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The effect of radio frequency heating on chemical, physical and sensory aspects of quality in turkey breast rolls

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Abstract

The effects of radio frequency (RF) heating on the chemical, physical and sensory properties of large diameter encased turkey breast rolls were compared to those of the same products cooked in a conventional steam oven. The time to endpoint temperature (minimum 73 °C) for an RF-cooked product at 500 W was 40 min as compared to 150 min for a steam-cooked product. Proximate analysis of macro components, assays of the B-vitamins, thiamine and riboflavin, and texture profile analysis (TPA) revealed no significant difference ($P \geqslant 0.05$) between the two cooking methods. However, RF-cooked turkey rolls had lower Hunter a values (redness) than their steam cooked counterparts. In addition, the rate of lipid oxidation in RF-cooked rolls, during refrigerated storage at 5 °C, was significantly slower than in the steam-cooked products. While a sensory panel could distinguish between RF- and steam-cooked rolls, panellists did not express a preference for rolls cooked by either method.

Keywords: Radio frequency (RF); Turkey; Vitamins; Colour; Texture; Lipid oxidation

1. Introduction

Meat products are relatively poor thermal conductors and, as most conventional methods of thermal processing rely on heat penetration by conduction from the outside to the inside of the product, the cooking times can be unacceptably long in industrial scale processing operations. By contrast, RF-heating, in a similar manner to microwave heating, generates heat volumetrically throughout the product (Rowley, 2001) and, because of the low frequency of the electromagnetic radiation used, RF-heating can achieve much greater penetration depth than the microwave process. This property is potentially very useful for meat products of uniform shape, which are enclosed in large diameter plastic casings.

RF energy has been used for heating of various food products for more than 60 years since it was first examined in the 1940s (Kinn, 1947) and applications of RF-heating in the food industry include blanching of vegetables, thawing of frozen products, post-bake drying of cookies and snack foods (Jones & Rowley, 1997; Moyer & Stotz, 1947; Sanders, 1966). The method has also been applied to the pasteurization and sterilization of a range of meat products. Bengtsson and Green (1970) reported that an RF-heating system operating at 60 megahertz (MHz) reduced cooking time and juice losses whilst also improving the sensory quality of cured hams. Houben, van Roon, and Krol (1990) achieved a 40-fold reduction in the pasteurisation time of moving sausage emulsions without adverse effects on product appearance. While the ability of RF-heating to reduce cooking times for meats is undisputed, it is more difficult

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to draw definitive conclusions with regard to the overall quality of the resulting products, since there have been relatively few detailed studies devoted to this aspect to date.

One important group of products, for which the potential of RF-cooking has not been exploited to date, is comminuted meat emulsions packed in plastic casings prior to cooking. Successful application of the RF method to the cooking of such products would be advantageous, not least because problems associated with post-cooking aseptic packaging would not arise. Investigation of RF-heating of cased meats in this laboratory encountered a range of problems, in particular, the possibility of localised overheating of casings as a result of arcing when such products were heated in air. For food safety reasons, the removal of this effect was mandatory, and it was found that it could be successfully eliminated by immersion of the product in water during cooking. This work, details of which will be described elsewhere, has allowed optimised RF-cooking protocols to be developed for assessment of quality in both small and large diameter cased meat emulsions (Brunton et al., 2004; Zhang, Lyng, & Brunton, 2004), as well as for the product which is the subject of the present study.

Processed cooked turkey breast meats, purchased from cold meat counters in supermarkets or delicatessens, are currently popular products in Ireland. These include boned or deboned oven-cooked whole breast sections, as well as a range of encased products, comminuted to different degrees, and cooked in steam ovens. Cooked turkey breast, which has a higher level of oxidatively labile polyunsaturated fatty acids in its membrane phospholipids than most other meats, is particularly susceptible to the development of lipid oxidation derived off flavours during refrigerated storage (Wu & Sheldon, 1988).

The objectives of the present investigation were to measure a range of quality related parameters for RF cooked encased turkey breast rolls and to compare them with the values obtained from conventionally cooked samples of the same products. Texture was evaluated by texture profile analysis (TPA), colour by colorimetric measurement, lipid oxidation by a spectophotometric assay and the B-vitamins thiamine and riboflavin, which were used as markers for micronutrient loss/retention, by high performance liquid chromatography (HPLC) analysis. A sensory panel was used to evaluate the overall quality of RF cooked turkey rolls compared to their steam-cooked counterparts.

2. Materials and methods

2.1. Equipment

The RF oven used was a custom built system (Capenhurst Technology, Chester, UK) consisting of two main components, a conventional fan oven and a RF heater, which can operate individually or in combination. For the entire duration of the study, the conventional oven fan and light were turned on with the temperature set at 25 °C. The RF heater, with maximum power output of 600 W and operating at 27.1 MHz, was controlled by a matching network and an RF generator (Coaxial Power Systems). The RF-generated energy was applied via a set of parallel rectangular electrodes, which were 215 mm apart. The steam oven used was a thermostatically controlled KERRES smoke-air steam oven (Type CS 350, Raicher-und-Kochanlagen, D-71560 Sulzbach-Murr, Germany) set at 80 °C.

2.2. Manufacture of turkey rolls

Turkey breast meat was purchased from a local producer (Kerry Food, Glenealy, Co. Wicklow, Ireland) and ground through a 4.5 mm plate using a meat mincer (Model No. TS 8E, OMAS Food Machinery, 21040 Oggiona S. Stefano, Italy). Salt was added in layers and worked evenly into the meat to give a final salt concentration of 1.2% (w/w) and the minced muscle was tumbled at 4 °C for 4 h using a mechanical tumbler (Model No. MC-25, Inject Star of the Americas, Inc., Brookfield CT., USA). The meat emulsion was then filled into 96 mm diameter plastic casings (Walsrode K-Plus, Casetech, GMBH, Germany), using a mechanical filler (Model No. EM-12, Equipaimentos Carnicos, Barcelona, Spain), and sealed with plastic ties (Maplin electronics, Dublin, Ireland) to make 180 mm long turkey rolls (1.2 ± 0.010 kg).

2.3. RF-cooking protocol

RF-cooking of the turkey rolls was carried out in recirculating hot water in a cylindrical cell made from semi-crystalline high density polyethylene (Alperton Engineering Ltd., Dublin Industrial Estate, Glasnevin, Dublin, Ireland). This cell, details of which have been published recently (Zhang et al., 2004), was specially designed to allow large diameter cased meat products of the dimensions used in this study to be subjected to RF-heating while mounted in a vertical position within the cell. After insertion of the roll, the cell was sealed with the top lid and placed between the two electrodes. It was then filled via the top inlet line with recirculating tap water (flow rate, 1.5 $l\,min^{-1}$) from a thermostatted water bath set at 80 °C and the RF power turned on. On completion of cooking, the RF power was turned off and the roll held within the cell for exactly 2 min. After cooking, rolls were cooled under running cold water for 1 h and then at 5 °C in a cold room for 2 h prior to carrying out quality evaluation.

2.4. Steam-cooking protocol

Samples for steam processing were prepared as described in Section 2.2 above and cooked in a thermostatically controlled steam oven set at 80 °C for 150 min. Product and oven temperatures were recorded at 3 points within the roll at 30 s intervals using a Grant Squirrel logger (Grant Instruments Ltd., UK) and type T thermocouples (Radionics Ltd., Ireland).

2.5. Texture profile analysis

A universal testing machine (Model No. 5544, Instron Corporation, High Wycombe, England) was used with a 500 N load cell and data interpreted using the Merlin software package (Version 2019). The cooked turkey rolls were cut into 2 cm thick slices and samples for analysis (diameter 20 mm and height 20 mm) were prepared using a cork borer. The meat sections were covered with a flexible plastic film to prevent water evaporation and allowed to equilibrate to room temperature (25 °C). The crosshead speed was set at 50 mm min^{-1} and the cores were axially compressed to 50% of their original height in a double compression cycle. Attributes were analysed according to: hardness (H1 and H2), cohesiveness, springiness, gumminess, chewiness.

2.6. Instrumental colour

Samples for internal colour measurement was prepared as described in Section 2.4 above. A Minolta colorimeter (Model No. CR-300, Minolta Ltd., Milton Keynes, UK) was used to determine Hunter *L* (lightness), *a* (redness/greenness) and *b* (yellowness/blueness). The colorimeter was calibrated for internal light (D65) before carrying out colour measurements.

2.7. Proximate and vitamin analysis

Prior to analysis the casing was removed from the cooled (5 °C) turkey rolls and the samples were ground through a food processor (Braun Multipractice, Germany) and stored in air-tight containers under refrigeration. Moisture, ash, fat and protein contents of the chopped meat samples were analysed according to the AOAC official methods 950.46, 920.153, 991.36 and 981.10, respectively (Soderberg, 1995). Salt (NaCl) was determined by titration of the macerated sample with $AgNO_3$, using the method described by Kapel and Fry (1974). The B-vitamins, thiamine and riboflavin, were measured using the recently developed simplified HPLC procedure described by Tang, Cronin, and Brunton (2003).

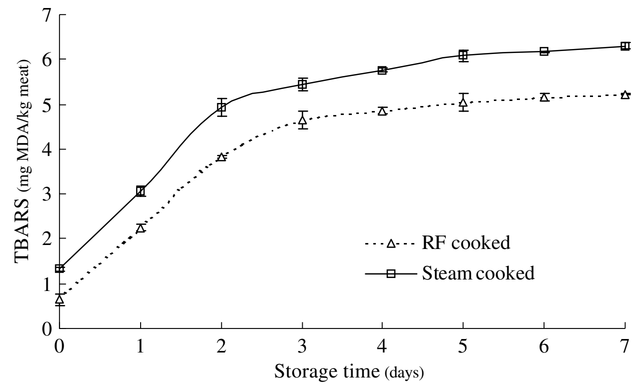

Fig. 1. Development of lipid oxidation in RF- and steam-cooked turkey rolls during storage at 5 °C.

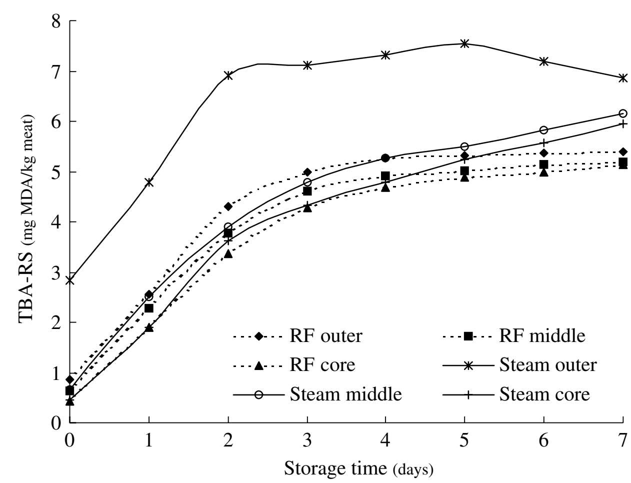

Fig. 2. Comparison of lipid oxidation in outer, middle and core sections of RF- and steam-cooked turkey rolls during storage at 5 °C.

2.8. Measurement of lipid oxidation

Lipid oxidation, in turkey rolls cooked by steam and RF oven, was monitored immediately after cooling at 5 °C and daily following storage at 5 °C for up to 7 days, using the 2-thiobarbituric acid (TBA) procedure of Buege and Aust (1970). Results were expressed as 2-thiobarbituric acid reactive substances (TBA-RS), in mg of malonaldehyde (MDA)/kg muscle. Data points shown in Figs. 1 and 2, respectively, are the means from duplicated steam and RF-cooking experiments.

2.9. Sensory evaluation

Following microbiological tests to confirm that the samples were safe for consumption, sensory evaluations on slices of 3 day-stored RF- and steam-cooked turkey roll samples were carried out in separate assessments by a triangle similarity test and a preference test, respectively. A total of 60 untrained panellists were recruited to carry out each test in a sensory analysis laboratory equipped with individual tasting booths and controlled lighting. During the triangle test, each panellist was given 3 samples (2 identical and 1 different) and asked to record the number of the odd sample, based on overall texture, juiciness, colour, flavour or other factors while, in the preference test, the panellist was asked to select the preferred sample from two different samples served.

2.10. Statistical analysis

The results of proximate and vitamin analysis, instrumental colour and TPA were analysed using the Statistical Analysis System (Version 8.2, Statistical Analysis Systems, Cary, NC, USA). A t test was used to determine significant differences between the means.

3. Results and discussion

3.1. RF cooking time and temperature distribution

Since it is recommended that foods be cooked above 73 °C to ensure microbiological safety (Bobeng & David, 1978), an optimised cooking time of 40 min with the RF power at 500 W was required to achieve an end-point temperature of 73 °C at the coldest point for RF cooking. This was established by cooking a number of rolls in triplicate for 35, 40 and 45 min, respectively. At the end of the 2 min holding period, each roll was quickly removed from the cell and multipoint temperature readings taken immediately, using a preheated (80 °C) 15 point thermocouple jig fabricated from a hollowed-out rectangular wooden block, based on the design of James (1993) and described in detail by Zhang et al. (2004).

At the end of 40 min RF-cooking and 2 min holding, a minimum temperature of 74 °C was achieved with a mean of 77.6 ± 0.6 °C and a temperature differential across the rolls of 5.3 ± 1.6 °C. In comparison, the steam-cooked product had a lower mean temperature of 74.1 ± 0.3 °C. RF-heating has been reported as having the characteristics of a uniform cooking method since the heat is generated volumetrically throughout the product (Zhao, Flugstad, Kolbe, Park, & Wells, 2000). However, the degree of uniformity may be dependent on the product composition and, specifically, on the uniformity of the distribution of the electrolytes therein. A lack of the latter has recently been suggested as a possible reason for a 20 °C differential in RF-cooked comminuted beef samples (Laycock, Piyasena, & Mittal, 2003). In this context, the temperature differential of the RF cooked product in the current study was quite small and relatively uniform cooking was achieved.

3.2. Proximate and vitamin analysis

The proximate compositions of the raw turkey breasts and cooked turkey rolls are presented in Table 1. All heat treatments were carried out three times on duplicated samples. No significant difference between RF- and steam-cooked samples, for any of the parameters analysed, was noted ($P \geqslant 0.05$). Cooking loss has been used as an indicator of the juiciness of a product (Laycock et al., 2003) and it has been reported that RF-cooking could reduce cooking losses as compared to conventional methods (Bengtsson & Green, 1970). However, in the current study, slightly higher cooking losses were obtained for RF cooked samples. The juice losses during cooking of RF- and steam-cooked turkey rolls were 2.69 ± 0.68% and 2.27 ± 0.75%, respectively. However, no significant difference between these values existed ($P \geqslant 0.05$) and the moisture content of the final products was unaffected. This indicated that the juiciness of the turkey rolls might not be affected by these two different cooking methods.

As shown in Table 2, the levels of the water-soluble vitamins, thiamine and riboflavin, from both RF- and steam-cooked turkey rolls were identical to those found in the raw turkey breast. Therefore, the low and similar juice losses given by the two cooking methods were manifested to the same extent in the status of these micronutrients as they were in the compositional data for the macro constituents.

Table 1
Proximate composition of raw turkey breasts and of RF- and steam-cooked turkey rolls*

Parameters (%)	RF-cooked	Steam-cooked	Raw
Moisture	71.70 ± 0.15	71.55 ± 0.19	73.48 ± 0.03
Protein	24.8 ± 0.50	24.6 ± 0.36	23.7 ± 0.20
Fat	2.00 ± 0.06	2.01 ± 0.03	1.16 ± 0.09
Ash	2.31 ± 0.03	2.32 ± 0.02	1.23 ± 0.04
NaCl	1.31 ± 0.04	1.31 ± 0.03	0.12 ± 0.01

* No significant differences between any parameters of RF- and steam-cooked turkey rolls ($P \geqslant 0.05$).

Table 2
B-vitamin contents of raw turkey breast and of RF- and steam-cooked turkey rolls*

Product	Thiamine (mg/100g)	Riboflavin (mg/100g)
Raw turkey breast	0.061 ± 0.005	0.104 ± 0.006
RF-cooked turkey rolls	0.059 ± 0.001	0.101 ± 0.004
Steam-cooked turkey rolls	0.059 ± 0.002	0.101 ± 0.003

* No significant differences between the vitamin contents of RF- and steam-cooked turkey rolls ($P \geqslant 0.05$).

3.3. Instrumental colour

Results for instrumental colour measurements are summarised in Table 3. RF-cooked turkey rolls had significantly lower Hunter a (redness) values when compared to steam cooked samples ($P < 0.05$), while both L and b values were similar for the two cooking methods. Meat colour is closely related to the status of the muscle heme pigments. During cooking, denaturation of the bright red oxymyoglobin at the surface and of the purple red myoglobin in the interior takes place, resulting in colour changes in the cooked product that are dependent both on the type of meat and on the severity of the cooking process. Although turkey breast meat has a lower myoglobin content than either beef or pork (Klettner, Ott, & Boehm, 2003), the retention of a pale red colour in the interior is a feature of turkey meat rolls cooked by conventional steam heating. It has been reported that the higher the endpoint temperature, the lower the mean Hunter redness values (Lien et al., 2002). The higher end-point temperatures of RF cooked samples are the most likely explanation for the lower Hunter redness values of those rolls.

3.4. Texture profile analysis

Table 4 lists the TPA parameters of RF- and steam-cooked turkey rolls. No significant differences were found in any of the TPA parameters tested, including hardness 1, hardness 2, cohesiveness, springiness, gumminess, and chewiness, between RF- and steam-cooked turkey rolls ($P \geqslant 0.05$). However, it should be noted that, while the RF-cooked turkey rolls had slightly higher average hardness values than steam cooked samples, the difference was not great. Previous studies on cooked meat doughs (van Roon, Houben, Koolmees, & van Vliet, 1994) and pork luncheon rolls (Zhang et al., 2004) found that RF-heated products displayed a firmer texture than conventionally cooked products. By contrast, Laycock et al. (2003) found significantly lower hardness values for RF-cooked comminuted beef products than for their-steam cooked counterparts.

Table 3
Mean internal colour parameters of RF- and steam-cooked turkey rolls

Cooking method	Hunter L	Hunter a	Hunter b
RF	73.39 ± 0.45^a	3.11 ± 0.17^a	8.78 ± 0.29^a
Steam	72.88 ± 0.19^a	3.75 ± 0.17^b	8.46 ± 0.04^a

[a–b] Means with the same letter in a column are not significantly different ($P \geqslant 0.05$).

Table 4
Texture profile analysis (TPA) parameters of RF- and steam-cooked turkey rolls[*]

Parameters	RF-cooked	Steam-cooked
Hardness 1 (N)	63.06 ± 6.33	59.45 ± 1.07
Hardness 2 (N)	53.38 ± 5.08	50.57 ± 1.05
Cohesiveness	0.425 ± 0.008	0.436 ± 0.009
Springiness (mm)	7.95 ± 0.11	8.24 ± 0.16
Gumminess (N)	26.70 ± 2.25	25.79 ± 0.21
Chewiness (mJ)	212.20 ± 20.72	212.11 ± 5.59

[*] No significant differences between any parameters of RF- and steam-cooked turkey rolls ($P \geqslant 0.05$).

3.5. Sensory evaluation

Both the triangle similarity test and preference test were carried out with 60 untrained panellists. During the triangle test, 35 panellists could distinguish the difference between RF and steam cooked turkey rolls. According to Meilgaard, Civille, and Carr (1991) this indicates that RF and steam cooked samples were significantly different ($P < 0.001$). Panellists indicated that they could distinguish between RF- and steam-cooked samples on the basis of texture (50%) and flavour (25%). RF-cooked rolls were considered to be tougher than steam-cooked samples. Although the difference was not significant ($P \geqslant 0.05$), this observation was reflected in the actual TPA hardness data.

Further sensory evaluation was carried out to determine whether or not panel members had a preference for RF- or steam-cooked samples using the 60 untrained panellists. Results indicated that over half the panellists (32) expressed a preference for RF-cooked turkey rolls while the remainder preferred steam-cooked samples. While not necessarily an indication of consumer preference, the results presented here indicate that panellists did not prefer traditional steam-cooked rolls over RF-cooked samples.

3.6. Lipid oxidation in stored meats

Because of the high content of oxidatively labile phospholipids in the muscle (Allen & Foegeding, 1981), cooked turkey meat has been shown to be more susceptible to the development of lipid oxidation-mediated off-flavours during refrigerated storage than meat from other species. The reaction of TBA with the by-products of lipid oxidation, particularly MDA to give the so-called TBARS assay, has long been used as a simple and sensitive colorimetric method to follow the course of lipid oxidation in foodstuffs.

Wu and Sheldon (1988) reported a negative correlation between sensory scores and an increase in TBARS in cooked turkey meat. The influence of storage time at 5 °C on TBARS concentrations in RF- and steam-cooked turkey rolls is presented in Fig. 1. Lipid oxidation for both samples increased rapidly over the first three days of storage and more slowly thereafter. Initial TBARS values were somewhat lower for the RF-cooked rolls and the overall development of oxidation in the latter remained slightly reduced compared to the steam-cooked samples for the duration of storage. Lipid oxidation derived off-flavour in cooked turkey breast has been shown to be detectable at a TBARS level of around 1.5 mg MDA/kg meat (Brunton, Cronin, Monahan, & Durcan, 2000). In spite of having undergone significant oxidation, as shown in Fig. 1, the flavour of the 3 day-stored meat used in the sensory analysis in the present study was quite acceptable. In addition, only 25% of the panellists claimed to be able to notice flavour differences between the two cooking methods, as mentioned earlier. Based on previous experience in this Department, using trained panellists to evaluate off-flavour in commercial turkey breast meats, it is unlikely that panellists would be able detect a difference between oxidised favour intensity in samples where the TBARS values were 4.6 and 5.5 mg MDA/kg for RF- and steam-cooked meats, respectively, after 3 days of refrigerated storage.

The more rapid progress of lipid oxidation in steam-cooked rolls is most likely due to the prolonged exposure of the outer sections of the rolls to the temperatures generated by the steam and the consequent effects of heat-denaturation of myofibrillar proteins and thermal damage to the membrane phospholipids. The latter will oxidise rapidly when exposed to air (Brunton, Cronin, & Monahan, 2002). A time/temperature profile for a steam cooked sample indicated that the outer portion (15 mm from the surface) of the roll reached a temperature of 73 °C after 90 min and remained at this temperature or higher for the remaining 60 min of the cook. To demonstrate the effects of this on lipid oxidation, steam- and RF-cooked turkey rolls were each divided into three portions along the axis comprising core, middle and outer sections, and TBARS measurements made on each during storage. The results, shown in Fig. 2, clearly illustrate the much greater susceptibility of the outer section of the steam cooked product to oxidation compared to either of the inner sections. The latter oxidised at a rate roughly comparable to that of the RF roll where the much shorter cooking time minimised the extent of thermal damage to the product. Wu and Sheldon (1988) have also reported similar results to those given here, in respect of the comparative rates of lipid oxidation in outer and inner parts of turkey rolls cooked in a water bath.

4. Conclusions

Comminuted turkey breast meats cooked in casings gave low and similar cook-out losses for RF- and steam-heating methods resulting in products of almost identical chemical compositions with respect to both macro constituents and selected micronutrients. The RF turkey meat, which was cooked almost 4 times more rapidly than the steam product, was slightly paler in colour and underwent lipid oxidation at a slower rate during refrigerated storage. While members of a sensory taste panel were able to detect a difference between RF- and steam-cooked samples, they did not express a preference for one over the other. Therefore, from a quality perspective, RF-heating technology is a satisfactory method for cooking poultry products of the type examined in the present study.

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