ELSEVIER

Meat Science 55 (2000) 361–370

MEAT SCIENCE

www.elsevier.com/locate/meatsci

# The effect of ionising radiation on the colour of leg and breast of poultry meat

S.J. Millar [a,1], B.W. Moss [a,b,*], M.H. Stevenson [a,b,✠]

[a] Department of Food Science, The Queen's University of Belfast, Newforge Lane, Belfast BT9 5PX, UK
[b] Food Science Division, Department of Agriculture for Northern Ireland, Newforge Lane, Belfast BT9 5PX, UK

Dedicated to the late Dr. M. Hilary Stevenson, OBE (1947–1994)

Received 20 August 1998; received in revised form 3 July 1999; accepted 16 November 1999

**Abstract**

The effect of irradiation (0 and 5 kGy) of chicken, goose and turkey breast and leg muscles and subsequent storage at 4°C was studied in relation to colour changes. The colour of the outside surface was measured on the breast on each day of storage for up to 7 days post irradiation and for breast and leg and day 7. The colour of a freshly cut interior surface of both breast and leg was measured after 7 days storage. $L^*$ values of control and irradiated chicken, goose and turkey breast muscles changed little during storage post irradiation. The $a^*$ values for unirradiated goose breast were significantly higher than irradiated goose breast but declined to values similar to irradiated goose breast after 7 days of storage. The $b^*$ values for irradiated turkey breast were significantly higher than unirradiated turkey breast at all times post irradiation treatment. Analysis of variance was performed on the day 7 CIELAB values of breast muscle for the effects of species, surface and irradiation and their interactions. After 7 days storage $a^*$ values of poultry breast were higher on the freshly cut surface due to irradiation in all species, with decreases in hue angle due to irradiation. The $a^*$ values of leg of all species at 7 day post irradiation was significantly higher in the irradiated treatment than the controls. The results for the turkey leg indicate that this effect may be mainly due to higher $a^*$ values of the freshly cut surface. The possible role of carboxy form of the haem pigments as the irradiated pigment form is discussed. 

## 1. Introduction

Ionising radiation can be used to bring about beneficial changes in foodstuffs (Urbain, 1986) and it has been suggested as a method of ensuring the safety of meat products (Stevenson, 1992). In addition to improving the storage life of meat products, however, irradiated meats can also suffer from a variety of side effects including undesirable smells, flavours and colour changes (Urbain, 1986). The colour of fresh meats is an important quality factor, influencing the purchase decision and so any deliterious effects on this parameter need to be understood and if possible eliminated. A range of studies have been performed on irradiated meats and meat extracts of different origins and the consensus appears to be that for beef (Tappel, 1956), beef extracts (Ginger, Lewis & Schweigert, 1955) and poultry (Coleby, Ingrann & Shepherd, 1960) treatment of the meat with ionising radiation causes the formation of a red colour in the meat. Various reaction mechanisms have been proposed to explain these changes and a number of workers have proposed that the red colour is due to oxymyoglobin (Satterlee, Brown & Lycometros, 1972; Tappel).

Although the phenomenon has been widely examined there have been very few comparative cross species/muscle type studies undertaken. Studies of the effects of gamma irradiation on the colour of meats with differing haem concentrations have also been limited to comparison of chicken leg and breast meat (Blythe, 1990). The present study aims to compare the results of treatment with ionising radiation on a number of poultry species and muscle types to further elucidate its effect on meat

* Corresponding author Tel.: +44-1232-250-666; fax: +44-1232-669-551.

[1] Present address: Campden and Chorleywood Food Research Association, Chipping Campden, Glos. GL55 6LD, UK.

✠ Deceased.

0309-1740/00/$ - see front matter 
PII: S0309-1740(99)00165-5

colour and evaluate the cause of any colour changes observed.

## 2. Experimental

### 2.1. Preparation of samples and irradiation

Eviscerated poultry carcasses (12 geese, 10 turkey and 12 chicken) were obtained from poultry processors 24 h post mortem and transported to the laboratory in a refrigerated van (4°C). On arrival, the breast muscles for all species were removed from the carcasses and a sample of 1 g taken for $pH_u$ measurement by the method of Bendall (1975). The breast muscles were then placed on polystyrene trays, overwrapped with oxygen-permeable film and stored at 4°C until irradiated. The legs were removed from the carcasses at different times post mortem since there was not sufficient sample space in the irradiator to accommodate replicates of all species at one time. The chicken legs were removed at 48 h post mortem, turkey legs at 72 h and goose legs at 96 h. After removal the legs were placed in polystyrene trays, overwrapped as described previously, and stored at 4°C until irradiated. Following irradiation all samples were stored at 4°C for periods of up to 7 days following irradiation. Note that the times referred to in the statistical analysis are times post irradiation treatment, not post slaughter.

One breast and leg from each carcass was irradiated using a $^{60}Co$ source (Gammabean 650 Irradiator, Nordion International, Canada), at an estimated dose of 5 kGy at 4°C. Amber perspex dosimeters (Type 3042D, AEA Technology, Harwell, UK) were attached to both sides of each sample to calculate the dose received (Millar, Moss, MacDougall & Stevenson, 1995). The remaining unirradiated controls were stored at 4°C during the irradiation process.

Following irradiation all samples were stored at 4°C and colour measurements made at different time intervals following storage. The timing of the colour measurements varied between the meat species and are given in detail below and summarised in Table 1.

### 2.2. Colour measurement

Reflectance was measured over the range 380 to 800 nm using a Monolight 6800 Spectrophotometer (Macam Photometrics, Livingston, UK) with an illuminating geometry of diffuse/0 specular excluded. The Monolight spectrophotometer was calibrated to a standard white tile (National Physical Laboratory, Teddington, UK). The instrument's software was used to calculate CIE colour parameters at 5 nm intervals using weighting functions for illuminant D65 10° observer.

The colour of the exterior surface of the turkey breasts, goose breasts, chicken legs and chicken breasts was measured through the overwrap film for both the irradiated and unirradiated control samples at 1, 2, 3, 4, 5, 6 and 7 days following irradiation. On day 7 a 1 cm thick slice was removed from the exterior surface following its colour measurement. The overwrap film was replaced and the colour of the freshly cut surface was measured within 30 s of cutting to obtain a colour measurement of the pigment state within the meat at the time of cutting.

For the goose leg and turkey leg, colour measurements of the exterior surface were made on day 1 and day 7

Table 1
Experimental sampling plan for colour measurements

| | Experiment 1A Goose | | Experiment 1B Goose | | Experiment 2A Turkey | | Experiment 2B Turkey | | Experiment 3A Chicken | | Experiment 3B Chicken | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Muscle type | Breast $n^a=24$ | | Leg $n^a=24$ | | Breast $n^a=20$ | | Leg $n^a=20$ | | Breast $n^a = 24$ | | Leg $n^a = 24$ | |
| Irradiation time post mortem | 24 h | | 96 h | | 24 h | | 72 h | | 24 h | | 48 h | |
| Surface measured | FC[b] | Ext[c] | FC | Ext | FC | Ext | FC | Ext | FC | Ext | FC | Ext |
| *Day* | | | | | | | | | | | | |
| 1 | x[d] | √[e] | x | √ | x | √ | x | √ | x | √ | x | √ |
| 2 | x | √ | x | x | x | √ | x | x | x | √ | x | √ |
| 3 | x | √ | x | x | x | √ | x | x | x | √ | x | √ |
| 4 | x | √ | x | x | x | √ | x | x | x | √ | x | √ |
| 5 | x | √ | x | x | x | √ | x | x | x | √ | x | √ |
| 6 | x | √ | x | x | x | √ | x | x | x | √ | x | √ |
| 7 | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |

[a] n, Total number of samples measured, i.e. both irradiated and unirradiated.
[b] FC, Freshly cut.
[c] Ext, Exterior.
[d] √, No measurement taken.
[e] No measurement taken.

and measurements of the freshly cut surface were made only on day 7. Details of timings of colour measurement are given in Table 1.

### 2.3. Statistical analysis

Regression analysis was used to test whether the change in CIELAB values with time during the 7 days of storage was significantly different due to irradiation. This approach was only applied where visual inspection of the graphs indicated linear trends with time. For each species/muscle type on each day the difference between irradiated and unirradiated samples was examined using the Students *t*-test.

Analysis of variance for the main effects of species, irradiation and surface and their interactions was undertaken for poultry breast muscle at 7 days post irradiation. For the leg muscle, analysis of variance for the main effects of irradiation and surface and their interaction was undertaken on each species on the CIELAB data 7 days post irradiation. A statistical analysis evaluating species differences was not undertaken since the leg muscles of the different species were irradiated at different times post mortem.

## 3. Results

### 3.1. Changes in CIELAB parameters during storage

The changes in $L^*$, $a^*$ and $b^*$ during storage are shown in Figs. 1 and 2. There were no marked trends in $L^*$ values for either control or irradiated chicken breast, chicken leg and turkey breast with days of storage. There was some indication in irradiated goose breast of an increase in $L^*$ values with days of storage. However, at no sampling times were the $L^*$ values of the irradiated samples significantly different from unirradiated controls. The $a^*$ values of chicken breast and turkey breast showed no marked changes during storage and on no days were there any statistically significant differences between control and irradiated samples. The $a^*$ values of irradiated chicken leg tended to be higher on all days than unirradiated samples and this difference was statistically significant on days 2, 5, 6 and 7 (Fig. 1b). There was a small trend for $a^*$ values of irradiated chicken leg to increase with storage (fitted slope 0.008 $a^*$ day$^{-1}$) and unirradiated chicken leg to decrease with storage (fitted slope $-0.203$ $a^*$ day$^{-1}$). Statistical analysis showed these two slopes to be significantly different from each other. For goose breast, $a^*$ values of control samples on day 1 were significantly higher ($P<0.001$) than irradiated samples, however $a^*$ values of the control declined with a fitted slope of $-0.618$ $a^*$ day$^{-1}$ to equal those of irradiated samples on day 7. The $a^*$ values of irradiated goose breast showed little change during storage ($-0.228$ $a^*$ day$^{-1}$) but were significantly ($P<0.01$) lower than unirradiated controls on all except day 7. The $b^*$ values for control and irradiated chicken breast on day 1 were similar, and in both cases tended to increase with storage (Fig. 1). This increase in $b^*$ values with storage was greater for the irradiated chicken breast than unirradiated chicken breast. The $b^*$ values of chicken leg (Fig. 1) and goose breast (Fig. 2) showed no marked trends during storage and no significant differences between control and irradiated treatments on any of the days sampled. The increase in $b^*$ values with storage although small was significantly higher in irradiated chicken breast (0.178 $b^*$ day$^{-1}$) than unirradiated controls (0.069 $b^*$ day$^{-1}$). The $b^*$ values for irradiated turkey breast were significantly higher than unirradiated controls on all days (see Fig. 2) and tended to increase with storage in both treatments. The rate of increase in both treatments was not significantly different (0.345 $b^*$ day$^{-1}$, 0.365 b* day$^{-1}$ 0 and 5kGy respectively).

### 3.2. Analysis of variance for CIELAB values taken on day 7

#### 3.2.1. Poultry breast muscle: effects of species, irradiation and surface

The results in Table 2 show that species had a statistically significant effect ($P<0.001$) on CIELAB parameters. The mean $L^*$, and hue angle ($h°$) values for goose were significantly ($P<0.001$) lower and $a^*$ values significantly higher ($P<0.001$) than those of chicken and turkey. The $b^*$ values for chicken were significantly higher than those of goose and turkey, whilst the metric chroma values ($C^*$) for turkey were significantly ($P<0.001$) lower than for chicken and goose. Irradiation at 5 kGy resulted in significantly ($P<0.001$) higher $a^*$, $b^*$ and $C^*$ values and significantly ($P<0.01$) lower $h°$ values, 7 days post irradiation. The $L^*$, $b^*$ and $h°$ values of the exterior surface were significantly ($P<0.001$) higher and the $a^*$ values significantly lower ($P<0.001$) than the freshly cut surface at 7 days post irradiation (Table 2). Both $a^*$ and $h°$ showed statistically significant two-factor interactions for irradiation/species, irradiation/surface and surface/species and also a three- factor irradiation/species/surface interaction. The irradiation/surface interaction for $a^*$ shows that irradiation resulted in significantly higher ($P<0.001$) $a^*$ values on the freshly cut surface 7 days post irradiation (4.72, 7.00, 0 and 5 kGy respectively) but not on the exterior surface (4.36, 4.03, 0 and 5 kGy respectively). Hue angles ($h°$) showed the opposite trend with irradiation resulting in significantly lower values on the freshly cut surface 7 days post irradiation (59.3, 49.5, 0 and 5 kGy respectively) and significantly higher values on the exterior surface due to irradiation (61.1, 66.0, 0 and 5 kGy respectively). The three-factor interaction for $a^*$ values shows clearly that the increase in $a^*$ values due to irradiation, noted in Table 2, was entirely

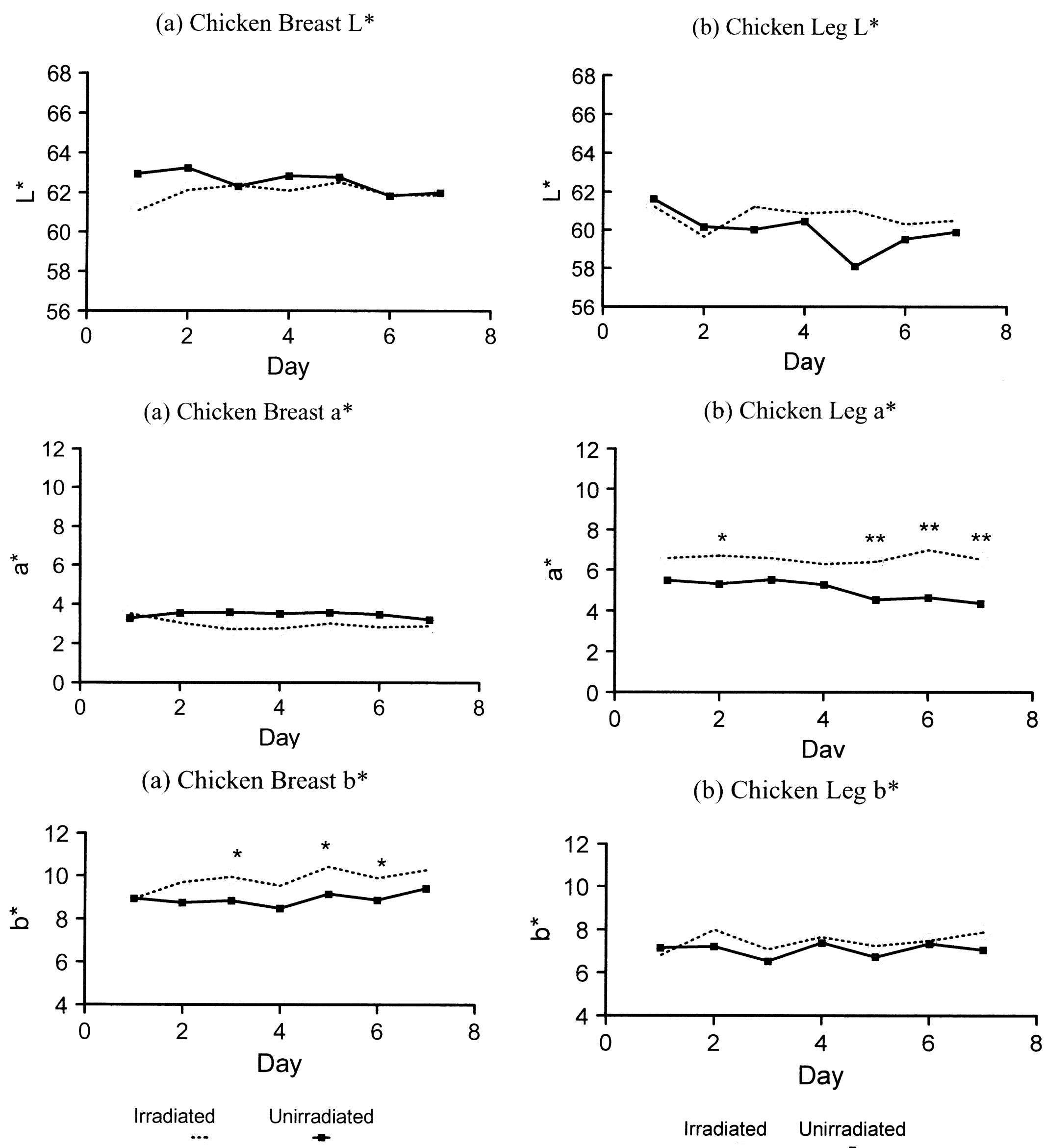


Fig. 1. Effect of irradiation and duration of storage on CIELAB parameters of chicken leg and breat muscle. Differences between unirradiated and irradiated for each day: $*P<0.05$, $**P<0.01$, $***P<0.001$; not statistically significant if no indication given.

due to the $a^*$ values on freshly cut surface (Table 3). There were no statistically significant differences in the a* values of the exterior surface of breast muscle 7 days post irradiation for any of the species (Table 3). At 7 days post irradiation $a^*$ values of the freshly cut surface of irradiated breast muscles of all species were significantly higher than the corresponding exterior surface (see Table 3). In unirradiated breast muscles, 7 days post irradiation, the $a^*$ values of the freshly cut surface of goose were significantly higher ($P<0.001$) than the exterior surface, whereas for turkey $a^*$ values of the freshly cut surface of unirradiated breast muscle were significantly lower ($P<0.001$) than the corresponding exterior surface.

Hue angles 7 days post irradiation on the freshly cut surface of chicken and turkey breast were significantly lower ($P<0.001$) following irradiation than the corresponding unirradiated freshly cut surfaces (see Table 3). At 7 day post irradiation the hue angles of the exterior surface of goose and turkey breast meat were significantly higher ($P<0.01$) in irradiated samples than unirradiated controls whereas for turkey the opposite was observed. A similar, although not statistically significant trend was observed for the exterior surface of chicken breast meat.

### *3.2.2. Chicken leg muscle: effect of irradiation and surface*

Irradiation resulted in significantly higher $a^*$, $b^*$ and metric chroma ($C^*$) and significantly lower hue angles (Table 4). The $L^*$, and $h^\circ$ values were significantly

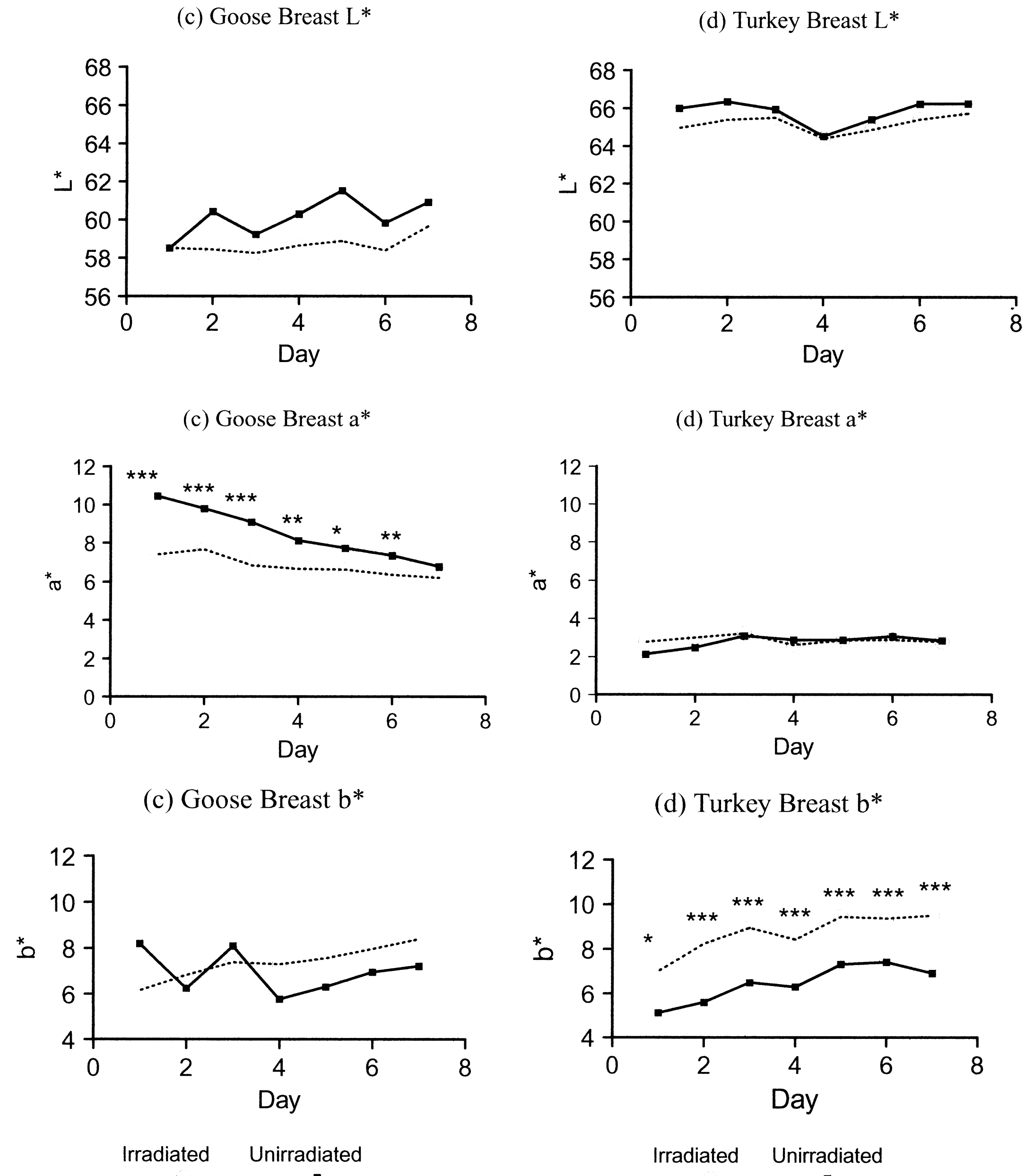


Fig. 2. Effect of irradiation and duration of storage on CIELAB parameters of goose and turkey breast muscle. Differences between unirradiated and irradiated for each day: $*P<0.05$, $**P<0.01$, $***P<0.001$; not statistically significant if no indication given.

higher ($P<0.001$) and the $a^*$ and $C^*$ values significantly lower on the exterior than freshly cut surface. There were no statistically significant interactions between irradiation and surface.

### *3.2.3. Goose leg muscle: effect of irradiation and surface*

Irradiation resulted in significantly ($P<0.05$) higher $L^*$, $a^*$ and significantly lower $h°$ values than unirradiated goose leg at 7 days post irradiation. At 7 days post irradiation the $L^*$ values of the freshly cut surface were significantly lower ($P<0.001$) and $a^*$, $b^*$ and metric chroma significantly higher than the exterior surface (Table 5). There was a statistically significant interaction between irradiation and surface for hue angle. This interaction shows that irradiation had no effect on the $h°$ values of the freshly cut surface (35.5, 33.3, 0 and 5 kGy, respectively) but on the exterior surface irradiation decreased the hue angle from 40.1 to 20.3 ($P<0.001$).

### *3.2.4. Turkey leg: effect of irradiation and surface*

Irradiation resulted in significantly higher $L^*$, $a^*$, $b^*$ and $C^*$ values in turkey leg at 7 days post irradiation (Table 6).

Table 2
Effect of species and surface on the CIELAB parameters of poultry breast muscle 7 days post irradiation

| | | CIELAB colour parameters | | | | | |
|---|---|---|---|---|---|---|---|
| | | *n* | $L^*$ | $a^*$ | $b^*$ | $h^\circ$ | $C^*$ |
| *Effect of species* | | | | | | | |
| Chicken | | 48 | 62.24[a] | 3.61[a] | 9.21[a] | 68.22[a] | 10.02[a] |
| Goose | | 48 | 56.35[b] | 8.05[b] | 7.25[b] | 41.80[b] | 11.03[b] |
| Turkey | | 40 | 65.19[c] | 3.10[a] | 7.78[b] | 68.49[a] | 8.50[c] |
| Statistical significance | | | *** | *** | *** | *** | *** |
| *Effect of irradiation* | | | | | | | |
| Control (0 kGy) | | 68 | 60.99 | 4.54 | 7.52 | 60.20 | 9.17 |
| Irradiated (5 kGy) | | 68 | 61.06 | 5.52 | 8.68 | 57.75 | 10.68 |
| Statistical significance | | | ns[b] | *** | *** | ** | *** |
| *Effect of surface* | | | | | | | |
| Freshly cut | | 68 | 59.51 | 5.86 | 7.55 | 54.40 | 9.99 |
| Exterior | | 68 | 62.54 | 4.19 | 8.64 | 63.56 | 9.86 |
| Statistical significance | | | *** | *** | *** | *** | ns |
| *Statistical significance of interactions* | | | | | | | |
| Treat type | Irradiation/species | | ns | *** | ns | *** | ** |
| Treat surface | Irradiation/surface | | ns[c] | *** | ns | *** | ns |
| Type surface | Surface/species | | *** | *** | ns | *** | *** |
| Treat/type/surface | Irradiation/species/surface | | ns | *[d] | ns | ** | ns |

[a] Within a column for a particular effect means with common letters are not significantly different ($P > 0.05$).
[b] ns, not statistically significant ($P > 0.05$); * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
[c] 0.056.
[d] 0.05.

Table 3
CIELAB parameters of poultry breast muscle 7 days post irradiation: irradiation, species, surface interaction[a]

| | Chicken | | | | Goose | | | | Turkey | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Freshly cut | | Exterior | Mean | Freshly cut | | Exterior | Mean | Freshly cut | | Exterior | Mean |
| $a^*$ | | | | | | | | | | | | |
| 0 kGy | 3.10 | (ns)[b] | 3.22 | 3.16 | 8.97 | (***) | 6.78 | 7.87 | 1.55 | (***) | 2.83 | 2.19 |
| | (***) | | (ns) | (**) | (***) | | (ns) | (ns) | (***) | | (ns) | (***) |
| 5 kGy | 5.21 | (***) | 2.91 | 4.06 | 10.26 | (***) | 6.21 | 8.23 | 5.25 | (***) | 2.78 | 4.01 |
| Mean | 4.16 | (**) | 3.06 | | 9.61 | (***) | 6.49 | | 3.40 | (ns) | 2.80 | |
| $h^\circ$ | | | | | | | | | | | | |
| 0 kGy | 68.28 | (ns) | 70.98 | 69.63 | 35.71 | (***) | 45.77 | 40.74 | 76.9 | (***) | 67.58 | 72.24 |
| | (***) | | (ns) | (ns) | (ns) | | (**) | (ns) | (***) | | (**) | (**) |
| 5 kGy | 59.86 | (***) | 73.77 | 66.82 | 33.64 | (***) | 52.08 | 42.66 | 56.01 | (***) | 73.47 | 64.74 |
| Mean | 64.07 | (**) | 72.38 | | 34.68 | (***) | 48.93 | | 66.45 | (ns) | 70.53 | |

[a] Significance of differences between adjacent means shown in parentheses.
[b] ns, not statistically significant; *$P < 0.05$; **$P < 0.01$; *** $P < 0.001$.

The $L^*$ and $h^\circ$ values were significantly higher on the exterior surface and the $a^*$ and $C^*$ values significantly lower than the freshly cut surface (Table 6). The statistically significant irradiation/surface interaction was due to the fact that at 7 days post irradiation the $a^*$ values of the freshly cut surface were significantly ($P < 0.01$) higher (8.93) for the irradiated than for the unirradiated turkey leg (6.45). On the exterior surface $a^*$ values of unirradiated turkey leg (5.58) were not significantly different from those of irradiated turkey leg (6.35) at 7 days post irradiation.

The day 1 values are included for comparison in Table 6. If the means of day 1 are compared with the exterior surface (which includes 0 and 5 kGy treatments), then it can be seen that there were small decreases in $L^*$, $a^*$ and $h^\circ$ values and increases in $b^*$ values from day 1 to day 7. $C^*$ values show negligible change from day 1 to day 7.

Table 4
Effect of irradiation and surface on CIELAB parameters of chicken leg muscle 7 days post irradiation

| | CIELAB colour parameters | | | | | |
|---|---|---|---|---|---|---|
| | *n* | *L** | *a** | *b** | h° | *C** |
| *Day 1*[a] | | | | | | |
| Control (0 kGy) | | 61.63 | 5.48 | 7.15 | 51.6 | 9.15 |
| Irradiated (5 kGy) | | 61.26 | 6.58 | 6.80 | 45.9 | 9.56 |
| Significance[a] | | ns[b] | ns[c] | ns | ns | ns |
| | | 61.45 | 6.03 | 6.97 | 48.8 | 9.35 |
| *to Day 7* | | | | | | |
| *Effect of irradiation* | | | | | | |
| Control (0 kGy) | 12 | 58.45 | 5.36 | 7.02 | 52.9 | 8.94 |
| Irradiated (5 kGy) | 12 | 58.50 | 8.00 | 7.70 | 44.5 | 11.22 |
| Statistical significance | | ns | *** | * | *** | *** |
| *Effect of surface* | | | | | | |
| Freshly cut | 12 | 56.76 | 7.92 | 7.25 | 43.0 | 10.80 |
| Exterior | 12 | 60.20 | 5.44 | 7.47 | 54.4 | 9.36 |
| Statistical significance | | *** | *** | ns | *** | *** |
| *Statistical significance of interactions* | | | | | | |
| Irradiaction/surface | | ns | ns | ns | ns | sn |

[a] The 7 day data is for the outside surface only and is included for comparison. The day 1 data was not included in the ANOVA, statistical significance was calculated using *t* test.
[b] ns, not statistically significant ($P>0.05$); $*P<0.05$; $**P<0.01$; $***P<0.001$.
[c] $P=0.59$.

Table 5
Effect of irradiation and surface on CIELAB parameters of goose leg muscle 7 days post irradiation

| | CIELAB colour parameters | | | | | |
|---|---|---|---|---|---|---|
| | *n* | *L** | *a** | *b** | *h°* | *C** |
| *Day 1*[a] | | | | | | |
| Control (0 kGy) | 12 | 54.90 | 7.39 | 1.95 | 14.3 | 7.69 |
| Irradiated (5 kGy) | 12 | 55.84 | 6.33 | 2.77 | 23.7 | 7.29 |
| Significance[a] | | ns[b] | ns | ns | ns | ns |
| Mean (day 1) | | 55.37 | 6.86 | 2.36 | 19.0 | 7.49 |
| *Day 7* | | | | | | |
| *Effect of irradiation* | | | | | | |
| Control (0 kGy) | 12 | 51.40 | 6.10 | 4.75 | 37.8 | 7.84 |
| Irradiated (5 kGy) | 12 | 52.99 | 7.38 | 4.08 | 26.8 | 8.63 |
| Statistical significance | | * | *** | ns | ** | ns |
| *Effect of surface* | | | | | | |
| Freshly cut | 12 | 50.24 | 8.18 | 5.78 | 34.4 | 10.10 |
| Exterior | 12 | 54.15 | 5.30 | 3.05 | 30.2 | 6.38 |
| Statistical significance | | *** | *** | *** | ns | *** |
| *Statistical significance of interaction* | | | | | | |
| Irradiation/surface | | ns | ns | ns | ** | ns |

[a] The 7 day data is for the outside surface only and is included for comparison. The day 1 data was not included in the ANOVA, statistical significance was calculated using *t* test.
[b] ns, not statistically significant ($P>0.05$); $*P<0.05$; $**P<0.01$; $***P<0.001$.

## 4. Discussion

The most striking species difference is the high $a^*$ values in goose breast (Table 2) and their fairly rapid decline post irradiation in the unirradiated samples compared to chicken and turkey breast (Figs. 1 and 2). Comparison of leg muscles is more difficult given the different times of irradiation post slaughter. The main feature when comparing the leg muscles is not the high $a^*$ values but the low $b^*$ values and consequently low hue angles in goose leg compared to the other two species (Tables 4–6). These differences between species in

Table 6
Effect of irradiation and surface on CIELAB parameters of turkey leg muscle 7 days post irradiation

| | CIELAB colour parameters | | | | | |
|---|---|---|---|---|---|---|
| | *n* | $L^*$ | $a^*$ | $b^*$ | $h°$ | $C^*$ |
| *Day 1*[a] | | | | | | |
| Control (0 kGy) | 10 | 59.21 | 6.39 | 5.72 | 41.8 | 8.64 |
| Irradiated (5 kGy) | 10 | 58.85 | 6.47 | 5.42 | 40.0 | 8.50 |
| | | ns[b] | ns | ns | ns | ns |
| Mean (day 1) | | 59.03 | 6.43 | 5.56 | 40.9 | 8.57 |
| *Day 7* | | | | | | |
| *Effect of irradiation* | | | | | | |
| Control (0 kGy) | 10 | 56.21 | 6.02 | 5.92 | 44.46 | 8.51 |
| Irradiated (5 kGy) | 10 | 57.32 | 7.64 | 7.05 | 43.10 | 10.48 |
| Statistical significance | | * | *** | ** | ns | *** |
| *Effect of surface* | | | | | | |
| Freshly cut | 10 | 55.33 | 7.69 | 6.59 | 40.52 | 10.20 |
| Extrior | 10 | 58.00 | 5.97 | 6.38 | 47.05 | 8.79 |
| Statistical significance | | *** | *** | ns | *** | ** |
| *Statistical significance of interactions* | | | | | | |
| Irradiation/surface | | ns | * | ns | ns | ns |

[a] The day 7 data is for the outside surface only and is included for comparison. The day 1 data was not included in the ANOVA, statistical significance was calculated using *t* test.

[b] ns, not statistically significant ($P > 0.05$); * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

the main are considered to reflect differences in haem pigment content, with chicken breast the lowest myoglobin content and goose leg the highest myoglobin content. Hazell (1982) and Millar, Moss and Stevenson (1994) have shown that white meats such as turkey or chicken breast have more haemoglobin than myoglobin. Millar (1994) also noted higher haemoglobin than myoglobin in chicken and turkey leg, but not goose leg where myoglobin content was almost twice that of haemoglobin. Thus when considering the nature of the pigment formed due to irradiation for poultry muscles the contribution of the haemoglobin derivatives may be more important than myoglobin derivatives.

It is clear that in studying the colour changes on the outside surface of the chicken breast and leg, and turkey and goose leg during the 7 day storage period that there are no consistent effects of irradiation treatment. In contrast to these results Millar et al. (1995) had observed significantly higher $a^*$ values on the outside surface of chicken breast irradiated at 5 kGy. CIELAB values changed little during storage apart from $a^*$ values for goose breast. Storage of red meats in overwrap packs results in oxidation of oxymyoglobin to metmyoglobin and a corresponding decrease in $a^*$ values. Millar, Wilson et al. (1994) noted the lack of oxymyoglobin formation in chicken breast muscle with myoglobin and metmyoglobin as the predominant pigments. A change from myoglobin to metmyoglobin would result in little change in $a^*$ values according to the data given by MacDougall (1983). The haem pigment content of goose breast muscle is higher than pork (Millar, 1994) and the changes in unirradiated goose breast muscle are more typical of red meats. The changes in $a^*$ values of goose breast, with lower $a^*$ values in the irradiated samples which show little change during storage are similar in pattern to those of beef (Millar, Moss & Stevenson, 2000).

When the effect of irradiation is considered after 7 days storage it is clear that in the breast muscles of all species the $a^*$ values of the freshly cut surface but not exterior surface is higher due to irradiation treatment. Comparison of the leg meat data with meat of breast may not be entirely valid, since the time that they were irradiated post mortem was different. It should be noted, however, that the increases in $a^*$ values observed following irradiation were generally greater on the freshly cut than exterior surface, although only for turkey leg was this statistically significant as seen by the irradiation/surface interaction (Table 6).

The state of the pigment on the surface and interior at the time of irradiation may be crucial to the form of pigment produced, since irradiation of predominantly metmyoglobin extracts resulted in an irradiated pigment of similar spectral shape to oxymyoglobin (Ginger et al., 1955). Giddings and Markakis (1972) found that when solutions were anoxic prior to irradiation, a state more typical of the interior of the meat, a reductive oxygeneation occurred giving oxymyoglobin. Evidence of oxymyoglobin formation following irradiation of deaerated solutions of myoglobin was not found by Whitburn, Hoffman and Taub (1981). Millar, Wilson, Moss and Ledward (1994) pointed out that chicken breast muscle does not bloom as readily as beef and the surface can be predominantly myoglobin or metmyoglobin. It would seem logical that turkey breast, a similar low haem pigment muscle might show similar characteristics, however, goose breast and the legs of the three poultry species with higher haem pigment contents may behave differently. The inside surface was measured within 30 s of cutting and the colour measured should be representative of the pigment state at the time of cutting. It is clear from the interactions observed on the poultry breast muscle that the 'pigment' formed by irradiation has persisted sufficiently for 7 days post irradiation to result in higher $a^*$ values. A number of different pigment forms have been proposed following irradiation (Bernofsky, 1959; Satterlee et al., 1972; Tappel, 1956). Millar and Moss (1994) interpreted the spectra of freshly cut irradiated pork as an indication of the presence of carboxymyoglobin. Higher $a^*$ values are obtained for oxymyoglobin compared to myoglobin or metmyoglobin (MacDougall 1983). Low concentrations (0.4%) of carboxymyoglobin in modified atmosphere packs resulted in higher $a^*$ values of beef and pork (Sorheim, Nissen & Nosbakken, 1999). Carboxymyoglobin is known to be less readily oxidised to brown metmyoglobin than oxymyoglobin (Wolfe, 1980). Carbon monoxide is produced during irradiation of meat (Dauphin & Saint-Lèbe, 1977) and has been proposed as a marker for irradiated meat (Furuta et al., 1992). Given this, it may be that the red pigment formed is due to the formation of a carboxy-haem pigment rather than an oxygenated haem derivative. In addition, it appears that the red pigment is at least as intense for chicken and turkey freshly cut surfaces, it would seem that the formation of oxymyoglobin is unlikely and that carboxy myoglobin is formed which persists in the anoxic interior. In low pigmented meats such as poultry breast muscle, there is more haemoglobin than myoglobin in the muscle (Hazell, 1982; Millar et al., 1996). Millar (1994) also observed a higher haemoglobin than myoglobin content in goose breast but not leg. Given the generally higher ratios of haemoglobin to myoglobin in poultry muscle it may be more important to consider the stability of the oxy- and carboxy haemoglobin forms and their oxidation as well as the comparable myoglobin forms. The affinity of carbon monoxide in haemoglobin is more than 200 times greater than its affinity for oxygen (Smith, Hill, Lehmen, Lefkowity, Handler & White, 1978). A more detailed evaluation of the spectra is required to identify the nature of the pigment and given the similarity between carboxymyoglobin and oxymyoglobin and haemoglobin derivatives, techniques using 1st or 2nd difference transforms of the spectra (Millar et al., 1996) may be required.

Irradiation prolongs the shelf life of meat by reducing microbial spoilage, and this microbial load should not be a contributing factor to the colour observed 7 day post irradiation in irradiated samples. Given that the goose legs were irradiated 96 h post mortem, it is considered that the unirradiated controls for goose leg may have been starting to spoil after the further 7 days storage although this was not assessed. Such changes, however, would not be expected to impact on the colour of the freshly cut surface. It was also noted that the goose leg was covered by a membranous layer which was not as evident in turkey or chicken leg. The CIELAB values were taken at the surface of the leg with this membranous layer intact. Although this would have influenced the CIELAB differences between species it would not have influenced the differences observed within a species due to irradiation.

## 5. Conclusions

The ionising radiation was shown to have an effect on poultry meat colour which was dependent on species, muscle type and surface measured. The common effect in all species muscles was to make the freshly cut surface redder. It is postulated that the red colour is a result of the formation of a carboxyhaem pigment; carboxymyoglobin and/or carboxy haemoglobin. More work is required on the spectral data to confirm the nature and origin of the irradiated meat pigment.

## Acknowledgements

S.J. Millar's contribution to this work was funded by a postgraduate studentship from the Department of Agriculture for Northern Ireland. Dr. D.J. Kilpatrick is thanked for statistical analysis of the data, and Mr. A. Gordon and Mr. G. Kirkpatrick for technical support.

## References

Bendall, J. R. (1975). Cold contracture and ATP-turnover in the red and white musculature of the pig post-mortem. *Journal of the Science of Food and Agriculture, 26*(1), 55–71.

Bernofsky, C., Fox, J. B. Jr., & Schweigert, B. S. (1959). Biochemistry of myoglobin VI. The effect of low dosage gamma irradiation in beef myoglobin. *Arch. Biochem. Biophys.*, *80*, 9–21.

Blythe, K. M. (1990). *The effect of irradiation on the organoleptic quality of fresh chicken carcasses.* MSc thesis, The Queen's University of Belfast, Northern Ireland.

Coleby, B., Ingrann, M., & Shepherd, H. J. (1960). Treatment of meats with ionising radiation III — radiation pasteurisation of whole eviscerated chicken carcasses. *Journal of the Science of Food and Agriculture, 11*, 61–71.

Dauphin, J. F., & Saint-Lèbe, L. R. (1977). Radiation chemistry of carbohydrates. In P. S. Elias, & A. J. Cohen, *Radiation chemistry of* *major food components* (pp. 131–185). Amsterdam, Netherlands: Elsevier.

Furuta, M., Dohmaru, T., Katayama, T., Toratoni, H., & Takeda, A. (1992). Detection of irradiated frozen meat and poultry using carbon monoxide gas as a probe. *Journal of Agricultural and Food Chemistry, 40*(7), 1099–1100.

Giddings, G. G., & Markakis, P. (1972). Characterisation of the red pigmeats produced from ferrimyoglobin by ionising radiation. *Journal of Food Science, 37*, 361–364.

Ginger, I. D., Lewis, U. J., & Schweigert, B. S. (1955). Changes associated with irradiating meat and meat extracts with gamma rays. *Journal of Agricultural and Food Chemistry, 3*, 156–159.

Hazell, T. (1982). Iron and zinc compounds in the muscle meats of beef, lamb, pork and chicken. *Journal of the Science of Food and Agriculture, 33*, 1049–1056.

MacDougall, D. B. (1983). Instrumental assessment of the appearance of foods. In A. A. Williams, & R. K. Atkin, *Sensory quality of food and beverages* (pp. 121–139). Chichester: Ellis Horwood.

Millar, S. J. (1994). *The effect of ionising radiation on the appearance of meat*. PhD thesis. The Queen's University of Belfast.

Millar, S. J., Moss, B. W., & Stevenson, M. H. (1994). The use of high performance liquid chromatography for the determinations of haem concentration in beef, pork and poultry. Paper no. s-v.03. *40th ICoMST*, The Hague, Netherlands.

Millar, S., Wilson, R., Moss, B. W., & Ledward, D. A. (1994). Oxymyoglobin formation in meat and poultry. *Meat Science, 36*, 397–406.

Millar, S. J., Moss, B. W., MacDougall, D. B., & Stevenson, M. H. (1995). The effect of ionising radiation on the CIELAB colour coordinates of chicken breast as measured by different instruments. *International Journal of Food. Science & Technology, 30*(5), 663–674.

Millar, S. J., Moss, B. W., & Stevenson, M. H. (1996). Some observations on the absorption spectra of various myoglobin derivatives found in meat. *Meat Science, 42*(3), 277–289.

Millar, S. J., Moss, B. W., & Stevenson, M. H. (2000). The effect of ionising radiation on the colour of beef, pork and lamb. *Meat Science*, *55*, 349–360.

Satterlee, L. D., Brown, W. D., & Lycometros, C. (1972). Stability and characteristics of the pigmeat produced by gamma irradiation of metmyoglobin. *Journal of Food Science, 37*, 213–217.

Sorheim, O., Nissen, H., & Nesbakken, T. (1999). The storage life of beef and pork packaged in an atmosphere with low carbon monoxide and high carbon dioxide. *Meat Science, 52*, 157–164.

Smith, E. L., Hill, R. L., Lehmen, I. R., Lefkowity, R., Handler, P., & White, A. (1983). *Principles of biochemistry* (7th ed.). Singapore: McGraw–Hill.

Stevenson, M. H. (1992). Irradiation of meat and poultry. In D. E. Knight, M. K. Knight, & D. A. Ledward, *The chemistry of muscle based foods* (pp. 308–324). Cambridge, UK: Royal Society of Chemistry.

Tappel, A. L. (1956). Regeneration and stability of oxymyoglobin some gamma irradiated meats. *Food Research, 21*, 650–655.

Urbain, W. M. (1986). Wholesomeness of irradiated foods. In B. S. Schweight, *Food irradiation, food science and technology*. *A series of Monographs* (pp. 269–275). UK: London Academic Press Inc.

Whitburn, K. D., Hoffman, M. Z., & Taub, L. A. (1981). A re-evaluation of the products of gamma irradiation of beef ferrimyoglobin. *Journal of Food Science, 46*, 1814–1816.

Wolfe, S. K. (1980). Use of CO- and $CO_2$ enriched atmospheres for meats, fish and produce. *Food Technology,* March, 1980 55–58 63.