion type of buffalo meat nuggets when compared to all the other binders. It might be due to better binding properties of corn starch in comparison with others. Also, the texture profiles and histological structure of the products indicated that products made with corn starch had firmer texture and denser protein matrix. Probably, the ability of corn starch to form firm gel caused significantly better texture of the product.

Rahimi and Ngadi (2014) studied the effect of wheat-flour-based batter with different pre-drying time and batter with different ratios of wheat to rice flour. Frying time and pre-drying time had significant effect on moisture loss and oil uptake. Increasing frying time resulted in higher moisture reduction and oil uptake. Increasing level of wheat flour increased surface and total oil content and decreased penetrated oil content. Pre-drying process decreased penetrated and total oil content of batters.

Effects of different starch types (amylomaize, corn, waxy maize, pre-gelatinized tapioca) on quality of deep-fat fried chicken nuggets was compared. Various starch developed texture of fried product, which was related to development in film forming properties of the coating materials. Moisture and oil content were important properties in determining quality of fried food products. The highest and lowest oil content was obtained when corn starch and pregelatinized tapioca starch was used, respectively. Pregelatinized tapioca starch also provided a product with highest moisture content, picked up of batter and volume due to its highly binding capacity and readily gelatinized feature (Altunakar *et al*., 2004).

Crispness is a textural parameter for fried foods which depend upon the ingredients, formulation and processing. Coating with amylomaize starch was found to be the crispiest, with the maximum texture value. It was due to linear molecular structure of high amylose containing starch, because of a positive correlation between crispness and amylose content (Arenson, 1969; Mohamed *et al*., 1998; Altunakar *et al*., 2004). Also use of cross-linked wheat starches increased batter crispness in deep fat fried foods which was related to more water evaporation from batter containing cross linked starch (Primo-Martín, 2012). So it could be used as an appropriate material in nugget batter coating. Oxidized starch is a hydrocolloid with granular structure, which swells up in existence of water and temperature. The use of this type of starch in comparison of hydroxypropyl-methylcellulose (HPMC) and Xanthan gum as a pre-dust agent gave the most excellent adhesion results in fish nugget. In presence of oxidized starch, coating adhered to the substrate without changing the general characteristics of the batter-coated product with different cooking procedure such as deep frying, conventional oven and microwave oven. HPMC and Xanthan gum showed better adhesion than commonly wheat flour used in microwave cooking manner (Albert *et al*., 2009).

Gums

Most food gums have an important effect on water-immobilization, and control the viscosity and rheology of liquid batter systems. gums can enhance the quality of fried food products by helping to retain moisture and form films (Duxbury, 1989). Due to forming thermal gels, Hydroxypropyl-methylcellulose (HPMC) and methylcellulose (MC) were recommended gums with film forming properties for use in batter formulations of deep-fat fried chicken nuggets (Duxbury, 1989; Desbrieres *et al*., 2000; Sahin *et al*., 2005; Salvador *et al*., 2008). Comparison the effects of Xanthan gum, guar gum, Arabic gum and HPMC on the quality of deep-fat fried chicken nuggets indicated that all the gums, except Arabic gum, were significantly effective on moisture content, batter pick-up and reducing oil content. Also they made the highest volume of the deep-fat fried chicken nuggets because of film forming abilities and gas-holding capabilities. The undesirable effects of Arabic gum might be due to its low apparent viscosity because it readily dissolved in water, so it could not increase coating pick-up dramatically, could not control moisture content and provide an efficient barrier for oil uptake. The effect of HPMC, Xanthan and guar gum on oil uptake was related to thermal gelation of HPMC and viscosity-building effects of Xanthan and guar gum. HPMC was most effective for reducing oil absorption, but Xanthan and guar gum made a softer texture (White, 1969; Sahin *et al.*, 2005).

Using of microwave for cooking nugget decreased textural properties of crust. In microwave heating evaporative drying, typical of processing in conventional ovens, does not occur. This process results in a soggy crust and decreases crispness. Different hydrocolloids had been used to decrease these undesirable effects. Albert *et al.* (2012) used high salty alginate gel as a film between coating and substrate. Salty alginate gel decreased cooking time and caused better heat distribution than control. In other study, battered mackerel nuggets were coated with HPMC before battering or coated by batter containing HPMC to improve crust crispness during microwave reheating. Because of formation of a thermal gel barrier in comparison of conventional battered, HPMC coating significantly enhanced crust crispness when reheated in a microwave. It was due to inhibition of water molecule diffusion from fish meat into the crust during microwave reheating in nugget coated HPMC (Chen *et al.*, 2008). Thus coating nugget before battering was recommended as a better procedure than using HPMC in coating batter. The suitability of thermal jellified batters containing 0.5% and 1% methylcellulose (process without pre-frying), significantly reduced oil absorption during frying in a wide variety of battered food items such as marrow, pork meat, cheese and squid (Salvador *et al*., 2008), but study the effect of MC on oil content of non–precooked nugget fried at 190°C indicated that by using of MC as a coating layer, oil absorption was lower than using it in batter formulation. Less suitability of batter containing MC was related to batter viscosity. Increasing batter viscosity decreased oil uptake (Soorgi *et al*., 2012).

Conclusion

Addition of hydrocolloids to meat products improved functional properties of low fat sausage; freeze/thawed sausages and low salt sausages. Myofibrillar protein play an important role in production of desirable texture of meat products. The effect of hydrocolloids on the properties of meat products was related to protein gel matrix formation in presence of hydrocolloids. There was no interaction between protein-polysaccharide by addition of CGN, alginate, rice bran fiber and BG to meat products. CGN was presented in interstitial spaces of meat protein network and produced an additional gel network. Alginate changed physical state of proteins. By addition of FG, protein-polysaccharide interaction occurred which improved functional properties of meat proteins while CMC negatively interfered in meat protein gel matrix formation.

Production of low caloric sausages was possible by addition of different starch types. CGN successfully incorporated in low fat sausages by itself or in combination of some other gums. It improved WHC, sensory characteristics and texture. Also konjac blend and curdlan were suitable fat replacers, but Xanthan gum was not suitable by itself and it could be used in combination with other gums. Also BG successfully used in meat products in combination of inulin and resistant starch. For improvement of freeze-thaw stability; addition of modified waxy maize starch, modified potato starch, ES, ECMS, native starch, tapioca starch, and k or iota-CGN with NaCl could be recommended. Using of ECMS was better than ES and native starch due to presence of negatively charged groups.

Addition of modified tapioca starch, carrageenan, carrageenan/LBG combination in presence of $CaCL_2$, sea spaghetti/konjac gel combination and dietary fibers improved functional properties of low salt meat products, while alginate and LBG showed undesirable effects on textural properties. Use of different hydrocolloids in batter formulation improved textural properties and decreased oil uptake in nugget. Addition of different starches, hydroxypropyl-methylcellulose (HPMC) and methylcellulose (MC), Xanthan gum and guar gum in nugget batter coating improved final product properties that were related to film forming ability of coating materials, but Arabic gum was not recommended because of its low apparent viscosity. Microwave cooking showed negative effects on textural parameters of crust. Use of high salty alginate gel, HPMC and MC decreased these undesirable effects and improved crust crispness.

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