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Developments in Science, Technology, Quality and Constraints of Restructured Meat Products-A Review

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ABSTRACT

To provide the consumer with a highly palatable product at a reasonable cost is the main objective of any food industry. Particular to meat industry, utilization of less valuable carcasses and carcass cuts and carcass components (plates, flanks, shanks, etc.) is of prime interest in periods of economic pressure. One such relevantly new technological approach is restructuring technology, which enables the production of value-added meat products from low value cuts and trimmings of carcasses. Although the economics and processing of restructuring meats appear favourable to producing a product that has the palatability attributes that are between an intact muscle steak and ground meat. This review of restructured meat products discuss the actual science and technology behind the restructuring of muscles, how muscle chunks are binding each together at protein molecules stage, factors influencing the meat pieces binding, type of restructuring methodologies, quality attributes of restructured meat products, problems of oxidation, use of natural antioxidants and recommends research needs for the future.

Key words: Restructured meat products, processing technologies, quality attributes, lipid oxidation, natural antioxidants

INTRODUCTION

Socio-economic factors viz., changed lifestyle, smaller family size, employment opportunities, health consciousness, lead to increased demand for lean and pre-cooked, ready-to-eat, meat products (Gurikar *et al*., 2014; Reddy *et al*., 2015). Many technologies are available to produce ready-to-eat and ready-to-cook meat products. One such relatively new technological approach is restructuring technology, which enables the production of value-added meat products from low value cuts and trimmings which is also most economical (Anandh *et al*., 2011; Dutra *et al*., 2012; Sharma *et al*., 2013). The increasing demand for convenient foods has led to the expansion in the variety of ready-to-eat meat products including restructured meat products (Sen, 2013; Reddy *et al*., 2013; Gadekar *et al*., 2014). Restructuring has been developed as a method for transforming lower value cuts and trimmings into products of higher value and considered as a way to expand the potential of muscle foods in the market (Najeeb *et al*., 2015a, b). Advancement in technology and mechanization makes the carcass meat to be disassembled and reassembled in such a way that it gives a texture similar to steaks, chops and roasts (Pearson and Gillet, 1996; Gurikar *et al*., 2014).

Restructuring refers to a group of procedures that reduce the particle size of the meat and then reform the meat particles into a shape that resembles a high value steak, chop, or roast (Boles and Shand, 1998; Najeeb *et al*., 2014a, 2015a). The advantages of restructuring of meat is (1) To transform relatively low-value carcass parts into products with an increased market value, (2) To create various new products to suit culinary needs in the form of steaks, roasts, slices, chops, dice, cubes and nuggets of practically any shape and size according to gourmet and traditional palates and (3) It facilitates food service manager to minimize wastage and design nutrient rich meat products with fortifications (Gadekar *et al*., 2013; Malav *et al*., 2013; Reddy *et al*., 2015).

Restructured meat products are commonly prepared using different methods of size reduction viz., chunking and forming, flaking and forming or sectioning and forming or the combination of them (Boles and Shand, 1998; Mandal *et al*., 2011; Gadekar *et al*., 2013). Chunking is accomplished by passing the meat through a coarse grinder plate leading to decrease in the particle size not greater than one and a half inch cubes (Malav *et al*., 2012; Talukder *et al*., 2013). This technique increases the surface for the extraction of myosin and aids in better binding during mixing. High speed dicing or slicing machine is being used for flaking and reforming of restructured meat products. Fine flakes produce more acceptable appearance, increase tenderness and decrease shear force value (Mandal *et al*., 2011; Reddy *et al*., 2015). Sectioned and formed meats are primarily composed of intact muscle or section of muscle that are bound together to form a single piece (Pearson and Gillet, 1996; Mandal *et al*., 2011; Sharma *et al*., 2013).

In restructuring of meat, tumbling and massaging are the two techniques used quiet commonly. Tumbling utilizes impact energy and massaging utilizes frictional energy (Talukder *et al*., 2013; Sharma *et al*., 2014). The action of tumbling and massaging not only aids in better extraction of proteins but also improves the speed of curing by increasing salt absorption. A tumbler consists of a stainless steel tank mounted on a set of rotating wheels to agitate the contents while spinning. Massager is a slow mixer designed to stir or agitate large chunks of meat (Hendrick *et al*., 1994; Talukder *et al*., 2013).

In this review, the definition, history, types of restructuring methods, factors relating the binding during restructuring of meat, mechanism of binding between meat chunks, various cold set binders and quality attributes of restructured meat products, problems of oxidation, use of natural antioxidants and recent research and developments are discussed in detail.

DEFINITION AND HISTORY

Most appropriate definition for "restructuring of meat" refers to a group of procedures that partially or completely disassemble meat and then bind together the meat pieces to form a cohesive mass that resembles an intact muscle (Pearson and Gillett, 1999). In its broadest sense, any meat products that are partially or completely disassembled and then reformed into the same or different forms are called restructured products. The common objective of restructuring was to achieve a product, not only imitates but also possess the attributes of a whole-tissue product and a restructured product from cheaper muscles of fore or hind quarters should look and taste like steak from the more expensive middle cuts such as the rib eye roll, strip loin or tender loin (Farouk, 2002). Meat restructuring involves the assembling of meat pieces into a cohesive product which aims to simulate or retain the texture of high quality muscle (Sheard and Jolley, 1988). Cohesion is developed during cooking by the gelation of meat proteins solubilised during processing by the action of salt. Many technological advantages on processing combination have been used in the preparation of restructured meat products to acquire sensory characteristics somewhere between ground meat and intact muscle steaks.

The idea of engineered steaks is not new. A book dating from the reign of Augustus (27 B.C-14 A.D) gives recipes for a round, chopped sausage product. Development of meat restructuring technology first emerged in the early 1940's but at that time the process was discarded as uneconomical due to a lack of suitable equipment (Ashton, 1971). Cafapbell *et al*. (1977) reported that flaking and forming machinery suitable for restructuring was available in the early 1970's.

RESTRUCTURING METHODS

Meat to meat binding in restructured meat products may be achieved through the formation of gels that set thermally (hot-set) or chemically (cold-set) (Boles and Shand, 1999).

Hot-set Binding System

Conventional restructured meat products depend upon hot-set binding (thermal) of meat proteins which are extracted with the combined effects of salt, phosphate and mechanical action (Schmidt and Trout, 1982). By using this technology, the product must be sold either precooked or frozen because the product binding is not very high in the raw state but high yields (25% above meat weight) are possible (Boles and Shand, 1998).

Mechanism of hot set binding: For production of well accepted restructured meat products, tumbling and massaging are well recognized and accepted techniques in the meat industry (Addis and Schanus, 1979). The increasing success of restructured meat products has been based on the efficient use of tumbling or massaging of meat with salt and phosphates for extraction of salt-soluble proteins which bind meat chunks in order to produce a texture similar to the more desirable steaks and chops (Pearson and Tauber, 1984).

Tumbling: Tumbling is a physical process which involves meat rotating, falling and contacting with metal walls and paddles in a drum and provides a transfer of kinetic energy to extract protein that forms a binding agent for muscle fibers (Addis and Schanus, 1979). Tumbling is performed in a rotating cylinder known as tumblers which consist of rotating stainless steel drums of different types, causing chunks of whole uncooked pieces of meat, either fresh or cured, to tumble or drop, with or without the help of baffles (Pearson and Gillett, 1996). The aim of tumbling is to activate, or solubilize protein, which improves cooking yield, firmness and texture as well as creating a layer of activated protein on the surface of meat which is responsible for slice coherency in the cooked product and more specifically, the sarcolemma surrounding the tightly swollen muscle cells is destroyed by the impact of energy from tumbling and solubilized myofibrillar proteins are released (Feiner, 2006).

Mechanism of tumbling: When pieces of meat are tumbled, some of the salt soluble proteins that include actin, myosin, actomyosin and other sarcoplasmic proteins, migrate to the outer surface of the meat and a tachy white exudate that includes fat, water and proteins is formed (Marsh, 1977). The basic mechanism of tumbling is that the baffles inside the tumbler move the injected pieces of meat up the wall of the tumbler and once the pieces of meat reach a certain height, gravity causes them to fall. As the meat moves up the tumbler, the pieces rub against each other and the associated pressure causes the activation or bursting of the highly swollen muscular protein cells. The kinetic energy released during falling of meat pieces at bottom of the tumbler which serves to disrupt cellular membranes, which in turn causes protein extraction (Feiner, 2006).

Functions of tumbling: Rust and Olson (1973) found that the extraction of myofibrillar proteins on the surface of meat has two functions. One is to act as a bonding agent holding the meat surfaces together and the other is to act as a sealer when thermally processed and therefore, aid in the retention of water in the muscle tissue. The other functions of tumbling are to improve yield, increase tenderness and cohesiveness and gain faster and more uniform ingredient distribution in the meat (Cassidy *et al*., 1978; Krause *et al*., 1978). In addition, cellular disruption of the meat tissue occurs during tumbling which together with the curing additives allows the meat to improve the yield (Chow *et al*., 1986). Constraining connective tissue sheaths around muscle fibres are disrupted, allowing further myofibrillar swelling introduced by salt (Katsaras and Budras, 1993).

Types of tumbling: Continuous and intermittent tumbling are two basic types of tumbling treatments that are used (Keerthi, 1998). In continuous tumbling, the meat is tumbled at a very slow speed, generally 2-4 rpm, over a period of 12-16 h until the desired number of tumbling revolutions were reached and tumbling is finished, the meat is processed straight away (Feiner, 2006).

Tumbling is often intermittent, the meat is tumbled and rested in intervals, aiming at a balance between optimal tumbling time and time for the brine to diffuse and increase brine absorption, yields, sliceability and reduce cooking losses (Krause *et al*., 1978). Even though several studies indicate the superiority of intermittent tumbling (Krause *et al*., 1978; Ockerman and Organisciak, 1978) others suggests continuous tumbling (Gillett *et al*., 1982).

Nevertheless, other parameters during tumbling influence the final product quality too. Speed of the drum and total number of revolutions are important (Lin *et al*., 1990), as well as the size of the drum and the extent to which the drum is filled with meat (Pearson and Gillett, 1996). Temperatures of 0-5°C are preferred during tumbling, not only for hygienic reasons, but also because of more favorable protein solubility (Lyimen, 1997).

Vacuum tumbling: The application of vacuum to tumbling has been found to produce more extractable protein in beef than non-vacuum conditions (Wiebe and Schmidt, 1982; Ghavimi *et al*., 1986). In non vacuum conditions air and oxygen lower the protein exudates capacity to adhere meat pieces thus vacuum is used during tumbling to reduce foaming and promote binding (Pearson and Gillett, 1996). A vacuum is also useful as it extracts air from the tumbler, preventing the formation of foam which is undesirable because it leads to protein denaturation and therefore reduced binding strength in the sectioned and formed product (Kerry *et al*., 2002).

Restructured beef steaks that were mixed under vacuum had better binding strength than steaks mixed in the absence of vacuum (Wiebe and Schmidt, 1982). Vacuum-tumbling appears to have no positive or negative effects on color and trained panel and hunter color evaluations did not find differences between non vacuum- tumbled, vacuum-tumbled or nitrogen back-flush-tumbled beef muscles (Ghavimi *et al*., 1986).

Massaging: The terms massaging, tumbling and mixing are commonly used interchangeably but, in tumbling the container (or barrel) revolves around its own imaginary axis and has no paddles inside whereas, in massaging, the container is stationary and mixing arms or paddles move inside it. The term massaging is used worldwide and generally means mixing (Feiner, 2006).

In meat industry massaging is the one of the widely known ways of loosening and damaging meat structure (Muller, 1991). He further reported that, final effects of massaging is connected with both raw material (type and muscle size) and massaging parameters (injection with curing brine, massaging time, temperature, drum speed, massaging cycle and kind of massaging devices). However, the final effects of massaging could be caused by two main determinants: massaging time and paddler (drum) speed. On the one hand, too shorter-lasting massaging causes tough and jammed product structure - on the other too longer-lasting massaged muscles (over-massaged) may be characterized with excessive damaging meat structure, decrease in WHC and yield. As a result of histological changes, massaging causes an increase in meat tenderness (Katsaras and Budras, 1993). Too slow speed, even with longer-lasting massaging may result in poorly damaged muscle structure and too fast speed may to worsen product structure (Leistner and Gorris, 1995).

Thermally induced meat protein gelation: According to Glicksman (1982), gelation is the association or cross-linking of randomly dispersed polymer chains in solution to form a three-dimensional continuous network which immobilizes liquid in the interstitial structure which resists flow under pressure. Protein gelation is important for imparting desirable sensory characteristics and textural properties in foods. The characteristics of each gel are different and dependent upon factors such as protein concentration, degree of denaturation caused by pH, temperature, ionic strength and/or pressure and protein gelation can be achieved by many means, among which, heat-induction is the most widely used method (Totosaus *et al*., 2002).

Upon heating, meat proteins can form a three-dimensional gel network which provides both structural and functional properties to meat products (Acton *et al*., 1983). Thermally induced gelation involves both intramolecular (conformational) and intermolecular changes in proteins. The mechanism of gel formation may differ among proteins due to most likely, the type of molecular interactions that stabilize the gel of different protein systems. Functionally, these events involve protein-water interaction, protein-fat interaction and protein-protein interactions (Acton and Dick, 1989).

These interactions of meat proteins may consist of disulfide linkages (Huggins *et al*., 1951), multiple hydrogen bonds (Eldridge and Ferry, 1954), peptide bonds (Bello, 1965), electrostatic and hydrophobic interactions (Wolf and Tamura, 1969).

In protein gelling firstly, the unfolding or dissociation of protein molecules is provoked by heat or other means, followed by the second step in which the association and aggregation reactions result in a gel system. It was important that the rate of the second step remains slower than the first one, because protein aggregation will then be ordered enough to allow gel formation (Kinsella *et al*., 1994).

Of the three major protein groups in muscle, myofibrillar proteins are the most important to the ultimate development of the gel structure in heat-processed products (Smith, 1988). Gelation of myofibrillar proteins is the most important functional property that occurs in restructured, formed and comminuted products and is also responsible for texture, viscoelastic traits, juiciness and stabilization of fat emulsions in processed meat products (Xiong, 1997).

Protein denaturation: Kauzmann (1959) proposed denaturation as a process (or sequence of processes) in which the spatial arrangement of the polypeptide chains within the molecule is

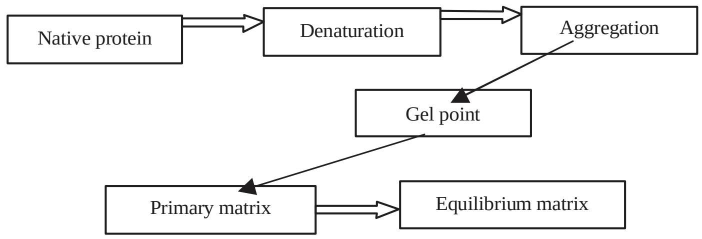

Fig. 1: Schematic overview of the thermal gelation process of myofibrillar proteins (Foegeding, 1988)

changed from that typical of the native protein to a more disordered arrangement. Tanford (1968) supplemented Kauzmann's definition by requiring that there be no alteration in the protein's primary structure. Denaturation can be restricted to the continuous process of native protein structural changes involving the secondary, tertiary, or quaternary structure during which alteration of hydrogen bonding, hydrophobic interactions, ionic linkages and oxidation-reduction or interchange reactions of covalent disulfide bonds occur without alteration of the amino acid sequence (Anglemier and Montgomery, 1976). For food scientists, denaturation is of great importance because it has a significant influence on protein functionality, such as water holding capacity, protein solubility, emulsification and gelation.

Nakai (1983) explained the protein denaturation process which indicated in brief: proteins are peptide chains composed of amino acids which possess hydrophilic or hydrophobic characteristics depending on the polarity of the side chain. During the formation of protein molecules, native proteins tend to orient the hydrophobic portions into the interior side of the molecule and the hydrophilic portions into the exterior side of the molecule to reach its most stable configuration. Upon heating, the energy imparted to the protein molecules can break the relatively weak forces that hold the proteins in their folded and helical tertiary and secondary configurations. As a result, the protein molecules unfold and the internally directed hydrophobic regions are exposed to the outside of the molecules. This process is called denaturation. When too many hydrophobic sites are exposed, the interactions become inevitable between the exposed hydrophobic sites, resulting in protein aggregation (gelation) (Fig. 1).

Protein aggregation: On the basis of observations of the heat-induced gelling properties of myosin and its proteolytic sub fragments, Samejima *et al*. (1981) proposed that the heat-induced gelation of myosin consists of two reactions: (1) Aggregation of the globular head segments of the myosin molecule, which is closely associated with the oxidation of sulfhydryl groups and (2) Network formation of the unfolded helical tail segments. In addition, head portions associate to form "super-junctions" which provide extra cross-linking to the gel network. While heating, the denatured, unfolded protein molecules re-orient themselves, interact at specific points and finally form an ordered three-dimensional network structure (Foegeding, 1988). Although, the mechanism of gel formation may differ among proteins, it appears that the heat-induced gelation occurs in two phases. At temperatures below 55°C, the major events are changes in protein conformation (denaturation). The subsequent aggregation and gelation begin at approximately 55°C when the myosin rods start to aggregate. It is essential that the rate of the aggregation remains lower than the denaturation step to allow an ordered gel formation (Totosaus *et al*., 2002).

Cold-Set Binding System

Several cold-set binding systems are commercially available to meet the demand for restructured meat products that can be sold in the chilled, raw state and that have eating characteristics similar to cuts from intact muscles (Means and Schmidt, 1986; Esguerra, 1994; Kuraishi *et al.*, 1997). Other advantages of cold-set over hot-set binding systems include reduced problems with discoloration which is common in hot-set products due to the use of salt (Means and Schmidt, 1987) and oxidative rancidity (Raharjo *et al.*, 1989). Cold-set products are also more versatile, because cold-set products can be treated (marinated) similar to fresh cuts of the same size and shape (Esguerra, 1994). Different commercial binding systems are available for the manufacture of value-added meat products that can be marketed raw. Each of the binding systems works in different ways and can react differently to changes in ingredients and conditions of the meat (Boles and Shand, 1999).

To form a viscoelastic cold-set protein gel, some modified interactions such as covalent bonding, hydrophobic interaction, sulfhydryl-disulfide exchange and hydrogen bonding are required at the molecular level and effective protein-protein interaction can be obtained by modifying one or more specific interactions for the desirable cold-gelation (Bryant and McClements, 1998). In general, cold-set gelation has been accomplished using hydrocolloids, high-pressure techniques or microbial transglutaminase (TGase) and among all, hydrocolloids such as alginates and carrageenan's are wieldy using for not only cold set gelation, but also improving water retention ability (Boles and Shand, 1999).

Alginates: Alginate $(C_5H_7O_4COO\text{-})_n$, also called algin, is one kind of electrolyte of organic macromolecule in brown algae cell membrane and sodium alginate is the sodium salt of alginic acid (King, 1983). In molecular terms, it is a family of unbranched binary copolymers of 1-4 linked -D -mannuronic acid and -L-glucoronic acid residues of widely varying composition and sequential structure (Moe *et al.*, 1995).

In modern food and meat processing, alginate is of great interest because of its unique colloidal properties, which include thickening, stabilizing, suspending, film forming, gel producing and emulsion stabilizing (King, 1983). The most useful and unique property of alginates is their ability to react with polyvalent metal cations, specifically calcium ions to produce strong gels or insoluble polymers (King, 1983). Such calcium-alginate gels are used in the meat processing industry for producing various restructured meat foods (Moe *et al.*, 1995).

Alginic acid is the only polysaccharide, which naturally contains carboxyl groups in each constituent residue and possesses various abilities for functional characteristics (Ikeda *et al.*, 2000). The most useful and unique property of alginates was their ability to react with polyvalent metal cations, specifically calcium ions to produce strong gels or insoluble polymers (King, 1983; Simpson *et al.*, 2004). Such calcium-alginate gels are used in the food processing industry for producing restructured foods such as meat products, onion rings, crabsticks and cocktail berries (Moe *et al.*, 1995).

Application of alginates in restructured meat products: Several researchers have used alginate and the algin/calcium reaction to modify texture and influence structure of formed and restructured meat products. Alginates have been incorporated into sausage products, for texture modification (Abd El-Baki *et al.*, 1981). An important property of algin/calcium restructured meat products is their ability to achieve and retain shape and acceptable appearance in the raw refrigerated condition (Means and Schmidt, 1986) and this property is an advantage over items which are manufactured using conventional restructuring technology (addition of salts and phosphates), which bind only in the cooked state. The process of manufacture of meat products using sodium alginate and calcium source was patented and approved for commercial production (USDA/FSIS., 1986). Furthermore, restructured beef steaks prepared with calcium alginate were less discoloured than conventionally prepared restructured steaks (Means *et al*., 1987).

The cold-set gelation process requires the availability of calcium ions for completion of the algin/calcium gelation reaction and calcium salts results in instantaneous surface gelation of sodium alginate, while sequesterants such as sodium hexametaphosphate or sodium tripolyphosphate may be used to delay gelation (Cottrell and Kovacs, 1977). Dicalcium phosphate, calcium carbonate or calcium sulfate are generally used if an internal (bulk) setting method is chosen such as in the structured meat system described by Schmidt and Trout (1982). Although, the low solubility of calcium carbonate allows the slow release of calcium ions during manufacture of meat products, presence of unreacted sodium alginate often results in an undesirable (slippery) mouth feel in the final product (Means and Schmidt, 1986). Further, proposed that the addition of slow release acids could prevent the poor mouth feel by lowering pH and thereby increasing the solubility of calcium carbonate. A study by Means *et al*. (1987) reported on the use of glucono-delta-lactone as an acidulant in structured beef but found no improvement in product bind strength or mouth feel. Calcium alginate also improved the color of restructured pork chops and indicated that the calcium carbonate used in the alginate binder was responsible for the improved colour (Trout *et al*., 1990).

Experiments with model systems have indicated that meat proteins and algin/calcium gels interact primarily through electrostatic forces (Imeson *et al*., 1977; Hughes *et al*., 1980; Bernal *et al*., 1987). Calcium and algin have been shown to destabilize the thermal transitions of actin and myoglobin, respectively, in differential scanning calorimetry studies (Bernal *et al*., 1987). Reddy (2011) reported that restructured mutton product incorporated with 1.5% calcium alginate showed significantly ($p<0.05$) superior quality in respect to cooking yield, batter stability, WHC, proximate composition, textural properties and sensory characteristics. Addition of alginates in restructure mutton products have excellent cold-set gelation and yielded superior slicebility.

Carrageenan: For many centuries, red seaweeds have been harvested and used as foods. In China uses can be traced back even to 600 B.C. The name carrageenan was derived from the county of Carragheen, located at the south coast of Ireland, where red seaweed of the *Chondrus crispus* species, also known as Irish moss, was already used in food and medicine more than 600 years ago (Trius *et al*., 1996; Imeson, 2000).

Carrageenan is a naturally occurring polysaccharide in numerous Rhodophyceae species. It has a galactose backbone with differing proportions of ester sulphate groups and 3, 6-anhydro-D-galactose. These differences in composition provide a wide range of functional properties which are utilized in a large variety of foods. The different types of carrageenan display an extensive diversity of rheological behavior ranging from a viscous, non-gelling thickener to thermo-reversible gels, which can be firm and brittle but also soft and elastic (Bixler *et al*., 2001). Nowadays, most carrageenan is extracted from *Kappaphycus alvarezii,* previously known as *Eucheuma cottonii* and the most important source of kappa-carrageenan and *Eucheuma denticulatum,* previously known as *E. spinosum* and the main species for the production of iota-carrageenan (Bixler *et al*., 2001; Van de Velde *et al*., 2002).

Various types of carrageenan can be distinguished, indicated by a Greek prefix and differing in sulphate and 3, 6-anhydrogalactose content. The three most abundant and commercially most important types are kappa -, iota- and lamda-carrageenan. The sulphate content of the three main carrageenan types is reported to be 20-25% for kappa, 32-33% for iota and 35-41% for lambda. Furthermore, kappa-carrageenan has an anhydrogalactose content of 34% compared to 30% for iota and little or none for lambda (Norman, 1990).

Unlike lamda-carrageenan, kappa- and iota-carrageenan possess the ability to form gels. The presence of 3, 6-anhydrogalactose leads to a conformational change of the β-1,4-linked galactose residue causing an increased flexibility of the polymer chain and allowing a larger contraction of the random coil structure (Therkelsen, 1993). It also allows a helical secondary structure which is an essential feature for the build-up of a gel network. Helix formation of lamda-carrageenan is sterically hindered by the presence of a 2-ester sulphate group on the α-1,3-linked galactose residue (Trius *et al*., 1996).

Norman (1990) explained mechanism of gelation by carrageenan. When a carrageenan dispersion is heated, no significant particle swelling or hydration takes place until the temperature is raised above 40-60°C. Hydration of carrageenan results in an increase in viscosity as swollen particles offer more resistance to flow. At temperatures around 75-80°C thermal agitation overcomes the tendency of the carrageenan molecules to form helices and a transition to a random coil conformation takes place, leading to a drop in viscosity. On cooling, the viscosity of the solution is again found to increase until gelation takes place at temperatures below 40-50°C. The low temperature induces the 3,6-anhydrogalactose sequences to twist in a double helical manner with the sulphate groups projecting outward from the double helix. Carrageenan helices are interrupted by irregularities along the molecular chain, consisting of dissacharide units deviating from the ideal structure by the absence of the 3,6-anhydro ring.

The formation of helices is a necessary first step in the gelation process. Both iota- and kappa -carrageenan form parallel, right-handed, threefold helices with a pitch of 2.60 and 2.50 nm, respectively and helix formation only occurs in the presence of positively charged counter ions and is importantly affected by the amount and valency of the ions present (Piculell, 1995).

Gelation of carrageenan in aqueous solutions is a complex process that depends on the chemical structure of the polysaccharide, the nature of co- and counter-ions, polymer concentrations and temperature (Mangione *et al*., 2003). In the presence of gel-promoting cations, both kappa- and iota-carrageenan easily form thermo reversible gels upon cooling which exhibit hysteresis, or a difference between the setting temperature and the melting temperature during subsequent heating (Kara *et al*., 2003).

Applications of carrageenan in restructured meat products: Because of their ability to form gels and retain water, carrageenan's are widely used as texture modifier in gelled meat products, where they serve many specific purposes. During heat treatments water will often escape from the meat, resulting in purge. The diffused water and extracted meat proteins may appear on the surface as an undesirable jelly-like substance. Addition of carrageenan to cooked meats reduces these cooking losses and prevents the occurrence of the unwanted gelled surface layer (Jensen *et al*., 1995). Due to its ability to form a continuous gel network, carrageenan is also able to provide consistency to meat products, which in turn influences the slicing properties. The addition of carrageen includes an increase in yield, moisture retention, mouth feel and juiciness and a decrease in fat content and slicing loss (Trius *et al*., 1996; Imeson, 2000).

Foegeding and Ramsey (1987) reported that the addition of iota- and kappa-carrageenan to low-fat meat batters led to an increase in water-holding ability, rigidity and force-to-fracture. Shand *et al*. (1994) incorporated 0.5-1% kappa-carrageenan in structured beef rolls and found an increase in cooking yield and an improvement of several textural properties like hardness, force-to-fracture and binding strength. The low-fat sausage containing kappa-carrageenan scored a higher overall acceptance than the reference high-fat sausage, as evaluated by a sensory panel (Xiong *et al*., 1999). Hsu and Chung (2001) reported an increase in cooking yield and texture parameters like hardness, chewiness and adhesion when adding up to 2% kappa-carrageenan to low-fat emulsified meatballs. A reduction in cooking loss and expressible moisture and a rise in hardness and fracturability of beef gels was observed upon kappa-carrageenan addition (Pietrasik, 2003). Ulu (2006) found an improvement in the cooking yield and textural properties of low-fat meat balls in the presence of carrageenan. Reddy (2011) reported that restructured mutton product formulated with 1.5% carrageenan showed significantly ($p<0.05$) superior quality in respect to cooking yield, batter stability, WHC, moisture content, textural properties and sensory characteristics.

EFFECT OF MEAT PARTICLE SIZE IN RESTRUCTURED PRODUCT

An important factor affecting the texture of restructured meat products is their particle size and an increase in meat surface area causes increase in the availability of myofibrillar proteins for binding is the net consequence of comminution (Acton, 1972). The percentage of cookout significantly decreased as particle size became smaller (Chesney *et al*., 1978). The particle sizes of 2.5 and 5.0 mm in pre-rigor and aged beef steaks were studied by Seideman *et al*. (1982) and it was indicated that larger particle sizes were associated with lower texture desirability ratings and less tender beef steaks. Marriott *et al*. (1986) showed that particle size had a minimal effect on muscle cut resemblance, cooking loss, shear value and sensory attributes. Berry *et al*. (1987) indicated that thickness of the flake particle was as important as width of the flake particle in affecting texture. Penfield *et al*. (1992) indicated that larger flake size (1.9 cm) and salt improved quality and acceptability of restructured reindeer steaks in comparison with smaller flake size (1.3 cm). Small *et al*. (1995) investigated particle size and mixing time effects on sensory and physical properties of low-fat, high moisture pork frankfurters and indicated that changes in particle size affected in measured characteristics more than changes in mixing time and products obtained with a 2.0 mm plate had higher hardness values and total energy to shear than 1.4 mm plate. In the study of Sen and Karim (2003), the mutton meat was reduced in a meat mincer with an opening size of 5, 8, 12 and 20 mm and results showed that purge loss percent, cooking yield, shear force value and sensory scores were significantly affected by meat particle size. Cofrades *et al*. (2004) found that precooked restructured beef made with coarsely ground meat (1.4 cm) had higher Kramer Shear Force (KSF) values than finely ground meat (0.6 cm). Reddy (2011) reported that restructured mutton product formulated with 100% high value cuts and 1.5 cm particle size showed significantly ($p<0.05$) superior quality in respect to cooking yield, batter stability, WHC, moisture content, diameter shrinkage, protein extractability and collagen solubility, textural characteristics and sensory scores than restructured mutton products added with low value cuts and 2.5 cm particle size formulations.

QUALITY OF RESTRUCUTRED MEAT PRODUCTS

Cooking yield: Cooking yield was the difference in weight of meat samples before and after cooking (Murphy *et al*., 1975). Cooking loss or cook yield was related to oven temperature, relative humidity, sample dimensions (Bengtsson *et al*., 1976), cooking method (Quenzer *et al*., 1982) and internal product core temperature (Tanchotikul *et al*., 1989). Cooking yield and cooking loss result is the most important test for the meat industry to predict the behavior of the products during cooking due to various binders, non-meat ingredients or other factors (Pietrasik and Li-Chan, 2002).

The effect of particle size on yield of cooked product was studied by Reagan *et al*. (1983) and reported that cooking losses decrease as particle size decreases in restructured meat products. Boles and Shand (1998) found that neither method of size reduction nor size of opening affected the cook yield of restructured beef steaks. Addition of various proportion of connective tissues significantly ($p<0.05$) reduced the cooking yield of restructured beef steaks (Liu *et al*., 1990). Cook yield of restructured mutton steaks was significantly ($p<0.05$) affected by meat particle size and 20 mm particle size has more cook yield than 12, 8 and 5 mm particle size (Sen and Karim, 2003). Addition of salt and phosphate increased cooking yield due to increase in ionic strength and pH in restructured beef steaks (Trout and Schmidt, 1984). Cooking losses of restructured lamb roasts were decreased ($p<0.05$) by increasing the level of maceration of the muscle and by higher salt level (Ahmed *et al*., 1989). Intact and restructured beef steaks produced with salt/phosphate and algin/calcium treatment had lower ($p<0.05$) cooking loss than the restructured steaks separately made with crude myosin, whey protein, wheat gluten, soy protein isolate and surimi (Chen and Trout, 1991). Shand *et al*. (1993) observed significant ($p<0.05$) highest cooking yield in salt/phosphate structured beef rolls than algin/calcium and controls and ranges of cooking yields were 56.7 to 94.6%. Various mechanical treatments did not affect ($p>0.05$) cook loss when steaks were restructured using Na-alginate/Ca-lactate or Na-pectate/Ca-lactate (Raharjo *et al*., 1995).

Boles and Shand (1999) found that alginate-bound beef steakettes had significantly ($p<0.05$) lower cooking loss than fibrimix steakettes. Water-binding properties were markedly improved by addition of k-carrageenan and treatments with k-carrageenan had lower cooking and storage losses than the samples containing 6% muscle proteins without the hydrocolloid (Pietrasik, 2003). Salt level and processing conditions significantly affected ($p<0.05$) the cooking loss of restructured pork shoulder and lower the salt level and higher the processing temperature had the higher cooking losses of the product (Dimitrakopoulou *et al*., 2005). Cooking yield of restructured buffalo meat blocks incorporated with 10% added water was significantly ($p<0.05$) higher than those with 15% added water (Kumar and Sharma, 2007). Cooking loss was highest for the Activa-bound reformed beef steaks compared to the alginate, textor and fibrimix bind steaks (Lennon *et al*., 2010). Reddy (2011) reported that cooking yield was significantly ($p<0.05$) influenced by both meat particle size and type of meat cuts in restructured mutton slices. More high value cuts with less particle size formulation had more cooking yield than low value cuts added and big particle size formulations.

Batter stability: Addition of salt, polyphosphates and mechanical agitation causes extraction of salt soluble proteins create a fine protein matrix in homogenous batter and binding of meat chunks, thus stabilize the batters during further processing and cooking of restructured meat products. Clarke *et al*. (1988) reported that alginate added structured beef rolls had higher batter stability than salt-phosphate structured rolls. Charged alginate polymers in meat system compete for water to form a viscous sol or visco-elastic gel, thereby interfering with their structure-forming ability and gel matrix formation (Tolstoguzov, 1991; Xiong and Blanchard, 1993). In structured beef, Xiong (1994) reported that addition of connective tissue reduced the stability of beef batters.

Hughes *et al*. (1997) found increased emulsion stability in frankfurters formulated with carrageenan and 0.7% carrageenan incorporation resulted in the highest ($p<0.05$) emulsion stability (as total volume released) compared to 0.5% and controls. Lin and Keeton (1998) found that alginate added beef patties had more stable batters than carrageenan added patties. Candogan and Kolsarici (2003) found the addition of carrageenan had highest stability compared with carrageenan with pectin gel, high fat control and low fat control of frankfurter system. Addition of k-carrageenan significantly decreased the percentage of water loss from gel samples after centrifugation and improved water retention of meat gels (Pietrasik, 2003). The stability for restructured buffalo meat batter was significantly lower ($p<0.01$) than that of the emulsion form (Thomas *et al*., 2006).

Water holding capacity: Water Holding Capacity (WHC) is defined as the ability of food to hold its own or added water during application of forces like pressing, centrifugation, or heating (Hamm, 1960). Functional differences in water holding among meat treatments were more evident when yield was calculated as per cent meat weight. Maximum binding had occurred in sodium/phosphate products with 15% added water and in 30% added water products, the decreased ionic strength and protein concentration may have contributed to the lack of complete water binding in structured beef rolls (Shand *et al*., 1993). Sen and Karim (2003) found significant ($p<0.05$) influence of meat particle size on the WHC of restructured mutton steaks. Addition of connective tissue significantly reduced the WHC of restructured pork (Schilling *et al*., 2004). Decreasing NaCl concentration reduced the WHC of the restructured pork and in regression model, both NaCl and GdL showed significant linear interaction and quadratic effects ($p<0.001$) on WHC of restructured pork (Hong *et al*., 2008). Increased WHC can be attributed to improvement of the hydration and binding properties of the product via gum-water interaction or gum-protein-water interactions, which further depends on pH, structure and concentration of the alginates (Shand *et al*., 1993; Berry, 1997; Lin and Keeton, 1998; Xiong *et al*., 1999; Devatkal and Mendiretta, 2001).

The effects of carrageenan on the WHC of salt soluble meat protein gels and different kinds of gelled meat products have been extensively studied. Most sources report a better water retention in the presence of carrageenan (DeFreitas *et al*., 1997; Pietrasik and Duda, 2000; Pietrasik and Li-Chan, 2002; Pietrasik, 2003). However, in some cases the addition of carrageenan seems to have no or a very limited effect on the WHC of meat gels (Bernal *et al*., 1987; Foegeding and Ramsey, 1987; Barbut and Mittal, 1992). Verbeken *et al*. (2005) reported that carrageenan improved the WHC of meat products by its gelling characteristics and a protein matrix must be formed by added NaCl to proffer spaces in which carrageenan presents and interacts. Furthermore, they concluded that increasing the carrageenan concentration from 0 to 2 wt % causes an increase in WHC of about 5%. Reddy (2011) reported that small particle size formulations had significantly ($p<0.05$) higher WHC than big particle size formulations in restructured mutton product. He further concluded that more connective tissue fibers had less ability to hold water is the possible reason for less WHC values in low value cuts added formulations of restructured mutton product than their respective high value cuts mutton formulations.

pH: The significance of pH is well known in relation to physico-chemical and textural changes in meat. The quality factor affected by pH includes: color, texture, cooking loss, WHC, tenderness and binding characteristics of meat, juiciness, drip loss and microbial growth etc. (Duston, 1983). Meat pH is an important factor which affects WHC of meat (Hamm, 1986). Even slight changes in pH can affect product quality. Textural properties of restructured meat products mainly affected by the structure of the matrix formed by protein gel, solutes and particles entrapped in the gel, which in turn depends on factors such as pH, protein water binding ability, salt, fat content and the addition of non meat ingredients (Flores *et al*., 2007).

Generally cooked/product pH was more than raw meat because of protein denaturation (Tanford, 1968). Clarke *et al*. (1988) noticed that hydrogen ion treatment (addition of NaOH or HCl) affected ($p<0.01$) raw product pH, but no interaction with algin binder treatment of structured beef. Further, they found that cooking slightly resulted in slight increase in the pH of almost all of the 72 structured products compared to pH values of raw product. Alginates produced a linear increase in pH ($p<0.05$) with increasing concentrations of calcium carbonate and both calcium carbonate and sodium alginate increased the pH of restructured pork chops compared with control (Trout, 1989). Shand *et al*. (1993) observed that pH of raw samples from control and algin/calcium treatment was similar and lower ($p<0.05$) than that of salt/phosphate structured beef rolls. Suman and Sharma (2003) reported that particle size had no significant effect ($p>0.05$) on pH of cooked buffalo meat patties.

Use of alginates increased pH in restructured beef logs (Glicksman, 1982; Means and Schmidt, 1987; Means *et al*., 1987; Raharjo *et al*., 1989) but Boles and Shand, (1998) found cold set binders such as alginates and fibrimix and particle size did not affect pH of the beef steakettes. The differences in literature could be from different levels of alginate and GDL used in the manufacture of restructured beef logs (Boles and Shand, 1998). Lin and Keeton (1998) reported that the pH of raw, cooked and preheated low fat, precooked ground beef patties containing carrageenan and sodium alginate varied among treatments; however, these differences were relatively small.

As the progressing of storage, gradual increase in pH of beef steaks (Means *et al*., 1987) and in restructured turkey meat (Ernst *et al*., 1989) were noticed. The pH of the structured steaks stored under vacuum packaging has decreased gradually during refrigerated storage and become significant ($p<0.05$) for steaks added with algin/calcium and sodium/phosphate after 8-13 days (Means *et al*., 1987). Ernst *et al*. (1989) found that initial pH values of aerobically stored raw restructured ground turkey meat were higher ($p<0.05$) in the alginate and salt/phosphate samples than control. The pH of restructured beef steaks (Esguerra, 1994) has been reported to increase slightly with frozen storage. Storage period significantly increased pH values of meat products (Lawrie, 1998) and traditional Greek sausages (Papadima and Bloukas, 1999). Serrano *et al*. (2006) observed that cooking induced increase of pH was observed for all restructured beef steaks added with walnuts and frozen storage did not affect ($p>0.05$) pH of any of the restructured beef steak samples. The pH of raw pork patties decreased from 5.7 to 5.5 over the 12 day storage period and were unaffected by the addition of GSE (Carpenter *et al*., 2007). Addition of GSE did not significantly affect the pH of cooked refrigerated pork and beef (Rojas and Brewer, 2007), ground chicken breast (Brannan, 2009) and cooked pork (Sasse *et al*., 2009).

Shrinkage in diameter: Distortion (interior swelling, edge shrinking and curling) has been identified as a major problem with restructured steaks (Field, 1982). Berry *et al*. (1987) reported that restructured steak distortion was more extensive in steaks manufactured with large and small meat flakes compared to steaks processed from intermediate size meat flakes. Chen and Trout (1991) observed the diameter change (%) in restructured beef steaks produced with algin/calcium, salt/phosphate, crude myosin, whey protein, wheat gluten, soy protein isolate and surimi and concluded that the diameter of all steaks decreased after cooking and ranged from 12.6 to 17.3%. However, these decreases were not affected ($p>0.05$) by the binders. Thickness of all steaks decreased after cooking except those produced with salt/phosphate, which increased in thickness by 8.7%. Raharjo *et al*. (1995) did not noticed any significant difference in diameter shrinkage of restructured beef steaks formulated with alginates. Dimensional changes were significantly ($p<0.05$) affected by type of binder used to manufacture restructured steakettes but were not affected by method of size reduction or size opening used to reduce the size of meat (Boles and Shand, 1998). Overall restructured mutton steaks distortion (dimension and thickness) was more extensive in steaks manufactured with small particle size (Sen and Karim, 2003). Percent shrinkage was significantly ($p<0.01$) less in restructured buffalo meat blocks with 10% added water compared with 15% added water (Kumar and Sharma, 2007). Control mutton kofta showed reduction in diameter whereas, carrageenan and oat flour containing mutton kofta showed an increase in diameter by cooking (Modi *et al*., 2009). The highest diameter shrinkage was found in restructured mutton product with big particle size and low value cuts (Reddy, 2011).

Protein extractability: The increasing success of restructured meat products has been based on the efficient use of mixing or tumbling of meat with salt and phosphates for extraction of salt-soluble proteins and these proteins bind together chunks of meat in order to produce a texture similar to the more desirable steaks and chops (Pearson and Gillett, 1996).

Vadhera and Baker (1970) suggested that the myofibrillar or salt-soluble proteins are the primary constituents of the exudates which contribute to the binding strength of sectioned and formed products. Studies have indicated that salt, phosphates and agitation affect physical properties and the histological structure of meat (Theno *et al*., 1978; Booren *et al*., 1982; Ockerman and Kwiatek, 1985). Most of these studies have been based on tumbling and massaging as the selected mechanical agitation process to enhance myofibrillar protein extractability. Extensive physical disruption of cell membranes during tumbling (Cassidy *et al*., 1978; Theno *et al*., 1978) causes enough salt soluble protein exudate to the surface and to produce a creamy tacky appearance on the surfaces of the meat chunks.

Tumbling conditions had a significant effect on protein extractacted from the surface of the meat. Ghavimi *et al*. (1986) reported that meat tumbled in a nitrogen back flush atmosphere had higher ($p<0.05$) protein extraction values than in either vacuum or non vacuum atmospheres and the differences between vacuum or non-vacuum were not significant ($p>0.05$), vacuum tended to produce more extractable protein. Cheng and Ockerman (2003) reported that vacuum tumbling is more efficient in extracting soluble protein than non-vacuum tumbling if one location injection is used.

Increase in the amount of salt-extracted myofibrillar proteins between meats surfaces produced a concomitant increase in the binding strength of sectioned and formed meat products (Acton, 1972; Randall and Voisey, 1977). Schmidt and Trout (1982) indicated that efficacy of muscle chunk binding in a restructured product is determined by the amount of protein extracted, mechanical treatment, presence and concentration of added salts and temperature on heating. Prasad *et al*. (1987) observed the higher amount of salt-extractable myofibrillar proteins in lamb and mutton restructured roasts and concomitant increased binding ability of muscle chunks. Reports on the effect of protein solubility on cook yield have been mixed. Rathgeber *et al*. (1999) found no relationship between protein extractability and cook yield of finely comminuted turkey products. Farouk (2002) found that finely comminuted beef sausages with reduced sarcoplasmic protein content had lower cook yield and gel strain, which they attributed to either extraction of proteins or reduced solubility due to changes in postmortem conditions. Restructured mutton product formulated with small size particle was recorded highest total protein extractability than other formulations. Addition of low value cuts significantly reduced the protein extractability due to higher connective tissue proportion (Reddy, 2011).

Collagen content and collagen solubility: Recently, technological advances and processing combinations have been used to develop restructured products which resemble intact cuts of meat in appearance and taste which requires larger meat pieces (Huffman and Cordray, 1982). With use of larger meat pieces (as in chunked, formed and sectioned products), there is greater potential for detection of connective tissue, especially when using lower value cuts (Gillet, 1987). The connective tissue component is mainly collagen, with lesser amounts of elastin and reticulin. However, determining the precise mechanism of its influence on texture is complex. Liu *et al*. (1990) found that particle size did not affect ($p>0.05$) the collagen content of restructure roasts.

Different types and levels of connective tissue, with collagen as the primary protein, have varying effects on the properties of restructured meat products (Hamm, 1972; Rao and Henrickson, 1983; Jobling, 1984; Recio *et al*., 1986; Hermansson, 1987). While various types of connective tissue/collagen have been reported as desirable ingredients in certain meat products and levels of addition may be limited by collagen's functional properties, such as thermal shrinkage and gelatinization (Rao and Henrickson, 1983) and by nutritional deficiencies involving the amino acids methionine and tryptophan (Bodwell, 1987).

The role of connective tissue in restructured meat products has been examined as connective tissue residue were considered a major obstacle to consumer acceptance of restructured beef steaks (Breidenstein, 1982). Recio *et al*. (1987) reported that removing some, but not all of the heavy connective tissue of restructured beef steaks yielded acceptable products, but later work Recio *et al*. (1986) indicated that a sensory panel preferred salt-phosphate restructured beef steaks manufactured from shoulder clods which had been extensively trimmed of connective tissue than intermediate or no trim levels.

Experiments with model systems have indicated that meat proteins and algin/calcium gels interact primarily through electrostatic forces (Imeson *et al*., 1977; Hughes *et al*., 1980; Bernal *et al*., 1987). Ensor *et al*. (1990) concluded that collagen and the algin/calcium gel system apparently interacted in some manner that altered the negative effect of collagen shrinkage and thus helped to maintain the integrity of the cooked product.

Although myofibrillar proteins are the most important in muscle chunk binding, collagen also contribute to the binding characteristics of meat and ultimate texture of meat products (Randall and Voisey, 1977). Under appropriate conditions, collagen imparts texturizing, moisturizing, lubricating, viscoelastic and emulsifying properties to any food (Asghar and Henricwson, 1982). Age related changes in collagen plays an important role in the process of muscle chunk binding (Prasad *et al*., 1987) and increase in pyridinoline probably decreases the amount of salt-extracted proteins on the meat chunk surface, especially surfaces covered with connective tissue. Restructured mutton product processed with low value cuts had significantly ($p<0.05$) more collagen content than their respective products containing high value cuts (Reddy, 2011). He further concluded that low value cuts added restructured mutton product had significantly ($p<0.05$) lower collagen solubility than respective high value cuts formulations.

PROXIMATE COMPOSITION

Proximate composition of restructured meat products depend upon various factors like type of meat, cooking methods, particle size, type of communition method, fat content and binders.

Chesney *et al*. (1978) reported that proximate analysis for per cent moisture, ash and ether extract and protein of the formed and sectioned product was not affected by flaking or grinding and no significant differences were determined between two methods and processing temperatures. The fat and moisture content of restructured beef steaks was affected by method of size reduction and steaks made from sliced meat had a higher fat content and lower moisture content than steaks made from ground or flaked meat (Boles and Shand, 1998). Sen and Karim (2003) observed that particle size had no significant difference in moisture and protein content but fat content was affected by method of particle size reduction in restructured mutton steaks.

Moisture and protein content was significantly ($p<0.01$) affected by tumbling time and percentage protein in roasts varied inversely with cook yield and moisture content (Pietrasik and Shand, 2004). The restructured nuggets had significantly higher moisture ($p<0.01$) and protein ($p<0.05$) contents and a lower fat ($p<0.01$) content than the emulsion nuggets (Thomas *et al*., 2006). Kumar and Sharma (2007) found that restructured buffalo meat blocks prepared with incorporation of 10 and 15% added water, respectively showed no significant difference in proximate composition. As salt concentration increased from 0.5 to 1.0%, moisture increased ($p<0.05$), but protein decreased ($p<0.05$) and higher salt concentration increased the water binding capacity of the meat which caused a subsequent dilution of the protein content (Ahmed *et al*., 1989). Ensor *et al*. (1991) noticed that myofibrillar proteins are very unstable in the presence of alginate ions in meat systems. Various researchers noticed that addition of alginate enhanced the moisture retention thorough more binding ability of alginate ions with water molecules (Shand *et al*., 1993) in restructured beef rolls and (Lin and Keeton, 1998) in low-fat ground beef patties. Boles and Shand (1998) reported both alginate and fibrimix binding systems did not ($p>0.05$) significantly influence the fat content of restructured beef steaks. Restructured beef steaks manufactured with alginate had a higher protein content than did steakkettes made with fibrimix but moisture content is vice versa (Boles and Shand, 1999). Xiong *et al*. (1999) observed that variation in protein content in low fat beef sausages added with various hydrocolloids. Salt level significantly affected ($p<0.05$) the moisture, protein, fat and ash content of restructured cooked pork shoulder and higher the salt level had more moisture content (Dimitrakopoulou *et al*., 2005). Reddy (2011) reported that small particle size formulations of batter and cooked restructured mutton product had more moisture content values than big particle size formulations. Protein content of both batter and cooked restructured mutton products were did not significantly ($p>0.05$) influenced by meat particle size and type of meat cuts. The variations in the per cent protein value due to addition of low value cuts are statistically not significant. The significant variations in fat percent in small particle size formulations of restructured mutton product might be due to more adhesive loss to machine blades while mincing. Addition of low value cuts did not significantly ($p>0.05$) influenced the fat content of restructured mutton product.

TEXTURE PROFILE

Texture, appearance and flavor are the three major component of food acceptability (Bourne, 1978). Texture is determined by using sensory panels or instrumental techniques. Sensory panels are costly, time consuming and require highly trained panelists for consistent results. Among instrumental techniques developed, Instron texture profiling is the most popular (Spadaro and Keeton, 1996). The binding between meat pieces is mostly achieved by physical entanglement of various sizes and shapes of pieces, aggregation of extractable proteins and subsequent gelation by using either hot-set (thermal) or cold-set (chemical) mechanisms (Boles and Shand, 1999).

Massaging resulted in a reduction of textural parameters of all the muscles massaged, compared to the non-massaged controls and depending on the massaging time, the rate of change differed between the muscles (Lachowicz *et al*., 2003). Pietrasik and Shand (2004) found that roasts tumbled for 16 h exhibited lower hardness and chewiness than those non tumbled and tumbling was applied for 2 h and increased tumbling time resulted in progressively higher hardness of non tenderized roasts. Further, they reported that regardless of the injection level, longer tumbling time also resulted in a decrease in cohesiveness and led to formation of softer and visually more brittle roasts. Pre-tumbling treatment significantly ($p<0.05$) reduced hardness and chewiness of beef roasts (Pietrasik and Shand, 2005). Massaging resulted in a reduction of hardness and chewiness and an augmentation of cohesiveness, however the drum speed and time-dependent changes differed between the muscles (Zych *et al*., 2007).

Cardello *et al*. (1983) found more springiness in steaks made with larger flakes than smaller flakes. Young *et al*. (1987) studied the effect of STPP and NaCl on the textural properties of chicken breast meat patties and concluded that as NaCl is increased, the patties became softer and springier and STPP increased cohesiveness and springiness but had little effect on hardness. Clarke *et al*. (1988) observed that more chewiness values of restructured beef steaks formulated with alginates than other hydrocolloids. Strange and Whiting (1990) observed more instrumental hardness values in restructured beef steaks by added connective tissue. Chen and Trout (1991) studied the textural properties of restructured beef steaks with various binders and found that calcium carbonate/sodium alginate binder had superior texture profile scores compared to the steaks added with crude myosin, salt/phosphate, whey protein, wheat gluten, soy protein isolate and surimi. Nath *et al*. (1995) found significant increase in gumminess values due to various particle sizes in restructured chicken patties. Letelier *et al*. (1995) reported significantly higher values for cohesiveness in pre-blended cooked beef salamis prepared from small size flaked sinews than that from larger sinews. A number of authors have found comminuted products with k-carrageenan to be tougher than control ones. It has been reported that addition of carrageenan increased gel strength of Salt Soluble Meat Protein (SSMP) in model systems (DeFreitas *et al*., 1997) and hardness, adhesion, chewiness in beef sausages (Xiong *et al*.,1999) and low fat emulsified meatballs (Hsu and Chung, 2001). Candogan and Kolsarici (2003) noted that alginate added steaks had more chewiness than control and other gums added restructured steaks. Further, they reported that salt-phosphate steaks had more gumminess values than alginate steaks. Addition of k-carrageenan in beef gels resulted in a decrease in their springiness and cohesiveness and led to formation harder but more brittle gels (Pietrasik, 2003). Serdaroglu *et al*. (2005) opined that the quality of gel matrix had an important role in determining the cohesiveness of cooked meat products. Addition of alginates increased springiness values in salami type products (Barbut, 2005). Thomas *et al*. (2006) reported that texture profile analysis of emulsion and restructured buffalo meat nuggets differ significantly in all parameters except hardness and chewiness ($p<0.01$).

Reddy (2011) reported that as the particle size increases and addition of low value cuts, more chewiness values of restructured product were noted. He further noticed that restructured mutton product formulated with big particle size and low value cuts had significantly ($p<0.05$) more chewiness values than other formulations. As the particle size decreases, more cohesiveness was noted in restructured mutton product. Restructured mutton product made with small particle size was significantly ($p<0.05$) higher gumminess values than big particle size formulations. As the particle size increases, the gumminess values were reduced due to the less requirement of sticking forces needed to break the meat particle by the probe of texturometer. Furthermore, reduced hardness values were observed in restructured mutton product processed with small particle size which might be due to more moisture retention than their respective big particle size formulations. Addition of low value cuts in restructured mutton product also significantly ($p<0.05$) increased the hardness values. As the meat particle size increased, the higher springiness values were noted and the possible reason is less adhesion between meat particles.

SENSORY QUALITY

Sensory evaluation is an attempt to predict consumer behavior with respect to food acceptance. A wide range of sensory tests- ranking, category and profile techniques- have been used to assess the tactile, appearance, texture, flavor, juiciness and hedonic (liking) attributes of restructured meats (Ford *et al*., 1978; Cardello *et al*., 1983).

The sensory perception of tumbled meat is studied previously, but results are conflicting. Cassidy *et al*. (1978) reported differences in the ultra structure after tumbling and suggested that an increased disruption contributed to a superior tenderness. Chesney *et al*. (1978) found slightly less desirable cohesion for pork chops restructured with 12.7 mm size meat particles compared to chops restructured with either 6.9 or 3.0 mm size particles. Instrumental tenderness measurements confirm this hypothesis that less force was needed to deform tumbled meat (Judge and Cioch, 1979; Chow *et al*., 1986), but sensory results diverge on this subject (Bedinghaus *et al*., 1992).

Marriott *et al*. (1986) reported that particle size had no effect on flavor and juiciness of restructured pork but tenderness was decreased as the particle size increased from 3 to 9.9 mm. Furthermore they found an increase in connective tissue detected by panelists with the larger particle size. Berry *et al*. (1987) reported a preference for steakettes made with larger flaked meat particles and method of size reduction influenced the acceptability of the beef steakettes. Boles and Shand (1998) reported that opening size had no affect on the acceptability of alginate restructured beef steakettes and juiciness of steakettes made from flaked meat was liked significantly ($p<0.05$) less than steakettes made from ground meat but was no different from steakettes made from sliced meat. Sen and Karim (2003) reported that opening size had no significant effect on acceptability of restructured mutton steaks.

In production of restructured steaks from veal trimmings and leg meat, use of salt/phosphate and 0.5% sodium alginate/0.5% calcium lactate did not increase ($p>0.05$) juiciness, flavor, texture or color scores compared to their respective (Raharjo *et al*., 1994). Restructured buffalo meat rolls had markedly better sensory scores in comparison to emulsion form meat rolls and smoking had improved the appearance, flavor and acceptability of the rolls (Anjaneyulu *et al*., 1995). Nute (1996) studied eight formulations of restructured steaks and assessed for texture, saltiness, juiciness, taste, meatiness and overall liking and concluded that consumer acceptability varied in fat level, salt level, mixing time and differences were found in saltiness, juiciness scores. He and Sebranek (1996) found that kappa-carrageenan improved the texture of sausages, but they still had lower scores than full fat controls. Bloukas *et al*. (1997) noted the beneficial influence of alginates and carrageenan on the sensory quality of low-fat sausages. The differences noted in the instrumental textural analysis were also detected in the sensorial evaluations. Boles and Shand (1999) reported that when alginate was used to manufacture restructured beef steakettes no difference in the acceptability of colour, flavor, juiciness, texture, mouth coating and overall palatability was determined but Fibrimex was used to manufacture the steakettes a significant difference in the acceptability of juiciness, texture and overall palatability was seen. Candogan and Kolsarici (2003) noted only slight improvements in the texture of low-fat frankfurters caused by carrageenan addition. Cierach *et al.* (2009) reported that sausages produced with 10% of fat and carrageenan was evaluated even higher than the higher fat control.

Juiciness scores of smoked buffalo meat chunks were reduced as the storage period advances. Reduced colour scores was mainly due to decline in nitroso pigment during storage (Thomas, 1992) and non enzymatic browning resulted from reaction between lipid oxidation products and amino acids (Man *et al.*, 1995). As the progressing of storage reduction in colour scores noticed by Das *et al.* (2008) in goat meat patties and by Thomas (2007) in shelf stable pork sausages.

Storage period did not significantly ($p>0.05$) influenced the chewiness, cohesiveness and mouth coating scores of various comminuted meat products (Awad *et al.*, 1968; Ockerman and Organisciak, 1979; Bhattacharya *et al.*, 1988; Esguerra, 1994; Wang *et al.*, 1999; Reverte *et al.*, 2003). But contrary to these reports, chewiness scores significantly influenced by storage, but cohesiveness scores did not significantly ($p>0.05$) influenced (Schwartz and Mandigo, 1976; Coon *et al.*, 1983).

Reduced flavour scores during refrigerated storage could be attributed to the oxidation of fat (Santamaria *et al.*, 1992) as evident from TBARS values and liberation of free fatty acids (Branen, 1979) as well as increased microbial load (Sahoo and Anjaneyulu, 1997).

A significant change takes place in sensory attributes of meat product during storage. Brewer *et al.* (1992) concluded that significant quality deterioration could be expected during frozen storage of high and low fat, carrageenan extended beef patties. Gupta *et al.* (1993) found reduced flavour scores in mutton and mutton+chicken sausages during refrigerated storage. Reduced juiciness scores were noted as the progression of storage period by Sahoo and Anjaneyulu (1997) in buffalo meat nuggets. Thomas *et al.* (2006) reported that sensory scores for the appearance and flavor of emulsion and restructured nuggets did not significant during the initial storage and restructured nuggets retained its juiciness throughout storage. Furthermore, they reported that panelists had a significantly higher preference for the texture of restructured nuggets, attributed to larger particle size and these were significantly ($p<0.05$) more acceptable than emulsion nuggets. The restructured beef steaks treated with beefy flavoring agent and antioxidant had scored higher ($p<0.05$) on overall acceptability, tenderness, juiciness and beefy flavor, when compared to control (Stika *et al.*, 2008). Reddy (2011) reported that neither the meat particle size nor type of meat cuts addition significantly ($p>0.05$) influenced the colour and flavour scores of restructured mutton product. He further concluded that there was a significant difference ($p<0.05$) found in chewiness scores of restructured meat products due to particle size, but not type of meat cuts. As the meat particle size increased, the chewiness scores tended to increase. The mean scores of cohesiveness differ significantly ($p<0.05$) between different formulations with respect to particle sizes, but no significance effect was observed in cohesiveness of restructured mutton product manufactured with different low and high value meat cuts. Furthermore, the mean scores of juiciness was significantly ($p<0.05$) influenced by different particle sizes, but no difference in juiciness scores were observed by addition of various type of meat (low and high value) cuts in restructured mutton product. Restructured mutton product with small particle size formulations rated with more overall acceptability than big particle size formulations.

Apart from these, many factors affecting the quality of restructured meat products namely colour, comminution and formation, flaking, various mechanical processing variables like tumbling time, tumbler design, massaging time, massager design, blending/mixing time, meat type, type of meat cuts, fat content, high pressure and various ingredients like salt, phosphates, vegetable additives, binders, enzymes like transglutaminase, other polysaccharides, blood based binding agents, crude myosin extract, surimi, egg white powder, gelatin and these factors/agents action on quality attributes of restructured meat products need to study in depth.

MAJOR CONSTRAINTS AND SOLUTION

Lipid oxidation: Lipid oxidation in meat products is initiated when polyunsaturated fatty acids react with molecular oxygen, via free radical chain mechanism, forming peroxides followed by a series of secondary reactions leading to the degradation of lipids and development of oxidative rancidity which adversely affect the nutritional quality and safety of meat and meat products (Gray and Pearson, 1987). Lipid oxidation is influenced by the composition of phospholipids, amount of polyunsaturated fatty acids, presence of metal ions, oxygen, haeme pigments, mechanical processes and addition of salt during processing. The changes in meat products quality caused by lipid oxidation are manifested by adverse changes in colour, flavour, nutritive value and production of toxic compounds (Jensen *et al*., 1998). Hence, it is radical to control these changes for better storage stability and acceptability of meat and meat products.

Lipid oxidation is one of the major problems in the development of new convenient meat products (Gray and Pearson, 1987). Oxidation and colour fading are two major problems in retail acceptance of the restructured meat (Pearson and Dutson, 1987). A highly acceptable restructured chicken slice without addition of extra fat has been developed as a novel meat product (Mandal *et al*., 2002). But increase in TBA and tyrosine values of this product were observed under refrigerated storage. The product was found to be acceptable only up to 10th day of storage under refrigeration. On 15th day, product had pale appearance and unpleasant odour. Gizzard was successfully added in the restructured chicken block up to 50% without any adverse effect (Mandal *et al*., 2011). The gizzard added product was also prone to oxidation both under refrigerated and frozen storage (Sudheer *et al*., 2011a). Sensory scores of the restructured chicken block decreased significantly ($p<0.05$) on the 10th day of storage (Sudheer *et al*., 2011b). The gizzard added product also had a storage life only upto 10th day under refrigerated storage. The product was not subjected to sensory evaluation on 15th day due to oxidative changes. Use of natural antioxidants has been found to have an ameliorating effect on these undesirable changes produced via oxidation.

The most common strategies for preventing lipid oxidation are the use of antioxidants and restriction of access to oxygen (Tang *et al.,* 2001). Antioxidants are those compounds which help to delay or inhibit lipid oxidation when added to foods, thereby minimizing rancidity, retarding the formation of toxic oxidation products, helping to maintain the nutritional quality and increasing the shelf life of food products (Fukumoto and Mazza, 2000). Antioxidants can bind to metals, scavenge reactive oxygen species that initiate or perpetuate oxidation, quench high-energy oxygen species thus prevent formation of peroxides or decompose lipid peroxides. The synthetic compounds with antioxidant properties like butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) etc., are not encouraging in meat and allied industry due to their toxic potential and carcinogenic effect (Jayaprakasha *et al*., 2003). Use of natural antioxidants has been found to have an ameliorating effect on these undesirable changes produced via oxidation.

NATURAL ANTIOXIDANT

The use of natural preservatives to increase the shelf-life of meat products is a promising technology since many herbs, plants, fruits and vegetable extracts or powders have antioxidant and antimicrobial properties (Biswas *et al*., 2012). Antioxidant activity of *drumstick* leaves has been reported in meat and meat products. The crude extract of *drumstick* leaf can actively scavenge free radicals and thus prevent cellular damage (Sreelatha and Padma, 2009). Hazra *et al*. (2012) reported a significantly lower thiobarbituric acid value in cooked ground buffalo meat treated with drumstick leaves extract (1.5%). Significant differences in the pH values were observed among the restructured chicken slices formulated with leaf powders at 1% (drumstick, mint and curry leaves) and BHT (200 ppm) including control during 20 days of storage at refrigerator.

Restructured chicken slices prepared with drumstick leaf and curry leaf powders (1%) did not show any significant differences in the FFA values during the entire storage period (Najeeb *et al*., 2014a, 2015a) and the sensory scores were not affected significantly even up to 20 days of storage under refrigeration due to their antioxidant activity (Najeeb *et al*., 2014a, 2015a). Addition of tomato powder at 2% level in frankfurters decreased the oxidation during 60 days of refrigerated storage (Eyiler and Oztan, 2011). Restructured chicken slices added with fruit powders (red grapes, gooseberry and tomato) at 1% and BHT (200 ppm) had significantly ($p<0.01$) lower TBA values than control products except on 1st day where difference in the TBA values of control and tomato powder added products were not significant (Najeeb *et al*., 2014b, 2015b).

It was found that raw ground goat meat product was not acceptable after three days while curry leaf powder added product was acceptable up to seven days in refrigerated storage (Das *et al*., 2011). Interestingly, it was reported that chicken patties treated with BHT had a higher TBARS values than curry leaves extract treated samples (Devatkal *et al*., 2011). Biswas *et al*. (2012) reported a significantly ($p<0.05$) lower TBA value in raw ground pork meat treated with curry leaf extract stored at refrigeration (4±1°C) temperature than control. Reduction in TBARS values were observed in chicken patties treated with curry leaf extract (2%) compared to control during eight days of storage under refrigeration.

RECENT DEVELOPMENTS IN RESTRUCTURED MEAT PRODUCTS

In recent years lot work has been done in different aspects of restructured meat products. Restructured buffalo meat rolls had better acceptability up to 15 days at 4±1°C in LDPE pouches (Anandh *et al*., 2011) during storage. The use of vacuum tumbling for 45 min improved the physico-chemical, microbiological and sensory quality of the chicken tikka (Bharti *et al*., 2011). Sudheer *et al*. (2011a) reported decreased flavour scores of restructured chicken product during refrigerated storage mainly due to oxidation problem. In low fat restructured chicken product there was a significant increase in standard plate count and oxidation values during frozen (60 days) storage (Sudheer *et al*., 2011b).

The fresh liquid whey were added to a restructured cooked ham formulations up to 38% with similar results to products cured with conventional formulation (Dutra *et al*., 2012). Fluid whey addition had non-significant effect on the products lightness (L^*) and yellowness (b^*); however, when whey replaced at more than 50%, it induced lowest redness (a^*) values (Dutra *et al*., 2012). The inclusion of liquid whey as a substitute for water in the cure formulation of cooked ham had no effect on overall impression and texture (Dutra *et al*., 2012). Malav *et al*. (2012) evaluated the effect of water chestnut flour on quality and storage stability of restructured chicken meat product and found that 10% water chestnut flour (1:1 hydrated) can be used as optimum level and the products were found acceptable up to 10 days at refrigerated storage.

Sen (2013) revealed that restructured mutton slices incorporated with 1.5% calcium alginate recorded significantly higher cooking yield, batter stability and water holding capacity, moisture and fat retention values compared to control and 0.5 and 1.0% calcium alginate samples processed by cold-set binding system. Addition of various levels of calcium alginate significantly influenced the per cent moisture and per cent protein content of restructured mutton slices developed by cold-set binding system (Sen, 2013). About 1.5% calcium alginate added restructured mutton slices had significantly highest chewiness, cohesivenss, gumminess and less hardness values than control sample. Furthermore, restructured mutton slices added with 1.5% calcium alginate had significantly highesr sensory scores than remaining formulations (Sen, 2013).

Addition of grape seed extract at 0.1% enhanced the shelf life of restructured mutton slices, which can be stored up to 28 days under refrigeration (Reddy *et al*., 2013). Restructured mutton slices prepared using grape seed extract had superior sensory scores when compared with butylated hydroxyanisole (BHA) during refrigerated storage under aerobic and vacuum conditions (Reddy *et al*., 2013). Addition of grape seed extract (0.1%) significantly reduced the total psychrophilic count and coliform counts in aerobic and vacuum packaged restructured mutton slices during refrigerated storage for 14 days and 28 days respectively (Reddy *et al*., 2013). Restructured Mutton Slices (RMS) added with 0.1% grape seed extract had significantly lower TBARS values, free fatty acid values than control and RMS added with butylated hydroxyanisole in both aerobic and vacuum packaging methods during refrigeration temperature (4±1°C) (Reddy *et al*., 2013).

For restructured chicken meat blocks 9% sorghum flour (1:1 hydration, w/w) and 6% potato (boiled and mashed) was found optimum as extenders. The product was acceptable up to 15 days at refrigeration storage (Malav *et al*., 2013). The restructured chicken meat blocks extended with 9% sorghum flour (1:1 hydration, w/w) and 6% potato (boiled and mashed) retained good to very good acceptability when stored aerobically in Low Density Polyethylene (LDPE) pouches under refrigeration storage for 15 days without any marked sensory quality (Malav *et al*., 2013). The restructure goat meat products with optimum physico-chemical and sensory attributes can be prepared by 15% level of added water, 15 min massaging time and 50 min cooking time (Gadekar *et al*., 2013).

The effect of 8 and 10% Green Plantain Pulp (GPP) and 6,9 and 12% Hydrated Soy Chunks (HSC) as an extender meat block were evaluated. The general appearance, flavour, binding strength, texture, juiciness and overall acceptability score decreased with increasing levels of extender whereas for soy added products binding and texture scored increased in comparison to control. However, all the sensory attributes of the meat block extended with 8% GPP and 6% HSC were comparable with control and found optimum for the formulation of restructured chicken meat product (Sharma *et al*., 2013). The restructured chicken meat product was extended with 5.0, 7.5 and 10% Hydrated Colocasia Flour (HCF) and the optimum incorporation level of HCF was found at 7.5% on the basis of sensory scores, physico-chemical properties and the microbial quality (Talukder *et al*., 2013). The sensory attributes of the restructured chicken meat product with 7.5% HCF showed significantly higher values for general appearance, flavour, texture and overall acceptability (Talukder *et al*., 2013). Total plate count for products without extender and 10% extender followed a gradual but non-significant increasing trend during refrigerated storage period, but in products with 5.0 and 7.5% HCF, increment was significant in comparison to without extender (Talukder *et al*., 2013).

The restructured pork block prepared with 2-3 cm meat chunks had significantly lesser shear force value and more tender compared to 4-5 cm meat chunks (Gurikar *et al*., 2014). Increased gumminess, chewiness and cohesiveness values were observed for the restructured pork block prepared with large size meat chunks (Gurikar *et al*., 2014). Massaging time of 10 min was found optimum compared to 6 and 8 min in preparation of restructured pork blocks (Gurikar *et al*., 2014).

Aerobic mesophilic count significantly declined on day 30th and thereafter showed an increase on 60th day. The psychrophiles were not detected in the restructured goat meat product on 30th days, but grew in the control and alpha tocopherol treatment on 60 and 90th days. Coliforms were not detected during frozen storage in the restructured goat meat product (Gadekar *et al*., 2014).

The effect of sodium ascorbate (500 ppm) and alpha tocopherol acetate (10 ppm) on storage stability of restructured goat meat during refrigeration and frozen storage indicated that use of antioxidants improved lipid stability of the products (Gadekar *et al*., 2014). The application of plasma powder rehydrated in sodium chloride aqueous solution (0.5%, w/v) on untreated meat surfaces produces the highest binding (De Avila *et al*., 2014). Flax seed flour (FF) as a binder in restructured mutton chops at 1% significantly improved general appearance, binding, texture and overall acceptability (Sharma *et al*., 2014). Addition of 1.5% carrageenan had significantly highesr cooking yield, batter stability and water-holding capacity than control, 0.5 and 1.0% carrageenan added Restructured Mutton Slices (RMS) (Reddy *et al*., 2015). The RMS processed with 1.5% carrageenan had significantly highest moisture and lowest protein than remaining treatments. Addition of carrageenan significantly improved both water and fat retention values than control (Reddy *et al*., 2015). The RMS formulated with 1.5% carrageenan had significantly higher chewiness, cohesiveness, gumminess, springiness and lowest hardness values than control and remaining treatments (Reddy *et al*., 2015). Addition of different levels of carrageenan significantly influenced all sensory attributes and rated better for RMS with 1.5% level of carrageenan (Reddy *et al*., 2015).

CONCLUSION

In response to shifts in consumer demand, different sectors of the food industry are competing to identify and provide a greater variety of processed and value-added meat products. The food service industry has benefited from consumer’s desire for convenience. The retail food and meat industry, however, is now responding to the new challenges by offering consumers a variety of processed, ready-to-cook and ready-to-eat meat and meat products. For catering to the consumer needs, these processed and restructured meat products are fulfilling the gaps. Restructuring technology has immense benefit for processers regarding the utilization of low value carcass cuts, different variety of non-meat ingredients for production of value added meat products thus increasing the economic strength of producers/processors. Consumers also greatly benefited due to availability of various convenient ready to eat and ready to cook meat products. For restructured meat products to become more economically feasible, less tender meat cuts such as the chuck, carcass and long bone trimmings must be used. Since the muscles of the chuck are more variable in collagen solubility, methods of reducing the sensory panel detectable connective tissue must be further investigated. In addition, restructured research should be aimed at finding methods of increasing meat binding properties so that the texture of restructured meat products more nearly simulates that of intact muscle steaks. Furthermore, for increasing the shelf life of restructured meat products use of different packaging methods, natural anti-oxidants, storage facilities are need to be developed for commercial applications.

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