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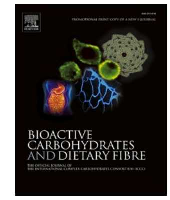

Incorporation of soluble dietary fiber in comminuted meat products: Special emphasis on changes in textural properties

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ABSTRACT

Comminuted meat products represent a diverse class of meat products that are popular for their characteristic texture and flavor. Comminuted meat products are incorporated with dietary fibers for various functional and nutritional purposes. These fibers are mostly the carbohydrate polymers of different types. The dietary fibers have been observed to affect the texture of meat products irrespective of the reason for their incorporation. These fibers have been shown to enhance the functional properties and health benefits of meat products. The effect of different fibers on the textural and other quality attributes has not been reported uniformly by the researchers making it hard to compare these studies. In this review, we have given an overview of the textural properties of comminuted meat products and summarized the existing researches reported on the textural changes of meat products due to soluble dietary fiber incorporation.

1. Introduction

Meat is one of the most nutritious foods widely consumed throughout the world. Traditionally, meat was obtained from the spent animals, which were not able to perform work in the field. Nowadays, young animals are reared to obtain high quality and tender meat. Perhaps, this has increased the consumption of meat throughout the world. Also, the improvement of the purchasing power of people has led to increased consumption of meat (Sans & Combris, 2015). Meat is an excellent source of protein and it contains all essential amio acids (Islam, Khan, & Islam, 2017). The chemical and biological value of meat proteins is high, next only to the egg proteins (Parkin & Parkin, 2017). Meat is a good source of minerals (Miller, 2017) and vitamins and one of the limited sources of vitamin B12 (Jesse & Gregory, 2017). Animal proteins including meat are also high in potassium especially cattle and organ meat (Sussman, Singh, Clegg, Palmer, & Kalantar-Zadeh, 2020).

Meat is processed in multiple ways before consumption. For instance, the processing may include simple roasting of the meat, but there are numerous meat products that involve complex processing operations to develop the final product. The origin of any meat product is associated with its unique quality parameters. Each product has its unique characteristics in terms of texture, color, taste, and aroma. Any change in these characteristics may fail the product in the market. The preferences may vary from person to person and place to place. Generally, the meat and meat products possessing appropriate tenderness, juiciness, and aroma are considered of high quality (Hoffman & Wiklund, 2006). Among the various quality parameters, tenderness is considered one of the major quality parameters which depend on various factors like species, age, feed, location of meat portions, marbling, connective tissue content, and slaughtering methods of the animal. Tenderness is evaluated using shear force, water content, fat content, microbial spoilage, and pH (Taheri-Garavand, Fatahi, Omid, & Makino, 2019).

Despite being highly nutritious, meat is deficient in dietary fiber (Das et al., 2020) and contains a high amount of cholesterol (Mafra et al., 2018). Recently, the World Health Organization has declared red meat as a possible cause of colon cancer. After reviewing more than eight hundred studies about the relationship between colon cancer and red meat they concluded that the consumption of red meat should be less than half kg per week and processed red meat should be avoided (WHO, 2015). Various theories have been put forth regarding the carcinogenic nature of red meat. Heme iron, fat rancidity, and the use of additives like nitrate have been proposed as potential cancer-causing agents present in

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meat (Corpet, 2011).

Researchers have been conducting experiments to overcome the above-discussed shortcoming of meat and meat products by applying multiple approaches. For instance; incorporation of chlorophyll (Sesink, Termont, Kleibeuker, & Van der Meer, 2001) and calcium supplements or α-tocopherol in red meat comminuted products has nullified the carcinogenic effect in *in-vivo* conditions (Allam et al., 2011; Corpet, 2011; Pierre, Santarelli, Taché, Guéraud, & Corpet, 2008). Comminuted meat products are the cooked or raw meat products like frankfurters, bologna-sausages, salami, patties, nuggets, meatballs, fermented sausages, etc., which have been prepared by cut, shredded, ground, and minced meat. Such products contain meat and non-meat ingredients like binders and spices (Bolger, Brunton, Lyng, & Monahan, 2017). Dietary fibers, which are being incorporated in different comminuted meat products for a long time, have also been related to minimizing the carcinogenic effect of meat. Dietary fibers are believed to reduce the residence time of fecal matter in the colon (Burkitt, Walker, & Painter, 1972) thus can reduce the time for a reaction to propagate. Dietary fibers also bind the minerals (Macagnan, da Silva, & Hecktheuer, 2016) thus reducing the activity of heme in the colon. Further, dietary fiber sources like fruit pomace, peel, vegetable trimmings (Fava et al., 2015), cereal by-products (Peanparkdee & Iwamoto, 2019) among others contain bioactive compounds like polyphenols which may help to prevent fat oxidation of the meat products. Dietary fibers not only make meat safe, but their functional properties help to improve various quality parameters of meat products like cooking yield, juiciness, emulsion stability, and shrinkage. Owing to these reasons, the incorporation of different types of dietary fibers in meat products has been researched extensively (Yadav, Malik, Pathera, Islam, & Sharma, 2016; Younis, Ahmad, & Malik, 2021). These dietary fibers may be the pure components like pectin, gum, glucomannan, carrageenan, alginate, inulin, resistant starch, fructooligosaccharides, polydextrose, carboxymethyl cellulose, hemicellulose, and lignin or in composite forms like bran, pomace, peel, and vegetable by-products.

The incorporation of dietary fiber in the meat products results in a change of texture which may be desirable (Younis & Ahmad, 2015) or undesirable (Younis & Ahmad, 2017). Some fibers are believed to increase the hardness of meat products while others may result in increased softness. The composite nature of dietary fiber generally added to meat products in the form of peel, pulp and bran is a reason for contradicting results on textural changes in meat products. In this review, we have summarized and analyzed the existing researches related to the texture of meat products incorporated with dietary fiber.

1.1. The texture of meat and meat products

The texture of meat and meat products can be measured before and after cooking by using a texture analyzer. The texture of the meat can be modified with the help of cooking and there is a general rule which says 'cooked meat pieces should be easily torn with the help of a fork'. Since the textural properties of raw meat plays an important role, therefore in the preparation of meat products fixed processing conditions are used. In comminuted meat products, the meat fibers are reduced in size thereby giving a tender texture. So, the adhesive and cohesive interactions between the meat fibers and non-meat ingredients contribute to the final texture. The addition of additives including binders, humectants, salts, dietary fibers, can produce different effects on the texture of meat products. There are two ways to determine the texture of meat and meat products viz. a. subjective or sensory analysis and b. objective analysis.

1.1.1. Subjective analysis

Sensory analysis is one of the quality analyzing procedures to determine the acceptability of the meat products by measuring the various quality attributes like color, taste, texture, aroma, overall acceptability using the senses of a person (Miller, 2017) The various sensory analysis procedures used by meat scientists are discriminative tests where the differences are detected, descriptive tests where the differences are measured or characterized, and consumer tests where the consumer preferences are determined (Miller, 2017). Sensory analysis of meat relies on cooking as the raw meat cannot be consumed as such. Among the various quality attributes, the texture is analyzed by the panelists with eyes, ears, fingers, teeth, tongue, palate, and oral processing (Lawless & Heymann, 2010). The texture of meat depends on cooking in addition to pre-cooking factors. Results of sensory analysis of meat and meat products vary from place to place and person to person due to the heterogeneous nature of meat and its composition (Torrico et al., 2018). The diet of animals has shown an effect on the texture and overall acceptability of different species of meat animals (Chail et al., 2017; Madeira et al., 2013). The effect on the texture of meat depends on the species, sex, age, transport, and slaughtering methods of the animal (Moore, Mullan, Kim, Trezona, & Dunshea, 2015). The muscle fiber of old animals is tough and has a high amount of connective tissue. The texture of meat also depends on post-mortem processing like aging, the temperature of aging, wet or dry aging (Colle et al., 2016), marbling level (Coombs, Holman, Friend, & Hopkins, 2017), packaging and cooking (Ferreira et al., 2016; Gaudette & Pietrasik, 2017).

There are two ways to incorporate dietary fiber in meat products viz., formulation of a new product, and enrichment of existing products with minimum changes in their quality attributes. In the former, the descriptive sensory analysis may be carried with the expert panelists followed by consumer testing, representing a target population to predict the acceptance of the new product. However, the incorporation of dietary fibers in the existing comminuted meat products changes the sensory attributes of the products concerning original products. Here, sensory analysis is used as a tool to identify a level of incorporation with which the minimum possible changes could be made to the original product. Initially discriminative or different tests may be used to differentiate the changes followed by consumer testing. The most powerful tool used for texture analysis is the sensory texture profile analysis. In this analysis the panel is selected and trained, then the standard rating is established followed by the formation of the score sheet, and finally, a comparative texture profile analysis ballot is developed which enables the identification and quantify of the small differences in the textural properties (Bourne, 2002c). Most of the researchers have used acceptability testing which provides information on the magnitude of acceptability (Torrico et al., 2018). The most common form is the hedonic scale which is used to score the products incorporated with dietary fiber. The score ranges from 1 to 9, where 1 denotes the least preferred, and 9 denotes the highly preferred (Younis & Ahmad, 2015, 2017, 2018; Yadav et al., 2016; Younis et al., 2019). All the prepared products (control and test samples) are provided to the panelists at the same time which helps them to compare the products. Other sensory tests employed by the various scientists are the duo-trio test, triangle test, paired comparison test, and ranking test which are known as discriminative or different sensory methods (Miller, 2017). In a descriptive sensory analysis, the panelists describe and rate the sensory attributes of the products in addition to the recording of any additional remarks (Hjelm, Mielby, Gregersen, Eggers, & Bertram, 2019).

1.1.2. Objective analysis

The instrumental analysis of texture is aimed to reduce the variations resulting from the subjective analysis. Besides, objective analysis is cost-effective, reproducible, and less time consuming (Bourne, 2002a). The major mechanical textural attributes of meat products are firmness, cohesiveness, and juiciness. The instrumental analysis measures the resistance shown by the meat and meat products against the force acting on them. The various texture analyzing methods used for meat and meat products are bulk analysis, compression testing, back extrusion technique, penetration and puncture test, shear testing, and tension (Table 1) (Bourne, 2002b). Bulk analysis test is done with Kramer shear cell which uses combined shear and compression force to measure the hardness of meat products. The sample is placed in a stationary metal

Table 1
Various texture analyzing methods used for meat and meat products.

Test	Method	Blade	Force	Use	Replication
Bulk analysis	Kramer shear cell	Verticle multiple blades of various shapes	Compression, shear, and extrusion	Used to know the hardness of reconstituted non-homogeneous meat products	Replicates the bulk analysis
Shear testing	Warner-Bratzler	Blades in V- notched, rounded or straight edges	Slicing or shearing	Used to know the tenderness and toughness	Replicates the action of knife, slicer and front incisor to peel or cut the meat
Penetration and puncture	MeullenetOwens razor shear	Cylindrical probes with different shapes of edges	Compression, shear	Used to know the crispiness	Replicates the action of the front incisors when food is introduced into the mouth
Compression testing	Texture profile analysis	Probe with the flat surface of different size	Compression	Used to know the hardness, cohesiveness, springiness, chewiness, and juiciness	Replicates the action of biting by mouth
Tension	Tension test	Probes using pneumatic grips	Stretch	Used to know the elasticity	Replicates the action of fork or canines to tare the meat pieces by pulling

box and the blades are allowed to get into the box to apply the forces. The results depend on the size of the sample, fat content, amount of connective tissue, the direction of the muscle fibers, speed of the blades, and the temperature of the products (Zhang & Mittal, 1994). The meat is an anisotropic food (Damez, Clerjon, Abouelkaram, & Lepetit, 2008) and the direction of analysis is an important parameter in measuring the texture. However, in comminution and mixing of meat fibers are reduced into particles thus may change them into isotropic substances. Warner-Bratzler shearing test is used to measure the force to cut the cooked meat sample of uniform dimensions with blade This method of measuring the tenderness and toughness is liable to technical variations which are cooking methods, thawing methods, shearing force, and location of the sample within a muscle (Holman, Alvarenga, van de Ven, & Hopkins, 2015). The force-time plot of the shear test of meat sausages is represented by Fig. 1A. Razorblade or blunt blade is used in the Meullenet Owens razor shear method where the force required to penetrate the probe through the meat is measured to predict the tenderness. This method demonstrates the texture layer by layer throughout the cross-section (Morey & Owens, 2017). This method does not need the sample preparation and specific sample size (Lee, Owens, & Meullenet, 2008). Texture profile analysis is also known as a two-bite test as it mimics the biting action of molar teeth. In this test, the sample is compressed two times with a probe having a flat surface. The sample taken should be smooth and small in size as that of the probe surface (Breene, 1975). The force-time plot of texture profile analysis of meat sausages is represented by Fig. 1B. Elasticity, stretching and stress relaxation can be measured by pulling the meat apart by applying tension force (Stanley, McKnight, Hines, Usborne, & Deman, 1972). A few information is available on the texture measurement by the tension test.

The above sensory and instrumental methods used for the texture analysis are time-consuming and often destructive respectively (Chen et al., 2020). Non-destructive methods of texture analysis like Raman spectroscopy (Chen et al., 2020), ultrasound signaling (Tokunaga et al., 2020), computer vision technique (Taheri-Garavand et al., 2019), and visible near-infrared spectral with hyper-spectral imaging (Reis et al., 2018) has been used for the texture analysis of meat. Non-destructive texture analyses of meat have great potential in saving time and cost. However, more research is needed to optimize these methods for getting accurate results.

2. Dietary fiber: properties and incorporation in comminuted meat products

Dietary fibers are categorized under the umbrella of functional foods. Dietary fibers represent the portion of food that is not digested by our bodies. These fibers are classified based on solubility viz. soluble and insoluble dietary fiber. Soluble dietary fiber is considered as water loving, non-crystalline, non-digestible constituents that are easily wetted by the aqueous fluid of gastrointestinal tract. Upon hydration these constituents have ability to produce a viscous colloidal dispersions or gels and are extensively fermented by microflora of the gut. These constituents are extensively used to modify rheological and textural properties in food industries. Colligative properties of food systems are

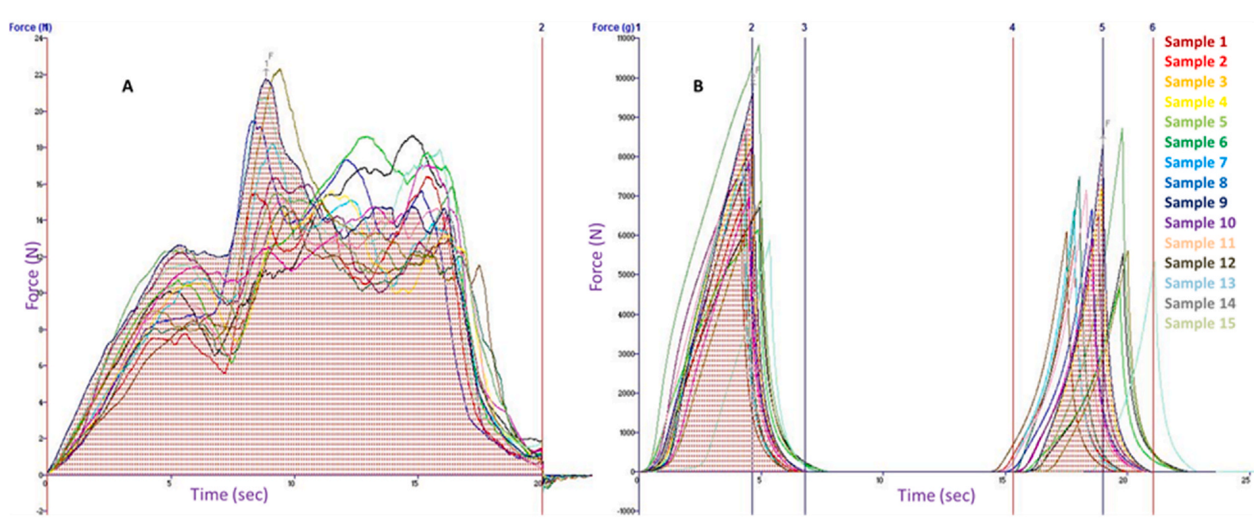

Fig. 1. (A) Shear force and (B) texture profile analysis of meat products.

also affected by the incorporation of soluble dietary fibers, hence promoted as functional foods thereby improving the market appeal of these food products. Soluble fiber consists of some hemicelluloses, oligosaccharides, mucilages, gums, pectin, inulin, arabinoxylans and β-glucans (Ciudad-Mulero, Fernández-Ruiz, Matallana-González, & Morales, 2019). On the other hand, insoluble fiber does not dissolve in water. Its consumption softens and increases the bulk of the stool by attracting the water passively thus decreasing the colonic passage time. It includes high molecular fraction of hemicellulose, cellulose, lignin, and modified cellulose (Yegin, Kopec, Kitts, & Zawistowski, 2020). It ensures the normal functioning of the tract and helps in preventing constipation and colonic diverticulosis. It also contains phenolic substances which has antioxidant properties thus boosts health (Ciudad-Mulero et al., 2019). The various health benefits of dietary fibers and their functional properties are presented in Fig. 2. The effect of different dietary fibers on the textural properties of comminuted meat products is presented in Table 2. The important dietary fibers which have been incorporated in various meat products and their effect on textural properties are briefly outlined.

2.1. *Oligosaccharides (low molar weight)*

2.1.1. *Fructooligosaccharides*

Fructooligosaccharides (FOS) is a general name given to the non-digestible oligosaccharides which are mainly composed of fructose. These oligosaccharides are non-digestible as the enzymes present in humans such as maltase, saccharase, and α-amylase are unable to digest them. In the human gut, FOS travel via the upper gastrointestinal tract undigested and unabsorbed followed by its entry into the intestine. It is here in the intestine, FOS is selectively utilized by a few acid-producing microbes, such as bifidobacteria and lactobacilli. FOS helps in the growth of such useful microbes and lessen the quantity of non-desirable microbes (Gibson, Beatty, Wang, & Cummings, 1995). Even if, FOS is not fully digested, it contains almost 40–50% energy to that of the digestive carbohydrates, resulting in a 1.5 kcal/g energy value. Accordingly, FOS is measured as a remarkable functional food ingredient, largely as a low-calorie diet source (Flamm, Glinsmann, Kritchevsky, Prosky, & Roberfroid, 2001). FOS is used for its low energy content and as a fat replacer in various food products which generally include confectionary items, dairy, cereal, and dietetic products (Rodríguez, Jiménez, Fernández-Bolaños, Guillén, & Heredia, 2006). Consumption of FOS has revealed very effective health-related effects which include lower total serum and cholesterol in diabetic patients, prevention of coronary diseases, and its effectiveness against colon cancer (Jenkins, Kendall, & Ransom, 1998; Luo, Yperselle, Rizkalla, Rossi, & Bornet, 2000). FOS has high water solubility (80%), hygroscopic and water retention properties which makes it more important as compared to sucrose and sorbitol. Due to its low water activity, FOS does not contribute in maillard reactions and therefore prevents the development of off-colors in food products. It has a neutral taste and is considered stable over a wide range of pH (4.0–7.0) and temperature (140 °C) in meat products (Kumar, Sripada, & Poornachandra, 2018; &; Câmara, Paglarini, Vidal, dos Santos, & Pollonio, 2020). However, in low pH and at higher temperatures, FOS are said to be less stable compared to other oligosaccharides. This is believed to be due to the partial hydrolysis of β-(2-1) glycosidic bond in acidic nature (Kumar & Dubey, 2019). The gel forming capacity of FOS decreases with decrease in the degree of polymerization. In addition, FOS is considered a viscosity compatible ingredient in the food industry providing viscosity characteristics of 100 MPa after using as a food ingredient at a 60% concentration (Kumar et al., 2018; & Câmara, Paglarini, Vidal,; dos Santos, & Pollonio, 2020). FOS have found a wide applications in many food products such as bakery products, meat replacers, dietetic products, frozen desserts, beef sausages, biscuits, yoghurt etc., owing to its improved texture, water retention, and shelf-life (Kumar et al., 2018).

2.1.1.1. *Effect of fructooligosaccharides on the texture of meat products.*

Fructooligosaccharides (FOS) are amply used in meat products as dietary fibers, effective fat substituent, and efficaciously used in meat emulsion foods with promising sensory characteristics. These results are due to the FOS properties of a neutral flavor, water retention capacity, and reduced losses of cooking (García, Cáceres, & Selgas, 2006; Selgas, Cáceres, & García, 2005).

Cáceres, García, Toro, and Selgas (2004) studied the effect of FOS on the sensory properties of cooked sausages. As per the study, an evident variation was observed as the sausages with reduced-fat were softer in comparison to the conventional sausages. It was also reported that the hardness diminished with an increase in the concentration of dietary fiber. The authors also reported that higher springiness was found in the sausages with the reduced-fat than the conventional batches. This transformation was due to the gel-forming property of FOS which resulted in elastic characteristics of the products. It was also observed in the study that due to the presence of FOS, the textural properties of the product remain unchanged during the storage period. In general, the study revealed, that the overall texture, sensory, and consumer acceptability of the meat products was enhanced with the presence of FOS. Subsequently, with the incorporation of FOS, a product with added soluble fiber and reduced calorie content is acquired. In a similar study (Salazar, García, & Selgas, 2009), reported that the decreased fat levels

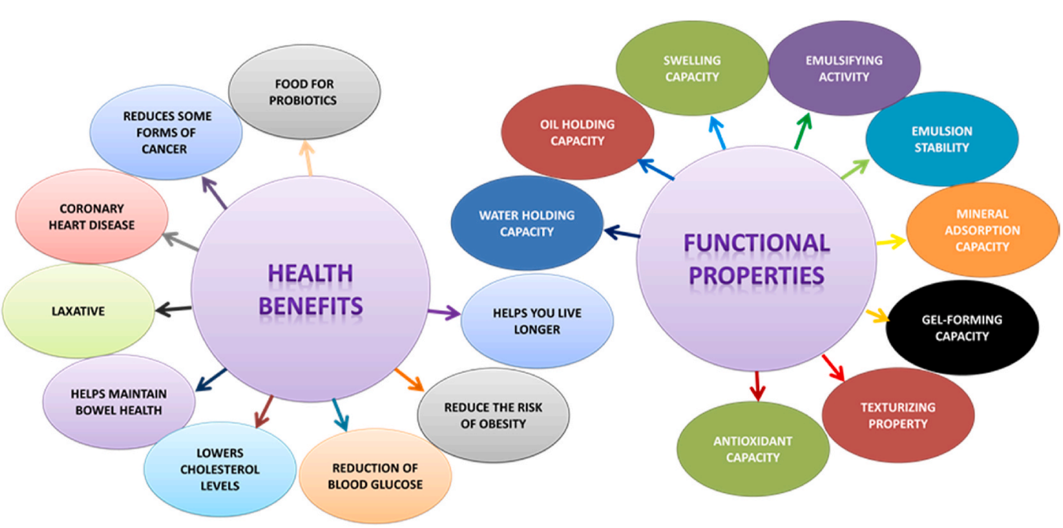

Fig. 2. Functional properties and health benefits of dietary fiber.

Table 2
Effect of different dietary fibers on the textural properties of comminuted meat products.

S. No.	Source	Meat product	Effect on texture	Reference
	Full-fat soya paste	Goat meat patties	Decreased shrinkage, hardness, springiness, chewiness, and shear force values	Das, Anjaneyulu, & Kondaiah (2006)
	Raw and cooked albedo	Bolognas sausages	Increase in hardness	Fernández-Ginés, Fernández-López, Sayas-Barberá, Sendra, & Pérez-Álvarez (2004)
	Textured soy protein	Baked goat meat patties	Increased Gumminess, Hardness, Puncture force, Back extrusion force. Decreased Cohesiveness Adhesiveness Chewiness	Gujral, Kaur, Singh, & Sodhi (2002)
	Dietary inulin	Low-fat dry fermented sausages	Increased hardness, gumminess and chewiness and decreased springiness, cohesiveness and adhesiveness	Mendoza, Garcí;a, Casas, & Selgas (2001)
	Inulin and pectin	Frankfurter sausages	Shear force, hardness, fracturability, gumminess, and chewiness were decreased.	Méndez-Zamora et al. (2015)
	Cellulose (CMC) and microcrystalline cellulose (MCC)	Beef patties	Firmness decreased with increasing concentration of CMC. Firmness increased with increased concentration of MCC.	Gibis et al. (2015)
	Carboxymethyl cellulose (CMC) and microcrystalline cellulose (MCC)	Sausages	Firmness initially increased upon addition of 0.3 wt % CMC. At higher concentrations of CMC (0.5, 0.7 and 2 wt %) firmness decreased. Addition of MCC increased firmness.	Schuh et al. (2013)
	Inulin Cellulose Carboxymethyl cellulose (CMC) Chitosan Pectin	Model meat product	Addition of CMC and pectin decreased the hardness. Addition of cellulose and chitosan increased the hardness. Inulin had insignificant effect	Han & Bertram (2017)
	Pineapple dietary fibres	Beef sausage	Hardness, chewiness, gumminess and springiness were decreased by the addition of pineapple dietary fiber	Henning, Tshalibe, & Hoffman (2016)
	Inulin	Breakfast sausage	Hardness increased with increasing inulin concentration.	Keenan, Resconi, Kerry, & Hamill (2014)

lead to increased hardness, gumminess, and chewiness of sausages. The integration of FOS with meat resulted in softer sausages and was more apparent with the lower level of fat. An evident variation in texture was found among the samples incorporated with 4–6% FOS and those without it, which was obviously due to the presence of fibers. Results were clear that the FOS form stable and soft gels that are responsible for modifying the textural properties and thus leading to the softer sausages and simultaneously mimicking the impressions and mouth feel of fat to the food products. In the case of cohesiveness and springiness, lesser variation was found among all the batches. Fat reduction leads to a stronger blending among the components of the sausage which favors cohesiveness. Adhesiveness increased significantly with the amount of FOS. The increase in adhesiveness was attributed to the formation of gels and this effect was more perceived at the FOS concentration of above 4%.

Felisberto, Galvão, Picone, Cunha, and Pollonio (2015) studied the effect of Fructooligosaccharides and other dietary fibers on meat products. The results of the textural analysis showed significant changes with the decreased levels of fat. Higher penetration and compression forces were observed in the control in contrast to the sausages with FOS, which was credited to the exceptional gel-forming capability of the FOS. In this study, the significance of fat in the meat emulsified products was also emphasized. It is evident that fat is an essential ingredient for the improved texture of the meat products which in turn is responsible for the sensoria; characteristics like flavor, juiciness, and palatability of meat products (Tobin, O'Sullivan, Hamill, & Kerry, 2012). Likewise, Bis-Souza et al. (2020) reported that the incorporation of FOS resulted in a substantial effect on the textural parameters of the meat products. The characteristics of hardness, gumminess, and chewiness of these meat products amplified considerably over the ripening period. The study also reported that cohesiveness and springiness decreased significantly during this ripening time. It is observed that the sweetness level of the meat is enhanced with the accumulation of FOS in the meat products (Dos Santos, Campagnol, Pacheco, & Pollonio, 2012). Considering these studies, it is apparent that the textural characteristics of these meat products are predominantly linked to the fat content and the fusion of dietary fiber. Fructooligosaccharides has a noteworthy effect on the textural and sensorial properties of these food products.

2.1.2. *Polydextrose*

Polydextrose is a low glycemic carbohydrate that possesses low-calorie content and is sugar-free. Polydextrose is known to have several physiological effects that are found to be very effective in attaining health benefits. These properties of Polydextrose make it a viable component to be utilized in the production of new functional food products. Polydextrose is broadly used in various food items such as bakery products, dairy items, sweets, confectionery, and salads. Polydextrose is also known to be an effective dietary fiber and has potential usage in foods. Polydextrose is ineffective in achieving the textural characteristics of the food products owing to its characteristics of high solubility, visible clarity, and sucrose mimicking property. It is immensely efficient in sweet foods, fat-rich foods, and foods devoid of bulking agents. It helps in sustaining the mouthfeel and texture of the foods which is generally lost during processing. Polydextrose is thus a treasure trove of several properties which makes it a versatile agent in the food industry and can be used as a soluble fiber, prebiotic, stabilizer, thickening agent, and humectant for the development of foods with better sensory characteristics (Veena, Nath, & Arora, 2016).

2.1.2.1. Effect of polydextrose on the texture of meat products. Polydextrose is used as a dietary fiber and is incorporated in various meat products for enhanced functional and textural quality. It is also used as a substitute for nutritive sweeteners or polyols in comminuted meat and fish products. It is observed that Polydextrose with its property of being a cryoprotectant, maintains the functional properties of minced meat products during long-term chilled or frozen storage (PARK, LANIER, & PILKINGTON, 1993). Due to its sugar-free property, when added to the meat products, the impact on the flavor is of the least significance (Tomaniak, Tyszkiewicz, & Komosa, 1998). It is also reported that the Polydextrose is odorless and is highly soluble in water, which leads to the development of viscous solutions and an enhanced texture of food products by replacing fat (Murphy, 2001; Sajilata, Singhal, & Kulkarni, 2006).

According to Satsuba & Okuma (1995), polydextrose was used in chicken nuggets as a moisture binder to bind moisture in the patties. It was observed that the loss in the moisture was reduced during cooking. It was also observed that the moisture migration to the batter and bread crumb coating was also reduced. Due to this effect, chicken nuggets remain juicy and moist; moreover, the coating crispiness was also enhanced and remained crispier even after cooking. Likewise, Sadler and Swan (1997) examined the effect of polydextrose on the characteristics of minced beef. Results showed that, with the incorporation of 2.6% Polydextrose to the salted mince, the batter strain and stress was enhanced in contrast to the non-additive and salt-only samples. Kovačević, Mastanjević, and Kordić (2011) explored the effects of Polydextrose on chicken surimi. Samples of chicken surimi were incorporated with various mass fractions of Polydextrose (2–10%) with κ-carrageenan (0.5%), polydextrose (2–10%) with sodium chloride (2%), and polydextrose (2–10%). It was reported that the polydextrose enrichment resulted in the stabilization of myofibrillar proteins, signifying that polydextrose forms a network with the proteins in chicken surimi and acts in harmony with cryoprotecting mechanism. Polydextrose, because of its water holding capacity, folding test and gel strength property, was capable in sustaining better physico-chemical characteristics that other sugars and sucrose during frozen storage of chicken surimi for six months. Polydextrose, besides a low-sweetened sugar, can also be used as a cryoprotectant (Nopianti, Huda, Fazilah, Ismail, & Easa, 2012). In another study, Felisberto et al. (2015) studied the effect of polydextrose and other dietary fibers on meat products. The results presented significant differences in the formulations containing polydextrose, which can be complimented to the tremendous gel-forming ability of the fibers. Polydextrose is thus, suitable enough in upholding the textural and functional property of the meat products.

2.2. Non-starch polysaccharides (high molar weight)

2.2.1. Soluble dietary fibers

2.2.1.1. β-glucan. β-glucan is an important non-starch polysaccharide that is comprised of D-glucose monomers linked through β-glycosidic bonds. It can be found in different sources like cereal grains especially barley and oat, yeast, bacteria, mushrooms (Zhu, Du, Bian, & Xu, 2015). Depending on the source, β-glucan may be comprised of short and medium chains such as (1 → 3) or (1 → 4) and (1 → 3) or (1 → 6) bonds (Bozbulut & Sanlier, 2019). β-glucans derived from cereal grains are comprised of β-(1 → 3) and β-(1 → 4) glycosidic bonds. However, other β-glucans obtained from cell walls of yeast and fungi contain β-(1 → 3/1 → 6) glycosidic bonds (J. Chen & Raymond, 2008). β-glucan present in lichen consists of β-(1 → 3) and β-(1 → 4) as well as β-(1 → 3) and β- (1 → 6) glycosidic bonds. Curdlan is a β-glucan with β-(1 → 3) and cellulose is a β-glucan with β- (1 → 4) glycosidic linkages (Zhu, Du, & Xu, 2016).

Macromolecular structures of β-glucans obtained from different sources vary and such differences provide β-glucan with different biological activities (Du & Xu, 2014). The various physicochemical properties like solubility, molecular weight, viscosity, and gelation may differ which are correlated to the conditions and methods of extraction. Solubility of β-glucan is decreased when the degree of polymerization is increased and vice versa (Zeković, Kwiatkowski, Vrvić, Jakovljević, & Moran, 2005). β-glucans with varied viscosity, gelation, the molecular weight can be used as a food additive such as texture modifier, thickening agent, and fat substitute to produce food products of low lipid profile (Maheshwari, Sowrirajan, & Joseph, 2019).

2.2.1.1.1. Effect of β-glucans on the texture of meat products. β-glucans have been used as thickeners in beverages, and fat substitutes in dairy and bakery products to reduce calories and cholesterol as well (Bai et al., 2019). β-glucan is used as a fat replacer, binding agent, extender, filler agent in processed meat products. It can also be used to improve various physicochemical and sensory properties of meat products by providing a synergistic effect with other nutrients (Talukder, 2015). Regarding meat products, β-glucan affects textural properties to a great extent and no literature has been compiled related to such studies. In a study by Vasquez Mejia et al. (2018), β-glucan with starch and carrageenan was investigated in meat emulsions. The incorporation of β-glucan modified the textural properties of meat emulsions. It was observed that hardness, springiness, adhesiveness, and cohesiveness were greater at higher levels of β-glucan. The increased hardness in meat emulsions was owed to the high viscosity of soluble fiber β-glucan. It was suggested that the free water in the emulsion system was immobilized by forming a stable matrix with soluble fibers which may have increased the hardness of the paste. In another study, the beef emulsion was incorporated with different levels of barley β-glucan, microcrystalline cellulose, and starch (1% and 2% each) and a mixture of β-glucan and microcrystalline cellulose (1.5% each). Texture profile analysis of samples prepared with starch and microcrystalline cellulose showed no change. However, emulsions added with β-glucan presented lower hardness, gumminess, cohesiveness, and chewiness than microcrystalline cellulose and starch samples. The gelling properties of the fiber are held responsible for the different textural attributes (Vasquez Mejia, de Francisco, & Bohrer, 2019). The effect of β-glucan, inulin, and breadcrumb was observed on the textural characteristics of low-fat beef burgers by Afshari et al. (2015). The hardness of patties was increased as the levels of β-glucan, breadcrumb, and inulin increased being lowest in β-glucan samples. Interaction between the corresponding additives showed the opposite effect on the hardness of patties. A similar effect was observed for cohesiveness and gumminess of patties. It was proposed that the incorporation of β-glucan and inulin in low-fat burgers improved its textural characteristics without affecting the sensory properties of the patties. Likewise, Vasquez Mejia et al. (2019) observed the effect of β-glucan in combination with carrageenan and starch in beef emulsions. The addition of β-glucan provided higher hardness to sausages which were attributed to the high viscosity of β-glucan preparations. However, in another study the combined effect of β-glucan and resistant starch showed the opposite effect on the textural characteristics of sausages and developed softer texture. This synergistic effect of β-glucan and resistant starch was probably due to the negative effect of β-glucan on the gel strength of resistant starch which produced a softer texture in sausages (Amini Sarteshnizi, Hosseini, Bondarianzadeh, Colmenero, & khaksar, 2015). In another experiment, a lower shear force was observed in oat's β-glucan added patties which were attributed to the replacement of fat with oat's fiber which could have produced a softer mushy texture to the patties (Piñero et al., 2008). These results were confirmed by Troy, Desmond, and Buckley (1999) and Desmond, Troy, and Buckley (1998).

2.2.1.2. Inulin. Inulin, a soluble dietary fiber, comprises several polymer levels of oligosaccharides and polysaccharides (about 60 fructose monomers linked via β-2-1 glycosidic bond) and is often used as a fat substitute in meat products (Selgas et al., 2005). Jerusalem artichoke and chicory are the chief sources of inulin in nature. Inulin possesses an exclusive quality of forming highly stable particle gels which enhance the textural and rheological characteristics of the food products. These inulin gels are white creamy fat like assembly which can be incorporated into the food products and can accordingly act as a fat replacer. It is used in meat products like low-fat sausages as a fat replacer for improved quality of the sausages (Boeckner, Schnepf, & Tungland, 2001). Similarly, as a fat replacer, it is used in non-meat products like chocolate cakes and milk products providing desirable mouthfeel, flavor enhancement, and low energy value (Izzo & Franck, 1998). Inulin is, furthermore, used in some food products to boost the textural and rheological characteristics and also aid in the foams and emulsions stability. Thus, as a versatile food constituent, works in the food products as a fat replacer, agent for reducing energy, enhancing water-holding capacity and emulsion stability, along with modifying the properties of viscosity and texture of these food products (Boeckner et al., 2001). Inulin is also known for its various health assistance. Studies have reported that it helps to control the blood glucose level (Jackson, Taylor, Clohessy, & Williams, 1999); lessen the threat of arteriosclerosis, avert osteoporosis; regulates the triglycerides and cholesterol levels in serum; reduces the chances of gastrointestinal diseases; lessens the release of carcinogens; and, regulates the immune system (García et al., 2006).

2.2.1.2.1. Effect of inulin on the texture of meat products. Inulin, as a dietary fiber, is incorporated into various meat foods which include minced meat, meatballs, sausages, and restructured meat products. Overall results have acknowledged its quality of a good texturizing agent and an effective fat substitute. These properties of inulin may be attributed to the factor that it, being a water-soluble fiber, has the potential to bind with water to form soft, stable, and firm gels. Due to this property, inulin incorporated meat products are easily cut and also imitates the perception fat (Huang, Tsai, & Chen, 2011). Furthermore, the addition of Inulin up to the concentration of 6% has the least effect on the structural and sensorial characteristics of meat products. Inulin incorporation in the meat products significantly affects the texture of products (Felisberto et al., 2015).

Mendoza, García, Casas, and Selgas (2001) studied the effect of inulin on dry fermented sausages. The results showed that the textural characteristics of the dry fermented sausages were comparable to conventional sausages but possess a softer texture, springiness, and adhesiveness. In another study, Franck (2002), reported that the addition of inulin to the meat products provides a creamier mouthfeel without conceding texture and taste. García et al. (2006) worked on the implications of inulin dietary fiber on sensory and textural characteristics of the cooked meat product (Mortadella) of Spain. The results of the textural profile analysis showed that the incorporation of powdered inulin in the sausages which were prepared with conventional fat content did not render any significant changes in the cohesiveness and springiness of these products. However, an increase in the adhesiveness and the hardness of the product was observed. Consequently, the addition of inulin in the form of the gel had the least impact on the adhesiveness or springiness of the control batches. On the other hand, hardness and cohesiveness of sausages was altered at the insulin concentration of 7.5%. Sausages thus formed were considerably softer and with less cohesiveness in comparison to the control batch. The results of the study further indicate that the concentration of inulin at 7.5% in the powdered form is amply high to make the sausages harder. Conversely, with the incorporation of inulin in gel form, it adds its creamy texture to the sausages and makes them softer. Similarly, Inulin recovered from the chicory root, when added as the dietary fiber to the fish sausages, enhanced gel strength and hardness of the sausages (Cardoso, Mendes, & Nunes, 2008).

Flaczyk, Górecka, Kobus, and Szymandera-Buszka (2009) reported in their study that inulin gel was used to replace fat in meatballs. Meatballs differed in their basic chemical composition with the incorporation of inulin as a fat substitute in contrast to control. Results showed that the addition of inulin leads to the drop of both fat contents as well as the energy value of the meatballs. It was also observed that the overall acceptability of 10% added inulin gel was better for aroma, juiciness, and taste compared to the other sets of variations. An overall undesirable consequence on the sensory characteristics of the meatballs during storage was also inhibited by the use of inulin. On the contrary, Nowak, Von Mueffling, Grotheer, Klein, and Watkinson (2007) stated that the incorporation of inulin, in the amount exceeding 6% in the meat products, resulted in the inferior texture. As per the authors, the incorporation of inulin, as the fat replacer, does not show any significant effect on the textural characteristics of these products.

In the meat products like sausages, adhesiveness and cohesiveness remain essential factors in determining their acceptability and storage (Nowak et al., 2007). The incorporation of inulin in the sausages for suitable adhesiveness and cohesiveness is desirable. A decrease in the hardness, cohesiveness, springiness, and chewiness of canned meat products was found which was developed with altered amounts of inulin gel (Cegielka & Tambor, 2012). In another study, Menegas, Pimentel, Garcia, and Prudencio (2013) reported that adding inulin in sausages leads to the harder edges but at the same time with better chewiness in the central portion compared to the sausages with lesser content of the oil. In contrary to the sausages having normal oil content, the sausages with inulin were less elastic, harder, and chewier in the central portion but harder at the edges.

Incorporation of inulin in the low-fat meat products such as sausages with less than 20% fat, results in the products with retained textural and sensorial properties analogous to the conventional products with better consumer acceptability (Beriain, Gómez, Petri, Insausti, & Sarriés, 2011).)Cava, Ladero, Cantero, and Rosario Ramírez (2012studied the effect of various dietary fibers on the textural characteristics of the cooked chicken products. It was reported that the products with inulin have the same hardness as that of the control. It was also reported that the inulin incorporated products possess the lowest gumminess. However, Álvarez and Barbut (2013)worked on the effect of inulin on emulsion stability, color, and textural parameters of meat batters. The results of the study revealed the softer and creamier textured products are formed with the addition of inulin. Besides, the improved texture and sensory characteristics, the addition of inulin lead to the improved product quality and color in terms of L, a, b values as well (Kılınççeker & Kurt, 2018).

2.2.1.3. Polysaccharide gums or hydrocolloids. Polysaccharide gums belong to non-starch soluble dietary fiber. Hydrocolloids, or more commonly gums, can be defined as complex nondigestible polysaccharides which dissolve or disperse in water having viscosity building or thickening properties (Anderson & Ando, 1988). They play an important role in food formulation to improve gelling effect, increasing food consistency, and regulating the texture, microstructure, flavor, and shelf life of foods (Gawai, Mudgal, & Prajapati, 2017). Carrageenan, alginate, modified starch, pectin, gelatin, gellan, agar, methylcellulose, and hydroxypropyl methylcellulose are some of the important gums that are used in foods (Saha & Bhattacharya, 2010). Intensive hydrogen bonds are formed when the gums are dissolved in water. As a result of the configuration and size of the gum molecules, these polysaccharides make the aqueous solutions viscous by thickening or gelling. This is attributed to both intermolecular frictions when shear is applied and the formation of hydrogen bonds between the chains of the polymer (Nieto, 2009). The functionalities of gums are determined by their physicochemical properties which in turn are determined by the chemical configuration of gums. In addition to their chemical structures, the shapes of the gums are also influenced by the aqueous environment in which the molecules are surrounded like pH, temperature, types of salts and other solutes, shear, etc. (BeMiller, 2008). The polysaccharide gums are believed to consist of various sugars, such as D-mannose (Man), D-galactose (Gal), D-arabinose (Ara), and D-rhamnose, and two acidic sugars, D-Glucuronic acid and D-Galacturonic acid (Elzain & Mariod, 2018).

In broader sense plant gums can be divided into two classes i.e. exudate and non-exudate gums. The first category of gums is found in some plants which can be produced by a process known as gummosis in response to mechanical injury or defense against the attack of microorganisms. In contrast, non-exudate gums or mucilage are found in the tissues of plants which can be produced by a process of extraction (Hamdani, Wani, & Bhat, 2019). The gums can also be classified on the basis of their source which include higher plants (guar gum, tara gum, locust bean gum, etc), algae (agar, alginates, etc.), microorganisms (gellans, dextrans, xanthans, etc.), and cellulose derivatives (cetyl hydroxyethylcellulose, carboxymethyl hydroxyethylcellulose, etc) (BeMiller, 2008).

Plant gums can be used as food ingredients or additives in various food preparations because of their various functional properties. The various properties which make them useful to the food industries include stabilization and emulsification of non-miscible phases, rheological properties. As a result of such functional properties they possess, gums are used as a food additive in various foods such as ketchup, sauces beverages, meat products (Hamdani et al., 2019; and; Lurueña-Martínez, Vivar-Quintana, & Revilla, 2004). The effect of some important gums on the textural properties of meat products are discusses below.

2.2.1.3.1. Carrageenan. The word carrageenan denotes a group of sulfated polysaccharides composed of 3,6-anhydrous-D-galactopyranosyl and/or D-galactopyranosyl units produced by extraction of red seaweeds (Rhodophyta). The main backbone in the structure of carrageenan is sulfate and galactose groups. Also, other residues like glucose, xylose, uronic acids, methyl ethers, and pyruvate groups are present (Sedayu, Cran, & Bigger, 2019). Traditionally, carrageenan has been divided into six types based on their chemical classification and commercial production. These include Kappa (j)-, Iota (i)-, Lambda (k)-, Nu (m) - Mu (l)-, and Theta (h)–carrageenan (Campo, Kawano, da Silva jr, & Carvalho, 2009). In general, κ-carrageenan possess the strongest gelling power which contains ester sulfate groups of about 25–30% and 28–35% of 3,6-anhydro-D-galactopyranosyl units. I-carrageenan contains ester sulfate groups of about 28–30% and 25–30% of 3,6-anhydro-D-galactopyranosyl units and λ-carrageenan has ester sulfate groups ranging from 32 to 39% with 0% of 3, 6- anhydro-D-galactopyranosyl (Barbeyron, Michel, Potin, Henrissat, & Kloareg, 2000). 3,6-anhydrogalactosyl units are generally involved in gelation and the degree of sulfation is directly related to solubility, gel texture, and protein reactivity properties.

2.2.1.3.2. Effect of carrageenan on the texture of meat products. Carrageenan can be used as a fat substitute in meat products which can modify the textural properties of meat products without interfering in organoleptic properties. Atashkar, Hojjatoleslamy, and Boroujeni (2018) incorporated κ-carrageenan in low-fat sausages as a fat substitute. It was suggested that the addition of κ-carrageenan can be added as a partial fat substitute without affecting the textural properties of low-fat sausage. Similarly, the incorporation of carrageenan as a fat substitute and its effects on textural properties of low-fat frankfurters was observed by Cierach, Modzelewska-Kapituła, and Szaciło (2009). It was noticed that hardness, gumminess, and chewiness values were increased as a result of carrageenan addition. It was suggested that the addition of carrageenan as a fat substitute improved textural characteristics in low-fat sausages without affecting sensory properties.

Low-fat sodium-reduced sausages prepared with κ-carrageenan, potato starch, and locust bean gum was developed. The harder structure of sausages was observed at higher levels of potato starch and equal amounts of κ-carrageenan and locust bean gum. However, lower hardness was observed with no potato starch and equal amounts of κ-carrageenan and locust bean gum. Interaction of locust bean gum κ-carrageenan decreased cohesiveness. Functionally, textural properties (hardness and cohesiveness) were improved by the addition of κ-carrageenan whereas sausage structure was distinctly weakened by locust bean addition. It was proposed that potato starch may be utilized as an extender in the lowest tested amounts in low-fat cooked sausages only if κ-carrageenan and locust bean gum are used in similar amounts (García-García & Totosaus, 2008).

2.2.1.3.3. Pectin. Pectin is a carbohydrate polymer of high-molecular-weight which is present in the primary cell wall and an intracellular layer of plant cells and it provides structure to the cell. Structurally pectin is regarded as the most complex carbohydrate polymer found in nature and constitutes up to 35% of primary cell walls in certain species (Liang & Luo, 2020). Pectin is a linear structure polymer that consists of a backbone of α-(1 → 4)-D-galacturonic acid monomer units which are substituted by α-(1 → 2) rhamnopyranose residues in some regions which may lead to the side chains of glucose, mannose, xylose, and galactose. It is found in many fruits, such as apples, oranges, lemons among others. In citrus fruits, pectin is majorly contained in the peel part and comprises about 0.5%–3.5% (Mudgil, 2017). Pectin is formed from the protopectin which is present in the middle lamellae of cells. Protopectin is insoluble, however as the fruit ripens or when heated in an acidic medium protopectin is converted into a soluble form (Smith, 2003).

Depending on the degree of esterification (DE), the two major classes of pectin are high methoxyl pectins (HMP) and low methoxyl pectins (LMP). HMP is characterized by more than 50% degree of esterification and LMP with less than 50% degree of esterification (Marić et al., 2018). HMP can form gels when heated in low pH (2–3.5) acid solutions and sugar with concentrations as much as 55–75%. On the other hand, LMP may form a gel in the presence of calcium ions. Gels can be formed with or without the presence of sugar over a wide range of pH (2–6) (Fishman, Cooke, Chau, Coffin, & Hotchkiss, 2007).

2.2.1.3.4. Effect of pectin on the texture of meat products. The pectin has diverse applications in food industries and can be used as an emulsifier, stabilizer, gelling agent, and thickener in the manufacturing of jams and jellies. Similarly, pectin can also be used in meat and fish products as a texture modifier, fat replacer, and cryo-protectant (Kim, Miller, Lee, & Kim, 2016).

Kim et al. (2016) incorporated soy hull pectin and insoluble fiber in fresh and frozen/thawed beef patties. Results showed that pectin incorporation resulted in lower hardness in fresh and frozen/thawed beef patties compared to control. However, a non-significant difference was observed for other textural properties like springiness, gumminess, and chewiness of beef patties. These authors attributed the decrease in hardness due to improved moisture retention by the addition of fiber. Further, the differences in hardness between fresh and frozen/thawed beef patties may be eliminated as similar hardness was noted for fresh and frozen/thawed beef patties. Hardness and shear stress were significantly affected by pectin type in surimi prepared from silver carp (Barrera, Ramírez, González-Cabriales, & Vázquez, 2002). Pectins with varying degrees of esterification were analyzed. Hardness and shear stress of surimi gels were improved by amidated low methoxyl pectin however, these properties were not improved by anyone of the high methoxyl pectins and, non-amidated low methoxyl pectin. Pectin and inulin were used as fat substitutes in the formulation of frankfurter sausages. It was observed that hardness, shear force, gumminess, fracturability, and chewiness were lower as compared to the control. These authors suggested that these ingredients could be employed as fat substitutes to produce functional meat products (Méndez-Zamora et al., 2015). A new clove essential oil enriched pectin-based edible coating was developed to preserve bream fillets during refrigerated storage (Nisar et al., 2019). A significant difference was observed between treated and untreated samples for all textural properties except cohesiveness and resilience. It was suggested that the applied coating reduced the loss of texture in treated samples during cold storage. In an *in-silico* study, the interaction of pectin with actin, myosin and collagen showed good compatibility by forming total number of hydrogen bonds of 8, 12 and 6 respectively as shown in Fig. 3 (Ahmad, Khalid, & Younis, 2020).

2.2.1.3.5. Glucomannan. Glucomannans are believed to be neutral polysaccharides that may be utilized as a soluble dietary fiber. They have extremely high viscosity characteristics as compared to other soluble fibers. Glucomannans is derived from Amorphophallus konjac roots known as konjac glucomannan. It can also be obtained from dicotyledons and certain microorganisms for example bacteria, yeasts, and fungal cell walls. These polysaccharides consist of a primary sugar mannose and secondary sugar glucose along with some galactose side chains and acetylated residues (Tester & Al-Ghazzewi, 2017). Konjac glucomannan is a heteropolysaccharide that consists of sugar monomers D-glucose and D-mannose which are joined by β-(1–4) glycosidic linkages having a mannose to glucose molar ratio of 1.6:1. The typical acetylation of the polymer accounts for 5–10%, although the acetylation degree may vary with diverse types of glucomannan (dos Santos & Grenha, 2015).

Konjac glucomannan is a highly viscous, fermentable, and water-soluble fiber. However, it requires continuous stirring to dissolve it to a complete degree in the water at room temperature. Also, it is not effective to dissolve it using hot water (Cui, Wu, & Ding, 2013). Glucomannan preparations are believed to reduce fat absorption and stimulate satiety which in turn may result in weight loss (Witkamp, 2010).

The most prominent characteristic of konjac glucomannan is gelation performance. It is also characterized by good film-forming ability, biodegradability, and biocompatibility (Yang et al., 2017). Konjac glucomannan is used and sold most often in the form of konjac flour. A heat-stable gel is produced when it is dissolved in calcium hydroxide, sodium, or potassium carbonate alkaline coagulant. This strong gel mimics the fat and may thus reduce calorie content as well.

2.2.1.3.6. Effect of glucomannan on the texture of meat products. Konjac glucomannan fiber has been used in meat preparation as a fat substitute, water binder, etc. (McArdle & Hamill, 2011). Konjac glucomannan affects the textural properties of meat products as well. Low-fat dry fermented sausages were developed by substituting pork back fat with an equal amount of konjac gel. The hardness and chewiness of sausages were increased by increasing the konjac gel level and decreasing fat content. The higher hardness was attributed to the percentage weight loss of sausage. Cohesiveness decreased and springiness showed no clear trend by partial replacement of pork back fat with konjac gel, these results were attributed to the reduction of fat and addition of konjac gel (Ruiz-Capillas, Triki, Herrero, Rodriguez-Salas, & Jiménez-Colmenero, 2012). These results were confirmed by Lorenzo, Munekata, Pateiro, Campagnol, and Domínguez (2016) in which hardness, chewiness, and gumminess of Spanish salchichón significantly increased by decreasing animal fat and increasing konjac gel proportions. However, no effect on cohesiveness and springiness was observed in treated samples which were attributed to the constant protein content in treated and control samples. In contrast, Jiménez-Colmenero, Triki, Herrero, Rodríguez-Salas, and Ruiz-Capillas (2013) reported a decrease in hardness and an increase in the

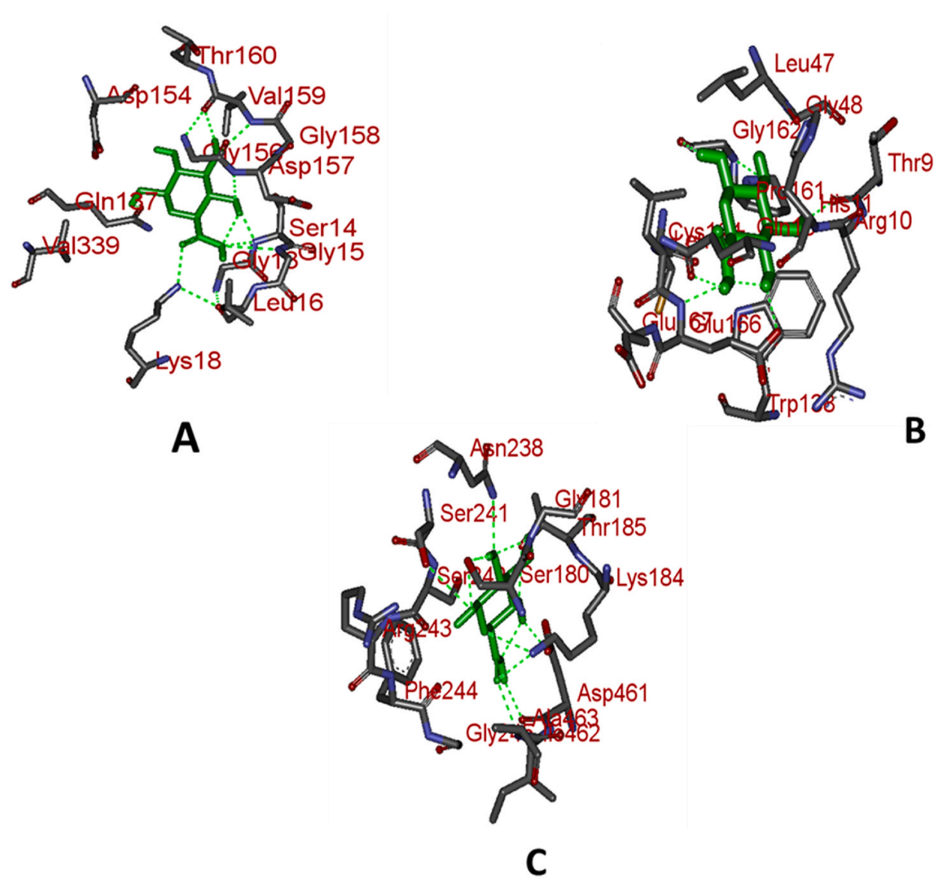

Fig. 3. (A) Interaction of pectin docked with the actin protein. Pectin has been shown in 'green stick' representation. (B) Interaction of pectin docked with the collagen protein. Pectin has been shown in 'green stick' representation. (C) Interaction of pectin docked with the myosin protein. Pectin has been shown in 'green stick' representation. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

cohesiveness of dry fermented sausages by partial replacement of animal fat with konjac gel. This evident difference in the findings was attributed to the higher moisture content of sausages as compared to those reported by other authors mentioned above. It was suggested that different conditions were applied in both studies to complete the process of ripening to obtain different characteristics of the products. The completion of the ripening process of sausages was determined by weight loss level in this study, which resulted in sausages with higher moisture and protein ratio that explains the lower hardness of sausages.

Fernández-Martín, López-López, Cofrades, and Colmenero (2009) observed that hardness and springiness of pork meat batter made with konjac gel, measured by texture analyzer, decreased non-significantly with konjac gel addition. Cohesiveness and chewiness of meat batter significantly decreased reduced with the addition of konjac gel. It was believed that the reduction in hardness with konjac gel addition may be attributed to the formation of a weak three-dimensional network on subsequent gelation since the raw protein matrix was used as a dispersion medium for konjac gel in the process of batter preparation.

2.2.1.3.7. Carboxymethyl cellulose. Carboxymethyl cellulose is a biopolymer obtained from cellulose. It is obtained by copolymerization of β-D- glucose and β-D-glucopyranose 2-O-(carboxymethyl)-monosodium salt joined together by β-1, 4 glycoside bonds (Muppalla, Kanatt, Chawla, & Sharma, 2014). It is chemically modified cellulose. One way to obtain carboxymethyl cellulose is heating cellulose with alkali and later with chloroacetic acid, which leads to the etherification of hydroxyl groups with methyl carboxyl groups (Gibis, Schuh, & Weiss, 2015; Schuh et al., 2013).

CMC is a cellulose derivative polymer which is an anionic and water-soluble. CMC is soluble in both hot and cold water owing to its negatively charged carboxyl groups. Water solubility of CMC relies largely on the degree of polymerization, degree of substitution as well as uniformity of the substitution distribution. As the degree of polymerization is decreased and carboxymethyl substitution and substitution uniformity is increased, water solubility of CMC is increased. However, increasing concentration and degree of polymerization increases the viscosity of solution and decreases as the temperature is increased. CMC is usually used in beverage drinks and beverage dry mixes providing rich mouthfeel because of its high degree of solubility and solution clarity (Ergun, Guo, & Huebner-Keese, 2016; Holtzapple, 2003). The physicochemical properties of carboxymethyl cellulose like meat binding capabilities (Arancibia, Costell, & Bayarri, 2011), water holding capacity, and gelling properties (Gibis et al., 2015) have grabbed the attention of the meat industry for its use in meat products. The carboxymethyl cellulose has been used as a fat replacer in meat patties.

2.2.1.3.8. Effect of carboxymethyl cellulose on the texture of meat products. The incorporation of carboxymethyl cellulose in lamb patties has shown a decrease in hardness springiness, gumminess, cohesiveness, and chewiness (Guedes-Oliveira et al., 2019). Similar results were found by Schuh et al. (2013) in the Lyoner-style sausages incorporated with the carboxymethyl cellulose and they reported that the concentration of carboxymethyl cellulose more than 0.7% destabilized the textural and rheological properties of the meat product which further destabilized the meat network after heating. In this support, research showed the inclusion of carboxymethyl cellulose levels of more than 2% has weakened the protein network between the protein and fat particles thus, destabilizes the texture (Gibis et al., 2015). This weakened protein network between the fat and meat particles has been shown to decrease from 6.13 N/g (control) to 2.75 N/g (3 wt% CMC) in fried beef patties (Gibis et al., 2015).

2.2.1.3.9. Other gums. Various studies have been carried out to analyze the effects of gums in meat and meat products. Textural properties of low-fat sausages can be improved by the application of gum tragacanth (Abbasi et al., 2019). These authors studied the effects of gum tragacanth on textural properties of sausages and reported that the hardness was decreased by increasing gum tragacanth proportion. The decrease in hardness of sausages has been attributed to the destabilization of batter upon cooking and hence it was not able to convert into a proper protein matrix. Similar results were observed for cohesiveness and springiness of low-fat sausages which might be due to the ability of gum to bind and hold water molecules in the gum matrix which must have reduced the cohesiveness in the gum incorporated samples. Similar results were reported by Rather et al. (2015) where hardness was decreased in a xanthan gum added restructured meat products. However, a non-significant effect was observed for cohesiveness, gumminess, and chewiness whereas an increase in springiness was noted in restructured meat products added with xanthan gum. These results were further confirmed by (Rather et al., 2016) in mutton goshtaba enriched with guar gum as a fat replacer. In another study, a combined effect of locust bean and xanthan gum was assessed on the textural properties of low-fat frankfurters (Lurueña-Martínez et al., 2004). These authors found no significant change in all textural properties of frankfurters by the addition of locust bean and xanthan gum as compared to control. Feng et al. (2013) investigated the effect of a mixture of Mesona Blumes gum, an ionic gum extracted from an herb, and rice starch gels as a fat replacement in Chinese sausages. Mesona Blumes gum/rice starch gel added sausages showed a non-significant effect on hardness, chewiness, and shear force as compared to sausages contained high fat. However, higher hardness, chewiness, and shear force was observed in Mesona Blumes gum/rice starch gel added sausages than sausages with low fat. In a study conducted by Somboonpanyakul, Barbut, Jantawat, and Chinprahast (2007), the effect of Malva nut gum, extracted from the seed of Scaphium scaphigerum, was assessed in chicken Frankfurters. Hardness, springiness, and chewiness were increased by increasing the Malva nut gum proportion. This increase is attributed to the strength of the gel formed by the interactions of Malva nut gum with meat particles. However, no effect was observed on the cohesiveness of frankfurters by the addition of Malva nut gum.

2.3. Resistant starch

Resistant starch is a non-digestible starch as it escapes the enzymatic degradation in the small intestine, and acts as a soluble fiber with fair palatability and mouthfeel. Resistant starch has an immense application in the food system and is categorized into four elementary types. Type 1 (RS1) is composed of granules of starch bounded by a non-digestible plant matrix which makes it isolated and stable to heat. Type 2 (RS2) is found in its usual form such as in the raw potato and maize with high amylose content. Its structure is compact and resistant to enzyme hydrolysis. Type 3 (RS3) is an extremely resistant form of crystallized starch that is prepared by a distinct cooking procedure. Lastly, Type 4 (RS4) is the starch with a modified structure and comprises of the various structural bonds in place of α-(1,4) and α-(1,6) bonds. Chemical alteration in this starch is prompted by the processes of crosslinking, esterification, or transglycosylation which makes it liable for the restricted digestibility in humans (Haub, Hubach, Al-Tamimi, Ornelas, & Seib, 2010). Resistant starch as a dietary fiber is observed to have numerous health benefits when complemented in the diets. It holds possible influence on the energy intake and diabetes; serves as the fermentable starch for colonic microbes; and delivers short-chain fatty acids that are beneficial to the colon and also own other physiological functions (Bird, Lopez-Rubio, Shrestha, & Gidley, 2009).

2.3.1. Effect of resistant starch on the texture of meat products

Resistant starch due to its micro particulate structure can be easily added and mixed into food products as it does not alter the form of the final product (Sajilata et al., 2006). Nevertheless, there seems to be a limited number of studies on the application and implication of resistant starch as dietary fibers, and its potential usage is thus not adequately studied. In one of the rare studies, Amini Sarteshnizi et al. (2015) studied the effect of resistant starch on the texture of meat sausages. The results of the study indicate an increased hardness of the sausages with the incorporation of resistant starch. This increased hardness was ascribed to the presence of amylose in the resistant starch. On heating, amylose leaks out of the starch granules leading to the retrogradation of the amylose which in turn results in an increased hardness of the sausages. Additionally, amylose contributes to the firmness and gel strength and thus decreases the stickiness of starch gels. It was also found that the addition of resistant starch caused an increase in the resilience and springiness of sausages. Gumminess and chewiness were also found in agreement with the hardness.

3. Conclusion

The incorporation of soluble dietary fiber in meat products for technical and health purposes has shown diverse effects on the textural properties of meat products depending upon the type of dietary fiber used. Some of the fibers have been shown to decrease the hardness while others have shown an increased effect. Other textural properties have also shown the same trend. There are further variations due to the subtypes of fibers incorporated, for instance, the two forms of pectin (low methoxylated and high methoxylated) have different effects on texture. The properties of meat which are affected by factors like age, sex, and species also influence the texture. To find the effect of dietary fiber incorporation on the textural properties of meat products, individual fibers need to be tested along with the *In-silico* studies to pursue the chemical reactions that affect the textural properties of meat products. These studies will surely help to interpret the textural changes of comminuted meat products caused due to the incorporation of soluble dietary fibers.

Ethical approval

This review article does not comprise any studies with human members or animals carried out by any of the authors.

CRediT authorship contribution statement

Kaiser Younis: Conceptualization, Methodology, Software. **Owais Yousuf:** Visualization, Investigation. **Ovais Shafiq Qadri:** Data curation. **Kausar Jahan:** Writing – original draft, Supervision. **Khwaja Osama:** Investigation. **Rayees Ul Islam:** Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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