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PROCESSING EFFECTS ON MEAT PRODUCT MICROSTRUCTURE

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Abstract

Animal species, meat ingredient properties, comminution equipment, mechanical action, product composition, type and level of non-meat ingredients, and thermal processing greatly affect the structural and organoleptic properties of meat products. However, additional research in the area of restructured meat products, meat protein functionality and lipid properties in meat products remains to be done. The interaction of meat proteins with lipids, water and ions should be further investigated. Considerable control of raw materials, mechanical action and heat processing is essential to make research applicable to product and process development.

Introduction

Meat processing affects meat microstructure. However, meat processing is a very complex and diverse technology for modifying properties of meat to fulfill perceived needs of consumers. Meat products may be affected by properties of the meat, method of comminution, addition of ions, mechanical action, and thermal treatment. Meat products are sold either frozen, refrigerated or heat processed. The level of heat processing is minor for some dried products, more severe for pasteurized products and extensive for commercially sterile shelf-stable products. These factors have an effect on the microstructure, cook yield and rheological properties of the product.

The purpose of this paper is to depict the many properties of meat products that may affect microstructural characteristics. The review of literature is selective to prevent excessive length. Recommendations are presented for future work and precautions to be taken in designing experiments are offered.

Factors Relevant to Processed Meat Microstructure

Meat Source

Meats derived from many sources are processed for human consumption. The source and treatment of animal tissue prior to further processing affects many product characteristics, including microstructure. Beef, pork, poultry, fish, and lamb are the primary species used for processed products. These tissues can be fresh, aged, fresh frozen or mechanically deboned prior to use in processed meat products.

Products

The products produced are diverse in several traits. Meat may be utilized as intact muscles or comminuted to various extents (Huffman and Cordray, 1982). In some meat products various organs such as livers and hearts are included (Chyr et al., 1980; Ray et al. 1981). The degree of comminution has a great impact upon the microstructure of the finished product (Cross and Stanford, 1976; Costello et al., 1981). Addition of various ions, alteration of pH and degree of mechanical action will affect the level of disruption of tissue microstructure.

Mechanically separated chicken and turkey, including skin, is widely used to make processed, finely comminuted poultry products. The type of machine used as well as the properties

Key Words: Meat, emulsion, meat products, protein matrix, fat, microscopy.
of the poultry affect the chemical and structural properties of mechanically separated poultry meat (Baker et al., 1969; Angel et al., 1974). In Europe, pork skin is frequently included in meat products, but it is not widely utilized in the United States (Schut, 1978a, 1978b).

Tradition and consumer acceptance play important roles in determining the composition of various products. Certain hams and beef roasts contain little added water and less than five percent fat. Other meat products contain up to 20 percent added water or up to 70 percent fat. The wide disparity in chemical composition of various meat products indicates that research results from a specific experiment may be applicable to a relatively narrow group of products.

Heat treatment determines many of the ultimate properties of a meat product. Therefore it is often necessary to examine the product prior to and subsequent to heat application. The heat applied at the site of manufacture as well as the heat treatment applied by the consumer alters product properties.

Packaging itself affects appearance, yield and palatability of a meat product. Some products are processed in a metal mold or casing which is removed after heat processing and chilling. Product is then repackaged in a moisture and oxygen impermeable film. Other products may be processed in a heat stable film or metal can and sold directly to the consumer. The interaction between the package and the product may affect yield as well as the convenience that the consumer has in preparing the product for consumption.

Light microscopy can be used effectively to observe properties of packaging films. Ham (Fig. 1) and turkey breast (Fig. 2) are seen with their packaging films. Samples were embedded in paraffin, sectioned, deparaffinized with xylene, hydrated to water, fixed in picric acid, rinsed in water, and stained with Mayer's Hematoxylin for 15 min. at pH 3.4.

**Comminution**

Products are manufactured from whole meat cuts with or without subcutaneous fat. Other products have muscles removed whole and further sectioned into large portions to manufacture sectioned and formed products or sections are reduced in size by knife, dicer or grinder to be processed to produce chunked and formed products which have a texture similar to intact roast or steak. An alternative to grinding is flaking using a Comitrol. The method and extent of particle reduction as well as the sharpness of the machine parts can have an effect on the appearance of the particles as well as other properties (Chesney et al., 1978; Hermansson, 1980; Berry, 1980).

Extremely fine comminution is accomplished using a bowl chopper or an emulsion mill. These machines break down the fine structure of muscle and fat to create a homogeneous texture for a finished meat product such as a wiener or bologna. A scanning electron micrograph (Fig. 3) shows the presence of large fat globules and smaller fat droplets embedded in a protein matrix. This photo is similar to results shown by Bugail et al. (1983). Caution must be exercised in sample fracturing, glutaraldehyde fixation and osmium tetroxide fixation to prevent the formation of artifacts. In addition, samples should be processed fresh to prevent excessive contamination with bacteria which may be visualized on micrographs as spheres with diameters of approximately 1 μm. Bacteria are clearly seen in Fig. 4.

Fig. 5 is a transmission electron micrograph of a freeze fractured frankfurter. The sample was frozen in liquid Freon 12 at -150°C, fractured in a Balzer 301 unit, etched for 5 minutes at -100°C and coated with carbon-platinum to form a replica. The tissue was digested from the replica with chlorine bleach. The replica was examined with a Philips 400T operated at 80 kV.

The ability of machines to reduce particle size is highly dependent upon sharpness and setting of knives as well as temperature of product. The greatest amount of comminution, in the case of the bowl chopper, takes place with very sharp knives set in close tolerance to the bowl. In the mill, knives and plates must be very carefully sharpened and matched for maximum contact. One property that may be varied in a bowl chopper is whether vacuum is applied. Use of vacuum during comminution affects the ability of the knives to disrupt tissue microstructure. In addition, vacuum excludes air from the finished product. Absence of air produces a very dense product which has different textual and structural properties than if air were included (Solomon and Schmidt, 1980; Wiebe and Schmidt, 1982; Tantikarnjathep et al., 1983).

A treatment widely applied in Europe is to pre-emulsify fat and water with emulsifying protein prior to blending these materials into the final batter (Schmidt et al., 1982). In this case the fat, water and non-meat proteins such as dried milk, modified whey or soy proteins are utilized to form an emulsion in the bowl chopper. Salt is often included in the pre-emulsion to prevent spoilage. Non-meat proteins in a pre-emulsion bind water and fat during severe heat treatment needed for commercial sterility of canned products. In products which have little added fat and water this treatment may not be necessary.

**Mechanical Action**

Preblending is widely used to incorporate sodium nitrite, sodium chloride and water with some of the meat tissues for 24 to 48 hours prior to the manufacture of the final product (Acton and Saffle, 1969). Preblending gives meat time to combine extensively with added ions and water prior to final mechanical action. Connective tissue and sarclemma membranes inhibit movement of ions within meat. By allowing additional time after preblending for ions to equilibrate throughout tissue, the effect of ions on tissue is more homogeneous. Sodium chloride and sodium nitrite bind to meat proteins, but migrate through meat slowly which requires adequate time and mechanical action (Solomon et al., 1980).

Blending or mixing is widely used to disrupt tissue sufficiently to allow salt, nitrite and phosphates to interact with myofibrillar proteins at the molecular level. The combination of ionic strength, pH and mechanical action assist in disrupting the microstructure of meat tissue. This disrupted microstructure interacts with the ions to cause a swelling of meat tissue (Offer and Trinick, 1983). Swelled meat tissue has an enhanced ability to retain fat and water during heat processing.

If large sections of meat are to be cured and processed, mechanical action is applied by tumbler or massagers subsequent to injection of pickling containing water and ions. Injection is essential since ions will not migrate extensively throughout a large chunk of meat. Subsequently, tumbling and massaging disrupt internal structure of meat tissue allowing ion migration and enhancing water binding capacity (Theno et al., 1978b).
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Fig. 1. Light micrograph of commercially prepared ham. The bilayer plastic laminate package is designed to cohere to the product. The plastic film (F) coheres to the exudate (E) which surrounds muscle fibers (M). Bar = 1 mm.

Fig. 2. Light micrograph of commercially prepared turkey breast. The four layer plastic laminate package is designed not to cohere to the skin. The skin (S) is covered with a heat coagulated exudate (E). The plastic film (F) has been dislodged during preparation. Bar = 1 mm.

Fig. 3. Scanning electron micrograph of commercially prepared frankfurter. The sample was frozen in liquid nitrogen; fractured; fixed for 1 hour in 3% glutaraldehyde, 0.1 m phosphate buffer, pH 7.2; post-fixed for 14 hours in 1% osmium tetroxide, 0.1 m phosphate buffer, pH 7.2 at 4°C. The sample was dehydrated in acetone, critical point dried, sputter coated in a Hummer unit, and examined on a Philips 505 SEM. Large fat globules (F) and smaller fat droplets (S) are visible. Bar = 100 µm.

Fig. 4. Scanning electron micrograph of commercially prepared frankfurter. Sample was frozen in liquid Freon 12; fractured; fixed in 1% osmium tetroxide in ethanol at dry ice temperature, −56.6°C; critical point dried and sputter coated. Medium size fat globules (F) are visibly coated with some material. This product was stored for some time and bacteria (B) are visible as 1 µm spheres. Bar = 10 µm.
addition, abrasion of the surface of meat chunks produces an exudate of meat proteins. Upon heating, this exudate acts as a heat set gel to bind one meat particle to another (Theno et al., 1978a,c; Siegel and Schmidt, 1979b).

The proper combination of mechanical action, ionic environment, pH, and temperature are essential for maximum tissue swelling and heat gelling ability (Shults et al., 1972; Shults and Wierbicki, 1973; Siegel et al., 1978a; 1978b; Siegel and Schmidt, 1979a). An ionic strength of about 0.6, pH of 6.0 and temperature of less than 7°C contribute to maximizing protein extraction and subsequent heat set gel formation (Gillett et al., 1977; 1982; Trout and Schmidt, 1983).

Composition

The appearance and palatability of a meat product is greatly affected by the level and degree of saturation of the incorporated fat (Lee et al., 1981). Beef fat is often comminuted to 20°C during processing. Poultry fat may be processed successfully at or below 0°C. The amount of fat dispersion during comminution affects the ability of protein to retain the fat in the product during processing. The interaction of the levels of fat, myofibrillar protein, non-meat ingredients, (Kempston et al., 1982; Lauck, 1975) and the melting temperature of the fat all play an important role in flavor and texture of the finished product (Helmer and Saffle, 1963; Jones and Mandigo, 1982).

The major classes of proteins in meat are myofibrillar, stromal and sarcoplasmic. A number of model system studies investigating the fat binding ability of the three classes of meat proteins have been completed (Grabowska and Sikorski, 1976; Randall and Voisey, 1977; Samejima et al., 1969). Studies that do not include cooking of the emulsion are of questionable value. Myofibrillar proteins play a major role in entrapping fat and water in cooked meat products (Hansen, 1960; Borchert et al., 1967; Theno and Schmidt, 1978). The myosin molecules act to form a heat set matrix to entrap both water and fat (Tsai et al., 1972; Ishioroshi et al., 1979; 1980; Samejima et al., 1981). Little is known of the role of stromal and sarcoplasmic proteins in cooked meat products (Macfarlane et al., 1977). Heat breaks down the major stromal protein collagen to gelatin. If higher levels of collagenous material are utilized in meat products, pockets of gelatin are formed during cooking. This is especially true in high fat, finely comminuted meat products. However, little is known of the use of higher levels of stromal proteins in low fat meat products where the level of myofibrillar protein is more than sufficient for optimal fat and water binding.

Sarcoplasmic proteins do not form a rigid heat set gel at pH, ionic strength and temperature conditions generally used in processed meat. Upon heating, sarcoplasmic proteins tend to form a flocculent. However, sarcoplasmic proteins are important in contributing to the color, flavor and aroma of meat products.

Ions cause swelling of meat tissues during product preparation. Sodium chloride and alkaline phosphates at the proper level extract myofibrillar proteins from postmortem muscle. A lower ionic strength can be utilized in prerigor meat. If inadequate ionic strength and too low a pH is utilized, there will be a large cook loss of both fat and water during heat processing (Trout and Schmidt, 1983). In addition, the product will have a soft texture. A high ionic strength applied to lean meat during extensive mechanical action may result in excessive extraction of myofibrillar proteins. The resulting product will form a tough skin during heat processing and be rubbery in texture. Therefore, the optimization of product composition, mechanical action, ionic environment, and heat treatment are all necessary to produce a palatable meat product.

Little is known of the effect of levels of stromal proteins on optimizing meat product texture (Saffle, 1969; Puolanne and Ruusunen, 1981; Jones et al., 1982a,b). In low fat meat products it may be desirable to include additional stromal protein to substitute for reduced fat levels so as to inhibit the formation of a rubbery texture. Non-meat proteins function in finely chopped (Cassens et al., 1975; Schmidt et al., 1982), as well as sectioned and formed meat products (Siegel et al., 1979a; 1979b; 1979c).

Microstructure research in the area of stromal and non-meat proteins in meat products is certainly warranted.

Future Research

Other than the work of Swasdee et al. (1982), little research has centered on the role of cooking temperature on the texture and microstructure of meat products. Our laboratory is currently investigating the role of binders to cause meat particles to cohere prior to thermal processing. Restructured meat products must either be cooked or sold in the raw frozen state to prevent structural disruption. It would be useful to develop a binder that would bind meat particles together in the raw refrigerated state. As heat would be applied another binder could function to form a heat set gel to bind the cooked meat particles together. There is virtually no research on the role of non-meat binders in raw refrigerated meat products. Gelatin may be useful in this regard and there is some microstructure research in this area (Lewis, 1981).

Most research has been done on meat products cooked to about 80°C. As heat treatment becomes more severe (commercial sterilization) additional microstructure alteration takes place (Schmidt et al., 1982). The effect of heat on meat protein gelation has not been adequately investigated. Research in the area of thermal alteration of structure of myofibrillar, stromal and sarcoplasmic proteins is needed.

Dried sausage production is extensive in many parts of the world. Additional research is needed to understand the microstructural changes that take place during this process. The role of case hardening in blocking moisture release from products should be investigated. New techniques of understanding the microstructural changes in the product during drying could assist processors in more uniform drying of sausage products.

There are certain questions that must be asked before embarking on microstructure research of meat products. One of the most basic questions is whether one should work on a complete commercial product or isolate components and work on them in a model system. Both approaches are probably valid if caution is taken in interpreting results. It is important to understand that an isolated protein may not act the same in a product when it is interacting with physiological ions, other proteins, lipids and other biochemical constituents. There are many structural components of meat products that inhibit the free movement of ions within tissue. When model systems utilize purified proteins, these inhibitors to ionic movement are removed. It may be wise to utilize various isolated components and then do additional research by combining several of these components.
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Research should be performed in such a way as to subject the material being investigated to as many of the mechanical, ionic and thermal treatments as are anticipated in the manufacture of the finished product. Ionic environment should be investigated within the range utilized in the product. Mechanical energy should be applied in such a way as to mimic existing or anticipated blenders or comminutors.

Additional research is needed to develop methods to accurately identify components of processed meat products (Froning et al., 1970; Coomaraswamy and Flint, 1973; Cassens et al., 1975; 1977; Ray et al., 1979; Bagall et al., 1983). The localization of protein, lipid, water, and ions within meat products would be useful in determining functionality of these components. Transmission and scanning electron microscopy as well as light microscopy to accurately localize meat product components would assist in developing new products and optimizing composition of existing products.

Conclusions

Research of the microstructure of meat products must consider the diversity of meat products. Species of meat utilized, product produced, degree of comminution, application of mechanical energy, composition desired, and thermal treatment of the product affect basic properties of raw and finished material. Well designed factorial experiments should be utilized to determine basic effects as well as interactions. Basic research tools should be utilized to determine which treatment effects are compatible with industrial production practices. Basic research on the components of processed meat products is useful to produce background material for application in product testing. Integration of modern research tools to determine which factors affect meat product properties should be a continuing effort of researchers.

References


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Discussion with Reviewers

D.F. Lewis: In the “Mechanical Action” section, you mention . . . “The combination of ionic strength, pH . . . assist in disrupting the microstructure of meat tissue.” What combination of ionic strength, pH and temperature is optimal?

Author: A pH of 6.0; ionic strength of 0.6 with pyrophosphate present and heating from 65°C to 87°C are optimal.

D.F. Lewis: Are you sure sarcoplasmic proteins do not form a rigid heat-set gel?

Author: I have not observed this during my work at pH 5.0 to 7.0.

R.J. Carroll: What is severe heat treatment of pre-emulsion product as discussed under “Comminution”? How does the severe heat treatment help to improve binding of water and fat? What happens at lower temperatures?

Author: Since severe heat treatment for commercial sterility causes the greatest cook loss, lesser heat treatment would result in even less loss.

K.W. Jones: One of the basic problems with meat microstructural studies is the lack of accurate, quantifiable techniques. What's being done in this area?

Author: I know of no work in this area. In fact, a thorough understanding of distortion of material due to fixative techniques is not yet available.

K.W. Jones: Fred Ray and coworkers (see Ray et al., 1979) have developed a procedure for identifying fat in comminuted meat systems using serial sections and both SEM and LM procedures. How might other specific components (i.e., specific proteins) be identified on the SEM in meat systems without serial sectioning which may produce surface artifacts?

Author: The use of labeled antibodies specific to a protein may aid in their locations. Stains specific for collagen may be used in light microscopy.

K.W. Jones: What is being done in the area of fluorescence microscopy and specific fluorescence antibody stains in meat products?

Author: As mentioned in the answer to your last question, this is a possibility. However, I know of no research in this area on processed meat. Numerous references exist on the topic for fresh muscle.

F.K. Ray: Does sodium chloride and alkaline phosphates extract or solubilize myofibrillar proteins? I have heard this explained both ways.

Author: The combination of pH, ionic strength and phosphate type cause muscle tissue to swell. Mechanical action may be necessary to disrupt tissue sufficiently to cause protein solubility.

F.K. Ray: Is there an interaction between myosin and gelatin which affects the final bind strength of restructured meat products?

Author: I do not have any information on this. It is worth future research.

F.K. Ray: What is the difference between an emulsion and the final batter of processed meat?

Author: The final batter contains much more than emulsified fat. The heat set protein matrix binds emulsified fat, fat particles, connective tissue and water. The emulsion of fat may not be of much importance in cooked meat batters.