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Effect of processing temperature on tenderness, colour and yield of beef steaks subjected to high-hydrostatic pressure

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ABSTRACT

Our aim was to achieve a single-step pressure-heat process that would produce tender, juicy beef steaks from meat that would otherwise be tough when cooked. Steak portions (25 mm thick) from hind-quarter muscles were subjected to heat treatment at 60, 64, 68, 72 or 76 °C for 20 min, with or without simultaneous application of high pressure (200 MPa). Control steaks were heated at 60 °C for 20 min with or without pressure and cooked at 80 °C for 30 min. Compared with heat alone, pressure treatment resulted in higher lightness scores at all temperatures and overall yield was improved by pressure treatment at each temperature. Even at 76 °C, the overall water losses were <10% compared with >30% for heat alone. Meat tenderness (peak shear force) was improved for the pressure–heat samples at temperatures above 64 °C, and was optimal at 76 °C. Therefore, subject to microbial evaluation, this single-step pressure-heat process could be used to produce tender, high moisture content steaks ready for consumption.

1. Introduction

About 25% of meat from beef carcases produces consistently tender primal meat cuts, leaving a large proportion of the remainder of the carcase muscles as low-value cuts. Some of these muscles, which may be tough because of high connective tissue contents or from cold-shortening during rigor development, might be suitable for value-adding, particularly those muscles that are of suitable size and shape to be sold as steaks. The ability to sell low-value meat with assured tenderness, packaged as convenient, ready-to-heat products, with extended shelf life, would be of great benefit to the industry. High pressure processing (HPP), which is commercially available in many countries (Heinz & Buckow, 2010; Sun & Norton, 2008), has the potential to be of benefit for value-adding and tenderisation. Not only has HPP been used to extend the shelf life of ready-to-eat foods through destruction of micro-organisms (Campus, 2010; Gill & Ramaswamy, 2008), and inhibition of endogenous enzymic activities that lead to loss of quality (Bang & Chung, 2010; Ohshima, Ushio, & Koizumi, 1993), but also it has successfully been used to modify functionality of muscle protein systems as in emulsion-type products (Jiménez-Colmenero, 2002; Macfarlane & McKenzie, 1976; Sikes, Tobin, & Tume, 2009).

Specifically, HPP of meat has been widely investigated since the extensive studies reported by Macfarlane (1985) that has led to much of our present knowledge in this area. An important observation made by Macfarlane's group, was that HPP treatment of post-rigour meat resulted in improved tenderness, but only when treated at temperatures greater than 60 °C (Bouton, Ford, Harris, Macfarlane, & O'Shea, 1977; Macfarlane, McKenzie, & Turner, 1986). It was later shown that pressure caused the release of various cathepsins from lysosomal structures leading to an increase in proteolytic activity (Homma, Ikeuchi, & Suzuki, 1994). More recent studies (Ma & Ledward, 2004; Sikes, Tornberg, & Tume, 2010) have confirmed these pressure–heat effects on meat tenderness.

Simultaneous application of pressure and heat to meat has been shown to improve tenderness but there are differences in effectiveness depending on temperatures and pressures used (Ma & Ledward, 2004; Macfarlane, 1985). Also, some results are difficult to interpret as it is not stated whether further cooking had been applied, and if so, how and when (e.g. Bertram, Whittaker, Shorthose, Andersen, & Karlsson, 2004). In our work with pressure–heat treatment of beef muscle (35 mm thick, approximately 100 g) at 200 MPa at 60 °C for 20 min (Sikes et al., 2010), we were only able to demonstrate an improvement in beef tenderness when the meat was subsequently cooked at 80 °C. In the current work we investigated the effect of pressure at specific temperatures between 60 and 76 °C on thin beef steaks from hind quarter primal cuts. We determined the minimum temperature that could be used during pressure treatment at 200 MPa to achieve tenderisation, and then used this information to develop a single-step process to achieve a tender, safe product with minimal weight loss. In order to ensure that food safety issues would not be compromised, the range of temperatures investigated included those likely to exceed the

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recommended internal temperatures for whole beef meat (63 °C [145 °F] with a resting time of 3 min) (USDA, FSIS, 2012).

2. Materials and methods

2.1. Single-step pressure-heat process

At about 48 h post-slaughter, *M. semimembranosus* (n = 2) and *M. biceps femoris* (n = 4) were obtained from six individual beef carcases. Two muscles were collected on each occasion and taken to the laboratory where they were each cut into 13 uniform steak-sized portions, having a weight of about 80–100 g and a thickness of 25 mm. Muscles were sliced so that the muscle fibre direction was perpendicular with the cut surface of the steak. All treatments were randomly allocated within a muscle, with 6 replicates per treatment. Prior to treatment, each steak was weighed, the pH and colour recorded and then sealed in a vacuum bag. The treatments were:

- Heat and cook —heat treatment at 60 °C for 20 min in a water bath, cooked at 80 °C for 30 min in a water bath
- Heat-only —heat treatment at 60, 64, 68, 72 or 76 °C for 20 min in a water bath
- HPP-heat and cook —200 MPa, 60 °C, 20 min, cooked at 80 °C for 30 min in a water bath
- HPP-heat —200 MPa, 20 min at 60, 64, 68, 72 or 76 °C.

At the end of all treatments, samples were placed in ice water for 20 min. The vacuum bags were opened, the pH and colour were recorded and each steak was weighed. Immediately following measurements, samples allocated for cooking were placed in a water bath at 80 °C for 30 min and then cooled in ice water for 30 min. All samples were then stored overnight at 5 °C. On the following day, subsamples were assessed for tenderness using the Warner–Bratzler device with a modified holder.

2.2. High pressure processing

Pressure treatments were performed using a 0.3 L capacity 850 Mini FoodLab high pressure vessel (Stansted Fluid Power Ltd., Stansted, UK) connected to a circulating water heater (PolyScience 9702, Niles, USA) set so that the temperature of the compression fluid in the chamber could be adjusted between 60 and 76 °C. The compression fluid used in the sample chamber consisted of 30% propylene glycol in water (v/v). The inherent ramp rate was 20 MPa/s, so the time to reach 200 MPa was approximately 10 s. A decompression procedure over a period of 45 s was used, consisting of 'open' 5 s and 'closed' 2 s. Following release of pressure, all samples were held in ice water for 20 min and then stored at 5 °C until required for analysis. Pressure treatment causes a temperature increase of the compression fluid and the meat samples as a result of adiabatic heating (Ting, Balasubramaniam, & Raghubeer, 2002). Under the conditions used here (200 MPa) it can be estimated that adiabatic heating resulted in an immediate increase in temperature of about 4–6 °C above the set temperature. As soon as the maximum pressure had been established, this additional heat was rapidly lost back into the system and the samples remained at the pre-determined set temperature for the majority of the processing time (data not shown).

2.3. Weight loss following treatments

Steaks, previously weighed before treatment, were removed from their packs and carefully dried with a paper towel and re-weighed. Weight loss was expressed as a percentage of the original weight.

2.4. pH

Muscle pH was measured on all samples prior to and following treatments using a digital pH meter (TPS WP-80, Springwood, Australia) fitted with a combination electrode (Ionode IJ44, Tennyson, Australia; glass body with a spear tip) with temperature compensation.

2.5. Meat colour

The surface colour (L*, a*, b* values) of each sample was measured using a chromameter (Konica Minolta Inc., Osaka, Japan; illuminant = C, aperture = 10 mm), before and immediately after treatment.

2.6. Tenderness

Tenderness of steaks was determined as Warner–Bratzler peak shear force but the small sample size necessitated using a modified holder to allow the small fibre-length samples to be adequately secured for shearing. Briefly, the samples (fibres approximately 25 mm long) were cut so that they had a rectangular cross-sectional area of 0.2 cm^2 (6.42 mm × 3 mm). Shear force was measured (n = 8) using a rectangular blade pulled upwards at a speed of 100 mm/min at right angles to the muscle fibre direction, as described previously (Bouton & Harris, 1972; Bouton, Harris, & Shorthose, 1971). Tenderness of each sample, without further cooking, was assessed as peak shear force (N). Because of the different cross-sectional area, shear force values reported for these samples cannot be compared with other values measured using the standard device (Sikes et al., 2010).

2.7. Statistical evaluation

Statistical analysis showed no muscle effect (*M. semimembranosus* and *M. biceps femoris*) on the response to treatment ($P > 0.05$), so data were combined. A confidence level of 5% was used to compare significant differences between means ($P < 0.05$) using Student's *t*-test pairwise (Microsoft Excel, XP).

3. Results and discussion

3.1. Single-step pressure-heat process

The aim of the current study was to determine the lowest temperature that could be used when applying pressure at 200 MPa that would achieve an increase in product yield and a significant improvement in tenderness, without the need for further cooking. At the same time, consideration was given to temperature–time profiles used to ensure that the meat product would meet the regulations for food safety, without the need for further heat treatment.

3.1.1. Processing effects on meat pH

In our studies, the pH of the raw meat without treatment was 5.58 ± 0.023 (mean of 6 muscles ± SE) (Fig. 1). When the meat was heated at 60 °C in a water bath, or subjected to pressure (200 MPa) at 60 °C, and then subsequently cooked at 80 °C, the mean pH of the meat was 5.98 and 5.88, respectively, thus supporting previous findings (Cheah & Ledward, 1996; McArdle, Marcos, Kerry, & Mullen, 2011). However, the increase in pH of meat subjected to HPP–heat was not as great as with heat-only (pH 5.88 compared with 5.98) ($P < 0.05$). This was clearly evident when meat samples were subjected to either heat-only or HPP–heat (temperature range of 60 to 76 °C) without further cooking. Thus it would seem that this is further evidence that pressure restricts certain thermal denaturation processes (Fernández-Martín, 2007) that would normally occur at these temperatures or during cooking.