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Poultry – the versatile food

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3.1 INTRODUCTION

Poultry meat continues to play an important role as a source of high-quality protein in the human diet, although as stated earlier [1] the *per capita* consumption varies widely from country to country. The diversity of the product continues to grow, with 'corn-fed' and 'farm-house' chickens readily available in the UK, where 'free-range' turkeys make up some 10% of the turkey market [2]. The Bronze Breasted turkey, which attracts a price premium over the conventional white-feathered bird, has been reintroduced in the UK, albeit on a limited scale.

Breeding programmes continue to develop faster-growing birds and in some cases alter the characteristics of the bird. For instance, currently broiler chickens have higher yields of breast meat and lower yields of legs than their counterparts of the early 1980s [3].

The forms in which poultry is marketed continue to change, with uncooked chilled whole chickens taking an approximately equal share of the market to frozen birds compared with a ratio of 1:2 some 10 years ago. Overall the proportion of whole birds sold continues to decline as more carcasses are converted to portions [4].

As reported previously [1], there are advantages to be gained in further processing the carcass as soon as possible after slaughter, but the time *post mortem* when carcasses may be portioned or stripped of meat is determined by the fact that cutting before the onset of rigor induces toughness in the meat. In attempts to alleviate the problem,

research groups in Europe and the USA have studied the effect of electrical stimulation on meat tenderness. The general conclusion to be drawn from the work to date is that the technique can be used to reduce the time chickens should be held before deboning, but that its application does not completely eliminate the requirement for a holding period [5]. However, recent studies in which chickens were stunned using argon rather than electricity suggested that chilled carcasses might be deboned 1 h after slaughter without loss of meat quality [6].

The range of value-added and restructured products available to the consumer continues to expand. The mechanisms by which the meat proteins interact during the formation of such products have been under intensive investigation in recent years, and the main purpose of this chapter is to review both this work and that relating to new studies on mechanically recovered poultry meat.

3.2 FUNCTIONALITY OF POULTRY MUSCLE PROTEINS

The light breast meat of chicken and turkey contains more protein than the dark leg meat, although the actual quantities present may vary with bird sex or strain, or method of carcass preparation, e.g. immersion-chilling vs air-chilling [1, 7–9]. Thus one could expect to find a variation in product quality in those cases where formulations are determined on meat weight alone.

3.2.1 Extraction and solubility of proteins

Studies on poultry meat proteins continue to attract a great deal of attention, with particular emphasis on the salt-soluble protein (SSP) fraction which is generally extracted at ionic strengths above 0.3 and contains many of the myofibrillar proteins. Since components of this fraction are essential in determining the binding properties of meat pieces in products such as roasts, and probably act as emulsifiers during sausage preparation, much recent research work has been concerned with the extractability and/or solubility of SSP under various conditions.

Investigations using ratios of comminuted poultry meat : extractant ranging from 1 : 2 to 1 : 20 have shown that more protein is extracted from breast meat, and that the amount of protein extracted from muscle homogenates is influenced by time of extraction, salt concentration, presence and absence of phosphates and the pH value

at which extraction is performed [7, 8, 10–12]. Such variation may be expected to influence the properties of processed products, e.g. hardness of frankfurters and sausages can be changed by altering the salt and phosphate levels in the meat batters [12, 13].

Richardson and Jones [8, 14] showed that at the natural (ultimate) pH value of the tissue, the amount of protein extracted from turkey muscle rose rapidly between 0.0 and 0.15 M NaCl and then rose more slowly up to 1.2 M. When the pH values of homogenates in either 0.5 or 1.0 M NaCl were adjusted to between 5.0 and 7.0, it was found that the increase in extractability was greatest between pH 5.0 and 5.7 and then tailed off. In contrast to the above studies with turkey tissue, an investigation in which chicken myofibrils were used rather than meat homogenate showed that protein extractability in 0.6 M NaCl was minimal at pH 5.5 but both leg and breast showed a pH-dependence, breast being more affected between pH 5.75 and 6.0 [15]. Whether the noted variations were actually due to species difference or to differences in methods used in the two laboratories was not resolved.

A somewhat different approach to the question of protein solubility was adopted by Foegeding [16] who used 0.5 M NaCl containing pentasodium tripolyphosphate to isolate proteins from washed turkey muscle and then investigated the solubility of the salt-soluble protein fraction at salt concentrations of 0.25 and 0.5 M and pH values of 5, 6 and 7. Solubility was greatest at 0.5 M NaCl, pH 7.0, while at pH 6.0 solubility was markedly dependent on salt concentration. Gel electrophoresis indicated that insignificant quantities of the myofibrillar proteins, myosin and actin, were soluble at 0.25 M NaCl, pH 5 or 6, or at 0.5 M NaCl, pH 5.0. A subsequent study [11] showed that extraction for 120 min at pH 6.5, 0.5 M NaCl produced more total protein and larger quantities of myosin and actin than 10-min extraction, but that when the solubilities of extracts were examined at salt concentrations between 0.15 and 0.5 M, 90% of the protein in the 10-min extract remained soluble at 0.15 M compared with the 73% of the 120-min extract. Major decreases in solubility for both types of extract occurred between 0.30 and 0.25 M NaCl. These observations go some way to explaining why other authors failed to find significant quantities of myosin when turkey meat slurries or patties were extracted with low concentrations of NaCl (0.17–0.34 M) and various phosphates [10, 17].

Some of the observations on homogenates and comminuted meat bear directly on the situation with pieces of meat. Froning and Sackett [18] found that the injection of 1.2 M NaCl and various

phosphates into turkey breast meat generally increased the quantity of myofibrillar protein present in the surface exudate after 'tumbling' of the meat, the greatest effect being noted with a mixture of sodium triphosphate and sodium hexametaphosphate. SDS polyacrylamide gel electrophoresis showed actin and the heavy chains of myosin to be the major myofibrillar proteins present in the exudate.

3.2.2 Gelling of poultry muscle proteins

In many instances desirable quality attributes such as texture and the water-holding properties of meat products result from thermally induced unfolding and subsequent gelation of muscle proteins to form a three-dimensional matrix. The salt-soluble myofibrillar proteins, myosin and actomyosin, are particularly involved in the gelation process, while the water-soluble, or sarcoplasmic proteins, or connective tissue, are said to play little or no part in the process [19]. However, while myofibrillar proteins from duck breast muscle formed stronger gels than sarcoplasmic proteins under the same conditions of pH and ionic strength, sarcoplasmic gels were apparently formed more easily [20].

Although turbidity measurements on chicken breast actomyosin at a concentration of 0.5 mg/ml showed that protein-to-protein interaction was initiated at 30–31°C [21], studies in which higher levels of myosin (10 or 25 mg/ml) were employed [22] showed that gelling commenced at temperatures above 40°C, the actual temperature of initiation depending on whether heating was carried out isothermally or by thermal scanning when the temperature was changed at a uniform rate. Wu *et al.* [22] used a thermal scanning rheology meter to continuously measure changes in shear stress and found two stages of gelling. In the case of isothermal heating the strongest and most elastic gels were formed between 48 and 50°C, while the second type of gel, formed between 60 and 70°C, were less rigid. A recent viscometric study on a mixture of chicken leg sarcoplasmic and myofibrillar proteins [23] also showed a bimodal response, but here it was concluded that gel strength was greatest as temperatures approached 75°C. Cooling the solutions from 75 to 25°C resulted in a further increase in viscosity. Likewise, Ball and Akamittath [24] noted an increase in gel rigidity when crude actomyosin from deboned turkey meat was cooled from 75 to 25°C, indicating that there was a refolding of the aggregated protein molecules.

It may therefore be assumed that the results obtained in various rheological studies will depend on whether measurements are carried

out during continuous heating of the gels or on gels which have been heated and then cooled, as may happen when shear stress and shear strain, properties which may be associated with sensory properties of the product, are measured. For instance, Foegeding [25], when comparing the rigidity of frankfurters during continuous heating to that of frankfurters heated to a given temperature and then cooled to 20°C before evaluation, found similar results between the two methods up to 50–60°C, but thereafter rigidity at failure increased in the case of cooled samples.

(a) *Breast muscle vs leg muscle*

Meat products are manufactured from both breast and leg meat, tissues known to differ in composition and pH value [1] and biochemical properties such as rate of proteolysis [26]. Hence, investigations on model systems on the gelling behaviour of poultry meat have frequently included both types of meat.

In one of the first studies when chicken myosin was used as the model, Asghar *et al.* [27] noted that heating of myosin from whole-leg muscle of 42-day-old broilers produced a less rigid gel than that from breast muscle at ionic strengths of 0.2 and 0.6, the greatest gel strength being noted at 0.2 M KCl when the protein would have been in the filament form rather than the monomer, as at 0.6 M. Expansion of the study to specific muscles of adult hens confirmed that breast myosin displayed a greater gel strength than leg and that breast myosin gel strength was more readily affected by the pH at which the study was performed. Scanning electron microscopy (SEM) of heat-induced gel showed that at 0.15 M KCl, leg myosin produced a more porous network of filaments than breast, while at 0.6 M differences in porosity were less noticeable, and junctions, presumed to be due to head-to-head interactions between monomers, were observed with both types of myosin. A subsequent study [28] using myosins from whole breast and legs, confirmed that breast myosin exhibited greater gel strength and produced further evidence for differences between the myosins, since at 0.6 M, pH 5.7, breast myosin formed long filaments, whereas leg did not. At 0.6 M KCl, pH 5.4, breast myosin filaments increased in length and leg myosin also assembled to form filaments, although these were shorter than breast filaments. Under the same conditions breast myosin rods produced by chymotryptic digestion formed filaments which were longer and more dispersed than those from leg, which tended to cluster [29]. However, SEM of gels revealed marked differences, the leg myosin

rods showing a finer network structure than breast rod gel which was coarse and aggregated. This may explain why leg rod gels showed a greater strength than breast rod gels at its pH optimum, which had increased from 5.1 to 5.4.

When ionic strength was reduced from 0.6 to 0.2 by dilution, both breast and leg myosins produced short spindle-shaped filaments with a mean length of approx 0.48 μm , while long filaments (1.0 μm breast : 2.63 μm leg) were formed when ionic strength was reduced by dialysis [30]. While in general there was a direct relationship between filament length and the strength of the heat-induced gel, the rigidity of the leg myosin filaments produced by dilution was almost twice that of the corresponding breast protein (11.7×10^3 vs 6.8×10^3 dyne/cm). The reason for the discrepancy between these results and earlier data from the same laboratory was not clear.

Further evidence for differences between 'white' and 'red' myosins was obtained in studies using gels formed by heating hen myosin with rabbit actin [28]. In the case of leg myosin at pH 5.7 and a myosin:actin weight ratio of 15:1, rigidity was some eight times that of myosin alone. Gel strength was increased about two-fold with a myosin:actin ratio of 30:1, although maximum gel strength was only about one-quarter of that at pH 5.7. A slight enhancing effect was also noted with breast myosin at pH 6.0 and a weight ratio of 30:1, while at pH 5.4 and 5.7 gel strength decreased markedly with the addition of actin. The authors concluded that at pH 5.7 breast 'actomyosin' had undergone complete dissociation, whereas leg 'actomyosin' had not.

Other studies on gelation of proteins from various types of muscles have involved more complicated systems. Application of the least concentration end-point method to the SSP complex prepared from meat processed under kosher conditions showed that turkey leg proteins in 0.67 M NaCl tended to form a heat-set gel more readily than breast proteins, particularly at pH 5.8 [31]. It was concluded that the different gelation properties were related to the initial pH values of the respective meats.

Kopec and Smolinska [12] found that more force was required to break gels prepared from chicken leg proteins extracted in 0.375 M NaCl for up to 4 h than for the corresponding breast gels, although at 24 h extraction breast gels were stronger, perhaps reflecting the large differences in the protein contents of these extracts.

Foegeding [16] found that heat-set gels (heated from 20 to 65°C at 0.5°/min) prepared from turkey breast or thigh SSP in 0.5 M NaCl, pH

6.0 were stable to centrifugation and that at pH 7.0 breast SSP formed stable gels at both 0.25 and 0.5 M, whereas thigh SSP did not. As with the situation on stability, 0.5 M NaCl, pH 6.0 produced gels with the greatest rigidity. Although under these conditions breast gel strengths tended to be greater than thigh, meat type did not have a significant effect on rigidity. Uniaxial compression was used to evaluate the rheological properties of the gels at failure: it was shown that breast SSP gels formed with 25 or 35 mg protein/ml were stable to handling whereas under the same conditions thigh gels ruptured. Raising the protein concentration of breast SSP from 25 to 35 mg/ml caused a 99% increase in the apparent shear stress (measure of gel strength) but only a 5% increase was noted in the apparent shear strain which measures a gel's ability to deform before it breaks. Thigh SSP gels at 40 mg/ml were similar to 35 mg/ml breast gels with regard to shear stress, but resembled 25 mg/ml breast gels in shear strain, again demonstrating that the proteins from the different tissues form gels with differing rheological properties.

Further work from the same laboratory [32] using myosin/actomyosin (MAM) suspensions confirmed the marked effect of protein concentration on apparent shear stress and showed that breast protein formed gels more readily than thigh. In this study the breast myosin:actomyosin ratio of 3.8:1 was very close to the 4:1 ratio claimed to produce maximal gel rigidity in the case of rabbit proteins [33], while in thigh MAM the corresponding ratio was 6.9:1. Differential scanning calorimetry (DSC) thermograms of turkey MAM at 0.5 M NaCl and pH 7.0 showed one endothermic peak with a maximum at 59°C for breast and 59.5°C for thigh. This peak was assumed to be due to myosin which comprised 69–76% of the total protein of MAM. Similarly a single peak was noted with chicken breast and leg SSP at pH 6.5 and ionic strength 0.1 [34]. The thermograms obtained with SSP differ from those of myofibrils where breast shows two or three peaks, and thigh two [34, 35]. Kijowski and Mast [35] found that increasing the level of NaCl in the system dramatically reduced the activation temperature of actin while myosin was affected to a lesser degree. Myosin in myofibrils was stabilized by the presence of pyrophosphate or tripolyphosphate, the greatest effect being noted at 0.25 or 0.5%: actin was destabilized under these conditions [36]. The use of NaCl in combination with phosphates showed NaCl to be the dominant factor. Shiga *et al.* [37] showed that on addition of NaCl to ground chicken muscle, the heat denaturation temperatures of both myosin and actin declined, suggesting that the salt-induced lowering of actin denaturation temperature in

particular might be a reason for the observed increases of strength and water-holding capacity of heat-set gels.

Although information obtained with isolated protein systems may prove useful in characterizing the gelation process, the situation with meat products may be more complex in that the solubilization of proteins from intact myofibrils may be time dependent, as suggested by studies with homogenates. Xiong and Brekke [38] isolated myofibrils from hen breast and leg muscles at 48 h *post mortem* and suspended them in 0.6 M NaCl, pH 6.0 for up to 48 h at 4°C. It was found that protein solubility increased rapidly during the first 10 h of storage, breast myofibrils showing the greatest increase, and that the weight ratio of myosin : actin increased with time. Gel strength of the soluble protein, as measured by penetration force, increased rapidly during the first 10 h of storage and showed a slow, steady increase during the rest of the storage period. A similar pattern was noted with leg myofibrils, although gels were much weaker. For example, at 10 h, the force required to rupture leg gels was approximately 10^4 dynes, while the corresponding force for breast gels was about 10^5 dynes. The authors felt that the study demonstrated the benefit of pre-blending meat with salt in the production of muscle foods.

The work on gelation was extended [39] to gels prepared from SSP which had been isolated from pre- and post-rigor chicken muscles. No gel formation was noted at temperatures below 48°C, but there was a marked increase in the force required to penetrate gels set at 50 to 60°C. Gels from post-rigor (24 h) breast SSP had strengths about twice those from pre-rigor (0.42 h) breast and which showed wide variation between replicates. No analyses were carried out to determine whether the variation resulted from lack of uniformity in the protein composition of the various extracts. However, pre-rigor breast SSP gels were generally stronger than those of both pre- and post-rigor leg SSP gels, which did not differ one from another. Pre-rigor breast gels showed a greater ability to retain moisture during heating than other types, causing the authors to speculate that this was a pH effect.

(b) Inter-species variations

The differing experimental conditions used in the various investigations reviewed above have made inter-species comparisons difficult. The problem is further compounded by the fact that birds of different species will not be at identical stages of development at a

particular age. However in one recent study, Amato *et al.* [9] examined the gelling properties of ground breast, thigh and drumstick meats from both chicken and turkey. Shear strain values showed that thigh and drumstick muscle gels were more deformable than breast muscle gels at the same protein concentration of 12%, and that in the case of breast meat there was a significant species \times NaCl interaction, the addition of 2% vs 1% NaCl affecting turkey breast gels more than those from chicken. Shear stress values with 2% NaCl in the gel were two or three times higher than with 1% present, probably reflecting the fact that less SSP was extracted at the lower level. At 2% NaCl, the gels from turkey tissue were significantly stronger than those from chicken, the gels from breast meat being weaker, with poorer water retention properties, than those from leg. The authors concluded that such differences could not be explained by the variable fat contents of the meats, and that differences in stress values between replicates and samples might be influenced by the collagen content of the meat, i.e. the amount of functional protein available for gelation was varying between samples. High collagen levels have been shown to influence gel strength at low protein concentrations [40]. Another explanation for the results obtained by Amato *et al.* is that the pH values of the breast meat batters (meat, water, NaCl) at about 5.8 were not at the optimum for gelation, while leg batters at pH 6.0–6.2 were. This supposition that the pH value of the source material would be important in determining the quality of the product was supported by studies on chicken SSP, which showed that gels formed at pH 5.5 were less viscous, with less cross-linking, than those formed at pH 6.5 [41].

It was shown earlier that in the case of chilled (fresh) poultry meat, gel quality can depend on the rigor state of the muscle used, and recent evidence has indicated that quality may be adversely affected by frozen storage of the meat to be used for product manufacture. The yield point of myofibrillar gels from duck breast muscle declined by some 25% between 0 and 15 days' storage at -2°C and did not change further up to 40 days, while at -18°C the decrease was only 4–5% over the same 40-day period [20]. The decline in yield point was correlated with reduced solubility, a finding confirmed by Smith [42] in a study on heat-set gels of myofibrils isolated from a mixture of white and dark turkey meats which had been stored at -20°C . Here, no significant difference in cohesiveness (determined as force applied when the gel was ruptured) was found between unfrozen meat and that frozen for 7 weeks, but thereafter cohesiveness declined. Syneresis increased between 0 days and 1 week of storage,

but thereafter did not alter significantly up to 16 weeks of storage. Scanning electron microscopy helped to explain the measured differences in gel strength and water-holding ability. Gels prepared from unfrozen meat were filamentous, with an open, continuous network, while gels from frozen material contained large holes surrounded by networks of highly aggregated protein. In both this and a subsequent study involving chicken meat [43], both protein solubility and gel strength declined as a result of lipid oxidation.

Although the sulphhydryl group content of SSP has been claimed to be important in determining the thermally-induced properties of chicken proteins [44], the estimation of these groups is not routinely performed in studies on poultry proteins or meat, while little or no recent work seems to have been carried out on their mode of action during the gelation process.

In summary, the plethora of recent studies on the heat-induced gelation of poultry meat proteins has shown the relevance of factors such as muscle type, pH, ionic strength, protein concentration, lipid oxidation and method of heating on gel properties. To this end, a general mathematical model has been developed to predict the combined influence of a number of these factors on the strength of chicken myofibrillar gels [45].

Those formulated products dependent on heat-induced gelation for their structural integrity are marketed in the precooked or frozen state. Hence, if raw, chilled products are to be available, other ways of binding the meat must be found.

A product capable of being formed into a log and sliced in the chilled state was formed from ground turkey meat by the sequential addition of sodium alginate, calcium carbonate and encapsulated lactate (30% lactic acid, 20% calcium lactate and 50% hydrogenated vegetable oil) [46]. Apart from assessment of product spoilage during refrigerated storage, no sensory analyses were carried out.

A recent study using blocks of beef rather than comminuted meat indicated that much larger pieces might be formed into structured products using the alginate/calcium system [47]. Here, the aqueous gel mixture was spread on to the surface of one block, and a second block brought into contact with the solution. Rather than lactic acid, encapsulated adipic acid was used to release free calcium ions from the carbonate and hence bring about gelation of the algin. As yet, this technique does not appear to have been applied to poultry products.

3.3 MECHANICALLY RECOVERED MEAT

It is now common practice in Europe and the USA for those poultry processors who remove intact pieces of meat from the carcass for use in 'value-added' products to increase overall product yield by mechanically removing any meat adhering to the skeleton or from parts such as wings and necks. The resulting product is variously termed 'mechanically recovered meat' (MRM) or 'mechanically deboned meat' (MDM).

The various pieces of deboning equipment now being marketed generally operate either by the application of high pressure to force the meat off the bones, or by forcing the meat through screens [1]. Although the quantity of intact muscle fibres in the MRM varies with the type of deboner, in general the material produced has a purée-like consistency and appearance.

3.3.1 Product stability

Although several studies [48, 49] have shown mechanically deboned poultry meat to have a more consistent composition than similar materials prepared from beef, pork or veal, considerable variations in the protein and fat contents of poultry MRM do occur [1, 48–50]. Among factors likely to influence composition, and also sensory properties, of manufactured products are the types of material used (backs, wings, necks, racks, presence or absence of skin), the ratios of these parts in the starting material, and the type and setting of the deboning machine. Regarding the latter, it is interesting to note that in an instance where deboner head pressure was almost quadrupled in increasing the yield from 45 to 82%, the fat content of the product was significantly reduced and the moisture content increased [50].

The fact that MRM is readily susceptible to rancidity problems is not surprising in view of its method of preparation. Air is introduced into the product, while incorporation of bone marrow means that the levels of iron present are greatly increased over those normally found in meat [50]. Fat may also be expressed from bone marrow and skin and while the phospholipid fraction only comprises 1–2% of the total lipid content of poultry MRM, according to Dawson and Gartner [51] over 60% of this fraction may be unsaturated, oleic, linoleic and arachidonic acids predominating. It is generally these acids which decrease in concentration during refrigerated or frozen storage of ground turkey meats or nuggets formed from chicken

MRM [52–55]. A partial explanation for the observed decrease in polyunsaturated fatty acids came from the work of Grossman *et al.* [56] who reported chicken muscle homogenates to contain enzymes capable of oxidizing both linoleic and arachidonic acids, and found that one of these, 15-lipoxygenase, was stable during frozen storage.

While the iron present in MRM is generally accepted as acting as a catalyst in lipid oxidation, the question of whether haem or non-haem iron plays the dominant role in poultry has been the subject of debate in recent years. Although Lee *et al.* [57] concluded that the haem proteins, comprising some 50% of the total iron, were the predominant catalysts for lipid oxidation in poultry MRM, other authors, using muscle rather than MRM, have challenged this view. For instance, Igene *et al.* [58] claimed that the ‘warmed over flavour’ of cooked chicken meat came about as the result of the non-haem iron released during heating catalysing oxidation, while Kanner *et al.* [59] concluded that one reason why haem proteins affected lipid peroxidation only after heating was that catalase activity was inhibited and this allowed H₂O₂-activated myoglobin to initiate peroxidation. In the case of uncooked meat, the latter authors reported that an iron–redox cycle initiated lipid peroxidation and that the soluble fraction of turkey muscle contained reducing substances which stimulated the reaction. Free iron present in the white and red meats of chicken and turkey increases in concentration with storage time, and is capable of catalysing lipid oxidation [60].

Decker and Schanus [61] used gel filtration to separate an extract of chicken leg muscle into three major protein fractions, one of which catalysed over 92% of the observed total linoleate oxidation. Ion-exchange chromatography of this ‘active’ fraction revealed three proteins capable of oxidizing linoleate. Of these, haemoglobin was responsible for some 30% of total oxidation, while two components, judged by Soret absorbance to be non-haem proteins, were responsible for over 60%. One of these with a molecular weight of 51 kDa, had 52% of total activity. The authors did not preclude the possibility of the protein containing non-haem iron or transition metals such as copper or cobalt.

There still seems to be scope for further work in the area of iron-mediated oxidation, especially to define the situation with poultry MRM.

3.3.2 Modification of poultry MRM

In general the paste-like nature of poultry MRM has largely limited its use in products such as frankfurters and bologna, but it may be used to replace some of the ground meat normally used in products such as chickenburgers [62] and summer sausages [63, 64].

Attempts have been made to further use MRM by texturizing the material either by the addition of plant protein to the meat [64, 65], or by various heat treatments [66–68]. However, the sensory properties of the resulting product are not always acceptable [69].

Several investigations [70–72] using twin-screw extrusion cookers have shown that treatment of poultry MRM alone gives unsatisfactory results, probably because of the high fat content of the raw material. However, satisfactory products resembling meat loaf or luncheon meat were obtained if binding or gelling agents such as cereal flours, corn starch, egg white concentrate or soy protein isolate were combined with the MRM. While Alvarez *et al.* [71] found that, in the case of chicken extruded with 10 or 15% corn starch, lipid oxidation decreased as extrusion temperature rose from 71 to 115.5°C and suggested that antioxidants were produced with increasing temperature, Hsieh *et al.* [72] reported that a mixture of turkey MRM (40 parts) and corn flour (60 parts) increased in susceptibility to lipid oxidation above 110°C. In the latter case the antioxidant BHA (butylated hydroxyanisole) had been added to the raw materials before extrusion.

In addition to their effects on product stability, the high levels of haem pigments in poultry MRM tend to impart a dark colour to products. Hence in recent years much effort has been expended in trying to remove these pigments and so extend the range of products in which the MRM may be used.

Although Froning and Johnson [73] showed that centrifuging poultry MRM would remove haem pigments, many research groups have more recently examined the possibility of using washing procedures paralleling those first developed in Japan to remove haem proteins, enzymes and fats from fish during the production of the myofibrillar protein concentrate, surimi. However, there are several reasons why surimi technology might not be applied directly to poultry MRM, viz:

1. Surimi is prepared from whole muscle while poultry MRM will generally be isolated from bones after most muscle tissue has been removed.
2. Poultry MRM may contain considerable quantities of connective

- tissue, e.g. histochemical investigations have shown the connective tissue : muscle ratio of chicken MRM to be 1 : 1.2 [49].
3. Fish mince is frequently washed during preparation but water washing is not an efficient means of removing haem pigments from MRM.
 4. According to Lee [74] the size of perforations in the deboner drum of fish deboners ranges from 1 to 5 mm, with orifices of 3 to 4 mm giving the best quality and yield of surimi. Poultry deboners seem to have a pore size below 1 mm and thus the particle size of the products will differ.

Since the term 'surimi' has long been associated with the product isolated from fish muscle, it is perhaps debatable as to whether the term should be applied to the material prepared from poultry MRM. Several other terms have been used to denote such a product: 'washed mechanically deboned chicken meat' [75], 'myofibrillar protein isolate', (MPI) [76], 'isolate of myofibrillar protein, (IMP) [77]. The use of the acronym IMP in this way is perhaps unfortunate in view of its widely accepted use as an abbreviation for inosine monophosphate. Clearly some rationalization of nomenclature is required and perhaps a term such as 'poultry myofibrillar protein extract' would be more appropriate.

In one of the first studies on poultry [78], turkey neck MRM, considered to be the darkest poultry MRM, was washed either three times in water or once in 0.04 M phosphate at various pH values, followed by two water washes. The mixtures were pressed through cheesecloth to remove as much moisture as possible. Although the yield of paste from water-washed MRM was higher than that which had been treated with phosphate, it generally had a darker colour, and the authors concluded that washing with 0.04 M phosphate at pH 8.0 provided the most efficient means of removing red pigment from turkey MRM.

Whereas Froning and Niemann [79] reported that extraction of chicken MRM with 0.1 M NaCl significantly reduced fat concentration and colour, and increased protein concentration, other authors [75, 77, 78, 80], using different washing techniques, particularly the use of bicarbonate as the washing medium, have found that either the protein content of the washed material was similar to that of the starting material, or was up to 7% lower, although all authors agreed that washing drastically reduced the fat level of the recovered material.

While washing with bicarbonate appeared to afford the most

efficient means of removing pigment from poultry MRM, presumably due to the fact that the pH value of the slurry [78] makes the blood proteins more soluble [80], other factors may also influence the final colour of the washed product. For instance, Trziszka *et al.* [76] found that if, following bicarbonate extraction, water washing was carried out at pH 5.5, the product was lighter than at pH 6.0, while the variable amounts of connective tissue present in the washed residue [81] can influence the appearance of the material, as shown by Kijowski *et al.* [40], who found that removal of connective tissue by sieving increased both the darkness and redness of water-washed chicken MRM.

The overall yield of material obtained after washing has been reported to range from 13.5 to over 62% of the starting material [76, 77, 80, 82], the variation noted between laboratories probably being due to a number of factors such as source material for MRM, grinding of MRM before washing, nature of washing medium, washing time, adjustment of pH, number of washes, ratio of MRM to extractant and centrifugal force applied during separation of 'meat' and extractant.

The addition of cryoprotectants, such as mixtures of sugars and/or phosphates, is required if washed material is to retain its gelling and water-holding abilities during frozen storage [77, 82].

Although washing improved the functional properties of the material in that after cooking the washed MRM was more chewy, less cohesive and had increased stress values [75, 79], the cooking losses from washed material were higher, probably reflecting the addition of 'free' water during washing [75].

Perhaps the test of how successful or useful the washing procedure will be in practical terms depends on the performance of the myofibrillar complex in products, and several recent studies have examined this aspect. Frozen-thawed, bicarbonate washed turkey MRM at a level of 10% reduced the fat level of frankfurters, while increasing the expressible moisture content and resistance to shear compared with control frankfurters. Scanning electron microscopy did not reveal any obvious structural differences between controls and frankfurters containing 10% washed MRM [83]. Hernandez *et al.* [78] found that the protein paste from washed turkey MRM could be incorporated into patties at levels up to 20% without adversely affecting sensory quality, while Trziszka *et al.* [76] found that up to 50% of the ground chicken meat in hamburgers could be replaced by carbonate-washed turkey MRM without reducing the acceptability of the product. In this study a sensory panel gave slightly lower flavour scores to hamburgers containing the protein extract, although

whether this was due to the 'soapy' taste reported by Dawson *et al.* [80] is not clear.

Although the protein complex isolated from washed MRM could be of use in altering textural properties of poultry products, further possibilities of effecting such changes exist. For instance, Smith and Brekke [84] found that limited acid proteolysis improved the emulsifying capacity of actomyosin isolated from fowl MRM, as well as improving the quality of heat-set gels.

Kurth [85] used a model system to demonstrate the crosslinking of myosin and casein by a Ca-dependent acyltransfer reaction catalysed by transglutaminase (EC 2.3.2.13; R-glutaminy peptide amine gamma-glutamyl transferase). Application of the technique to actomyosin prepared from turkey MRM [24, 86] showed that actin did not polymerize, but that the disappearance of myosin monomer was accompanied by a concomitant increase in polymer content and that the gel strength of enzyme-treated protein was greater. The polymerization could occur at temperatures as low as 4°C, thus opening up possibilities for the manufacture of new products.

3.4 CONCLUSIONS

The poultry industry continues to market an ever-expanding range of products. Although many aspects of the mechanisms by which meat pieces bind together during formulation are understood, some points, such as the role of sulphhydryl groups in gelation, remain obscure.

In several parts of the world much effort is expended in upgrading mechanically deboned poultry meat, although whether such an exercise is cost effective in terms of the extra manipulations required and effluents produced remains unclear.

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