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INSTRUMENTAL EVALUATION OF COLOUR CHANGES IN BROILER BREAST AND THIGH MUSCLES AFTER IRRADIATION TREATMENT

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Colour changes in *Biceps femoris*, *Rectus femoris* and *Pectoralis major* broiler chicken muscles were determined with a reflectance colorimeter after irradiation with gamma ^{60}Co rays. The muscles were irradiated with doses of 2, 3, 5, 7 and 10 kGy. The colour parameters L*, a* and b* were measured after 2, 5, 7 and 9 days of refrigerated storage of muscles at 1°C (±0.5°C) using a MINOLTA CR-200b reflectance colorimeter. The saturation of colour C* was also calculated and the significance of redness and yellowness effect on saturation was estimated by a linear regression analysis.

Only in the *Biceps femoris* muscle were all the examined colour parameters found to be dependent both on storage time and irradiation treatment, however, the relationship between the dose and the measured effect demonstrated no linear characteristics. It was noted that the difference between the irradiated and control *Biceps femoris* muscles resulted from different trends of L*, b* and C* changes during storage.

The values of partially standardised regression β coefficients for C* as the linear function of a* and b* revealed that in all examined muscles, a more important contribution to saturation was noted for the redness a* in the irradiated samples, whereas the yellowness parameter b* appeared to be more important in the control, non-irradiated samples. That finding was in accordance not only with reports in the literature but was also confirmed by the visually observed pink hue of muscle colour after irradiation.

INTRODUCTION

According the database of the International Atomic Energy Agency, the irradiation treatment of fresh (chilled) and frozen poultry meat with doses from 3 kGy to 10 kGy has been officially accepted in nineteen countries [Nanke *et al.*, 1998; FDA, 1997]. The radiolytic changes in meat and its constituents after irradiation are very small but there are difficulties with the identification of the irradiated meat and the supply of evidence for the use of this preservation technique. The growing international trade in food products has stimulated the publication of numerous review papers devoted to the identification of irradiated food [McMurray *et al.*, 1996; IAEA, 1991; Haire *et al.*, 1997; Delincee *et al.*, 1998; 2002]. In the Member States of European Union, standards are in force pertaining to the identification of irradiated food products containing cellulose, crystal sugar, bones, fats and silica.

To date, Poland has accepted four of the eight UE standards: PN-EN 1784, 1785, 1786, 1787.

Meat colour changes affected by ionising radiation have been subjected to ample studies [Du *et al.*, 2000; Millar *et al.*, 2000a; Nam *et al.*, 2002]. In poultry meat, a clearly visible lighter and reddened colour has been noted [Du *et al.*, 2000; Kim *et al.*, 2002; Liu *et al.*, 2003]. It is maintained over 7 to 8 days during storage at a temperature of 4°C [Millar *et al.*, 2000b] and was explained by the formation of carboxymyoglobin and/or carboxyhaemoglobin. It was also reported that the influence of irradiation on meat colour was dependent on animal species, on the type and surface of muscle being examined [Jo *et al.*, 2000].

The investigations on colour changes in irradiated chicken meat have not been conducted so far under the aspect of the detection of radiation processing. That problem requires determination of whether there are relationships between meat colour changes and irradiation dose and to what extent those changes are stable. The experiment presented below attempted to answer these questions.

MATERIAL AND METHODS

Breast and thigh muscles of broiler chickens from the local poultry processing plant were taken as experimental material 24 h *post mortem*. *Rectus femoris* and *Biceps femoris* muscles were excised from the thighs and the *Pectoralis major* muscle from the breast. Each muscle was tightly packaged into a polyethylene bag without evacuation and stored thereafter at 1°C (±0.5°C) for 24 h. After that period, the muscles were irradiated in the PChM-gamma 20 ^{60}Co radiation equipment at the dose rate of 2.5 kGy/h. Nominal doses of 2, 3, 5, 7 and 10 kGy were applied and the calibration of the geometric layout of the irradiated samples was conducted according to the standard procedure of Fricke [IAEA, 1977]. The CIE L*, a*, b* parameters were measured with CR-200b MINOLTA reflectance colorimeter after storage at 1°C (±0.5°C) for 2, 5 and 7 days. The exper-

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iment was repeated three times and the determinations of each colour parameter were carried out 3 to 5 times in various muscle parts directly on the surface of each muscle.

RESULTS AND DISCUSSION

In the evaluation of colour changes, the basic parameters L*, a* and b* and also their derivative, *i.e.* colour saturation (chroma) C*, were used which describe the proportion between the grayness and colour of meat. The C values were calculated from the following formula:

$$C = \sqrt{a^2 + b^2}$$

The results of variance analysis pertaining to the effect of radiation dose level and storage time on the examined colour parameter are shown in Table 1.

In two cases, the calculated results revealed no effect of radiation dose on L* brightness for m. *Pectoralis major* and m. *Rectus femoris*. In the *Pectoralis major* muscle, the calculated F=0.5844 value was below 1.0. It means there was a greater effect on L* by variability factors not controlled in the experiment than the dose level. For all other parameters, the significance levels of calculated F were below the 0.05 critical value and F values were higher than 1.0. This demonstrates that the storage time and the radiation dose influenced the results and the effect of experimental error was considerably lower than the effects of main variability factors.

TABLE 1. The influence of main variability factors on colour parameters of irradiated chicken muscles.

Muscle type	Colour parameter	Variability factor	F calculated	Significance of F calc.
Pectoralis	L*	dose level	**0.5844**	**0.6344**
major		time of storage	3.3339	0.0319
	a*	dose level	32.4431	0.0000
		time of storage	7.6479	0.0009
	b*	dose level	173.1976	0.0000
		time of storage	7.4870	0.0011
	C*	dose level	184.3156	0.0000
		time of storage	8.6389	0.0005
Biceps	L*	dose level	32.0119	0.0000
femoris		time of storage	11.3835	0.0001
	a*	dose level	31.5289	0.0000
		time of storage	21.7270	0.0000
	b*	dose level	64.3324	0.0000
		time of storage	7.8381	0.0008
	C*	dose level	56.6341	0.0000
		time of storage	6.7834	0.0017
Rectus	L*	dose level	**3.1648**	**0.0640**
femoris		time of storage	10.3144	0.0007
	a*	dose level	8.9920	0.0012
		time of storage	12.4255	0.0001
	b*	dose level	41.9413	0.0000
		time of storage	8.5818	0.0005
	C*	dose level	28.7408	0.0000
		time of storage	13.3576	0.0000

Note: bold letters – lack of significant effect of variability factor on colour parameter.

The irradiated *Biceps femoris* muscles and the values of all colour parameters were dependent both on storage time and radiation dose. These changes are presented in Figures 1, 2 and 3.

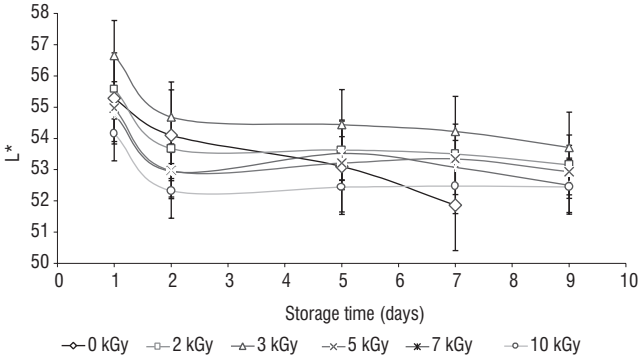

FIGURE 1. Changes in L* parameter during storage of the irradiated *Biceps femoris* muscles (mean ± standard deviations).

The interval of *m. Biceps femoris* L* absolute values (54.2 to 56.6) after 24-h storage time following irradiation was lower than those reported by Millar *et al.* [2000a] and shown in Figure 1. In the described experiment, the L* values for chicken thigh muscles measured with a different type of reflectance spectrophotometer accounted for *ca*. 62. A comparison of those data is difficult since it is not known which thigh muscles were taken for experiments.

The course of changes in L* lightness shown in Figure 1 indicates that despite a significant effect of irradiation on the measured result, the demonstration of the relationship between dose level and L* is difficult. The curves for doses 7 and 10 kGy run below those for the non-irradiated control samples, whereas those for the 2 kGy dose run above the control. Moreover, the crossing curves of 5 and 7 kGy can be a classic graphic example of the interaction between dose and storage time observed with those two doses.

Over the entire storage period of up to seven days, the lightness of the non-irradiated *Biceps femoris* muscle was decreasing and the trend of L* changes was nearly linear. By the second day of storage after irradiation, the L* values of the irradiated muscles were also decreasing, while in a further storage period the determined effect was found to remain almost at the same level. This demonstrates that the changes of L* in the irradiated meat samples were characterised by another trend. In that case, CO-myoglobin or its

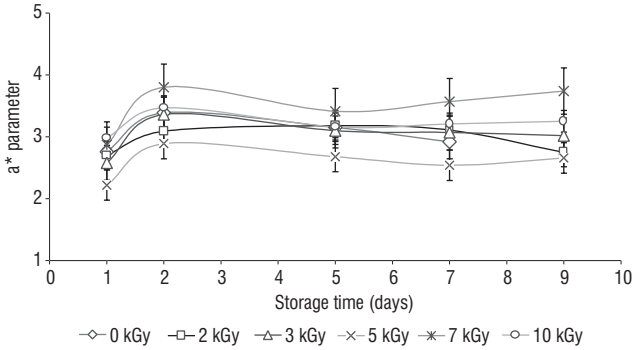

FIGURE 2. Changes in a* parameter during storage of the irradiated *Biceps femoris* muscles (mean ± standard deviations).

derivatives can stabilise the lightness of meat colour. It is known that during meat irradiation, considerable quantities of carbon oxide are generated [Kim *et al.*, 2002].

The course of a* changes as a function of dose and of storage time gives no basis for drawing any conclusions about the occurrence of a proportional relationship between dose and effect (Figure 2). The course of curves for samples 2 kGy, 3 kGy and 10 kGy points to the existing interaction among those doses and storage times.

Changes in b* value in the irradiated muscles differed from those in the controls (Figure 3). In the latter, the share of yellow colour appreciably decreased, beginning from the second day of storage after treatment, whereas that effect in the irradiated muscles remained nearly stable between the second and the ninth day of storage after irradiation.

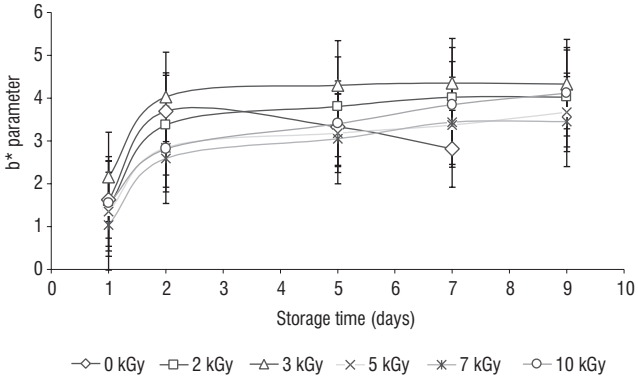

FIGURE 3. Changes in b* parameter during storage of the irradiated *Biceps femoris* muscles (mean ± standard deviations).

Very similar trends could be observed in colour saturation C* (Figure 4). The convergence of those changes with b* changes suggests that the differentiated size of a* and b* share in the formation of C* colour saturation prior to and after irradiation could be the cause. Verification of this hypothesis required the application of multiple linear regression equations to estimate the "importance" of the a* and b* effect on colour saturation in the irradiated and non-irradiated muscles (Table 2). That is considered possible since the additional effect results from the equation for C* and the values of partial, standardised β regression coefficients facilitating the evaluation of any a* and b* effect on C* value [Elandt, 1964]. The results of the measurements for the *Pectoralis major* and *Rectus femoris* were also used in the calculation, since the statistical significance of a dose level affecting a* and b* was confirmed by an analysis of

TABLE 2. Colour saturation C* of chicken muscles as a linear function of a* and b* and the values of partial, standardised β regression coefficients.

Dose kGy	Regression formula and the fit R^2	Partially standardised regression coefficients β	
		a*	b*
0	C*=0.021+0.437a*+1.192b*; R^2=0.9868	0.4603	0.5599
2	C*=0.006+0.649a* +0.831b*; R^2=0.9976	0.6291	0.3973
3	C*=0.660+0.504a*+0.950b*; R^2=0.9822	0.5084	0.5034
5	C*=-0.2154+0.593a*+0.953b*; R^2=0.9965	0.5783	0.4527
7	C*=0.110+0.635a*+0.8534b*; R^2=0.9969	0.6151	0.4185
10	C*=0.091+0.638a*+0.818b*; R^2=0.9982	0.5796	0.4405

variance. The calculation of regression and β value was carried out with the use of a SPSSPC + sheet and the significance level ≤0.000 of all equations was evaluated by an analysis of variance for regression.

The absolute values of β coefficients indicate that in the non-irradiated muscles, a more pronounced role in the formation of C* saturation was played by the yellowness (β for b* + 0.5599) than the redness (β for a* = 0.4603) regardless of the storage time. After muscle irradiation, the relationships showed a reverse position for the doses of 2, 5, 7 and 10 kGy where the β values for a* were always greater than the β values for b* coefficients. In the case of muscles irradiated with a 3 kGy dose, the difference was not so distinct, however, the proportion was also maintained.

It has to be emphasised that the values of partial, non-standardised coefficients at a* and b* in the regression equations demonstrate the dynamics of changes in the variables only and are dependent on the absolute values, hence, may not be taken as a measure of their contribution to the C* effect [Elandt, 1964].

The fact that the share of the red colour in the irradiated chicken muscles influences the saturation to a greater extent than the yellow colour not only confirms recent reports [Millar *et al.*, 2000b; Kim *et al.*, 2002; Liu *et al.*, 2003] but is also an instrumental expression of colour changes usually observed. It also demonstrates that a greater role in the instrumental evaluation of colour changes in the irradiated poultry meat will be played not so much by the basic parameters but the mutual relations among them or their derivatives. An example is shown in Figure 5. After irradiation, the colour tone was shifted from greyish/weak to the direction of dull on a greyish – vivid axis, regardless of muscle type, the dose value and storage time. How much those

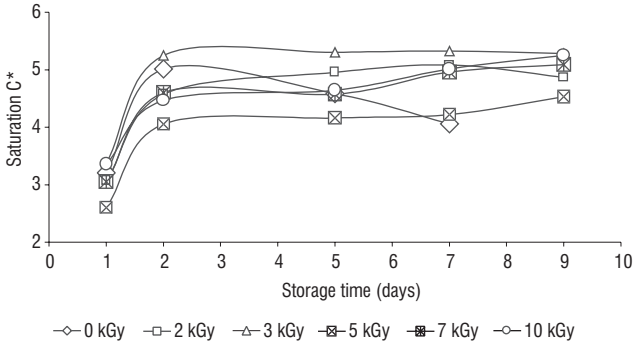

FIGURE 4. Changes in C* saturation values during storage of the irradiated *Biceps femoris* muscles.

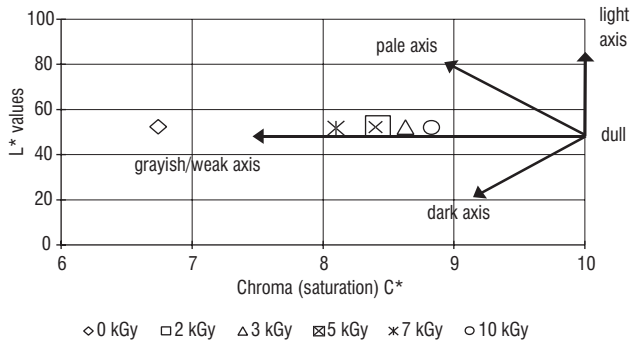

FIGURE 5. Effect of irradiation on the colour saturation C* (average values of 3 muscles and storage time).

relations can be applicable to the detection of irradiation treatment of meat requires further investigation.

CONCLUSIONS

The study revealed that colour changes in the breast and thigh chicken muscles determined in the L* a* b* system after irradiation treatment showed a differentiated course of reaction, particularly during refrigerated storage. Another trend was found in L* and b* changes in the thigh muscles in the control (non-irradiated) and irradiated samples being stored. No relationship was noted between the colour changes and radiation dose. However, it was proved on the basis of regression analysis that in all irradiated muscles, regardless of the dose level, the saturation C* was dependent to a greater extent on the redness, whereas in the non-irradiated on the yellowness. Additionally, a shift of colour saturation to a dull direction was noted after treatment. This experimental result requires further study to find out whether it can be useful in the identification of the irradiation treatment of meat.

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INSTRUMENTALNA OCENA ZMIAN BARWY MIĘŚNI PIERSIOWYCH I UDOWYCH KURCZĄT BROJLERÓW PO ZABIEGU NAPROMIENIANIA

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Wykorzystując kolorymetrię odbiciową badano zmiany barwy mięśni *Biceps femoris*, *Rectus femoris* i *Pectoralis major* kurcząt brojlerów po zabiegu radiacyjnej higienizacji przy pomocvy promieniowania gamma ^{60}Co. Mięśnie napromieniowano dawkami 2, 3, 5, 7 i 10 kGy. Parametry barwy L*, a* i b* mierzono po 2, 5, 7 i 9 dniach przechowywania w temperaturze 1°C 0,5°C stosując kolorymetr odbiciowy MINOLTA CR-200b. Ponadto obliczano nasycenie barwy C*, a o ważności wpływu barwy czerwonej i żółtej na nasycenie wnioskowano na podstawie analizy regresji liniowej.

Stwierdzono, że tylko w mięśniach *Biceps femoris* wartość wszystkich badanych parametrów barwy zależała zarówno od czasu przechowywania jak i od zabiegu napromienienia, jakkolwiek zależności pomiędzy dawką a mierzonym efektem nie miały charakteru liniowego. Wykazano też, że różnice pomiędzy mięśniami *Biceps femoris* higienizowanymi radiacyjnie a kontrolnymi (nienapromienionymi) wynikają z odmiennych trendów zmian L*, b* i C* w czasie przechowywania.

W oparciu o wartości cząstkowych, standaryzowanych współczynników regresji β dla C* jako funkcji liniowej a* i b* wykazano, że dla wszystkich rodzajów badanych mięśni, zawsze w próbach napromienionych ważniejszy udział w nasyceniu miała barwa czerwona (a*), podczas gdy w próbach kontrolnych (nienapromienionych) – barwa żółta, to jest parametr b*. Jest to nie tylko zgodne z danymi literaturowymi, ale także jest potwierdzeniem obserwowanego wizualnie zaróżowienia barwy mięśni po napromienieniu.