Chapter 4
Fiber

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Introduction

A United States Department of Agriculture (USDA) survey shows that the average American consumes only 15.4 g of dietary fiber per day (United States Department of Agriculture, Agricultural Research Service [USDA-ARS], 1997). Using a 2,500 cal per day diet as a reference, this is only 52% of the United States Food & Drug Administration's (FDA) Daily Reference Value for dietary fiber of 11.5 g of fiber per 1000 cal (Food and Drug Administration [FDA], 1999). Although a thorough discussion of the eating habits that led to this fiber "deficiency" is beyond the scope of this chapter, Cordain et al. (2005) identified seven nutritional characteristics, including a reduction in fiber consumption, that have changed over the course of time, in the human diet. These changes have occurred over time as society has shifted from a primarily hunter/gatherer base thru an agricultural period and into an industrialized era. The types of food we eat and the methods used to prepare and process these foods changed dramatically during this time. The increased use of refined sugars and starches along with finely milled flours has resulted in a decrease in fiber consumption compared to the diet of early man.

Throughout the years, fiber containing ingredients such as whole grains, flours, and bread crumbs have been used in a wide variety of food products, including processed meats. But it was not until the 1980s that consumer awareness of dietary fiber came to the forefront. In 1987, in response to increasing scientific data showing a link between diet and disease, the FDA initiated a change in its long standing policy barring health claims on food labels (Farley, 1993). This change ultimately culminated in the passage of the Nutrition Labeling and Education Act of 1990, which reaffirmed and defined the FDA's authority to regulate the health claims made on food labels.

This new marketing ability, however, did not completely transfer to meat products regulated by the USDA. The USDA has a long standing policy prohibiting nutrient fortification of meats (United States Department of Agriculture, Food Safety and Inspection Service [USDA-FSIS], 2005b). This policy has at its origin the FDA position that fortification of fresh produce, meat, and fish is not appropriate. Unlike meat producers in other areas of the world, American meat companies have not

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been able to incorporate fiber into their products for the purpose of nutrient fortification. They have, however, discovered that the functional properties of certain dietary fibers, such as increased water and fat absorption, can be used to improve the economic and quality profiles of meat products irrespective of fiber fortification.

Types of Dietary Fiber

Finding agreement between various scientific groups and regulatory agencies on a definition for dietary fiber has proven difficult. In a report submitted to the Board of Directors of the American Association of Cereal Chemists (AACC) (AACC International, 2001), the AACC Dietary Fiber Definition Committee defined dietary fiber as follows:

> Dietary fiber is the edible parts of plants and analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation. (p. 1)

As noted in the report, the difficulty in defining dietary fiber is finding a balance between the physiological effect of fiber and the analytical methods used to detect and quantify it in foods. Since the USDA prohibits fiber enrichment of meats, the details of the fiber definition are of limited importance to US meat producers. It is, however, possible to fortify meat products with fiber in other areas of the world. The more important consideration for the inclusion of fibers in meat products is an understanding of the functional attributes of the various available fiber sources. In order to better grasp the functional properties of dietary fiber it is helpful to categorize the fibers into groups. Historically, dietary fibers have been classified based on their relative solubility in water. Fibers that are composed primarily of cellulose, hemicellulose, and lignin, such as oat fiber and wheat bran, are primarily insoluble. Fibers that include substantial portions of gums, polyfructoses, pectins, and mucilages, such as psyllium, fruits, and oat bran contain significant fractions of soluble fiber. Within the categories of insoluble and soluble fiber it is also helpful to further classify the fiber ingredients as native or refined. This is a more subjective classification and refers to the level of processing or extraction the fibers undergo relative to their starting substrate.

Some common insoluble, native fiber sources used in food products include wheat bran and corn bran. These bran ingredients are produced through the dry milling of cereal grains. Although these fibers find wide use in items such as breakfast cereal and bakery products for fiber enrichment, their use as a functional ingredient in meat is limited. As shown in Table 4.1, the water and fat absorption of these ingredients is significantly lower compared to the more refined fibers. In addition to the reduced functional attributes, the native, insoluble fibers typically contribute flavor and color components of the raw substrate which may not be acceptable in

Table 4.1 Properties of various fibers

Type	Dietary fiber, % Total	Insoluble	Soluble	Water Absorption, %[a]	Oil Absorption, %[a]
Cellulose (300 μm)	95	95	<1	740	470
Cellulose (20 μm)	95	95	<1	350	210
Oat fiber (minimal extraction)	85	81	<5	350	240
Oat fiber (fully extracted)	93	90	<3	800	580
Wheat fiber	93	91	<3	830	600
Soy fiber(from hulls)	90	89	<1	300	200
Soy fiber (cotyledon)	70	62	8	1,000	280
Pea fiber (cotyledon)	70	65	5	1,100	300
Carrot fiber	85	65	20	1,500	300
Citrus fiber	88	68	20	2,000	290
Potato fiber	69	56	6	1,500	250
Sugar beet fiber	68	48	20	500	230

[a] Modified centrifuge method.

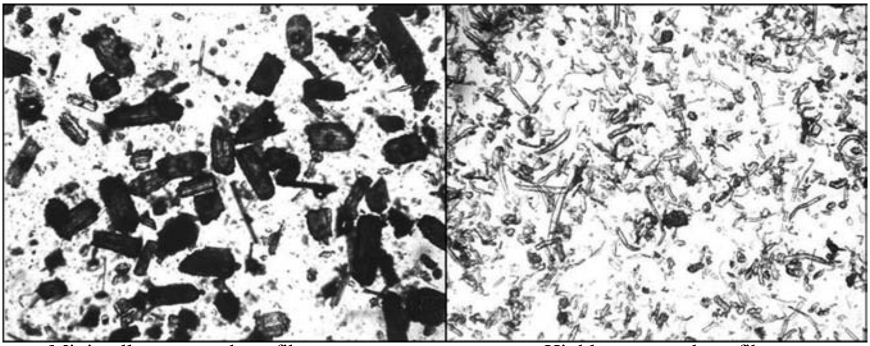
certain meat products. They can also impart a more gritty texture, owing primarily to the larger particle sizes available in commercial trade.

Powdered Cellulose

One of the first commercially available, insoluble, refined fibers was powdered cellulose. Cellulose, a glucose polymer, is one of the most abundant organic compounds on earth. It is the major structural component of green plants. To manufacture food grade powdered cellulose, organic plant material is cooked in a caustic solution, usually with sulfur compounds, at high temperatures and pressure. This hot caustic solution dissolves the lignin structure and other extractives which are then removed in subsequent filtering and washing steps. The resulting fibrous pulp is bleached to remove color, dried, and ground. Powdered cellulose can be produced from a number of raw material sources. As a result, the Food Chemicals Codex definition for powdered cellulose (Institute of Medicine, 2003) is not specific to a particular substrate. Any plant material which has been processed adequately to meet the purity and quality standards of the Codex can be labeled as powdered cellulose. Due to availability of supply and cost considerations, most powdered cellulose is sourced from either wood-, cotton-, or bamboo-based plant material. Commercially, powdered cellulose is available in a number of variations, the primary differences being fiber length. The absorption capability of the cellulose fiber is largely based on capillary action. The ability to absorb more or less water through the capillary action is at least partially dependent upon fiber length. Longer fibers tend to absorb more water than shorter fibers. In commercial trade water absorption is typically measured using a centrifuge-type method similar to that used to measure protein absorption. In the test, the fibers are over hydrated with water, centrifuged, and decanted. The mass of water held by the fiber after centrifugation divided by the mass of the starting fiber expressed as a percent of the starting fiber gives the absorption. While this method is useful for comparing the relative absorptions of various insoluble fibers, it is less useful for comparing fibers with high levels of soluble fiber or gel-forming properties. For oil absorption, the same methodology is used, only substituting vegetable oil in place of water. Powdered cellulose is available in fiber lengths ranging from less than 20 μm to over 500 μm. While the longer fibers can impart increased water absorbing capability to meat systems, they can also result in detrimental changes in texture, depending upon the usage level. In practice, the length and water absorption of the fiber must be balanced against the textural changes the fiber causes. Table 4.1 gives an example of the impact of fiber length on absorption. Powdered cellulose is bright white in color and very bland in taste. In addition to its use as an ingredient, cellulose has also been widely used for many years in the production of casings for sausage products. Powdered cellulose is listed in Food Safety and Inspection Service (FSIS) Directive 7120.1 (USDA-FSIS, 2007) as an approved ingredient for use in comminuted poultry, at a level not to exceed 3.5% in various nonstandardized products. Cellulose can also be further processed and modified to produce cellulose ethers such as carboxymethyl cellulose or methyl cellulose.

Oat Fiber

When considering oat fiber, it is important to differentiate between the dry-milled grain products such as oat bran or oat flour and the refined insoluble oat fiber extracted from oat hulls. The first commercial varieties of refined, insoluble oat fibers appeared on the market in the 1980s1987. In two US patents, Gould (1987) and Gould and Dexter (1987) describe an alkaline peroxide treatment of agricultural residues, including oat hulls, which yielded a higher absorbing insoluble fiber. Just a few years later, Ramaswamy (1991) patented the application of a process similar to soda pulping used in paper production to oat hulls, which resulted in a very high absorbing oat fiber product. Oat hulls had long been a low value by-product of the oat milling industry. Although oat hulls naturally have a high total dietary fiber content (75–80%), they also contain silica. This silica results in an abrasive mouthfeel and texture, which limits the use of oat hulls in food or meat products. In the above patents, the inventors both applied process conditions that partially (Gould) or fully (Ramaswamy) removed the lignin from the oat hulls. As the lignin is removed, the silica is also washed from the oat hulls, resulting in a fiber with a much softer texture. The extraction of the lignin also allows the individual cellulosic fiber strands to separate. This increases the surface area and allows the fibers to swell and absorb larger amounts of water. In the case of the Ramaswamy process, the high temperature and pressure removes most of the lignin and silica from the oat hulls. The rapid decompression process from the high pressure cooking also adds a mechanical shear action which further defibrillates the fiber strands, leading to absorption enhancement.



Minimally-extracted oat fiber Highly-extracted oat fiber

Fig. 4.1 Comparison of oat fiber structure at 100× magnification (courtesy of J. Rettenmaier & Söhne GmbH + Co KG, Rosenberg, Germany. Reprinted with permission)

Oat fiber absorption levels can range from 250% to over 800%, depending upon the level of extraction applied in the manufacturing process. Once the oat fiber is fully extracted, the absorption can be further manipulated through milling, as with powdered cellulose. Figure 4.1 gives an example of the structure differences between a minimally extracted and highly extracted oat fiber. Oat fiber is available in colors from light tan to white. The more extracted versions have very little taste. Oat fiber is listed as an ingredient in the FSIS *Food Standards and Labeling Policy Book* (USDA-FSIS, 2005a). In keeping with the USDA policy forbidding nutrient fortification of meat products, the handbook states that oat fiber should be labeled as "Isolated Oat Product" on meat products.

Wheat Fiber

The processes described for the production of powdered cellulose can also be applied to other agricultural materials. In Europe, an insoluble wheat fiber made from wheat straw has been widely used in meat products. This material is produced using a process identical to that used for powdered cellulose. The resultant wheat fiber has very similar characteristics to a fully extracted oat fiber. In fact, in most applications, wheat fiber and oat fiber can be used interchangeably with little formula alteration. Wheat fiber is bright white in color with very little taste. At present, wheat fiber is not listed as an approved ingredient for use in meats by the USDA. It is, however, allowed for use in certain meat products outside the USA.

Soy and Pea Fiber

Soybeans and peas are both legumes and have very similar properties relative to the fibers produced from them. In both cases there are two types of fiber available, either from the outer hulls or from the cotyledon portion. In the case of the hull-based fibers, these can range from simply a dry-milled material to a fully extracted material. A two-step process to produce a fiber from legume hulls has been described in a patent by Vail (1991). The extracted fibers of the pea and soy hulls are shorter and more cube-like rather than the long thread-like structures seen with oat and wheat fiber. As a result, the absorption characteristics of these materials tend to be lower. The cotyledon-based fibers are typically produced as a by-product of the protein extraction process. The cotyledon-based fibers generally have a higher level of soluble fibers, which can boost the water absorption capability, but they tend not to have the oil/fat-binding capability of the higher insoluble fraction varieties. The extracted versions of the legume hulls are white to off-white in color and carry very little flavor. The cotyledon and minimally extracted hull versions are tan/yellow to white in color and have a definite taste. In some cases, the taste profile may be significant enough to limit application of the material.

Carrot Fiber

Carrot fiber is a relatively new fiber to find application in meats. A recent US patent describes a process for producing a carrot fiber from the cuttings and peelings of carrots (Roney & Lang, 2003). This process uses benzoyl peroxide as bleaching agent to reduce color and flavor. The resulting fiber from this process is off-white in color and most of the typical carrot flavor has been removed. The high-water-absorption capability (1500%) of this fiber makes it useful for many meat applications, but like many mixtures of soluble and insoluble fibers, the oil absorption is relatively modest at 300%. Carrot fiber is listed in the FSIS *Food Standards and Labeling Policy Book* (USDA-FSIS, 2005a) and is approved for use in meat products in the USA. The specified labeling for carrot fiber in meat products would be as “isolated carrot product”.

Citrus and Fruit Fibers

There are a number of variations of citrus and fruit fibers available in the market. The source of these materials is usually the by-products of juice and pectin manufacturing. Fibers sourced from the juicing process, like apple pomace, tend to contribute significant color and flavor properties that can limit their application. Fibers derived from pectin manufacturing are normally higher in fiber content and more consistent in their nutritional profile. As seen in Table 4.1 the absorption of a citrus fiber is actually extremely high, likely based on the high soluble fiber content. An important consideration when formulating with citrus fibers is the taste profile. Some of these fibers have a very low pH which can cause an acidic/bitter taste when applied in meat products. Citrus fiber is not specifically listed in the FSIS *Food Standards and Labeling Policy Book* but would be covered under the vegetable extract guidelines.

Potato Fiber

Potato fiber is manufactured from the cuttings and peeling by-products of the potato processing industry. The cuttings and peelings are washed in a water solution, which may or may not include other extraction chemicals, to remove residual sugars and other solubles. The resulting fiber is a mixture of fiber and starch. It is interesting to note that potato fiber contains a portion (12%) of resistant starch. Resistant starch is the starch fraction that is resistant to digestion in the small intestine, but which is available for bacterial fermentation in the large intestine. In potatoes, the resistant starch is largely due to the high amylose starch content. The tightly bound nature of the amylose starch granule that provides the resistance to digestion also results in a low water absorption capability. In the case of the potato fiber, the low absorption nature of the resistant starch fraction is offset by the nonresistant starch content (16%). This results in a fiber with good water absorption capability (1500%), but relatively low oil binding capability (250%). The residual starch content should also be taken into consideration when formulating products as well. While in the initial cooking phase the gelatinization of the starch granules will increase viscosity and absorption, these granules can retrograde upon cooling and storage, leading to syneresis. Potato fiber is tan to off-white in color and has some residual potato flavor. The water-only-extracted potato fiber would meet the guidelines described in the FSIS *Food Standards and Labeling Policy Book* for "vegetable extract" and be labeled as "potato extract".

Sugar Beet Fiber

Sugar beet fiber is derived from the fibrous pulp remaining after the extraction of sucrose from sugar beets. During the sugar refining process, the beets are thinly sliced and washed to solubilize and remove the sugars. In the most common process, the leftover pulp is washed, dried, and milled to form sugar beet fiber. In other processes, more complicated washing steps, including the use of further extraction and bleaching chemicals, can be used. Sugar beet fiber has a high level of soluble fibers. The water absorption and oil absorption of sugar beet fiber is low compared to other fiber sources, limiting its use in meat product. Sugar beet fiber also has a flavor, best described as "earthy," which can also limit its application in food products. The color of sugar beet fiber ranges from tan/gray to off-white. Like potato fiber, sugar beet fiber would be labeled as "sugar beet extract" in meat products.

Soluble Fibers: Inulin and Hydrolyzed Oat Flour

The functionality and application of soluble fibers in meats encompasses a wide array of ingredients. Modified cellulose ethers like methylcellulose and carboxymethyl cellulose, along with hydrocolloid ingredients like xanthan and acacia, can also be considered soluble fibers under some definitions. Since a thorough review of hydrocolloids is beyond the scope of this chapter (see Chap. 3 for an in-depth discussion), the present discussion will be limited to those soluble fibers that are also typically used as fiber sources. Inulin is a soluble fiber extracted by a washing process from chicory roots. It contains both oligo and polysaccharides. The polymer is composed of fructose connected by β -(2,1) links and usually terminates with a glucose molecule. The degree of polymerization (chain length) ranges from 2 to about 60 (Orafti Active Food Ingredients, 2006b). The use of inulin in meat products has been especially focused on fat replacement. Inulin has the ability to form a stable gel network which can be used to mimic some textural properties of fat when applied to low-fat meat products. By substituting the inulin gel for fat processed meat applications, it is possible to achieve acceptable textural and sensory properties in low-fat products (Orafti Active Food Ingredients, 2006a). Inulin is a fine off-white to white powder with little flavor or odor and is listed in the FSIS *Food Standards and Labeling Policy Book* (USDA-FSIS, 2005a) as approved for use in meat products.

Another soluble fiber that has been used in meat products is hydrolyzed oat flour. In two US patents, Inglett (1991, 1992) describes a method for producing a hydrolyzed cereal flour with increased content of soluble fiber in the form of β -glucan. This product, developed by the USDA Research Labs in Peoria, IL, was licensed under the trade names "Oatrim" and "TrimChoice." β -Glucan is another glucose polymer (like cellulose) but soluble in nature, forming thick gels. β -Glucan is widely associated with its cholesterol-lowering benefits. The FDA currently permits a "reduced risk of coronary heart disease" health claim for food products which contain soluble fiber from oats at a level of at least 0.75 g per serving. In addition to its use as a soluble fiber supplement, hydrolyzed cereal flours are also useful in meat applications for water absorption and their impact on texture. In particular, the gel-forming capability of the hydrolyzed cereal flours can be used to mimic the textural properties of fat in meat products. A 1994 US patent (Jenkins & Wild, 1994) describes a food composition comprising hydrolyzed cereal flour, a hydrocolloid, and a comminuted meat product. The patent further points out that the high-water-binding and gel-forming characteristics of hydrolyzed cereal flour, when used alone, contribute to a weak or mushy texture. In fact this effect is seen when applying many of the very high absorbing fibers previously discussed. Hydrolyzed oat flour is listed in the FSIS *Food Standards and Labeling Policy Book* (USDA-FSIS, 2005a) and must be labeled as "hydrolyzed oat flour."

Colloidal Fibers

Like the soluble fiber β -glucan, mentioned above, colloidal fibers also form gels. In this case, however, the gel is not due to soluble fiber, but to the formation of a colloidal dispersion of very small insoluble fibers. When insoluble fibers are wet-milled to an extremely small fiber diameter, they can form a stable thixotropic gel. As early as 1961, Battista, Hill, and Smith (1961), in a US patent, describe a method for producing an insoluble gel from microcrystalline cellulose. In that case, hydrolyzed cellulose was subjected to shearing in a blender, forming a stable gel. It is also possible to produce this fibrous gel via microbial fermentation. The technology for this type of material, called Cellulon, was developed by the Weyerhauser Company using *Acetobacter xylinum* (Deis, 1997). The small microreticulated fibers form an extremely stable gel which exhibit reversible shear thinning. The wet milling technology used to produce insoluble fiber gels can be applied to a number of substrates, including oat fiber, wheat fiber, cellulose, and corn bran. From a logistics point of view it is impractical to ship and store these very high water content gels. As a result, the gels are normally dried for commercial sale. In these cases it is necessary to include a dispersing agent (e.g., hydrocolloid, protein, polysaccharide, etc.) to coat the fibers and prevent re-agglomeration upon drying. Although high shear is still necessary to re-activate the colloidal gel, the coating reduces the needed activation force. Activation in a high-shear mixer or bowl chopper is usually adequate to re-form the gel. These colloidal gels exhibit many of the same fat replacement properties seen with the soluble fibers, including smooth texture and water-holding capability. Approval for use in meats of the colloidal gel products would be dependent upon, and the same as, the fiber substrate from which they were derived.

Application of Fibers in Meat Products

As previously noted, the existing group of commercially available dietary fiber concentrates display an incredible variation in functionality. In nature they play a role as structural components and aid in the binding or transport of water. These characteristics, along with fat binding and functionality as a fat mimetic, offer interesting concepts for the food industry. Ongoing economic pressure forces meat processors to look for reliable solutions to produce competitive, high-quality, products. This also opens the door for an economic-driven use for most of the fiber concentrates.

During the last 20 years, articles have been published covering low-fat meat products using different fiber types to increase water dosages. In these investigations, the technological and functional diversity of the fiber types has been only partially highlighted. Comparing three existing studies (Aleson-Carbonell, Fernández-López, Pérez-Alvarez, & Kuri, 2005; Chang & Carpenter, 1997;

Steenblock, Sebranek, Olson, & Love, 2001), totally different systems have been utilized for the commonly described "oat fiber." With dissimilar fiber extraction levels, variations in water and/or fat binding impacted the results. While two of these research groups applied a traditionally produced bran, Aleson-Carbonell et al. (2005) utilized oat bran containing higher β -glucan content to push the health aspects of the soluble fiber fraction. From a nutritional point of view it was a noble intent, but the low fiber content in oat bran makes it very difficult to reach adequate nutritive fiber levels without serious detrimental effects on the product's organoleptic properties. Another crucial attribute is the fiber particle size. Chang and Carpenter (1997) found that graininess was more detectable and juiciness was reduced with increasing bran dosage. An option to handle this organoleptic challenge was to increase water dosage. However, too large of an increase could exceed some regulatory limits. Much like the in the USA, in Germany, for example, when legal limits are exceeded, the additional water has to be labeled in the ingredient list. As discussed earlier, low/no extraction fibers such as oat bran usually have limited water-holding capacity. Increasing the water dosage to compensate for the missing fat will be evident as purge in the package. Furthermore, the gritty mouthfeel is a real problem. Large particle sizes with rough edges do not fit into low-fat systems, where the reduced fat content amplifies sandiness. Comparable results were obtained by Claus and Hunt (1991). In low-fat, high added-water bologna trials, they observed that 40 mesh (425 μm) sugar beet pulp fiber attained an unpleasant profile in graininess, whereas, by comparison, a highly extracted oat fiber at 3.5% dosage scored very close to the control product. Their final recommendation was a defined particle size reduction

In recent decades fiber manufacturers have offered new tailor-made products for processed meat applications, and have promoted additional health benefits. When defining grain fibers the extraction level is vital. Studies by Steenblock et al. (2001) and Claus and Hunt (1991) cast a first light on this topic. Steenblock et al. (2001) chose two varieties of oat fibers reflecting different processing levels. More recent research has proven that highly extracted, long-chain cellulosic fibers offer increased functionality for processed meat.

The broad range of nutritionally important fibers offers additional health concepts to the meat industry. The diet of the Western world suffers from a distinct lack of dietary fibers, and processed meats could be a vehicle for increased consumption. Public awareness of the benefits of fiber is continuously growing and many marketing concepts in other food applications are using this strategy to boost consumer acceptance. US and Canadian meat regulations inhibit this concept, while health-oriented meat products are being actively marketed in Europe and South America. Over the last two years several German meat products marketed as "enriched with fibers" and "rich in fibers" have been launched. For success of these products, taste and organoleptic properties are crucial. Customers are not willing to change their traditional quality expectations and a comparable price level has to be achieved. Marketing concepts based on digestive health and protection against colon cancer are examples of the way fibers can be applied to take advantage of their prebiotic effect (i.e., improvement of the microbial flora in the large intestine).

Besides the nutritive aspects of fat reduction or fiber enrichment, the second model is driven by economics. High water binding and significant water retention can help decrease cooking losses or purge in vacuum packages. Further benefits can be obtained from the structural characteristics of the fiber. Improved meat product quality reflects an optimized bite, texture, springiness, hardness, or snap. An understanding of the overall technological model of fiber incorporation can be constructive in order to maintain the standard properties of the product, even with a reduction in the quality of the starting meat block. The fiber portfolio offers concentrates with overlapping functionalities, diverse production processes, numerous raw material sources, and unique chemical compositions.

Fiber Application Goals

With product options continuing to grow, it is vital to understand the functionality of the various fiber sources. There is no standard recommendation. The conceptual possibilities cover a wide range of nutritional, technological, economical, and marketing aspects. Table 4.2 summarizes the most important physical and chemical aspects of fibers used in meat products.

One single fiber is not able to provide all possible features, but new progressive strategies combine the unique characteristics of different fibers. In a recent review article on the use of fat replacers in meat products, Tokusoglu and Ünal (2003) stated that "to obtain any reformulated processed meat with desirable characteristics, several of the available technological aspects have to be combined." In the last five years numerous German processed meat products have been launched containing two different fiber sources. These fat-reduced products offer combinations of soluble and insoluble fibers and offer a combined fiber content of 3–6%.

The German Federal Research Centre for Nutrition and Food (BfEL), located in Kulmbach, developed comprehensive analytical concepts to evaluate the total and singular fiber content. Münch (2006) analyzed inulin with an enzymatic method and insoluble fiber with a gravimetric procedure. In the detection of the total and single fiber content, inulin interfered with the overall results. Reality shows there is still a need to improve the analytical methodology used to quantify the different sources of fibers in all kinds of foods. Analytical results are also influenced by the different ratios of protein, fat, and carbohydrates, as pointed out by Hadorn, Piccinali, and Suter (2007).

Regional Meat Quality

With the growing use of mechanically deboned meat (MDM) or mechanically separated chicken meat (MSCM), products reveal different textural and structural

Table 4.2 Overview of fiber grades commonly used in processed meats

	Grain (oat & wheat)	Potato	Pea	Citrus	Inulin	Soy	Sugar beet	Carrot
Price	$$	$$	$$	$$$$	$$$	$$	$$	$$
WBC[a]	1: 11	1:15	1:3 – 1:12	1:20	1:4	1:3	1:4	1:18
Fat binding	1:8		1:3	Low	–	Low	Low	1:4
Fiber length	>500 µm			<250 µm	DP 2–60	>80 µm		15–160 µm
Particle size		> 4 mm	70–300 µm				32 µm–2 mm	
Flowability	+/–	++	++	++	++	++	++	++
Taste/Flavor	Neutral	Sweet/potato flavor	Neutral to mild pea flavor	Neutral	Slightly sweet	Neutral	Off-taste	Sweet
Composition	Cellulose, hemicellu-lose, lignin	Cellulose, hemicel-lulose, pectin, resistant starch, protein	Cellulose, hemi-cellulose, resistant starch, starch, protein	Cellulose, hemicel-lulose, pectin	Oligo- and polysac-charides	Cellulose, hemicellu-lose, lignin	Hemicellulose, pectin, cel-lulose, lignin, protein, sugar	Cellulose, pectin, protein
Insoluble fiber	90	60	80	70		90	50	78
Soluble fiber	5	14	2	20	97	2	24	14
pH value	6.0–8.0	5.0–7.0	4.0–7.0	3.5–4.5	5.0–7.0	6.5–7.5		4.5–5.5
Extraction	Very high	Mid	Low to mid	Very high	High	Low	Low	Mid
Color	White to Off-white	Brownish	Green gray to bright	White	White	White	Brownish	Off-white

[a] WBC: water-binding capacity.

properties. In markets like the USA, MSCM is often used in low-fat comminuted meat products (i.e., bologna and frankfurters). MDM can also be found nowadays in dry sausages. When using MDM, manufacturers have to address its negative effects on final cooked product texture (soft or "mushy" texture), fluid loss during storage (purge), and reduced palatability (marginal taste). As a result of the mechanical deboning and storage process, the primary MDM meat protein, myosin, loses some of its ability to bind water and has reduced interaction with the myosin from the other lean meat trimmings used in the product, resulting in inferior texture. The incorporation of some fiber sources offers an alternative to recover product texture, resulting in an improved bite or snap, and fit into the economical concept. The best performing fibers for structural enhancement are primarily cellulosic, such as potato, wheat, oat, or citrus. In contrast, inulin, with its short-chained molecule dimension, is not able to improve the texture. A number of insoluble fibers are limited by particle size and structure. Higher dosages could result in a grainy or rough mouthfeel, while the highly refined cellulosic structure from citrus fiber contributes a hard texture without sandiness.

Allergenicity and GMO

In a world of growing numbers of food-related diseases consumers are becoming increasingly concerned with the status of ingredients in processed food. The new European legal standards for labeling intend to inform consumers about potential allergens. To avoid a negative image and to reach the widest possible range of potential consumers, manufacturers are attempting to substitute relevant ingredients. The needed recipe modification can be a technological and economical challenge. The properties of these allergenic ingredients cover a wide range of functionality, including water binding, fat holding, or textural improvement. Extracted fiber concentrates can be used in the replacement of some allergen-containing ingredients. Based on the raw material selection and the severity of the extraction process, many refined fiber concentrates have allergen-free status. Even with wheat fiber, where gluten is a concern, ELISA (enzyme-linked immunosorbent assay) analysis has shown this material to be gluten-free. A Scandinavian processed meat producer labeled "wheat fiber (gluten free)" in the ingredient list of a ground meat product.

In recent years the media has documented increased anxiety and concern regarding the topic of gene modification. Especially, in Europe, and increasingly in North America, food producers and consumers are trying to avoid genetically modified ingredients. Even when soy fiber producers can prove their GMO-free status by using certified GMO-free raw material, markets like central Europe are resistant to accept soy-related products. A different situation is seen in regions like Eastern Europe and South America. The long-term use of soy isolates, concentrates, and texturized vegetable proteins has resulted in an advantage point for this type of fiber.

Nutritive Fiber Usage

Fiber Enrichment

The market for fiber-enriched food is fairly large. Although the bakery and cereal industries have been the traditional platforms in this area, the development of extracted and refined fiber concentrates has opened the door for new food applications. Based on tradition and geographic preferences, research scientists and producers have focused on distinctive product types. The European market has developed products with fibers from wheat, potato, inulin, pea, and other sources, while the US market has shown a preference for oat sources and, in a few products, isolated carrot.

When discussing fiber applications in meat worldwide, it will become obvious that the regulatory and labeling requirements are not consistent. In the European market the high-fiber dosages required in the Codex Alimentarius for a fiber claim are not easy to achieve. Furthermore, the properties of different fibers have to be reconciled with consumer expectations. High-fiber inclusions are easier to handle in coarser, structured ground meat products than in finer emulsions. Often the structure and dimensions of the particle limit the possible dosage and the range of processed meat products to which it can be added. Combined fiber concentrates – soluble and insoluble – are very effective for achieving Codex requirements. A different model could involve the use of a rounder structure, like in sugar cane fiber or soluble fibers, offering a smearing effect. While insoluble fibers struggle with organoleptic limitations, many soluble fibers display restrictive digestive tolerance. With low water binding, a bland taste profile, and small particle size, inulin would be an ideal solution with minimal technological difficulties. A limiting factor is its potential digestive side-effects. At high concentrations there would be, in addition, the possibility to claim both prebiotic benefits and improved calcium uptake, but many consumers would complain about flatulence and abdominal pain. Some studies have already involved this combination strategy. In dry sausage studies, Mueller (2006) used both inulin and wheat fiber to limit the negative properties of each. He was able to add 3%, and even 6% (on a dried finished product basis), and meet the WHO recommended combination of soluble and insoluble fibers. In Hadorn et al. (2007) and Münch (2006) a comparable strategy can be found. Comparable processed meat products can be found in the German and Swiss markets. In the US market, fiber enrichment of meats is not possible due to USDA regulations. In Canada only a few refined fibers, specifically those approved under the novel fiber regulations, are allowed to be used for fiber and calorie claims (Canadian Food Inspection Agency, 2007).

Fat Reduction

Fat reduction in processed meats is another area where the functional properties of fibers can make important nutritional contributions. Commercial low-fat products can be found in the USA, Germany, Switzerland, and Scandinavia. Because fat is not just a simple caloric filler hidden in a protein matrix, a fat replacement strategy for processed meats must address the diverse influence of fat on structure, texture, and mouthfeel. Since the addition of a single fiber cannot solve the problem, combinations of fibers and other ingredients with unique and complementary properties may be used in order to take advantage of synergistic effects, in terms of water binding, creaminess, and structure.

Fibers from different sources exhibit varying degrees of water binding and holding. Based on fiber content and structure, citrus and wheat fiber display the highest water absorption and inulin the lowest. Potato and pea fiber show high values, due to their significant starch and protein content. A disadvantage of this digestible carbohydrate content is recrystallization and, consequently, water leakage in vacuum-packaged products. In addition to water binding and juiciness, other essential quality factors are graininess, springiness, hardness, and cohesiveness. Chang and Carpenter (1997) showed that insoluble fibers, like bran, and added water have complementary effects on springiness, hardness, and cohesiveness of frankfurters. However, large fiber particle sizes and increased dose levels led to increased graininess. Since the early 1990s, several new fiber ingredients with better organoleptic properties than bran have been launched. Nevertheless, sandiness is still an issue for several cellulosic fibers. Dose levels up to 1.5% are generally possible without creating sandiness. Customized milling and advanced lignin extraction can also improve the organoleptic profile of cellulosic fibers. In the case of citrus fiber, the cellulose and pectin combination, combined with a high-extraction production process, creates a nice round mouthfeel, but high price and low pH values limit its usage level. The combination of cellulosic fibers with a low dose of psyllium is a good option. Psyllium's extremely high-water-binding and gel properties could aid in overcoming the sandiness of cellulosic fibers. Higher psyllium dosages are a challenge, since further water binding continues to occur during storage. This makes it difficult to control the texture and structure of the processed meat product throughout its storage life. A second disadvantage of psyllium is that it melts during reheating and releases a brownish, slimy purge.

In the European processed meat industry inulin has captured much attention. Based on the market growth of prebiotic dairy products, customers have become aware of inulin's nutritional benefits. Long-chained inulin in water under high-shear forces can create a particle gel (Jánváry, 2006) that contributes a smooth mouthfeel that resembles the characteristics of fat. With inulin, two usage scenarios are possible: Preactivation in water or addition at the beginning of the bowl chopper process. When working with crystalline inulin, 24 h are required for complete gelling. In a comparison of fat replacers with a 24 h swelling activation modus, maltodextrin and inulin were used in 10%-fat frankfurters, with both resulting in a white exudate in vacuum-packaged product (Orafti Active Food Ingredients, 2006a). The water-holding capacity of inulin and maltodextrin was not strong enough to immobilize the water for the duration of shelf life. Based on its molecular weight and particle size, inulin responds to the osmotic pressure and migrates from the meat batter into the purge. To avoid this scenario, lower doses of inulin in combination with other high-water-holding fibers can be applied. Commercially, products in the German market have been launched with combinations of inulin and wheat or citrus fiber. A second reason to use lower levels of inulin has to do with digestive tolerance problems (consumption of inulin at levels higher than 4 g per serving can lead to the formation of unpleasant amounts of gas). Hadorn et al. (2007) tested a combination of inulin and wheat fiber in boiled sausages to control both problems. An even higher dose of wheat fiber in this study could be possible since, at a 1% level, no roughness in mouthfeel was noted. The functional benefit of an insoluble fiber would improve the sausage quality. In this test, sliceability was improved by the addition of the long, insoluble wheat fiber.

Combinations of fibers with hydrocolloids also offer a potential solution for low-fat meats (Tokusoglu & Ünal, 2003). A commercial product line introduced in Europe takes this approach. It utilizes a patented (Christensen & Mogensen, 1995) combination of ingredients (modified or native starches plus dietary fibers) and a defined preparation process. An example of this product line, shown in Fig. 4.2, uses a combination of fiber, starch, and carrageenan.

Fig. 4.2 The *Den Grønne Slagter* product line contains 3% fat and relies on a combination of modified starch, potato fiber, and carrageenan. Ingredient line for product Jægerpølse (shown in figure): Lean pork meat (52%), water, *modified gluten-free starch*, salt, *potato fiber*, acid regulating component (sodium lactate), stabilizer (*carrageenan*), spring onion, antioxidant (sodium ascorbate), garlic extract, dextrose, spice extracts, glucose syrup, preservatives (sodium nitrite) (courtesy of Tulip Food Company, Randers, Denmark. Reproduced with permission).

Nutritionally Enhanced Processed Meat Products

Nutritionally functional food concepts have been considered for some time. Consumer demand for these products has been increasing, spurring new and more creative developments. Based on their technological functionality and nutritional benefits, fibers can be used, either alone or in combination with other ingredients, for fiber enrichment, as sources of prebiotic fiber, to improve calcium uptake, to reduce fat, saturated fat, and/or cholesterol, to reduce salt or phosphate, and to enable the use of plant oils rich in omega three fatty acids. Unfortunately, current US regulations limit health claims in processed meats, thus limiting the potential application of fibers primarily to fat and cost reduction. The European market, however, has already seen the launch of several of these more advanced concepts, with fat reduction, as well as fiber enrichment and other benefits.

These functional food concepts include a wide range of ideas, where the nutritive as well as the technological properties of fibers are very useful. Two of these strategies highlight the idea of replacing or reducing added salt or phosphates. The current impetus to reduce sodium levels across processed foods poses a particular challenge for the meat industry, given the key functional role of salt in meat systems, as it relates to protein solubilization and water binding (Chap. 1). Because of the peculiar challenge this poses, many different approaches to reduce sodium in processed meats have been attempted. The use of high-water-binding fiber concentrates constitutes one more tool to address this important issue. A comparable strategy can be discussed in processed meats for phosphate reduction. Due to concerns that the modern human diet contains excessive amounts of phosphorus, attempts have been made to replace phosphates in meat products. Unlike phosphates, fibers are not able to work at the molecular level on the actin–myosin complex, but their high ability to bind water and improve texture can help achieve partial phosphate replacement in different types of processed meats.

In addition to aiding in fat replacement and calorie reduction, some soluble fibers have the ability to bind bile acids in the small intestine, thus blocking their recycling through the ileal mucosa and forcing their excretion in the stool. The body is, consequently, forced to consume more cholesterol to regenerate the lost bile acids. As in the previously mentioned German product, animal fat may be partially or totally replaced by more polyunsaturated vegetable oil. In these instances, insoluble fibers may help stabilize the product batter and avoid fatting out. To achieve the best fat binding, these fibers could be premixed with the oil. The recipe below demonstrates a German "healthy" cooked poultry sausage concept developed by the company J. Rettenmaier und Söhne. It illustrates the combined use of soluble and insoluble fibers, poultry white meat, carbonate as a cutter process aid, and vegetable fat.

The second German recipe, a 65% fat-reduced Wiener sausage with a 65% fat reduction, contains 10% fat and enough fiber to permit the use of the claim "source of dietary fiber," based on the requirements of the Codex Alimentarius (Codex Alimentarius Commission, 2007). For fat replacement, two different concepts are possible. The first option involves the use of a combination of different fibers to

Wellness concept poultry boiled sausage (Lyoner type)	
Ingredients	%
Poultry meat	48.30
Rape seed oil	22.75
Water/ice	28.95
Wheat fiber	1.8[a]
Inulin	1.5[a]

[a] Calculated on meat block basis.

avoid the labeling of *E* numbers, while the second option takes advantage of the functionality of cellulose gum and colloidal microcrystalline cellulose. With either application, high-shear force equipment is essential to open the co-processed particle structure and achieve the needed dispersion. Preactivation of the fiber alone with shear could be done, but it is also possible to achieve the same result by adding the fiber blend at the beginning of the chopper step. The mechanical shear in the bowl chopper is normally adequate to fully activate the gel from the inulin or colloidal microcrystalline cellulose. The activated fat replacer exhibits thixotropic behavior, and resembles the mouthfeel of fat and provides juiciness.

Wiener sausage – 65% fat-reduced (10% fat) and dietary fiber-enriched (3%)	
Ingredients	%
Beef trimming 80/20	15
Pork trimmings 80/20	44
Pork fat	9
Pork back fat	3
Water	29
Oat fiber	1.2[a]
Fat replacer	1.4[a]
Inulin	0.4[a]

[a] Calculated on meat block basis.

Process Implementation of Fibers

Most fiber concentrates have a strong tendency to bind and hold water, which allows them to influence, or even modify, production parameters. Regardless of the manufacturing equipment used, the following must be considered and controlled: fiber hydration time, fiber dispersion in the meat batter based on mixing or comminution time, handling or timing during production, protein solubilization, batter extensibility, batter viscosity, temperature control, emulsion stability, cooking and smoking yields, and peelability. In the case of high-water-binding and holding fibers, an adequate fiber:water ratio is crucial to sufficiently hydrate the batter components; otherwise the meat matrix could be too dry and its process temperature could rise faster than expected. In low-water environments, the stickiness of soluble fibers, like pectin, could make it difficult to disperse them since they show a strong tendency to lump. Some fibers or fiber systems require a pretreatment, usually with shear, to achieve their full technological potential.

Wherever fibers are added in the process, it is critical that they be well dispersed in order to gain maximum technological benefit. Fibers can be added either in combination with other ingredients or functional seasoning compounds, or in a single step at the beginning or end of comminution or mixing. The process timeline may need to be adjusted based on physical energy input from the blender, cutter, or the brine agitation. Another consideration is whether the process is continuous or in batches.

In most production scenarios the fibers are combined with the seasoning blend or the other dry ingredients. When combined with the other dry ingredients, the fibers will compete for water in the system. It is important that all formulation constituents be adequately hydrated. Due to differences in water affinity and fiber structure which can affect the timing of water uptake, diverse technologies or adaptations have to be considered. Pure cellulosic fibers absorb water very fast without the need for special processing. Mixed fiber/starch systems, like potato or pea fiber, require heating to gelatinize the starch fractions. Long and thin fiber versions, like wheat and oat fiber, have to be thoroughly dispersed during the mixing and/or comminution steps in order to set up a network-like system. In this system, fibers are able to create a drainage system, holding and dispersing the water in the meat system. Inulin can be handled as a dry powder with a 24 h set-up time or as a preactivated paste. At higher concentrations (20–25% solution) the long inulin molecules create a particle gel that mimics fat. This solution incubated overnight in a cooling chamber will result in a heat- and shear-resistant paste. Psyllium husk fiber has extraordinary water-holding ability but needs hours to reach full hydration. During this time, the dry powder is transformed into a system that exhibits plastic rheological behavior. The dry powder has a tendency to stick, so care must be taken during mixing. Good preblending with other dry ingredients is necessary in order to ensure that the material is sufficiently dispersed in the meat batter. Under high-shear forces, the water binding of highly extracted citrus fiber increases and the fiber thickens into a creamy paste.

When using blender or mixer systems, fibers should be added early in the process to allow maximum hydration. During the initial grinding step, a reduction in the size of the meat pieces and a first release of soluble protein take place. After transferring the ground meat into the mixer, protein solubilization increases by the mechanical forces of the rotating shaft. In order for the fibers to form a well-dispersed fiber network, they should be added early in the process, before batter viscosity increases dramatically.

At higher fiber dosages, sufficient water for hydration has to be taken into consideration. An improper fiber:water ratio can have a negative influence on batter viscosity, as insufficient water could result in a very viscous, dry, and dense batter. With more friction in between batter and mixing tools, a faster temperature rise is to be expected. An additional consequence of this scenario could also be an insufficient dispersion of fibers. The worst case would be a sandy mouthfeel based on fiber agglomerates and an uneven water distribution in the meat batter. To avoid this, the addition of sufficient extra water or water/ice is recommended, as is a combination of different fiber types. The prehydration of the fibers would be an extra step in production which is not necessary in most cases.

In comparison to blenders, the high-shear forces from a bowl cutter enable different production schemes, including fiber addition at a later stage of comminution. This flexibility makes it possible to achieve different technological aspects and enables the use of colloidal fiber products as fat replacers. However, during comminution and mixing, the friction of the knives causes a gradual increase in batter temperature, which is controlled by using combinations of water and ice or nitrogen. If temperature control is inadequate, viscosity-increasing ingredients like starch or fibers should be added in the last third of the process. High-water-absorbing concentrates, like citrus fiber, must be handled with care. If added too early in the process, the fiber will bind all the available water and disturb the emulsification process.

When using a bowl chopper, the high-absorption fibers can modify the appearance of the batter obtained during and at the end of the process. During or after chopping, the surface of products which contain phosphate as a cutting processing aid are glossy and the emulsion displays a long structure with good extensibility. When a high-absorption fiber is applied, the free water on the surface is reduced and the meat batter that results is not as glossy and has a shorter texture.

Premixes and Compound Mixes

Fiber concentrates vary greatly in terms of particle size, bulk density, flowability, ability to lump, and dusting. Since many meat processors often work with premixes or automatic dosage systems, these characteristics need to be considered in order to avoid stratification and separation during handling and storage.

Table 4.1 gives a good overview of the particle size and shapes of the existing fibers. The sizes range from a very fine powder (e.g., inulin) to particles of up to 2 mm in diameter (e.g., potato fiber). Depending on their extraction level, cellulosic fibers from wheat and oat have a length up to 500 μm. All powders show good flowability and are easy to mix. Fine powders or fibers have a great tendency to generate dusting. Many fiber manufacturers have produced low dust versions of their fibers by the addition of very small amounts of food grade oils or lecithin. These oils bind the very fine particles and prevent dust during handling. These oils are applied at very low levels and have no impact on fiber functionality. A second option would be granulation through compaction. For most applications, however, compaction granulation is not recommended, as the agglomerated particles formed by this process can greatly increase the hydration time of the fibers. Any remaining agglomerated particles that are not fully hydrated could also lead to textural problems.

Specific Product Applications

Cooked Sausages

There is a large variety of processed meat products worldwide. Despite the use of common labeling names (e.g., frankfurter), products with vastly different formulations and concepts have been launched based on historical and economical distinctions. Below, three different recipes, from Germany, Mexico, and Russia, are given, all of which represent one product commonly described as *Wiener*.

In higher meat quality markets like Germany, the conceptual fiber strategy highlights fiber enrichment, fat reduction and, of course, cost control. High quality meat cuts in the formulation guarantee a stable emulsion and, consequently, a finished product with strong bite, expected snap and superior mouthfeel. With reduced meat content, lower meat quality, and higher fat percentage, the technological benefits of fiber increase significantly. Fibers are added to these products in doses ranging from 0.4% to 2.5%.

German Wiener formulation

Ingredients	%
Beef trimmings 80/20	22
Pork trimmings 80/20	20
Pork cheeks	15
Fat	15
Water/ice	28
Wheat fiber	1.5[a]

[a] Calculated on meat block basis.

After cooking, color evaluation sometimes reveals a slight reduction in redness. Depending on the ratio of fiber to added water, the hemoglobin content in the overall recipe may have been diluted. The use of coloring agents is not universally approved; hence a shift in meat composition can alternatively help. A higher proportion of beef can help regain some of the lost red color.

In Russia, low-cost recipes, binders, and extenders are more common than in Central Europe. This reflects the economic environment of Eastern European countries. Meat substitutes, binders, and extenders are used at higher levels to cope with the technological and cost challenges. High amounts of water and fat need to be bound in the meat batter to reduce losses during heating and storage. Highly extracted, cellulose-based fibers (e.g., wheat fiber, oat fiber) work best under these circumstances. The structural hardness and high fat-binding ability of the highly extracted wheat fiber have resulted in strong market acceptance in Eastern Europe.

Citrus fiber, with its extremely high-water-binding ability, would also be a good fiber option but, in addition to its the acid content, its paste-like structure is not able to create the desired bite or texture in these high-fat recipes. MDM use dominates the product's organoleptic profile; therefore, formulation adaptations need to address the soft and mushy texture associated with it, since most consumers prefer a denser structure and snap.

Russian "Urkainskie" sausage formulation

Ingredients	%
Beef trimmings 90/10	20
MDM	12
Pork trimmings 30/70	13
Skin emulsion	10
Pork fat	20
Water	25
Soy isolate	3[a]
Tapioca starch	3[a]
Plant fiber	1.5[a]

[a] Calculated on meat block basis.

In this product a skin emulsion is used to avoid a soft bite, since skin's high collagen content is effective for improving texture. During skin processing, high temperatures and friction result in a burnt flavor. Cellulosic fibers, which offer a neutral taste and structural support, work well with skin emulsions at acceptable addition levels, without sacrificing taste.

Fibers and Hydrocolloids in Sausage Products. Hydrocolloids like carrageenan, soy protein (texturized, concentrated, and isolated), and native or modified starches are also commonly used in sausage products. Fibers show good synergistic behavior with these ingredients. As opposed to kappa carrageenan or native starch, most fibers do not need a heating step to activate their full technological potential. This is a huge processing advantage. Fibers are easily incorporated to control meat batter viscosity before and during stuffing and also during the formation of meat patties or in the batter and breading of restructured items. Fibers bind water immediately, thus guaranteeing optimum batter consistency during transfer, handling, and stuffing procedures. In low-cost patty formulations, where softness and stickiness cause problems during molding using high-pressure forming equipment, insoluble fibers from potato, sugar beet, pea, grain, or citrus can reduce free water and create a drier, less sticky product surface. A stable fiber network, at dose levels higher than 1.5%, provides the additional benefit of maintaining product shape (Chap. 12). At high concentrations, carrageenan can lead to rubbery or gummy consistencies. Cellulosic fiber grades can economically help reduce the hydrocolloid content and create and maintain a meat-like texture, counteracting this effect. When using citrus and sugar beet fiber, the soluble fiber portion is able to stabilize the emulsion and improve bite. Comparable results can be obtained with pea cotyledon fiber or potato fiber containing protein and starch. In these, a portion of their functionality is delayed until the final heating process, but the fiber and protein components are active from the start of the mixing process.

Several starch types are commonly used in processed meat products worldwide. In the European meat industry, potato starch is common. Its high amylopectin and phosphate content give it a lower gelatinization point and a lesser tendency to retrograde. The higher amylose ratio in other starches leads to faster recrystallization, but purge in the package is often unacceptable. Fibers, with the exception of inulin, can help improve this situation. The high-water-binding and -holding capacity of fibers can be utilized to reduce free water. Corn starch, often used in combination with MDM, creates a gel with increased firmness. A disadvantage in this case is its high gelatinization temperature and its tendency to lose water during storage. Fibers with good water-holding capacity can reduce water losses and help achieve the desired textural characteristics.

Alternative protein sources are often used to replace expensive skeletal muscle meat. In Central Europe soy protein is not accepted; however, milk, wheat, and other proteins have been used. The high-water-binding properties of fibers allow for the partial or total replacement of these additional protein sources. Milk protein is one of the best emulsifiers available to the meat industry (Chap. 6), but, when dairy prices are high, many manufacturers seek alternatives. Empirical feedback from the Eastern European markets shows that 50–100% of the milk protein could be reduced by addition of wheat fiber. In these cases, manufacturers in these markets work with systems called fat emulsions, which use protein:fat:water ratios of approximately 1:7:7. Due to their sterical structure, insoluble cellulosic wheat or oat fibers are able to bind fat and water in a three-dimensional network, which can help stabilize the emulsion and allow for reduced protein use. A unique processed oat fiber with a higher degree of extraction allows it to bind and hold more fat, due to the removal of most of the lignin during fiber production.

Potato fiber or sugar beet fiber also cause a rough sensation on the tongue and soft palate, and its particles may stick between the teeth. Furthermore, they can also provide sweet potato or dull earthy off-flavors. Using carrot fiber, Nitsch (2003) observed similar flavor issues as well as color changes. At the higher concentrations required for a fiber claim, brownish spots in the meat product could be found. Citrus fiber does not suffer the same mouthfeel limitations as potato or sugar beet fiber, but the low pH level and high price level severely limit its application in sausage.

Ground Meat Products

The use of fibers in ground meat products offers all possibilities: nutritive, economical, and technological. Due to their coarser structure as compared to emulsified sausage, these types of products typically tolerate the use of higher levels of fiber, even up to levels that meet health claims. While fiber enrichment, alone or in combination with fat reduction, is a new trend, fat-reduced products have been on the market since many years. At reduced fat levels, ground meat patties become harder and drier, leading to an unpleasant mouthfeel. Insoluble fiber's ability to bind high amounts of water and to release it under pressure could help overcome these organoleptic drawbacks. The lubricity of some soluble fibers could be another solution. When exposed to high-shear forces these fibers form a thixotropic gel that resembles fat.

Production adjustments are not necessary when using fibers in ground meat products. The fibers should be added early in the mixing process, together with sufficient water to control meat viscosity. The fast water-binding characteristics of fibers aid in high-speed production. As opposed to other binders and extenders, which need to be heated in order to absorb water, cellulosic and pectin-containing fibers are able to control the water immediately upon mixing. This binding characteristic helps reduce stickiness of the mixture, thus enabling patties to be formed at faster rates. The use of high-water-holding-capacity fibers also helps control frying yields, which is advantageous in the production of prefried ready-to-eat products, as in the foodservice area, for example. A higher postfrying moisture content will generally result in a juicier product. In addition, water bound in the cellulosic structure is not influenced as much by freeze–thaw cycles, as evidenced by observations of reduced ice crystal growth.

Restructured and Injected Ham

In restructured hams, fibers can be added to the tumbler either mixed in with the brine or separately in a later step. Fiber dosage should be adjusted based on the size of the meat chunks and pieces that make up the product's meat block: As the amount of finely ground material is increased, so should the fiber level. Since the fiber molecules are too large to penetrate into muscle, the mechanical action of the tumbler simply scatters the fibers in and around the matrix. By becoming incorporated into the solubilized protein matrix that covers the surface of the meat chunks, the fiber can impact texture and reduce cooking losses and purge.

When injecting fibers, needle diameter as well as size and number of needle holes are critical. To prevent needle blockage and further enable injection applications, fibers with smaller particle size distribution have been developed. Insoluble fibers have a tendency to settle, while soluble ones could increase viscosity and stickiness. Simple solutions to avoid settling are agitation or increased brine viscosity. Specialized brine systems with a defined viscosity are obtained, for example, when using xanthan or cold-soluble carrageenan. After injection, insoluble fiber particles are not able to migrate deeper into the muscle or even penetrate muscle bundles. To overcome particle agglomeration, which can lead to a rough mouthfeel, fiber levels are limited to 0.5–1% of the meat block, and an injection rate of at least 60% is necessary. The good water-holding capacity will help increase the amount of brine.

Dry Sausage

With drying times up to 8 weeks and distinctive weight losses, the production of dry or raw fermented sausages requires good processing understanding. Over the past decade, dietary fiber concentrates have emerged as economical alternatives in this area. Partial meat replacement and faster drying cycles using cellulosic fibers have sparked much interest. In 1999, W. Voesgen, together with the German company J. Rettenmaier, developed the first strategy using different grades of wheat fibers, achieving a 25% reduction in drying time. Long cellulosic fibers well dispersed in the meat batter create a three-dimensional network, first inside the meat sol, and then in the solid meat matrix. The fibers build a "channel" that functions like a drainage system able to take up water and guide it more rapidly from the area of high humidity, the sausage center, to the surface. This results in faster and more even drying. Comparable results were obtained by Roth (2002), who used wheat fiber, with additional water, to obtain higher yields without any negative influence on pH development and water activities. Harsher drying conditions led to case hardening in the control products, but not in the fiber-containing sausages. The best way to add fibers with additional water is by premixing them. The additional humidity can thus be bound by the fiber in advance and will not influence water activity. Huber, Voesgen, and Le Mintier (2003) have shown comparable results using carrot fiber (i.e., shorter ripening time, improved yield, and increased firmness).

Based on the German regulations for raw fermented sausages, Mueller (2006) highlighted the option of enriching dry sausages with 3%, or even 6%, dietary fiber. Half and half combinations of soluble inulin and insoluble wheat fiber showed good results. The fiber use was not combined with additional water. This functional food concept was expanded with a reduction in fat content and the use of rapeseed oil as a plant fat rich in omega 3 fatty acids, as well as of prebiotic lactic acid bacteria as starter cultures. pH development and water activity in these modified products were not much different than in the standard product.

Conclusion

Growing competition and price expectations have made cost control a never-ending topic in the entire food industry. This has placed enormous pressure on manufacturers to handle the price demands of grocery chains and customers. Therefore, meat quality adaptations utilizing fillers or extenders have found a place in the meat industry as processors search for ingredients with high water-binding and -holding capacities that enable them to develop products that are at the same time cost-effective and of high quality. This has brought many fibers into the spotlight. This combined strategy of cost control and product development with nutritive aspects sounds promising and presents a good alternative to unnecessary caloric intakes. The wide range of fibers available to processors offers technically viable and market relevant options to optimize processed meat products.

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