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Effect of cooking temperature and time on the physico-chemical, histological and sensory properties of female carabeef (buffalo) meat

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Abstract

The effect of cooking temperature (80–100 °C) and time (30–60 min) on collagen solubility of *Semimembranosus* muscle in carabeef were investigated. The pH, cooking loss, shear force value, collagen content, collagen solubility, sensory evaluation and histological observations of water bath cooked and pressure cooked *Semimembranosus* meat samples were measured. Increase in pH, cooking loss, collagen solubility and tenderness scores with decrease in shear force value and collagen content was observed with increases in cooking temperature and time. However, no statistical difference was observed for shear force values, collagen solubility values and tenderness scores in pressure cooked meat and meat cooked in a water bath at 100 °C for 45 min, inferring that cooking of buffalo meat at 100 °C for 45 min improved collagen solubility and tenderness to the same extent as that due to pressure cooking.

Keywords: Carabeef; *Semimembranosus* muscle; Collagen content; Collagen solubility; Tenderness; Shear force value

1. Introduction

Of all the attributes of eating quality, tenderness is rated the most important factor affecting beef palatability and much research has been focused on improving tenderness. Effect of cooking on meat tenderness has received considerable attention because, consumer acceptance and this quality factor usually dictates the method of cooking, in addition to efficiency and cost.

Buffaloes contribute about 22% of total meat produced in India. An FAO statistical report observed that buffalo meat production increased by 3.7% over the past 5 years (FAO, 2006). In terms of buffalo production and population, India is the most important place in the world. Buffalo meat is gaining popularity and does not possess any taboo against its consumption, hence there are opportunities for the development of the buffalo meat industry to cater for the needs of the domestic market (Sekar, Dushyanthan, Radhakrishnan, & Narendra Babu, 2006). Buffalo meat has several virtues such as high protein and low fat and cholesterol contents as well as less calories than beef (Murthy & Devadason, 2003). Consumption of buffalo meat in India as well its export to the Middle Eastern and South East Asian countries are increasing (Kondiah & Anjaneyulu, 2003).

Although buffalo meat is rated superior to beef (Keshava Rao & Kowale, 1986; Valin, Pinkas, Drahnev, Boikovski, & Polikronov, 1984) the meat from old buffaloes is not preferred because of its toughness. This necessitates improving tenderness of such meat by cooking. Numerous techniques have been employed to cook meat, however the variations in cooking time and meat palatability prevent the universal use of any single technique. The use of microwave cooking provides fast heating rates (Bakanowski & Zoller, 1984; Hines, Ramsey, & Hoes, 1980) but inferior cooking yields (Korschgen, Baldwin, & Snider, 1976) and less tender (El Shimi, 1992) and less flavorsome meat (Hines et al., 1980)

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than conventional cooking techniques. The use of ultrasound cooking has been shown to be a rapid, energy efficient method to improve meat's textural attributes (Pohlman, Dikeman, Zayas, & Unruh, 1997). However, an economic and simple alternative cooking method suitable for both household and industrial use is required. Though, the usual practice in Indian homes involves cooking meat in pressure cookers, cooking in water baths is also of significance and is believed to be a reliable method to optimize tenderness as this method of cooking ensures rapid and more consistent increases in the final internal temperature (Buck, Hickey, & Rosenau, 1979).

The mechanical properties of meat are affected by the connective tissue protein, collagen. Meat texture is influenced not only by the quantity of collagen but also its solubility on heating. Heat induced changes in muscle components are temperature and time dependent and the net effect on toughening or tenderization depends on the cooking conditions. A literature survey revealed that very little work has been done on buffalo meat collagen and its solubility at different temperatures. Since heat solubility of collagen is time and temperature dependent, this work aims to study the effect of temperature and time of cooking on buffalo meat collagen.

2. Materials and methods

2.1. Meat samples

Fresh buffalo *Semimembranosus* meat samples were collected from 15 female buffalo carcasses slaughtered at the Corporation slaughterhouse, Perambur, Chennai. The animals were 5–6 years old and weighed between 100 and 120 kg. The samples were collected within 6 h post-mortem during which time the carcass was hung by the achilles tendon. The samples were wrapped in sterile polyethylene bags in a thermocool container packed with ice and transported to the laboratory.

The external fat and connective tissue were trimmed off and samples were divided into cubes 2.54 cm thick and kept in the refrigerator at 4 ± 1 °C for about 24 h. The samples used in this study were post rigor. Meat samples taken from the proximal region of the *Semimembranosus* muscle were used for pH, cooking loss and taste panel evaluation. Meat samples taken from middle region of *Semimembranosus* muscle were used for shear force value estimation and those samples taken from distal region were used for collagen content and collagen solubility estimation.

2.2. Cooking

The pre-chilled meat cubes were packed in polypropylene bags, sealed and cooked in water baths at 80 °C for 30, 45 and 60 min, at 90 °C for 30, 45 and 60 min and at 100 °C for 30, 45 and 60 min. Meat cubes were also placed in a glass beaker covered with aluminum foil and cooked in a domestic pressure cooker at 121 °C, 15 lbs pressure for 30 min.

2.3. Physical parameters

2.3.1. pH

The pH's of raw and cooked meat samples were measured using a digital pH meter. About 5 g of meat sample was homogenized with 45 ml of distilled water in a laboratory blender for about 1 min and the pH was recorded. The pH value of raw meat was measured at room temperature just prior to cooking. The pH of the cooked meat was measured after cooking, once the inner temperature of the meat reached room temperature.

2.3.2. Shear force value (SFV)

Cores (1.27 cm diameter) were removed from the raw and cooked meat perpendicular to the muscle fibres and were sheared parallel to the muscle fibres (Nottingham, 1956). Three readings were taken for each core and the average of three values were taken as the mean shear force values for the *Semimembranosus* muscle. Cores were taken from cooked meat only after the internal temperature reached 20 °C (Williams, Field, & Riley, 1983) when cooled at refrigeration temperature.

2.3.3. Cooking loss

Cooking loss was assessed as outlined by Neel, Reagan, and Mabry (1987). The pre-chilled meat samples were blotted with blotting paper and weighed accurately just before cooking. After cooking, the samples were cooled and wiped with blotting paper and weighed immediately. The cooking loss as a percentage was the difference in weights of the sample before and after cooking.

2.4. Bio-chemical parameters

2.4.1. Collagen content

Hydroxyproline contents of raw and cooked samples were estimated as outlined by Neuman and Logan (1950) with minor modifications. Two grams of meat (dry basis) was hydrolysed with 50 ml of 6N hydrochloric acid at 105 °C in a sealed tube for 18 h. After completion of hydrolysis, the contents were filtered through a sintered glass funnel. The hydrolysis tubes were washed with distilled water and the contents were transferred to the glass funnel. Washing was repeated two or three times until the volume of filtrate reached 100 ml. Five-millilitre of the filtered hydrolysate was taken and neutralized with dilute sodium hydroxide solution until the pH reached 6.9–7.0. The neutralized hydrolysate was again diluted with distilled water to 10 ml in a volumetric flask. One millilitre of the neutralized hydrolysate was used to determine the hydroxyproline content (Neuman & Logan, 1950). A conversion factor of 7.25 (Goll et al., 1963) was used to estimate the collagen content.

2.4.2. Collagen solubility

Collagen solubility of meat cooked by water bath and pressure cooker were calculated as per Naewbanij, Dorothy, and Stone (1983).

2.5. Sensory evaluation

Eating qualities such as appearance (not so pleasing-1 to appealing-9), flavor (not so agreeable-1 to delicious-9), juiciness (less juicy-1 to more juicy-9) and tenderness (tough-1 to very tender-9) were judged by not less than 5 trained panelists. The samples were coded so as to mask the identity of the samples. Each panelist was provided with a "Sensory Evaluation Score Card" to mark their observations and preferences for each attribute for a particular sample, using a nine point hedonic scale.

2.6. Histological observation

Pieces of *Semimembranosus* muscle samples were fixed in buffered formalin and processed by routine histological techniques. Six-micrometer thick sections were cut and stained using Masson's Trichrome method (Luna, 1968) to observe the qualitative changes that occur in collagen fibers on heating.

2.7. Statistical analysis

The data obtained in this study were analyzed using a completely randomized design (CRD) as outlined by Snedecor and Cochran (1994).

3. Results and discussion

The mean values of pH, shear force value, cooking loss, collagen content, collagen solubility and taste panel scores of raw and cooked meat are presented in Tables 1 and 2. The histological changes that occurred during heating are presented in Fig. 1. The analysis of variance revealed highly significant ($P < 0.01$) differences between treatments for all the physico-chemical, bio-chemical and sensory parameters.

3.1. pH

The mean pH of the raw meat in this study was in accord with that observed by Talmant and Monin (1986). There were gradual increases in pH when cooked at 80 °C, 90 °C and 100 °C for different times in the water baths. This increase in pH may be attributed to the loss of free acidic groups (Lawrie, 1979). Tilgner (1958) stated that on cooking at temperatures above 80 °C, free hydrogen sulphide begins to form and increases with increasing temperature.

3.2. Shear force value (SFV)

The mean shear force value of the raw meat was similar to shear force values observed by Bouton, Harris, and Ratcliff (1981) and Robertson, Ratcliff, Bouton, Harris, and Shorthose (1984). Meat cooked under pressure had the lowest shear force value. Greater tenderization of pressure-cooked muscles could be due to greater thermal shrinkage of muscles (Mahendrakar, Dani, Ramesh, & Amla, 1988; Ziauddin, Mahendrakar, Rao, Ramesh, & Amla, 1994) and greater collagen solubilization at higher temperatures (Mahendrakar, Dani, Ramesh, & Amla, 1989). The shear force value of pressure cooked meat clearly indicates that greater thermal shrinkage accompanied an increase in tenderness. This finding is in agreement with the findings of Mahendrakar, Dani, Ramesh, and Amla (1990) in ovine muscles. There was decrease in shear force value with increase in temperatures and time in meat cooked in the water baths. This decrease may be due to the solubilization of collagen, which increases with increasing temperature (Draudt, 1972). Cooking temperatures thus dramatically affected the tenderness measurements as also observed by Combes, Lepetit, Darche, and Lebas (2003). Meat cooked in a water bath at 100 °C for 60 min recorded the lowest shear force value of those heated in water baths. This again could be due to the completion of collagen shrinkage within few minutes of heating (Machlik & Draudt, 1963). A similar finding was recorded in *Semimembranosus* meat cooked at 95 °C for 60 min by Bouton et al. (1981) and Robertson et al. (1984).

3.3. Cooking loss

The mean cooking loss of the pressure cooked meat is in the range of values observed by Rathina Raj, Jagannatha Rao, Narasimha Rao, and Mahendrakar (2000). The highest cooking loss was in buffalo meat cooked by pressure. This finding is in agreement with the findings of Rathina Raj et al. (2000) and Ziauddin et al. (1994). This could be due to a greater degree of shrinkage of the muscle fibres and protein coagulation (Asghar & Pearson, 1980). There was a gradual increase in cooking loss with increase in temperature and time of cooking in the water baths as observed by Seuss et al. (1986). An increase in cooking loss with temperature was also observed by Combes et al. (2003) in rabbit meat.

3.4. Collagen content

The mean collagen content of the raw meat was within the normal range (Lawrie, 1991a). There was gradual decrease in collagen content with increase in temperature and time of cooking in the water bath as also reported by Cover, Ritchey, and Hostetler (1962a) and Ritchey, Cover, and Hostetler (1963). The gradual decrease may be due to loss in with the cooking juice.

3.5. Collagen solubility

The collagen solubility increased with temperature and time of cooking in the water baths, as also found by Lawrie (1991b). This is in agreement with the findings of Paul, Suzanne, McCrae, and Hofferbee (1973), Penfield and Meyer (1975) and Williams and Harrison (1978). Highest

Table 1
Mean (±SE) pH, SFV (kg/cm^2), cooking loss (%), collagen content and collagen solubility of raw, pressure and water bath cooked meat samples

Parameter	Raw sample	Pressure cooked	Water bath cooked								
			80 °C			90 °C			100 °C		
			30 min	45 min	60 min	30 min	45 min	60 min	30 min	45 min	60 min
pH	$6.21^{a} \pm 0.09$	$6.41^{bc} \pm 0.02$	$6.30^{ab} \pm 0.05$	$6.33^{abc} \pm 0.05$	$6.37^{bc} \pm 0.05$	$6.38^{bc} \pm 0.05$	$6.40^{bc} \pm 0.03$	$6.41^{bc} \pm 0.03$	$6.43^{bc} \pm 0.02$	$6.45^{bc} \pm 0.02$	$6.48^{c} \pm 0.01$
SFV	$5.34^{f} \pm 0.14$	$1.85^{a} \pm 0.10$	$4.77^{e} \pm 0.05$	$3.86^{d} \pm 0.17$	$3.51^{cd} \pm 0.18$	$3.17^{c} \pm 0.13$	$2.61^{b} \pm 0.15$	$2.29^{ab} \pm 0.10$	$2.15^{a} \pm 0.02$	$2.10^{a} \pm 0.04$	$1.91^{a} \pm 0.12$
Cooking loss	–	$51.33^{g} \pm 0.42$	$40.21^{a} \pm 1.13$	$43.38^{b} \pm 1.01$	$45.70^{bc} \pm 0.47$	$47.05^{cd} \pm 0.45$	$47.89^{cde} \pm 0.41$	$48.84^{def} \pm 0.52$	$49.52^{efg} \pm 0.51$	$49.75^{efg} \pm 0.44$	$50.36^{fg} \pm 0.33$
Collagen content	$23.61^{g} \pm 0.54$	$16.16^{b} \pm 0.37$	$20.01^{f} \pm 0.47$	$19.03^{ef} \pm 0.43$	$18.05^{de} \pm 0.27$	$17.63^{cd} \pm 0.32$	$17.35^{bcd} \pm 0.34$	$16.83^{bcd} \pm 0.28$	$16.68^{bc} \pm 0.28$	$16.13^{b} \pm 0.30$	$13.83^{a} \pm 0.12$
Collagen solubility	–	$31.49^{e} \pm 1.10$	$15.22^{a} \pm 0.97$	$19.26^{ab} \pm 1.55$	$23.29^{bc} \pm 1.65$	$25.13^{cd} \pm 1.44$	$26.38^{cd} \pm 1.36$	$28.58^{de} \pm 1.05$	$29.20^{de} \pm 1.04$	$31.36^{e} \pm 1.23$	$41.63^{f} \pm 1.60$

Means bearing different superscript in a row differ significantly ($P < 0.01$).

Table 2
Mean (±SE) taste panel scores of pressure and water bath cooked meat samples

Parameter	Pressure cooked	Water bath cooked								
		80 °C			90 °C			100 °C		
		30 min	45 min	60 min	30 min	45 min	60 min	30 min	45 min	60 min
Appearance	$7.46^{c} \pm 0.09$	$5.13^{a} \pm 0.18$	$5.25^{a} \pm 0.18$	$5.58^{a} \pm 0.10$	$5.47^{a} \pm 0.17$	$5.49^{a} \pm 0.14$	$5.58^{a} \pm 0.16$	$6.34^{b} \pm 0.12$	$6.39^{b} \pm 0.10$	$6.60^{b} \pm 0.10$
Flavour	7.60C ± 0.20	$5.06^{a} \pm 0.33$	$5.19^{a} \pm 0.25$	$5.22^{a} \pm 0.22$	$5.30^{a} \pm 0.20$	$5.40^{a} \pm 0.20$	$5.50^{a} \pm 0.19$	$6.09^{b} \pm 0.10$	$6.28^{b} \pm 0.17$	$6.40^{b} \pm 0.08$
Juiciness	$6.97^{f} \pm 0.17$	$3.98^{a} \pm 0.15$	$4.40^{ab} \pm 0.19$	$4.47^{ab} \pm 0.20$	$4.82^{bc} \pm 0.22$	$5.09^{bc} \pm 0.12$	5.30C^{d} ± 0.17	$5.87^{de} \pm 0.21$	$6.06^{e} \pm 0.25$	$6.21^{e} \pm 0.20$
Tenderness	$6.92^{g} \pm 0.25$	$3.15^{a} \pm 0.19$	$3.67^{ab} \pm 0.26$	$4.22^{bc} \pm 0.24$	$4.36^{bc} \pm 0.13$	$4.86^{cd} \pm 0.14$	$5.51^{de} \pm 0.11$	$5.86^{ef} \pm 0.22$	$6.42^{fg} \pm 0.22$	$6.72^{g} \pm 0.23$

Means bearing different superscript in a row differ significantly ($P < 0.01$).

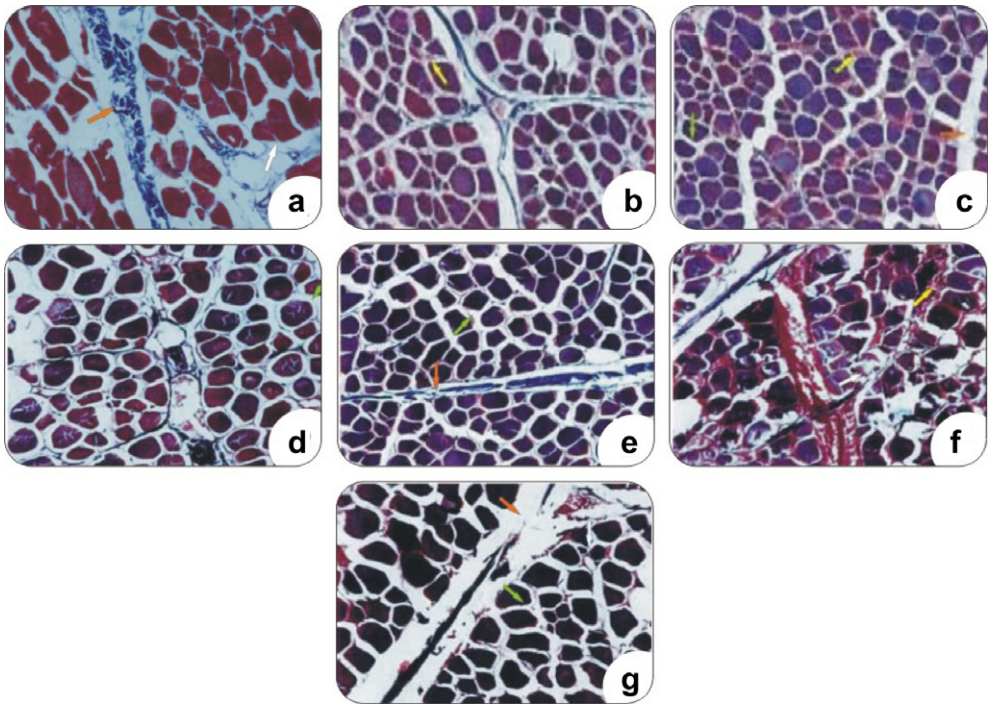

Fig. 1. Photo micrographs of raw *Semimembranosus* meat samples (a) and meat samples cooked in a water bath at 80 °C for 30 min (b), 100 °C for 30 min (c), 80 °C for 45 min (d) 90 °C for 45 min (e), 100 °C for 60 min (f) and pressure cooked for 30 min (g) ×200.

collagen solubility was in meat cooked at 100 °C for 60 min in the water bath. This could be attributed to the fact that marked conversion of collagen to gelatin occurs at this temperature (Dransfield, 1983; Paul, 1975). The increase in collagen solubility with increase in cooking temperature and time is associated with an increase in tenderness, due to conversion of collagen to gelatin on cooking (Lawrie, 1991b).

3.6. Sensory evaluation

The mean appearance, flavour, juiciness and tenderness scores of pressure cooked meat were higher than of those cooked in the water baths. There was an increase in taste panel scores with increase in temperature and time of cooking in the water bath as also reported by Cover et al. (1962a) and Ritchey et al. (1963) for tenderness scores. The softening of meat at 100 °C appeared to have been associated with somewhat greater ease of fragmentation, greater mealiness and very much greater tenderness of the connective tissue (Cover, Ritchey, & Hostetler, 1962b). The tenderizing effect observed at 80–100 °C is due to dissolution of connective tissue and probable development of myofibrillar fragility (Davey & Gilbert, 1974). As tenderness scores increased, scores for juiciness also increased with temperature and time of cooking in the water baths. Tenderness and juiciness are closely related, the more tender the meat is, the more quickly the juices are released by chewing and thus the juicier the meat appears (Cross, 1986). Cooking at 100 °C converts collagen to gelatin and thereby tenderizes meat (Dransfield, 1983).

3.7. Histological observations

The wavy or crimped thick collagen fibers were observed only in raw meat sections (Fig. 1a) as reported by Jones, Carroll, and Cavanaugh (1977) and Reid and Harrison (1971). The loss of crimp structure of the perimysium in cooked meat is due to shrinkage and denaturation of collagen fibres as reported by Lewis and Purslow (1989). Granular deposits were observed in the gaps between the endomysium and myofibrillar mass (Fig. 1b). These are the remains of plasmalemma, which are non-colloidal particles. The presence of granules indicates passive shortening of muscle fibres, which however remains, bound together by the open random network of collagen fibres. This finding is in agreement with the findings of Rowe (1989). Extensive deposits observed in Fig. 1c were due to the rupture of endomysium and perimysium, which occurred in meat cooked at higher temperatures.

Loss of structural integrity of myofibrils observed in meat cooked at higher temperatures is due to progressive distortion of endomysium and perimysium on cooking. These distortions started as a mild discontinuity of endomysium (Fig. 1d) and progressed as distortions as observed in Fig. 1e. Similarly the changes in perimysium started as a mild discontinuity in Fig. 1e and became markedly distorted in Fig. 1c. The distortions of endomysium and perimysium has led to the distortions of myofibrillar mass, thereby leading to the loss of structural integrity as observed in Fig. 1f. This trend of increase in fracturing is due to softening of endomysial collagen around fibres and progressive weakening of adhesion between fibres as

reported by Jones et al. (1977). Similar finding were observed in bovine *Semitendinosus* muscle cooked in the range of 80–90 °C on roasting (Palka, 2003). These qualitative changes indicate progressive denaturation changes in collagen fibres thereby leading to tenderness. Marked discontinuity and distortion of both endomysium and perimysium with loss of structural integrity was observed in meat cooked under pressure (Fig. 1g).

The data obtained in this study revealed that increase in temperature and duration of cooking increased pH, cooking loss, collagen solubility and tenderness scores and decreased shear force value and collagen content. The decrease in shear force value with corresponding increase in collagen solubility improved tenderness as evidenced by higher taste panel scores. Pressure cooked meat recorded maximum tenderness scores with lowest shear force values compared to the meat cooked in water baths at different temperatures. However, shear force values, collagen solubility values and tenderness scores in pressure cooked meat and meat cooked in a water bath at 100 °C for 45 min were not significantly different. Hence, it is concluded that cooking of buffalo meat at 100 °C for 45 min improved collagen solubility and tenderness to the same extent as pressure-cooking.

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