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The Use of Potato Starch in Meat Products

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ABSTRACT

Potato starch is one of the most non-meat ingredients employed in the meat industry. Starches had the ability to gelatinize with a considerable water uptake, improving cooking yielding and texture of emulsified or restructures meat products with minor effects on color. Application of starches in meat systems seems to be not quite adequate to allow the full functionality of starch. Gelatinization temperatures for most of native starches are above meat products thermal processing temperature, besides salts or sodium chloride presence increases this temperature interfering with the complete starch granule swelling. Nonetheless, potato starch lower gelatinization temperature close to meat products processing make it the most suitable extender for this kind of cooked meat products. This work is a revision about why potato starch is employed in meat systems with an acceptable functionality.

Keywords: functionality, hydrocolloids, meat extenders

CONTENTS

INTRODUCTION

It seems that potato was accidentally introduced in Europe in the Spanish galleons when the conquistadors returned from their failed try to reach the mythical Inca gold city, El Dorado, nearby 1560. Potatoes were an underestimated crop in Europe for almost two centuries until their acceptance during the Seven Years War. The potato dissemination around the world was made in ships by sailors, soldiers, missionaries and explorers, since potato tubers were easily stored and handled in ships during the long journey. Currently, Asia and Europe produce 80% of the world's potatoes. China is the main producer of this important crop, associated with a higher production of potato starch with a considerable (65%) growth in revenue, from €48,000,000 to €79,000,000, and a 48% hike in operating profit to €27,000,000 for the year ending March 2008 (Partos 2008). Potato processing implies the washing and peeling of potatoes to produce mainly French fries or chips and other processed products, as soups or instant purées. Other important products in many countries are alcohol, vinegar or liquors. Potato is a very nutritive food with a high amount of carbohydrates. For this reason, starches have had application in many industries like food, textile, paper, construction, pharmaceutical and others.

In the meat industry, starches are used for water retention and texture improving characteristics. Starches are added to meat product formulations as water binders to reduce formulation costs, increase yields, reduce cooking losses, improve texture, sliceability and succulence, besides increasing fat and water binding (Pearson and Gillett 1999; Murphy 2000; Luallen 2004; Kerry and Kerry 2006). Starch and related products, like dextrin or modified starches, have been approved for use in both standardized and non-standard meat products, where their use is regulated with several specifications (Luallen 2004). Non-meat ingredients as binders or extenders, and less frequently fillers, emulsifiers, or stabilizers, had to be added in sausages formulations according to the guidelines under legislation and maximum allowed content (Pearson and Gillett 1999). Extenders are protein material with a complementary effect of interacting with meat proteins, enhancing their functionality and nutri-

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Table 1 Functional properties of starches in foods (Adapted form Satin 1998).

Suspension	Gelatinization
Specific viscosity (hot and cold)	Gel texture, body at various temperatures
Viscosity resistance acid/mechanical sheer	Clarity, opacity
Flow properties	Emulsion stabilizing capacity
Mouth feel, lubricity, palate-coating	Adhesiveness
Suspension characteristics	Color
Hygroscopicity	Freeze-thaw stability (natural / modified)
Swelling and resistance to swelling	Film-forming properties

tional quality, and reducing costs. In contrast, binders are flour- or starch-based ingredients with no protein contribution but with a considerable uptake of water added (Güemes-Vera 2007).

FUNCTIONALITY OF STARCHES

Starches are used as thickening agents (sauces, cream soups, pie fillings), colloidal stabilizers (salad dressings), moisture retainers (cake toppings), gel-forming agents (gum confections), binders (wafers, ice cream cones), and coating and glazing agents (nut meats, candies). The functionality of starch in various foods is dependent on its physicochemical properties (Collado and Corke 2003). Many starch functional properties are listed in **Table 1**. These functional properties can be improved by modification to the starch granule and its component structure (**Fig. 1**). This chemical or physical modification impact starch temperatures for gelatinization (collapse or disruption of starch granule with changes in their solubilization, crystallite melting and loss of birefringence) and pasting (granular swelling and total disruption of granules after gelatinization) (Collado and Corke 2003).

Modified starches

Native starches present important differences due to their botanical origin, mainly concerning gelatinization temperatures, granule size and amylose/amylopectin content (**Table 2**). Chemical and physical modifications provide functionalities not readily available or controllable from commercially available native starches. There is a wide range of treatments that can be applied to raw starch to change its use. Properties sought from modified starches include enhanced rheological characteristics, textural qualities, optical properties, and enhanced stability of the system. Chemical modification of starch is made possible because of the many hydroxyl groups available for reaction with the chemicals used, including crosslink, stabilization and crosslink-stabilization (Collado and Corke 2003). Modified starches are used in foods for three reasons: (1) they provide functional attributes to food applications that native starches normally cannot provide, (2) starch is abundant and readily available, and (3) starch can provide an economic advantage in many applications where higher priced items such as gums must otherwise be used (Aktaş and Gençcelep 2006). The use of modified starches in processed meat products helps to bind moisture, besides providing heat and shear stability, extending shelf life, and improving freeze/thaw stability and texture (Anonymous 2008). **Fig. 2** lists the most common starch modifications. Modification of potato starches changes their functionality.

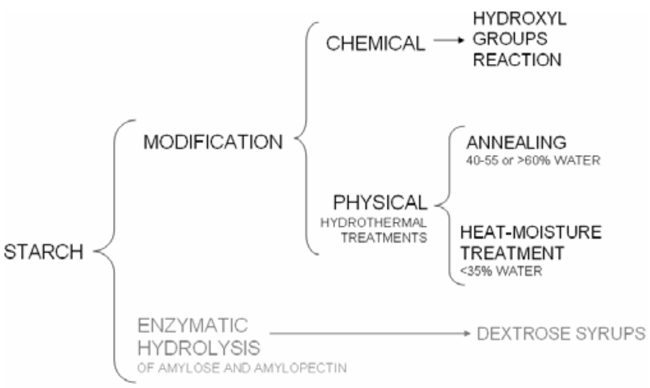

Fig. 1 Starch functionality improvement by chemical or physical modification. (Adapted from Collado and Corke 2003).

APPLICATIONS IN MEAT PRODUCTS

As a binder or extender, potato starch is employed in low or reduced fat meat products, restructured or emulsified with added water. Potato starch is often considered an ideal product because of its low gelatinization temperature, high water-binding capacity, high viscosity, and clarity in solution (Zhang and Barbut 2005).

Water- and fat-binding properties

Water binding affects the water properties of cooked meat products; moreover, when this kind of product had been reduced in fat content with added water. It has been reported that expressible moisture (Aktaş and Gençcelep 2006), cooking loss (Pietrasik 1999) and water exudation (Whiting 1987) decreased with the concomitant increase in moisture (Liu *et al.* 2008) and water holding capacity (Dzieszuk *et al.* 2005) when potato starch concentration was increased as well. Summer sausages and pepperoni formulated with potato starch presented more moisture than control full fat samples (Vickery and Rodgers 2002a, 2002b). The use of modified potato starch reduced cook and reheated loss in reduced-fat turkey batters (Hachmeister and Herald 1998). The addition of konjac flour and potato starch in reduced fat frankfurters improved water holding capacity, emulsion stability and less released fat in expressible fluid, in raw and cooked batters (Kao and Lin 2006). The use of lower potato starch concentration in fat-reduced emulsified meat products can be achieved with the addition of equal proportions of κ-carrageenan/locust bean gum, since the interactions among these components improved texture and water retention (García-García and Totosaus 2008). The amount of separated fat from emulsified meat products is reduced with modified potato starch by a stabilizing effect related to their

Table 2 Main starchs characteristics (Adapted from [1] Murphy 2000, [2] Collado and Corke 2003, [3] BeMiller and Whistler 2000, [4] Zobel and Stephen 1995).

Starch	Type	Granule Diameter Range (µm)	Gelatinisation Temperature Range (ºC)	Pasting temperature at 5% (°C)	Amylose-Amylopectin Ratio Range (%)
Potato	Tuber [1,3]	5-15–100 [1,2,3]	56-59–77 [1,2,3]	64 [1]	20-22–80-78 [1,2,3,4]
Maize	Cereal [1,3]	2-5–30 [1,3]	62–72-80 [1,3]	80 [1]	25-28–75-72 [1,2,3,4]
Wheat	Cereal [1,3]	1-2–45-55 [1,2,3]	53-58–64-72 [1,2,3]	77 [1]	25-28–75-72 [1,2,3,4]
Rice	Cereal [1,3]	3–8 [1,3]	61-66–78-85 [1,2,3]	81 [1]	17-19–83-81 [1,2,3,4]
Tapioca	Root [1,3]	4–35 [1,2,3]	52-62–64-73 [1,2,3]	63 [1]	17–83 [1,2,3,4]

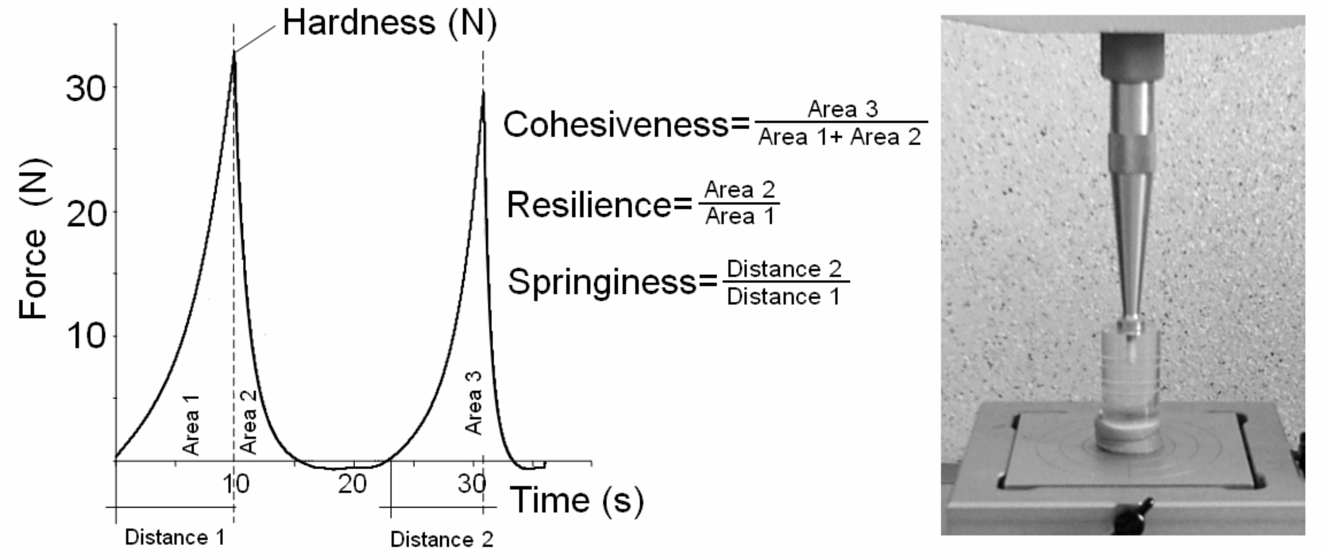

Fig. 2 Texture profile analysis force deformation curve resulting from the double consecutive sample compression and the main textural parameters calculated from the curve.

electrical charge having more hydrophilic-lypophilic groups within structure, increasing the lipid-water interaction (Aktaş and Gençcelep 2006). On other hand, in restructured meat products, like ground beef patties, pork nuggets or low-fat pork-crumbles, the addition of modified pregelatinized potato starch increased tenderness, moisture and cooking yields reducing fat retention after precooking and reheating (Berry and Wergin 1993; Berry 1994; Bigner and Berry 1997).

Texture

Meat products texture

Texture in meat products is the result of the internal structure created by components interaction. Muscle proteins in processed meat products are the main functional and structural components, determining the final product characteristics related to texture as a result of fat binding and water retention. Addition of other non-meat ingredients affects the product properties like texture and yielding (Totosaus and Guerrero 2006). When potato or other type of starch are incorporated in meat products formulation, the objective effect of its addition can be achieved performing a textural profile analysis (TPA) (Hachmeister *et al.* 1998; Pietrasik 1999; Li and Yeh 2003a; Kao and Lin 2006; García-García and Totosaus 2008; Liu *et al.* 2008), a methodology originally developed by Friedman *et al*. (1963), and adapted to the Instron Universal Testing Machine by Bourne (1978). Samples are axially compressed in a double cycle at a constant rate, calculating from the force-deformation curves parameters related to sample structure (**Fig. 2**). The most common reported are hardness, defined as the force necessary to attain a given deformation; cohesiveness, defined as the strength of the internal bonds making up the body of the product; and springiness, defined as the degree to which a product returns to its original shape once it has been compressed (Szczesniak, 1963; Bourne 1978). These parameters are highly correlated with sensory attributes (Bourne 1982), although to correlate TPA with textural sensory attributes is necessary a trained panel. However, most of the reports employ only instrumental TPA to determine textural differences related to starch incorporation. Unfortunately, there is certain confusion about the report of secondary parameters calculated in TPA, as gumminess and chewiness, according to the methodology clarification (Bourne 1995), because is not correct to report these both parameters in same sample, since definitions stated chewiness as the energy required to masticate a solid food, and gumminess as the energy to disintegrate a semi-solid food.

When fat content is reduced, textural characteristics of sausages are affected, decreasing hardness and cohesiveness with an increase of moisture content as added water. At normal fat content, a relatively high level of starch resulted in a harder and springiness structure than low-fat products, but was not able to reduce the gumminess of low-fat sausages as compared with full-fat samples (Pietrasik 1999). It has been suggested that the use of potato starch at levels higher than 4% has a detrimental effect on sausages hardness and gumminess (Dzieszuk *et al*. 2005)

Potato starch in emulsified meat products compensated the textural properties and increased the gel strength of the protein gel matrix structure (Aktaş and Gençcelep 2006); increasing samples' shear force (Bushway *et al.* 1982). The modified potato starch induced a noticeable hardness reduction in low-fat sausages, probably due to weakening of the gel structure as more water was with held in the protein-starch composite gel matrix (Liu *et al.* 2008). In reduced-fat turkey batters, modified potato starch increase hardness and cohesiveness with no effect on springiness (Hachmeister and Herald 1998). The addition of potato starch increased the gelation of meat proteins, reflected in the increase of the solid-like behavior (storage modulus G'), at temperatures above 50°C (Kerry *et al*. 1999; Li and Yeh 2002). At the same konjac flour level potato starch did not improve the hardness of reduced fat frankfurters (Kao and Lin 2006).

Color

Meat products color

Color is the first impression that consumers perceive from meat products. Objective determination of meat and meat products color is important for the technological improvement of actual process and in the developing of new meat products (Pérez-Álvarez 2006). Color is determined instrumentally employing colorimeters based on the Hunter Lab scale or CIE-Lab (Commission International d'Eclairage, France), and although both scales show the same directionality in the color information portrayed, differences among these scales are interpreted as differences caused by variations among instruments (MacDougall 1999). Recently, Yam and Papadakis (2004) proposed the use of digital imaging and the conversion to L*a*b* coordinates with the Abobe Photoshop software. The Lab color space has a solid uniform surface color scale with three axes: L*, the central axis or lightness (0 to 100, absolute white), and two perpendicular axes: a* for greenness-redness (-a* to +a*) and b*

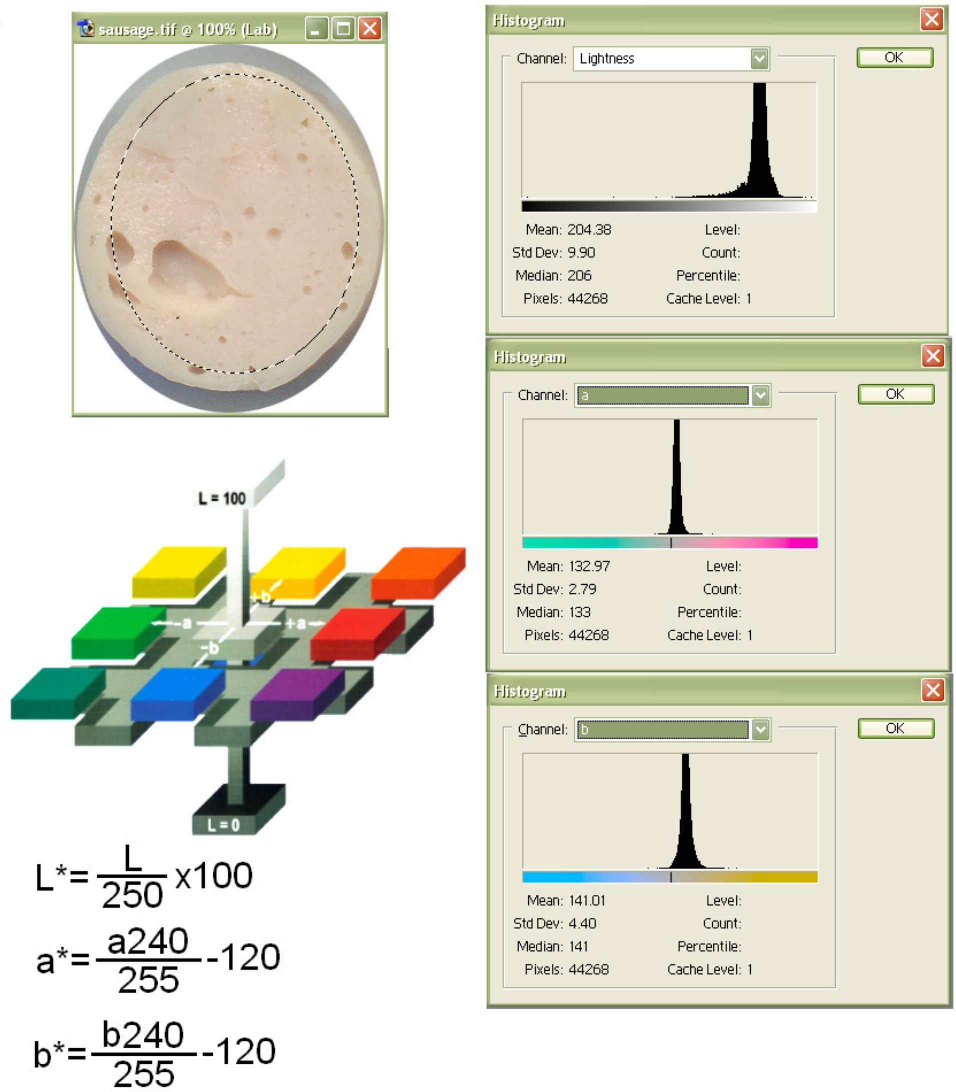

Fig. 3 Color in CIE-Lab coordinates calculated from the Adobe Photoshop software in LAB Coordinates employing the Histogram window to calculate color parameters and the standardized luminosity (L*), redness (a*) and yellowness (b*) values according to Yam and Papadakis (2004).

for blueness-yellowness (-b* to +b*). Although Hunter L*a*b* values only locate a single point within the color solid, the L-value has been useful to determine the extent of product lightening (increase of L) or darkening (decrease of L), and the a-value has been useful to determine the change in pink-to-red hue characteristic (Hunt *et al.* 1991), as reported by Baardseth *et al.* (1992), Pietrasik (1999), García-García and Totosaus (2008) and Liu *et al.* (2008). L*a*b* values as reported as well in tristimulus scale (Munsell Color) converting to hue angle (H= $\tan^{-1}$ [b*/a*]) and saturation index (S= $[a^{*2}+b^{*2}]^{½}$) (Sester 1984), as reported by Dzieszuk et al. (2005) and Kao and Lin (2006) (**Fig. 3**).

Color of sausages and frankfurters is influenced by fat and water content. In general, reduction in fat content makes sausages less yellow, darker and red (Pietrasik 1999). The main effect of adding potato starch seems to be its increased lightness (Baardseth *et al.* 1992; Vickery and Rodgers 2002a, 2002b; Dzieszuk *et al.* 2005; Liu *et al.* 2008), since a higher amount of water is retained in the products. The addition of konjac-potato starch mixtures in fat reduced cooked sausages had a minor effect on color perception (Kao and Lin 2006).

Sensory quality

Sensory properties of fat-reduced added-water meat products can be enhanced with potato starch. It has been reported that the organoleptic quality of sausages was improved with potato starch (Dzieszuk *et al.* 2005). The addition of modified potato starch increased sausages tenderness and improved juiciness, but at levels above 4% the product becomes tougher (Lui *et al.* 2008). Juiciness is related to two components: i) sample wetness during the first chews resulting from the release of meat fluids, and ii) the sustained juiciness due to the stimulating effect of fat on salivary flow and fat mouth coating (Winger and Hagyard 1999). In low-fat pepperoni with potato starch as a fat substitute there was no difference in tenderness, flavor or juiciness (Vickery and Rodgers 2002a), but summer sausages formulated with potato starch were more tender but less juicy, with no difference in flavor than the control (Vickery and Rodgers 2002b). A reduction in firmness and similar juiciness in low-fat pork-crumbles without modified pregelatinized potato starch has also been reported (Bigner and Berry 1997).

Fat-reduced samples with konjac-potato starch mixtures were similar in firmness and juiciness scores, with no significant difference in overall acceptability (Kao and Lin 2006). The use of potato starch alone or mixed with potato flour as an extender in frankfurters provides good sensory quality attributes, characterized as more tender and juicy than control samples containing no potato starch (Bushway *et al.* 1982). Sausages with increasing concentrations of starch and dairy ingredients (sodium caseinate, skim-milk powder and whey protein) become more sticky, fatty, juicy, rancid and white and also become stronger with a slight simultaneously effect of cooking temperature (Baardseth *et al.* 1992).

Potato starch in pale, soft and exudative meat

Potato starch has been employed to improve poultry pale, soft and, exudative (PSE) meat functionality. Since PSE meat has an abnormal light color, flaccid consistency, poor water holding capacity, and, hence, poor functional properties. PSE meat is a result of a rapid early-postmortem glycolysis, resulting in a lower pH due to the accelerated rigor mortis development, associated to stressing conditions before slaughter and high (>20°C) postmortem temperatures; and is some cases to genetic factors like the mutation in the poultry ryanodine receptor (Totosaus *et al.* 2007). The addition of potato starch to PSE poultry meat batters compensate part of the poor functionality of PSE poultry meat, reducing cooking loss and improving texture and gel quality (Nowsad *et al.* 2000; Zhang and Barbut 2005).

Starch degradation in meat products

Certain starch degradation activity has been reported; moreover, when the samples have been thermally processed. Starch degradation can be detectable as free glucose, indicating that a major part of the enzymatic starch degradation resulted in this compound (Skrede 1983a). Previously, Dahl (1957) reported that a common feature in starch degradation in meat products was the thermal treatment, since starch gelatinization is a prerequisite to be available for decomposition, probably by residual muscular amylases, where non-gelatinized starch remained unattacked. This property can be in fact employed to determine the starch content of meat products as glucose has been proposed in an enzyme-hydrolytic method with a thermo-stable α-amylase and amyloglucosidase for hydrolysis, with no interference of lactose in the analysis (Skrede 1983b).

EXTRUDED MEAT-STARCH PRODUCTS

Starches had also been employed in extruded meat products. In general, the addition of modified potato starches resulted in increased moisture sorption properties of extruded meat matrix, due to the increased moisture-sorption capacity of modified starches that suffer a less intense retrogradation compared with other additives. Functional groups in modified starches prevent retrogradation through a strong water-binding and electrostatic repulsion by steric hindrance, preventing the re-association of potato starch chains (Jean *et al.* 1996; Ray *et al.* 1996; Ing-Jenq *et al.* 1997; Ioffe *et al.* 2002; Moraru *et al.* 2002).

OTHER POTATO PRODUCTS IN MEAT PRODUCTS

Other potato products had been employed in meat products. Dehydrated potato powder (composed of 85% starch) presented antioxidant properties reducing rancidity and improved cooking yield in ground beef patties (Katsanidis *et al.* 2001). From the potato flour processing, potato pulp from potato peels had been employed as an ingredient rich in fibre with a high hydration capacity in low-fat high-fibre sausages and patties. Sensory properties of patties with fat substituted by potato pulp were evaluated as being satisfactory, with no off-flavors detected owing to the potato pulp. The texture of these reduced-fat meat products was significantly affected by the water: fibre (potato pulp) ratio (Kaack and Pedersen 2005a, 2005b). Enzymatic extracted fibres form potato pulp with a low content of cellulose and lignin and a high content of soluble non-starch polysaccharides resulted in patties with a very delicious texture and flavour and values of the measured texture characteristics determined by texture profile analysis, as compared with dry potato pulp (Kaack *et al.* 2006).

POTATO STARCH FUNCTIONALITY IN MEAT SYSTEMS

The process conditions of this kind of product (a relatively high ionic strength, 2.5% ≈ 0.6 M NaCl, and thermal processing temperatures close to 72°C) are not the most adequate to allow starch granules to swell and completely gelatinize, mainly since for most native starches the swelling temperatures are higher than the maximum process temperature in the cooking of meat products (**Table 2**). In addition, the presence of salt modifies the pasting-gelatinizing properties of starch. Starch increased their onset and peak gelatinization temperatures at 2-5°C due to the presence of salt in starch/meat proteins composites, although for potato starch these increase in onset temperature by 1.4°C and peak temperature by 1.7°C (Li and Yeh 2003a). The increase in gelatinization temperatures by the presence of salt is due to the swelling of starch granules being repressed (Bello-Pérez and Paredes-López 1995). Potato starch is the most suitable starch to be used in a complex emulsified meat system due to its lower gelatinization temperatures. In the same way, modified potato starch exhibits higher salt tolerance than other potato starches, resulting in rapid water binding and increased moisture retention at 15 to 21°C, a temperature range at which meat proteins start to lose water. As a result, starch can be reduced by 25% in emulsified meat products (Anonymous 2008). Part of the differences in the suitability of modified (acetylated distarch phosphate) potato starch for use in meat sausages could be ascribed to differences in gelatination properties of the starches (Skrede 1989). Potato starch is a high swelling starch system absorbing more water via its hydrophilic nature due to phosphate groups covalently linked to amylpectin, and after gelatinization this high viscosity system reduces moisture migration (Zhang and Barbut 2005).

During the thermal process, the behavior of starch depends on temperature. Potato starch/meat protein composites have a similar rheological behavior below 55°C, but when the temperature is increased gelatinization of the system increases as well by melting or dissolving starch (with a peak gelatinization temperature of 66°C). After being cooked at 56°C, potato starch granules are embedded in either a coating on the peripheral surface of the protein network or trapped in the protein matrix. Meat proteins start to denaturate before starch gelatinization, enhancing composite gel strength, and since starch gelatinization is lower than the denaturation temperature of meat proteins, the result is a continuous matrix. Nonetheless, at 59°C, temperatures below the potato starch onset temperature (66.6°C), starch granules are embedded into a protein matrix. The gelatinized starch enhances the gel strength of this potato starch/meat protein composite, as indicated by a dramatic increase in gel strength. Below the maximum gelatization temperature, between 64 and 65°C, starch granules are deformed probably due to the shrinkage of the protein matrix during heating, and they lose their integrity with an increase in temperature. When the temperature is close to 70°C, similar to gelation of meat proteins, starch granules lose their integrity. Apparently, potato starch granules are too large to be trapped in the protein network. Potato starch granules have a wide size distribution with a wider average diameter (38.3 ± 21.9 µm) than corn or rice starch granules (17.8 ± 7.8 µm and 6.4 ± 4.6 µm, respectively); in addition, the shapes of starch granules are different due to botanical origin, with the gelatinized structure of different starches being indistinguishable. Briefly, gelatinized starch absorbs more water resulting in the reduction in cooking loss and increase in gel strength coinciding with the gelatinization of starch. The authors who made the above findings also could not find any evidence to demonstrate any interactions between protein and starch during heating (Li and Yeh 2002, 2003a, 2003b).

Thermodynamic incompatibility

As a macromolecule, starch has a thermodynamic incompatibility in food systems due to its chemical nature. This incompatibility is typical in biopolymers due to the large size of the macromolecules in addition to the low entropy related to the mixing process. Self-association, which is typical of amylopectin due to molecular mimicry (tendency to maximize chemical similarity of hydrophilic surfaces hidden within the hydrophobic interior explaining dense packaging of polysaccharide helices) and molecular symbiosis (additional thermodynamic principle acting in the direction opposite to molecular mimicry) is intensified in the presence of other macromolecules such as amylose. In the case of starch, even when the structural units of the corresponding monomer are co-soluble in aqueous media, the polysaccharides assembled from these sugars are usually incompatible when their polymer chains which differ in structure and/or composition. An example is the monomer glucose that is involved in the formation of amylose and amylopectin chains. Under typical seeds' conditions, native mixtures of highly concentrated amylose and amylopectin present in starch granules tend to self-associate, crystallize and are thermodynamically compatible forming transparent single-phase mixed solution. Nonetheless, when the starches are gelatinized in excess water, there are several differences between amylose and amylopectin biopolymers that would cause thermodynamic incompatibility between them. There are three main factors related to this thermodynamic incompatibility. First, the difference in the length and flexibility between amylose and amylopectin chains could prevent mutual recognition as being of the same chemical nature. Secondly, differences in the regularity of chains and their tendency to self-associate. Finally, the interactions of these chains with starch lipids create a complex increasing solubility and rigidity of both chains. These factors resulting in different properties of the starches depend on their botanical origin. Gelation of starch suspension is accompanied by a continuous increase in viscosity, produced by the continuous leakage, entanglement and association of amylose, in turn increase by the high local concentration and high excluded volume of amylopectin inside the swollen starch granule. Since the rate of leaching can be either greater or lesser than the rate of amylose retrogadation, amylose can retrograde either between or within the starch granule (Tolstoguzov 2003).

CONCLUDING REMARKS

When macromolecules such as starch are added to complex food systems as meat batters, these thermodynamic considerations acquire other significance since the meat systems conditions (pH, ionic strength and mainly process temperatures) seem to degenerate starch's functionality. The key factor that seems to rule the correct and decent functional performance of starch in meat systems could be the concentrations employed, since besides the regulation on the maximum amount allowed, the interaction of starch with other macromolecules or gums will permit the development of new and better-quality meat products with an ingredients formulation with an acceptable degree of functionality. Although chemical or physical modification of starch reduces the gelatinization temperature, potato native starch has an acceptable functionality under the conditions found in meat systems. Obviously, any modification of potato starch will enhance its functionality but the interaction of starch with other macromolecules still needs to be explored.

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