Functional ingredients for poultry meat products

Massimiliano Petracci[1], M. Bianchi[2]
1 - Department of Food Science, Alma Mater Studiorum – University of Bologna, Bologna Italy.
2 - Prodotti Gianni S.p.A., Milan, Italy

Summary

This review deals with the main classes of functional ingredients able to modulate the ability to retain water (both "native" or added during processing) and the texture of further processed poultry meat products. Functional ingredients can be to divide them into those added in order to enhance functionality of muscle proteins or those with a direct functional effect on the meat system, which are added as an additional "system" to aid in the retaining of moisture or fat and modifying texture. The first group is basically consists of salts such as sodium chloride, phosphates as well as citrates and alkaline ingredients (i.e. bicarbonates), while the second one includes starches, cereal floors, vegetable hydrocolloids (i.e. carrageenans, alginates), collagen derivates, blood proteins (plasma and globin fractions), milk proteins (caseinates and whey proteins) as well as vegetable proteins (i.e. soy, pea) and fibres. This review further discusses the mechanisms of action, current status, main product applications and market trends of the use of functional ingredients in poultry meat processing.

Keywords: Poultry meat, processing, ingredients, water holding capacity, texture.

Introduction

In the past decades, worldwide poultry meat production and consumption have increased rapidly and, in many parts of the world, *per capita* consumption of poultry meat will continue to grow. However North and Central America as well as Europe have been gradually lost market shares, whereas South America and Southeast Asia have become new centres of production. Reasons for the success of poultry meat are: **i)** the healthy image of the product, mainly due to the high protein/low fat content coupled with a balanced n-6 to n-3 PUFA ratio; **ii)** the increased availability of further processed products (ready-to-cook, ready-to-eat products) which can be conveniently prepared at home without time-consuming preparation; iii) lower price in respect with red meats.

Poultry meat is fit for development of further processed products because of its bland flavour and soft texture which allow producers to impart desired flavour profiles (i.e. spicy vs. mild flavour) and textures according to market/marketing needs and consumers targeting (i.e. adult vs. children). A first classification of poultry meat products can be made by considering if they are sold as raw or cooked. Raw products include those produced with minced meat (i.e. sausages, patties, meat balls and loafs) or whole muscles (i.e. marinated or injected breast fillets, drumsticks, thighs and wings). Cooked products include a large variety of items which can be prepared with whole parts or comminuted meat. Among cooked poultry meat products, cooked breaded patties and nuggets are some of the most popular convenience items available both fresh or frozen.

Poultry meat products can be prepared from a variety of meat sources. The quality characteristics of raw meat, mainly represented by the chemical composition and functional properties, play a key role on final product quality. White meat (breast fillets and tenderloins) offers a soft texture (high soluble collagen), light colour as well as low-fat and high-protein content. Dark meat (leg and drumsticks) tends to present a harder texture (higher collagen content), darker colour, higher fat content, stronger flavour, but due to the lower economical value is widely used to reduce product formulation costs.

The shift towards further processed products has underscored the necessity for higher standards in poultry meat quality in order to improve sensory characteristics and functional properties (Fletcher, 2002; Barbut, 2008). However processors have to deal with a certain variability of raw meat quality which is caused by *ante-mortem*, *post-mortem* and processing factors (Petracci *et al*., 2009, 2010). This variability can be managed during further processing by the use of functional ingredients.

Functional ingredients include a variety of additives or ingredients from vegetable and animal sources which are used to achieve different functionalities on the final product. Main functionalities to be achieved by means of those ingredients are represented by water and fat holding capacity, binding properties (i.e. increase adhesion among meat parts or in minced meat systems), texture modulation (i.e. increase tenderness). Last but not least, functional ingredients offer possibilities to lower formulation cost by means of adding water to the meat, increase processing yield or allowing the use of cheaper raw meat sources (i.e. mechanically deboned meat) in product formulations.

Functional ingredients for poultry meat products formulation

Considering the overall functional properties of a poultry meat product, the most important ones can be considered the ability to retain water (both "native" or added during processing), and the ability to achieve the desired final texture. Increasing meat water holding capacity (WHC) is always a goal to reach, whereas texture can be managed in both direction of increasing tenderness (i.e. marinated breast meat) or improving bite (i.e. in nuggets produced with mechanically deboned meat) or knack (i.e. in emulsified sausages).

It is well known that myofibrillar proteins are mainly responsible for the WHC and textural properties of processed meat products. Myofibrillar proteins are generally extracted in intermediate or high-ionic-strength buffer, and so are referred to as salt-soluble proteins. They constitute about 55% to 60% of the total muscle proteins, or 10% of the weight of skeletal muscle (Sun and Holley, 2011). Within myofibrillar proteins, myosin and actin contribute most to the development of desirable gel characteristics in processed meat products. The heat-induced gelation of myosin results in the formation of a 3-dimensional network structure which holds water in a less mobile state. It has been suggested that the rheological and physical properties of globular protein gels are more dependent upon molecular size and less influenced by amino acid composition or distribution, and this is probably also the case for myofibrillar proteins. During network formation fat and water retention are enhanced and this influences yield, texture, and cohesion of the final product as well as determines the gelling capacity of myofibrillar proteins (Xiong, 2004; Sun and Holley, 2011).

As previously stated, functional ingredients can be defined as ingredients or additives able to modify the overall technological characteristics of a meat system such as water holding capacity, fat holding capacity and texture properties. One tentative of classification of functional ingredients can be to divide them into those added in order to enhance functionality of muscle proteins or those with a direct functional effect on the meat system, which are added as an additional "system" to aid in the retaining of moisture or fat and modifying texture (**Table 1**).

Salt (sodium chloride)

Salt, or sodium chloride (NaCl) is the world's oldest 'food additive' and the most important one in the production of meat and poultry products. In poultry meat products salt provides three major functions: **i)** assist in protein solubilising with beneficial effect on water binding ability and texture; **ii)** alter microbial growth; **iii)** enhance and provide flavour (Barbut, 2002). Salt addition assists in protein solubilising by extracting the salt-soluble myofibrillar proteins in raw meat. Main effects of extracted myofibrillar proteins in a complex meat system are: **i)** increased WHC and binding among whole muscles and/or meat particles; **ii)** assisting fat emulsification in finely comminuted products due to coating of fat globules with a thin layer of extracted myofibrillar proteins; **iii)** increased meat batter viscosity which counteracts fat segregation during processing. Upon heating, the extracted proteins coagulate and provide binding, water and fat holding (Barbut, 2002).

The theory about sodium chloride improving WHC of meat products has been reviewed by Offer and Knight (1988), Ruusunen and Puolanne (2005) and Cheng and Sun (2008). In solution, sodium chloride hydrolyses into sodium (Na^+) and chloride (Cl^-) ions, however the effect on meat proteins is most likely caused by the fact that Cl^- ions are more strongly bound to the proteins that the Na^+ ions

Table 1 - Main categories of functional ingredients used in poultry processed products formulation.

Ingredients to enhance the functionality of muscle proteins	Main functions
Salt (sodium chloride)	- Myofibrillar protein solubilisation - Improve muscle swelling - Promote ionic exchange (Na^+ replace Ca^{2+})
Phosphates	- Myofibrillar protein solubilisation - Sequestrating of meat calcium ions determining muscle swelling - Slight increase of meat pH
Citrates	- Improve muscle swelling - Slight increase of meat pH
Other alkaline ingredients (i.e. carbonates, bicarbonates)	- Improve muscle swelling - Increase of meat pH
Ingredients with a direct functional effect on the meat system	**Main functions**
Starches	- Water gelling - Texture modulator - Binder
Cereal floors	- Water gelling - Texture modulator - Binder
Vegetable hydrocolloids (i.e. carrageenans, alginates)	- Water gelling - Texture modulator - Binder
Collagen derivates	- Water gelling - Texture modulator - Improve fat emulsification
Blood proteins (plasma and globin fractions)	- Water gelling (plasma fractions) - Fat emulsification (globin fractions)
Milk proteins (caseinates and whey proteins)	- Fat emulsification (mainly caseinates) - Slight water gelling
Vegetable proteins (i.e. soy, pea)	- Moderate water gelling - Texture modulator - Fat emulsification
Vegetable fibres (insoluble and/or soluble fractions)	- Water binding - Texture modulator - Improve fat emulsification

(Sebranek, 2009). Chloride ions tend to bind to the thick (myosin) and thin (actin) filaments and increase the electrostatic repulsive forces between them. With increasing the repulsive forces, the protein structure matrix unfolds, the gaps between actin and myosin increase and then transverse swelling occurs (Offer and Trinick, 1983; Hamm, 1986). Moreover the adsorption of Cl^- ions with positively charged groups of myosin results in a shift of the isoelectrical point towards a more acidic pH value. As a result, increased levels of water can be bound without changing the pH value of the meat itself, as the shift of the isoelectrical point from 5.2 to 5.0 widens the gap between pH values present in the meat and the isoelectrical point. A larger gap between the two pH values increases the capillary effect of the muscle fibres and an increased capillary effect improves water-binding potential in intact meat and entrapment of extraneous water in processed meat (Feiner, 2006). Thus, high concentrations of salt, usually in the form of a brine, are commonly incorporated into meat by marinating through tumbling or injection. A salt concentration of 1.0-1.6% can be considered the most widely used in poultry meat formulations. Our unpublished data revealed that even low concentration (i.e. 0.5%) of salt can significantly improve water holding capacity of poultry meat.

In recent decades, with the increasing consumption of many different processed foods containing high level of sodium, the perception of dietary salt has evolved to a point where it is now considered, by some, to be a potential health threat. Since these high levels of dietary sodium are associated with a high prevalence of hypertension, prehypertension and, possibly, other adverse effects on health, many national and international health organizations recommend that sodium intake be significantly decreased (Doyle and Glass, 2010). World Cancer Research Fund recommended that average consumption of salt should be less than 5 g (2 g of sodium) a day (WCRF, 2007). Many processed foods contain high levels of salt and several countries have developed national programs for significantly reducing the sodium chloride content in many processed foods and encouraging a decrease in discretionary salt use (Doyle and Glass, 2010). It can be estimated that cured and processed meat contribute about 20% of the total sodium intake. Therefore, the addition of sodium chloride during meat processing should be restricted as little is possible (Ruusunen and Poulanne, 2005; Desmond, 2006).

One of the biggest barriers to salt replacement is cost as salt is one of the cheapest food ingredients available. Also, consumers have grown accustomed to salt through processed foods so in some cases it has being difficult to remove as previously discussed. Another issue is that although there are alternatives to salt in term of functionality some consumers and retailers may not be comfortable with these new ingredients on the label (Desmond, 2006).

In meat systems, besides the organoleptic factors, an important consideration when replacing NaCl with other chloride salts, is the effect on the physical properties of the final product. Sodium chloride reduction by itself will result in lowered WHC of the raw meat, which, upon heating, will result in higher cooking losses, drier product and, if cooking losses are too extensive, a totally unacceptable product (Barbut, 2002). The main strategy for salt replacement is the use of salt substitutes, in particular, potassium chloride (KCl). Potassium chloride tends to present a bitter flavour so that masking agents (i.e. special yeast extracts or other flavouring agents) were developed in order to counteract this bitterness. Another strategy for achieving a salt reduction in a meat product is represented by the use of flavour enhancers which enhance the perception of salt in the finished products so that one can formulate with a lower level of salt (i.e. 20% salt reduction) and achieve a similar saltiness in respect with the regular salt dosage. Sodium chloride is more effective than potassium chloride in promoting meat protein functionality, requiring some adjustments during processing when formulating for low sodium products (Lamkey, 1998). If sodium chloride has to be replaced by potassium chloride, around 15% more potassium chloride has to be applied in order to dissolve protein to the same extent; this is due to the different proportions of sodium or potassium bound to chloride. Chloride ions are mainly responsible for activating proteins and potassium chloride demonstrates a non-chloride part of 48% compared with 39% in sodium chloride. As a result, more potassium chloride has to be added to end up with the same concentration of chloride within the meat product (Feiner, 2006). However the differences are primarily due to other properties of salt, such as flavour and microbial stability, rather than protein functionality (Lamkey, 1998). People with heart problems must not consume high levels of potassium chloride as excess levels of potassium can cause heart irregularities (Feiner, 2006). Finally, some attempts have been done to enhance the taste bioavailability of salt by modifying its physical status (i.e. lowering particle size by means of micronization/encapsulation) (Broadway *et al.*, 2010). However this approach is more effective for product in which the salt maintains its original physical form (i.e. sprinkled in surface), whereas less effective when salt is solubilised in water such in a meat system.

Phosphates

Phosphates are the salts of phosphoric acid and are historically widely applied in the meat industry even if in the last decades in some EU countries, such as Italy and France, there was a huge drop in their usage because of bad consumer perception on the effect of phosphates on the health status. Phosphates are commonly used together with sodium chloride in order to enhance muscle protein extraction and, hence, improve water holding capacity and reduce cooking shrink (Barbut, 2002). There are many types of phosphates available on the market which vary greatly in properties (pH and solubility in water) (**Table 2**).

role in muscle contraction as well as relaxation and are present at the point where binding between actin and myosin occurs by myosin locking into actin (Feiner, 2006). Once actomyosin complexes are separated, with the addition of salts (mainly NaCl) which increase ionic strength, the muscular proteins become solubilised and are able to immobilize high levels of added water as well as emulsify a large amount of fat. Moreover nearly all phosphates, as well as blends of phosphates, utilized in the meat-processing industry, are alkaline phosphates and

Table 2 - Main phosphates in meat products (adapted from Lampila and Godber, 2002).

Common name	Abbreviation	Formula	pH (1% in solution)	Solubility (g/100g H_2O)
Monosodium phosphate	MSP	NaH_2PO_4	4.4	85 (20°C)
Disodium phosphate	DSP	Na_2HPO_4	8.8	7.7 (20°C)
Trisodium phosphate	TSP	Na_3PO_4	12	13 (20°C)
Sodium diphosphate				
(tetrasodium pyrophosphate)	TSPP	$Na_4P_2O_7$	10.2	6 (20°C)
Disodium diphosphate				
(sodium acid pyrophosphate)	SAPP	$Na_2H_2P2O_7$	4.2	12 (20°C)
Sodium tripolyphosphate				
(pentasodium phosphate)	STPP	Na_5P_3O10	9.8	15 (20°C)
Sodium hexametaphosphate	SHMP	$(NaPO_3)n$		High soluble

In meat-related applications, blends of different phosphates for every specific application are available on the market and such blends perform significantly better than a single type of phosphate. The most popular phosphates are the alkaline polyphosphates such as tripolyphosphate, which, according to some estimates, represents more than 50% of the phosphates used by the meat industry. Phosphate use is limited in dosages and in some countries cannot be used for all types of meat products (Feiner, 2006; Sebranek, 2009).

Phosphates themselves do not activate much proteins at all but their function is to remove the links from the actomyosin complex. They neutralize the cross-links between actin and myosin formed during *rigor mortis* and support the dissociation of the actomyosin complex into separate fibres again. Only phosphates are able to exert this function which is the primary reason for the worldwide use of phosphates. The separation of actin and myosin takes place as a result of the binding of the negatively charged phosphate ions with the positively charged magnesium (Mg^{2+}) or calcium (Ca^{2+}) ions. The positively charged Mg^{2+} and Ca^{2+} ions play a vital

the addition of alkaline phosphates to slightly sour meat leads to a rise in pH inside the meat product. A movement further away from the isoelectrical takes place and enhanced water binding capacity of the proteins is the result because greater electrostatic repulsive forces create larger gaps between actin and myosin and larger amounts of added water can be bound. Finally the addition of phosphates increases the ionic strength of the meat by leading to a more severe degree of swelling from the muscle fibres and activation of protein (Feiner, 2006).

Xiong *et al.*, (2000) found that addition of pyrophosphate facilitated myofibrilar swelling by reducing the minimal needed concentration for swelling of sodium chloride. Froning and Sackett (1985), in a comprehensive study, compared the effects of pyrophosphate, tripolyphosphate, and hexametaphosphate and they attributed the increase in WHC to the increased extractability of myofibrillar proteins induced by the phosphates, particularly the combination of tripolyphosphate and hexametaphosphate. More recently, Xiong and Kupski (1999a,b) found that ability of phosphates to improve the absorption and immobilization of water in the muscle follows the following order: pyrophosphate > (~) tripolyphosphate > hexametaphosphate. These differences can be attributed to different capabilities of penetrating into the chicken fillets (Xiong and Kupski, 1999a) instead of differences in marinade pH solutions. The similar effect of pyrophosphate and tripolyphosphate may be explained because tripolyphosphate is dephosphorylized to pyrophosphate, most likely by a endogenous enzyme (ATP-ase) present around the myofibrils (Xiong and Kupski, 1999a; Brewer, 2004). The relative ineffectiveness of hexametaphosphate might be due to the bulkiness of the compound which impairs diffusivity and, hence, water penetration in muscle. Both pyrophosphate and tripolyphosphate are able to specifically bind to heavy meromyosin (myosin head), thereby regulating the interaction between myosin and actin and changing the physical structure of the I- and A-bands (Muhlrad *et al*., 1991). The affinity of actomyosin for tripolyphosphate increases in the presence of high NaCl concentrations and Mg^{2+} and Ca^{2+} (Brewer, 2004).

The complementary action of salt and phosphate demonstrated the ability to reduce the level of either of them while compensating with the other one. Therefore, phosphates can be used in the development of low salt meat product (Ruusunen and Puolanne, 2005). However, recently there are also some nutritional concerns with the use of phosphates in foods. Some investigators have considered that the formation in the intestinal tract of insoluble salts of phosphate with calcium, iron and other metal ions might result in decreased absorption of such minerals and increase bone diseases (Sun, 2009). Moreover, high phosphorus intake has been a potential risk for chronic kidney disease (Uribarri, 2009). Uncooked meat and poultry products that are enhanced may contain additives that increase phosphorus content by as much as almost two-fold (Sherman and Metha, 2009). Apart from these nutritional drawbacks, nowadays term "phosphate" sometimes has negative connotations. To address natural and clean label trends, processors are interested in phosphate replacers that are natural and easy to understand for consumers. A big challenge for meat industry is to find ingredients that have equivalent functionality as phosphates for helping with the yield and eating quality of products.

Citrates and other alkaline ingredients

Citrate, and here specifically trisodium citrate dehydrate, is widely introduced into meat products to enhance the ionic strength, as the amount of solubilised proteins correlates to the ionic strength present in the meat product. Citrate is also used for its ability to metal chelation which can help to prevent oxidative processes. Citrate, unlike phosphates, has no specific effect (removing the links between actin and myosin) and it contributes only to the swelling of the muscle fibre structure and not to protein solubilisation. Given the fact that citrate is alkaline, it also assists slightly in raising the pH value within the meat product, therefore assisting the WHC of proteins itself (Feiner, 2006).

Sodium bicarbonate has a slightly salty, alkaline taste resembling that of washing soda (sodium carbonate). First studies were focused on using bicarbonate to minimize the problem of pale, soft and exudative (PSE) in pork (Kauffman *et al*., 1998; Van Laack *et al*., 1998; Wynveen *et al*., 2001) and poultry (Woelfel and Sams, 2001; Alvarado and Sams, 2003). More recent studies found that sodium bicarbonate was able to reduce shear force and improve yield of enhanced poultry meat (Sen *et al*., 2005; Petracci *et al*., 2012). When added in marinades, bicarbonate had a very high alkaline power on meat and showed a greater ability to increase meat pH in respect with sodium tripolyphosphate (0.7 *vs*. 0.3 pH units) (Petracci *et al*., 2012). This may be due to differences in buffering capacity and ionic strength. Petracci *et al*., (2012) observed that marinades containing sodium bicarbonate in association with salt allowed to greatly improve product yield. This effect must be mainly related to its alkalinisation effect which moved meat pH away from the isoelectrical point of myofibrillar proteins and increased net negative charge. This leads to muscle fibre expansion (swelling) caused by electrostatic repulsion which allows more water to be immobilised in the myofibrillar lattice (Offer and Knight, 1988). Observations done by LR-NMR technique showed that combined use of bicarbonate with sodium chloride determined a remarkable increase of proportion of entrapped water into myofibrillar spaces (Petracci *et al*., 2012).

Starches

Starch is a pure carbohydrate polymer and the most common sources are potato, wheat, rice, tapioca and corn. In meat products starches are mainly used as gelling agents to bind added water in both whole injected parts (starch can be easily incorporated into a brine without problems for obstructing needles or injector's filters) or in minced meat systems such as chicken nuggets by allowing to bind the water during cooking and subsequent improvement of shelf-life, as well as they can help to deliver the desired texture. Moreover, some particular starches can be used to provide freeze/thaw stability of the gelled water as well as to deliver a fat mimetic behaviour in lean products (i.e. prepared with breast meat) in order to ameliorate their sensory profile and helping flavour release. From a general point of view, starches are a polysaccharides which are formed by different ratios of amylose and amylopectin. Amylose is primarily responsible for the firmness or gel strength of a starch gel as the linear chains of glucose units can align themselves in a parallel way and close to each other. Amylose is also very unstable in aqueous solutions, and intermolecular interactions and associations with other amylose molecules can lead to an increase in viscosity, retrogradation and even precipitation of amylose particles. The level of retrogradation depends on the type of starch and for native starches increases in the sequence tapioca > potato > maize > wheat. Syneresis and purge (weeping) are seen as a result of retrogradation and this is very common in sliced and vacuum-packed poultry meat products (Feiner, 2006).

Amylopectin is responsible for the elasticity and viscosity of a starch gel and viscosity is primarily a function of molecular weight and particle size. Starches high in amylopectin are easier to cook and generally gelatinize at lower temperatures than starches high in amylose. Starches, which contain 97% or more amylopectin, and therefore little or no amylose, are collectively known as waxy starches. This type of starch results in clear and transparent gel and does not retrograde primarily because of the high percentage of branched molecules, but also because of the absence of amylose. Waxy starches generally demonstrate good freeze-thaw stability and are also used for heat-freeze processes. Native, or unmodified, starches are obtained from the original form of the starch-bearing material. Native starches generally exhibit limited resistance towards low pH values, impact of heat and shear during processing and poor performance regarding freeze-thaw stability. Therefore, modification of starch is common practice in order to improve the behaviour of starch towards such processing parameters. Modified starch is ordinary, or native, starch altered physically or chemically to modify its functional properties such as thickening or gelling. Pregelatinized starches are cold swelling and do not require much heat in order to thicken or form a gel or paste (Feiner, 2006).

In the processed meat industry, starches are used for their thickening, gelling, water retention and texture improving characteristics. Potato and tapioca starches are the most widely used. Potato starch is often considered an ideal product because of its low gelatinization temperature (60-65 °C), high water-binding capacity and high viscosity. Tapioca starch is used in the meat industry for its surface sheen, smooth texture and neutral taste. Modied food starches are often used in meat applications because offer a valid economic alternative in respect with their native counterparts with interesting technological behaviour such as a higher resistance to processing conditions (i.e. cooking temperature, pastorization and retorting) and retrogradation (i.e. purge formation of cooked products). However modied food starches are considered as food additives so that are not suitable for clean label products. In order to accomplish with this market requirement of clean label, special "native functional" starches, obtained by means of physical treatments carried out on native starches (i.e. potato, tapioca, waxy maize), have been introduced in the market (i.e. Novation™ from National Starch). Those starches exhibit a technological behaviour (i.e. resistance to retrogradation) in the final product and they have similar properties to chemically-modified starches with the advantage of a clean label status (Feiner, 2006; Joly and Anderstein, 2009).

Main applications of starches in poultry meat product development include whole parts to be injected (or chunked meat to be tumbled) with starch containing brine and subsequently cooked to yield sliceable products. Zhang and Barbut (2005) compared the use of different starches (regular and modified potato and tapioca) in PSE-like, normal and DFD chicken breast meat and they found that addition of starches allow to reduce to about 5% cook loss in PSE-like meat.

Because of the increasing demand for reduced- and low-fat frankfurters, modified starches are utilized during processing to bind additional water that replaces fat (Keeton, 2001). However, reduction of fat in finely ground meat products such as emulsified, boiled sausages (frankfurter style) is extremely challenging and poses difficulties in terms of appearance, flavour, and texture. For example, if the fat content is reduced and the meat content is simultaneously increased to compensate for the loss of fat, redness values of products increase, firmness increases and water holding decreases. For this reason, a number of hydrocolloid systems with high water-binding capacity which are able to promote the formation of gels have been examined for their ability to replace fat (Weiss *et al*., 2010). Hachmeister and Herald (1998) confirmed that modified starches varied in their ability to improve firmness and other textural characteristics of reduced-fat, high-added water, turkey batters. Incorporation of cross-linked waxy maize, cross-linked dent corn, modified potato and modified tapioca into turkey batters resulted in significant reductions in cooking and reheating losses and improve texture, while acid-thinned dent corn with xanthan gum did not exhibit good performances. Functional native starches are also able to replace the water-holding capacity and texture provided by phosphates in some recipes and applications (Joly and Anderstein, 2009).

Cereal floors

Cereal flours (mainly obtained from wheat and rice) both as native or most often as pre-gelatinized are common and largely available ingredients used in minced meat products (with average dosages of 1-3%) in order to retain water both in cold and warm conditions, bind meat particles, impart desired textures as well as helping the forming properties of comminuted meat batters (i.e. during the production of patties or nuggets). This behaviour is determined by the starch components of the flours (75-80%) as well as by the protein fractions (about 7% in rice and 12% in wheat). Pre-gelification of cereal flours allows to enhance the swelling and hydration of starch and proteins under cold conditions as well as to reach a complete gelling of the starch/protein matrix even in products to be cooked to low end-point temperatures (i.e. 68-70°C). Main differences among functional properties of the products available in the market are linked to the type of cereal (i.e. wheat vs. rice), the cultivar (i.e. wheat with higher or lower gluten content) as well as the degree of pre-gelification and the technology used for thermal treatment (i.e. drum drying of the flour vs. steam cooking of the cereal followed by dehydration and milling).

Hydrocolloids

Hydrocolloids, also commonly referred to as gums, originate from various sources and most of these are not digested in the human digestive system. Carrageenans, alginates and agar are obtained from seaweed, while ingredients such as guar gum, locust bean gum, and pectin are of plant origin. Guar gums are cold-swelling substances, whilst carrageenans and locust bean gum are hot-swelling materials. Gums do not interfere with the activation of meat protein, but they are very effective in forming a gel or acting as a thickener by reducing cooking loss and/or assisting to obtain the suitable texture in a meat products and to prevent syneresis in the finished product (Feiner, 2006). Among the many hydrocolloids available in the market carrageenans and alginates are the most commonly used in poultry meat products formulation.

Carrageenans are widely used for injected and/or tumbled meat parts (i.e. for injected turkey breast) and are active at a very low dosage (i.e. 0.1-0.3%). In those products carrageenans can improve yield, control purge, improve finished product sliceability, enhance juiciness. There are three main types of carrageenans, namely κ-, ι- and λ-carrageenan having different functional properties, however only κ- and ι- forms are incorporated in poultry meat products. κ-carrageenan forms a very firm but brittle gel (a strongest gel is obtained by the presence of potassium ions) which tend to produce syneresis, while ι-carrageenan yield an elastic gel which is resistant to syneresis. This is why κ- and ι- fractions are blended in commercial carrageenan preparations in order to modulate final product texture and control sysneresis and purge in final product. Carrageenans are often used in oven-roasted turkey breast products to assist in holding the injected brine which can reach 30-50% (Barbut, 2002). Verbecken *et al*., (2005) found that carrageenans did not interact with the meat proteins to participate in network formation, since the viscoelastic nature of the mixed protein/carrageenan network did not differ from that of a pure protein network. They hypotized that carrageenans are placed in the interstitial spaces of the protein network, where they bind water and may form gel fragments upon cooling. The use of polysaccharide gums such as carrageenans and alginates as water binders in low-fat meat products is of great interest to meat processors because of consumer demand for leaner and lower cost muscle foods. The effect of carrageenan addition on the functional properties of poultry meat products has been the subject of numerous studies (Verbeken *et al*., 2005). Bater *et al*., (1992) found that κ-carrageenan caused an increase in yield, sliceability and rigidity as well as a decrease in expressible juice in roasted turkey breasts. Amako and Xiong (2001) evidenced that carrageenan actions is very related to the type of meat (i.e. white vs. dark). Ayadi *et al*., (2009) studied the influence of carrageenan addition on technological and sensory properties of sausages formulated with mechanically separated turkey meat and they found that carrageenan addition increases water binding capacity and causes a significant change in sausage texture and microstructure. The increase in carrageenan concentration leads to harder and more cohesive sausages, while low (0.2% and 0.5%) and high (0.8% and 1.5%) inclusion levels determine an increase and decrease, respectively, of gel elasticity. However, at high level carrageenan addition causes a significant decrease in elasticity. Significant synergies were observed when blending carrageenans and whey proteins (Barbut, 2009). Another very common synergistic effect exploited for poultry meat product preparation is the combination of carrageenans with starches (i.e. potato starch). This combination is very useful for injected and or tumble meat parts with an high level of extension (i.e. 50-80%) as well as for emulsified sausages.

Alginate is the salt of alginic acid and a gum-like derivate from seaweed *Macrocystis pyrifera* and it is applied as a gelling agent or thickener. In the presence of calcium ions alginate forms a heat stable gel that "cold-sets" at refrigeration or room temperatures. In the poultry meat industry, it is used for binding small meat particles and also to enhance texture (Keaton, 2001; Barbut, 2002). Alginates can also be used for the production of meat replacers whereby a little amount of meat is combined with a high amount of water plus flavours and colorants to yield a gelled alginate matrix that can be subsequently used as a raw material for a variety of low-value meat products. Finally, some applications of alginate preparations allow to produce stable cold fat emulsions (i.e. with chicken skin) to be used for including a stable form of fat/skin in product formulations such as chicken nuggets or sausages.

Proteins from animal sources

Proteins from animal sources are ingredients derived from meat, milk and egg and they are obtained by animal product itself and its by-products (i.e. skin, bone, blood, whey, etc.) (Tarté, 2009; Xiong, 2009).

Main meat-derived protein ingredients are basically collagen (and gelatine) and blood derived proteins. The addition of ***collagen*** to meat products as a binder has been shown to be advantageous and collagen is believed to have the potential as a substitute for starches and other hydrocolloids in the formulation of meat products. The mechanism for collagen to improve water binding for products is supposed to be related with collagen-myofibrillar interactions, immobilizing free water, and preventing moisture loss during heat processing and storage through the formation of thermally reversible gel. During cooking, collagen binds fat and imparts a meat-like texture (Osburn and Mandigo, 1996; Cheng and Sun, 2008).

Collagen can be converted by heating into ***gelatine*** which has excellent functional properties, such as gelling, stabilization, film-forming, texturizing and water holding capacity. Gelatine is commonly used in canned meat products by holding juices lost during cooking and to provide a good heat transfer medium during cooking. Gelatine is also used in emulsified reduced-fat meat products and jellied products (Keaton, 2001).

Functional animal proteins available in the market include pork, beef and poultry collagen derivates with different levels of purity (collagen content) and functionality. A very large number of products came from pork and beef whereas only a few products are available from poultry sources. Moreover, pork and beef proteins are much more functional (i.e. gelling ability) than poultry derivates which are also more expensive. This is why in many poultry applications pork or beef collagen derivates are preferred to poultry ones. Main differences among available commercial collagen derivates are related to the ability to swell in cold or hot conditions which is a trait related to the target application. For example, a cold swelling product is suitable for the use in raw minced meat products (i.e. hamburgers and sausages), whereas a hot swelling product with no or very low cold functionality is useful for the preparation of brines to be injected in whole parts to be subsequently cooked. In this case the gelling of the brine is not desired.

Another source of functional animal proteins is represented by blood fractions of ***plasma*** and ***globin***. However, pork is the first source so that it is sometimes not easy to use pork derivates in chicken products. Plasma proteins are highly functional with excellent solubility, low viscosity and the ability to form strong, elastic and irreversible gels which increase gel strength as the temperature increases (Prabhu, 2002). These characteristics make plasma proteins very useful for incorporation in a brine to be injected since during cooking plasma proteins produce a very stable gelled matrix. In addition, plasma proteins are also good emulsifiers so that they are ideal for use in emulsified sausages to improve yield, knack (plasma gel is also thermal irreversible) and stability of fat when low quality meat is used, or to replace some of the lean meat fractions. In respect with plasma, globin fractions have very low water gelling capacity, but show a superior emulsifying behaviour so that they can be used for fat emulsions or emulsified sausages (mainly combined with plasma).

Nonfat dry milk, ***sodium caseinate***, and ***whey protein concentrates*** and ***isolates*** are used in comminuted and emulsified meats such as frankfurters and bologna, and coarse ground products, such as fresh sausage, meat patties and meatballs. Soluble dairy proteins, including whey protein concentrates and partially hydrolyzed caseins, are also used in marinated or injected meats. These dairy protein ingredients are used to improve moisture retention, fat-binding and textural characteristics of cooked meats (Xiong, 2009). Nonfat dry milk is widely used as neutral filler with good water-binding properties in comminuted products. Sodium caseinates have a quite limited WHC despite its excellent capacity to emulsify fat, a high viscosity in solution and do not gel as do other proteins such as soy proteins. Therefore, they do not bind meat pieces well, but contribute to overall firmness of meat products (i.e. hams) due to their ability to hold water. Smith and Rose (1995) found that functionality of whey protein concentrate is enhanced when used in combination with sodium tripolyphosphate in processed poultry products. Muguruma *et al*., (2003) verified that addition of biopolymers prepared with soybean proteins, caseins, whey protein isolate in the manufacture of chicken sausages may permit reduction in phosphate content without loss in texture. Barbut (2006), comparing the use of dry caseinate, whole milk, skim milk, regular, and modified whey protein powders in emulsified chicken meat batters, found that all dairy additives, except for the regular whey, significantly reduced cook loss, while only caseinate and modified whey protein powders contributed more to enhancing the textural properties of the meat batters. Modified whey was considered as the most cost-effective ingredient. In a further study, Barbut (2010) studied the effects of whole milk powder, two kind of skim milk powders, caseinate, and two types of modified whey proteins (2% protein level in the final product) in lean chicken meat batters and it was established that skim milk powders were the most beneficial in improving their yield and texture. In terms of cost, the skim milk powders were also the most cost effective, although on a weight basis, they had to be used at twice the level of whole milk powder. Finally Hongsprabhas and Barbut (1999) evidenced that cold setting of whey protein isolate improved the binding of raw and cooked meat batters, particularly at low salt level.

Egg albumen proteins are often used in poultry meat products. Most albumins as well as other proteins present in egg white denature by around 60°C and the proteins present in the egg yolk denature by around 70°C. Egg white is used in cooked sausages such as frankfurters because of its ability to form a stable and heat-irreversible gel, thus positively contributing to the firmness of low-cost emulsified sausages. The addition rate of egg white varies widely, high inclusion levels result in an egg flavour within the finished product (Keaton, 2001).

Protein from vegetable sources

Proteins from a variety of plant sources can be used as binders and extenders for increasing the ability of water retention of meat products. Rehydrated flaked textured vegetable proteins (i.e. from soy, wheat and pea) are heavily used in meat products such as burgers, patties, pies and salami for functional replacement of the lean meat components for economic reasons. Soluble plant proteins can be used to emulsify fat in finely comminuted meat products such as frankfurters and/or bind fat in coarse ground meat products such as patties or can be injected into whole muscle meat to provide structural integrity, increase water binding and so on (Egbert and Payne, 2009). The most common plant proteins found in meat products are those derived from soybeans or wheat, however pea proteins are became popular in Europe because they are currently produced from nongenetically modified organisms (non-GMO).

Soy and ***pea proteins*** are by far the most utilized nonmeat protein ingredients and are categorized as flours, concentrates, and isolates on the basis of their dry-weight protein content (50, 70, and 90%, respectively) as well as textured materials (Keaton, 2001). Soy isolates have a good ability to form a gel, while soy concentrates only form a paste. Soy proteins, in order to be fully functional, require sufficient water to be fully hydrated. and the addition of salt supports solubility of soy protein (very similar to meat proteins). Soy isolates are also excellent emulsifiers of fat as they have a high number of lipophilic (fat-loving or hydrophobic) groups within their molecules and can hold fat and water together in a meat product to create a stable network. In whole-muscle injected ham products, soy isolates are applied worldwide in order to add firmness and texture to the product. Hence, soy proteins act synergistically with meat protein and firmness is enhanced. Different injectable soy isolates exhibit different molecular structures which determine their dispersibility in cold water as well as their WHC (Feiner, 2006).

In meat emulsions such as frankfurters, both soy concentrates and isolates are used. Here as well, the addition of soy proteins increases firmness, texture and juiciness of the product whilst the amount of purge is reduced in packed products as well. Soy proteins are also used in burgers and nuggets worldwide. Binding of meat products such as burgers and nuggets is greatly enhanced owing to the addition of soy and juiciness is also enhanced as a result of reduced weight loss during frying. Soy is also occasionally applied for the purpose of protein enrichment of the finished product. Specialized soy proteins used in the manufacture of low-cost emulsified sausages, burgers, meatballs and nuggets show high gelling properties as those meat products are often produced with only small amounts of muscle meat. Soy proteins were, and still are, one of the food substances at the centre of the debate on the GMOs. Whereas many countries are comfortable with the use of genetically modified GM soy, others, such as Europe and Australia, show great resistance towards GM soy proteins (Feiner, 2006). Due to this issue, proteins obtained by non-GMO pea represent a good alternative. Pea protein isolates are soluble proteins with good gelation, emulsification and water binding properties which are needed for applications in processed meat products. However, until today, pea protein isolate are still not as neutral in flavour as are soy proteins and this could be an issue to consider when formulating a finished product with very mild flavour because of bean flavour notes could be advised.

Wheat Gluten is usually a cheap form of protein and it is used in the production of meat products such as sausages owing to its excellent water binding capacity and, to a lesser degree, their ability to emulsify fat. Injectable wheat protein isolates are profitably used for injected whole-muscle products as well as all reformed brine added products and hamburgers because of their very little impact on colour and taste of meat (Feiner, 2006). However, celiac concerns have been partially reduced the diffusion of wheat gluten in poultry meat industry. Gluten has found more use in coarse ground meat applications in the form of texturized pieces that mimic meat (i.e. meat-like bite characteristics) (Egbert and Payne, 2009 Toldra).

Vegetable fibres

From a technological point of view, the use of vegetable fibres from different sources is very promising for meat products development because of multifunctional behaviour of available-in-the-market products which can be incorporated into a meat product recipe with different aims (i.e. enhance WHC, modulate texture, stabilize fat in emulsified products, exert a fat mimetic behaviour in reduced fat products, etc.). Furthermore, incorporating a certain amount of vegetable fibres in a meat product could be exploited as a way for nutritional enrichment of processed meats. In fact, based on their technological functionality and nutritional benefits, fibres can be used, either alone or in combination with other ingredients, for fibre enrichment, as sources of prebiotic fibre, to reduce fat, salt or phosphates, and to enable the use of plant oils rich in PUFA n-3 (Fernández-Ginés *et al*., 2005; Grashorn, 2007; Bodner and Sieg, 2009; Sáyago-Ayerdi *et al*., 2009).

Fibres which are composed primarily of cellulose, hemicelluloses and lignin, such as bamboo, oat and wheat bran, are primarily insoluble, while those including substantial portions of gums, pectins and mucilages such as psyllium, fruit (citrus, apple) and chicory inulin contain significant fractions of soluble fibres. Other crucial aspects are level of processing (native of refined) and particle size (Bodner and Sieg, 2009). Dietary fibres have been included in the formulation of several meat products because of their ability to increase the cooking yield due to their water-binding and fat-binding properties and to improve texture. Various types of fibres have been studied alone or combined with other ingredients for formulations of reduced-fat meat products, largely ground and restructured products, and meat emulsions.

Most common commercial products include: insoluble cellulose based vegetable fibres from ***bamboo***, ***wheat*** and ***oat*** with different average length (i.e. 40, 90, 150, 200 µm); ***pea*** fibres extracted from the hull (insoluble fractions) or inner part (more soluble part with residues of native starch); ***carrot*** fibres (insoluble/soluble); citrus fibres (high content of soluble fractions); ***potato*** fibres (both insoluble or soluble products); psyllium husk (soluble fractions) and many other vegetable sources (apple, rice, soy, etc.).

The unique functionality of a vegetable fibre is given by the interaction of raw fibre source (i.e.

pea, carrot) x plant part utilized (i.e. pea husk vs. pea inner part) x physical status (i.e. fibre length or fibre "expansion") x technology (i.e. fractioning of desired fibres, chemical/physical treatment to obtain desired characteristics in the product, and so on). Thus it is quite difficult to speak about general functionalities of vegetable fibres derived from a certain plants, but it could be more the case that each commercially available product has some kind of special behaviour, and only very pure insoluble fractions (i.e. bamboo or wheat) from different producers, when standardized for a certain fibre size can show, comparable functionalities.

The main uses in poultry meat products include: **i)** raw comminuted meat products (i.e. sausages, hamburgers, and meat balls) where vegetable fibres (i.e. carrot, pea, citrus, etc.) can be used in order to enhance WHC in both cold (during fabrication and shelf-life) and warm (during home cooking) conditions; **ii)** marinated products where the use of some particular soluble fibre (i.e. citrus) can enhance WHC as well as juiciness and tenderness after cooking; **iii)** emulsified sausages, where the use of insoluble long fractions (i.e. bamboo 90-150 μm) can enhance knack and retard fat coalescence in the meat batter, whereas the use of more soluble fractions (i.e. citrus, pea, etc) can increase cooking yield and fat emulsification; **iii)** chicken nuggets and breaded patties where many types of fibres can be incorporated during the preparation of meat batter in order to increase WHC, enhance bite of high mechanically deboned meat formulations, increase juiciness of lean products (i.e. breast meat products), and also retard the migration of water from the cooked meat matrix to the coating system (i.e. predust/battering/breading).

Conclusions

Ability of retain water and texture of processed poultry meat products are very important quality characteristics and they can be extensively modified by incorporating functional ingredients such as some salts and several organic components of both animal or vegetable origin. Literature review reveals that there are theoretically almost infinite formulation solutions to produce further processed products, however market demands (i.e. national, ethnic and traditional values) and policies, legislation restrictions, food allergy and intolerance issues (i.e. celiac disease, protein allergens), available processing technologies and most important economic viability (i.e. least cost formula) limit very much feasible solutions.

Additional challenge for poultry meat industry is to address consumer demand for healthier meat products that are low in sodium, fat, cholesterol, calories and incorporate vegetable proteins and dietary fibres.

References

ALVARADO, C.Z. and SAMS, A.R. (2003) Injection marination strategies for remediation of pale, exudative broiler breast meat. *Poultry Science* 82:1332-1336.

AMAKO, D.E.N. and XIONG, Y.L. (2001) Effects of carrageenan on thermal stability of proteins from chicken thigh and breast muscles. *Food Research International* 34:247-253.

AYADI, M.A., KECHAOU, A., MAKNI, I. and ATTIA, H. (2009) Influence of carrageenan addition on turkey meat sausages properties. *Journal of Food Engineering* 93:278–283.

BARBUT, B. (2010) Effects of milk powder and its components on texture, yield, and color of a lean poultry meat model system. *Poultry Science* 89:1320-1324.

BARBUT, S. (2002) Poultry products-formulations and gelation, In: Poultry products processing. An industry guide, pp. 467-511. CRC Press, New York.

BARBUT, S. (2006) Effects of caseinate, whey and milk powders on the texture and microstructure of emulsified chicken meat batters. *LWT- Food Science and Techology* 39:660-664.

BARBUT, S. (2008) Use of transglutaminse in lean poultry meat patties. *Proceedings World's Poultry Science Association*, Brisbane, Australia.

BARBUT, S. (2009) Pale, soft, and exudative poultry meat-Reviewing ways to manage at the processing plant. *Poultry Science* 88:1506-1512.

BATER, B., DESCAMPS, O. and MAURER, A.J. (1992) Quality characteristics of hydrocolloid-added oven-roasted turkey breasts. *Journal of Food Science* 57: 1068-1070.

BODNER, J.M. and SIEG, J. (2009) Fibres, pp. 83-110. In: TARTÉ R. (Ed) *Ingredients in meat products,* by Springer, New York, USA.

BREWER, M.S. (2004) Water-holding capacity, In: JENSEN W.K. (Ed.) *Encyclopedia of Meat Sciences*, pp 242-249, Elsevier Ltd., Oxford, UK.

BROADWAY, P.R., BEHRENDS, J.M. and SCHILLING, M.W. (2011) Effect of alternative salt use on broiler breast meat yields, tenderness, flavor, and sodium concentration. *Poultry Science* 90:2869-2873.

CHENG, Q. and SUN, D.W. (2008) Factors affecting the water holding capacity of red meat products: a review of recent research advances. *Critical Reviews in Food Science and Nutrition* 48:137-159.

CLAUS, J.R. and HUNT, M.C. (1991) Low-fat, high added-water bologna formulated with texture-modifying ingredients. *Journal of Food Science* 56:643-648.

DESMOND, E. (2006) Reducing salt: A challenge for the meat industry. *Meat Science* 74:188-196.

DOYLE, M. and GLASS, K.A. (2010) Sodium reduction and its effect on food safety, food quality, and human health. *Comprehensive Reviews in Food Science and Food Safety* 9:44-56.

EGBERT, W.R. and PAYNE, C.T. (2009) Plant proteins. In: TARTÉ R. (Ed.) *Ingredients in meat products*, pp. 111-130, Springer, New York, USA.

FEINER, G. (2006) *Meat products handbook* - Practical science and technology. Woodhead Publishing Limited, Cambridge, England.

FERNÁNDEZ-GINÉS, J.M., FERNÁNDEZ-LÓPEZ, J., SAYAS-BARBERÁ, E. and PÉREZ-ALVAREZ, J.A. (2005) Meat products as functional foods: a review. *Journal of Food Science* 70:R37-R43.

FLETCHER, D.L. (2002) Poultry meat quality. *World's Poultry Science Journal*, 58:131-145.

FRONING, G.W. and SACKETT, B. (1985) Effect of salt and phosphates during tumbling of turkey breast muscle on meat characteristics. *Poultry Science* 64:1328-1333.

GRASHORN, M.A. (2007) Functionality of poultry meat. *The Journal of Applied Poultry Research* 16:99-106.

HACHMEISTER, K.A. and HERALD, T.J. (1998) Thermal and rheological properties and textural attributes of reduced-fat turkey batters. *Poultry Science* 77:632-638.

HAMM, R. (1986) Functional properties of the myofibrillar system and their measurements, In: BECHTEL P. J. (Ed.), *Muscle as food*, pp. 135-199, Academic Press Inc., New York, USA.

HONGSPRABHAS, P. and BARBUT, S. (1999) Use of cold-set whey protein gelation to improve poultry meat batters. *Poultry Science*, 78:1074-1078.

JOLY, G. and ANDERSTEIN, B. (2009) Starches, In: TRTÉ R (Ed.) *Ingredients in meat products*, pp. 25-56. Springer, New York, USA.

KAUFFMAN, R.G., LAACK, R.L.J.M., RUSSELL, R.L., POSPIECH, E., CORNELIUS, C.A., SUCKOW, C.E. and GREASER, M.L. (1998) Can Pale, Soft, Exudative pork be prevented by postmortem sodium bicarbonate injection? *Journal of Animal Science* 27:310-315.

KEETON, J.T. (2001) Formed and emulsion products, In: SAMS A. R. (Ed.) *Poultry meat processing*, pp 195-226. CRC Press, Boca Ranton, Florida, USA.

LAMKEY, J.W. (1998) Non meat ingredients for meat processing. *Proccedings of Reciprocal Meat Conference* 51:48-52.

LAMPILA, L.E. and GODBER, J.P. (2002) Food Phosphates, in: BRANEN A.L., DAVIDSON P.M., SALMINEN S. and THORNGATE III J.H.(Eds.) *Food Additives* - 2nd edition, Marcel Dekker Inc., New York, USA.

MUGURUMA, M., TSURUOKA, K., KATAYAMA, K., ERWANTO, Y., KAWAHARAA, S., YAMAUCHIA, K., SATHEB, S.K. and SOEDA, T. (2003) Soybean and milk proteins modified by transglutaminase improves chicken sausage texture even at reduced levels of phosphate. *Meat Science* 63:191-197.

MUHLRAD, A., PEYSER, Y.M. and RINGEL, I. (1991) Effect of actin, ATP, phosphates, and pH on vanadate-induced photocleavage of myosin subfragment 1. *Biochemistry* 30:958-965.

OFFER, G. and KNIGHT, P. (1988) The structural basis of water-holding in meat, in: LAWRIE, R.A. (Ed.) *Developments in meat science-4*, pp 63-243, Publ. Elsevier Applied Science, Amsterdam, The Netherlands.

OFFER, G. and TRINICK, J. (1983) On the mechanism of water holding in meat: the swelling and shrinking of myofibrils. *Meat Science* 8:245-281.

OSBURN, W.N. and MANDIGO, R.W. (1996) Reduced-fat bologna manufactured with poultry skin connective tissue gel. *Poultry Science* 77:1574-1584.

PETRACCI, M., BIANCHI, M. and CAVANI, C. (2009) The European perspective on pale, soft, exudative conditions in poultry. *Poultry Science* 88:1518-1523.

PETRACCI, M., BIANCHI, M. and CAVANI, C. (2010) Preslaughter handling and slaughtering factors influencing poultry product quality. *World's Poultry Science Journal* 66:17-26.

PETRACCI, M., LAGHI, L., ROCCULI, P., RIMINI, S., PANARESE, V., CREMONINI, M.A. and CAVANI, C. (2012) The use of sodium bicarbonate for marination of broiler breast meat. *Poultry Science* 91:526-534.

PRABHU, G., (2002) Utilizing functional meat-based proteins in processed meat applications, *Proceedings of the 55th Reciprocal Meat Conference*, pp.29-34AMSA, Savory, Illinois, USA.

RUUSUNEN, M. and POULANE, E. (2005) Reducing sodium intake from meat products. Meat Science 70: 531-541.

SÁYAGO-AYERDI, S.G., BRENES, A. and GOÑI, I. (2009) Effect of grape antioxidant dietary fiber on the lipid oxidation of raw and cooked chicken hamburgers. *LWT- Food Science and Technology* 42:971-976.

SEBRANEK, J.G. (2009) Basic curing ingredients, In: TARTÉ R (Ed.) *Ingredients in meat products*, pp. 1-24, Springer, New York, USA.

SEN, A.R., NAVEENA, B.M., MUTHUKUMAR, M., BABJI, Y. and MURTHY, T.R.K. (2005) Effect of chilling, polyphosphate and bicarbonate on quality characteristics of broiler breast meat. *British Poultry Science* 46:451-456.

SHERMAN, R.A. and METHA, O. (2009) Phosphorus and potassium content of enhanced meat and poultry products: implications for patients who receive dialysis. *Clinical Journal of the American Society of Nephrology* 4:1370-1373.

SMITH, D.M. and ROSE, A.J. (1995) Properties of chicken saltsoluble protein and whey protein concentrate gels as influenced by sodium tripolyphosphate. *Poultry Science* 74:169-175.

SUN, X.D. (2009) Utilization of restructuring technology in the production of meat products: a review. *Ciencia y Tecnología Alimentaria* 7:153-162.

SUN, X.D. and HOLLEY, R.A. (2011) Factors influencing gel formation by myofibrillar proteins in muscle foods. *Comprehensive Reviews in Food Science and Food Safety* 10:33-51.

TARTÉ, R. (2009) Meat-derived proteins ingredients, in: TARTÉ R. (Ed) *Ingredients in meat products* pp. 111-130, Springer, New York, USA.

URIBARRI, J. (2009) Phosphorus additives in food and their effect in dialysis patients. *Clinical Journal of the American Society of Nephrology* 4:1290-1292.

VAN LAACK, R.L.J., KAUFMAN, R.G., POSPIECH, E., GREASER, M.L., LEE, S. and SOLOMON, M.B. (1998) The effects of pre-rigor sodium bicarbonate perfusion on the quality of porcine. *Journal of Muscle Foods*, 9:185-181

VERBEKEN, D., NEIRINCK, N., VAN DER MEEREN, P. and DEWETTINCK, K. (2005) Influence of j-carrageenan on the thermal gelation of salt-soluble meat proteins. *Meat Science* 70:161-166.

WCRF (2007) *World Cancer Research Fund Panel Food, Nutrition, Physical Activity, and the Prevention of Cancer: A Global Perspective*. World Cancer Research Fund, Washington, DC.

WEISS, J., GIBIS, M., SCHUH, V. and SALMINEN, H. (2010) Advances in ingredient and processing systems for meat and meat products. *Meat Science* 86:196-213.

WOELFEL, R.L. and SAMS, A.R. (2001) Marination performance of pale broiler breast meat. *Poultry Science* 80:1519-1522.

WYNVEEN, E.J., BROWKER, A.L., GRANT, A.L., LAMKEY, J.M., FENNEWALK, K.J., HENSON, L. and GERRARD, D.E. (2001) Pork quality is affected by early post mortem phosphate and bicarbonate injection. *Journal of Food Science* 66:886-891.

XIONG, X.L. (2009) Dairy proteins, in: TARTÉ R. (Ed) *Ingredients in meat products*, pp. 131-144 by Springer, New York, USA.

XIONG, Y.L. (2004) Protein functionality, in: JENSEN W.K. (Ed.) *Encyclopedia of Meat Sciences*, pp. 218-225, Elsevier Ltd., Oxford, UK.

XIONG, Y.L. and KUPSKI, D.R. (1999a) Monitoring phosphate marinade penetration in tumbled chicken filets using a thin-slicing, dye-tracing method. *Poultry Science* 78:1048-1052.

XIONG, Y.L. and KUPSKI, D.R. (1999b) Time-dependent marinade absorption and retention, cooking yield, and palatability of chicken filets marinated in various phosphate solutions. *Poultry Science* 78:1053-1059.

XIONG, Y.L., LOU, X., WANG, C., MOODY, W.G. and HARMON, R.J. (2000) Protein extraction from chicken myofibrils irrigated with various polyphosphate and NaCl solutions. *Journal of Food Science* 65:96-100.

ZHANG, L. and BARBUT, S. (2005) Rheological characteristics of fresh and frozen PSE, normal and DFD chicken breast meat. *British Poultry Science* 46:687-693.