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The effects of light illuminance and wavelength on the growth of broiler chickens

BY C. M. WATHES*

Ministry of Agriculture, Fisheries and Food, Shardlow Hall, Shardlow, Derby

H. H. SPECHTER

Rothamsted Experimental Station, Harpenden, Hertfordshire

AND T. S. BRAY

Ministry of Agriculture, Fisheries and Food, Gleadthorpe Experimental Husbandry Farm, Meden Vale, Mansfield, Nottinghamshire

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SUMMARY

The effects of light illuminance and wavelength on the growth of male and female broiler chickens from day-old to 8 weeks of age were studied.

Different coloured lights, at equal illuminance and peak wavelengths of 425, 525 and 610 nm and a broad-spectrum white light of median wavelength 560 nm had no significant effect on the growth rate or cumulative food intake of birds of either sex.

The performance of male broilers was unaffected by light of different illuminances, equal to 0·7, 3·0, 15·0 and 46·5 lux. The weight gain of female broilers, adjusted for food intake, was progressively depressed at illuminances above 3 lux.

There is probably no commercial advantage in using broad-spectrum white light at intensities above 3 lux.

INTRODUCTION

In any experiment on the effects of light on poultry, four characteristics of the light environment must be specified: the photoperiods; the cycle length; the spectral composition; and the light illuminance. Light of different illuminance and wavelength may influence the growth of broiler chickens through its effects on the bird's pattern of activity (Morris, 1968). Although there have been many studies, involving small numbers of birds, which have examined the separate effects of wavelength (e.g. Barott & Pringle, 1951; Kondra, 1961; Cherry & Barwick, 1962; Foss, Carew & Arnold, 1972; Wabeck & Skoglund, 1974; Osol, Foss & Carew, 1980) and of illuminance (e.g. Barott & Pringle, 1951; Cherry & Barwick, 1962; Skoglund & Palmer, 1962; Beremski, 1976), most authors have confused these two factors and few have supplied a complete description of the spectral composition and illuminance of the light used.

The aim of these experiments was to test the hypothesis that lights either of low illuminance or of wavelengths at the limits of a bird's spectral sensitivity inhibit the bird's activity and thus influence its growth rate. In addition to the usual measures of growth performance, detailed behavioural observations were undertaken to assess the effects of different light treatments. In this paper we report the production traits; the behavioural observations will be the subject of a future communication.

* Present address: Department of Animal Husbandry, University of Bristol, Langford, Bristol.

MATERIALS AND METHODS

Two light experiments were conducted simultaneously in the eight rooms of a climatically controlled broiler house. Four rooms were allocated to each of the light wavelength and illuminance experiments. Each room was divided into eight pens measuring 3·05 × 2·44 m, and holding 100 birds each. A randomized-block design was used. Each room was one block containing all eight combinations of the four light treatments (four illuminances or wavelengths) and two sexes in separate pens. Thus there were 4 (rooms) × 2 (sexes) × 4 (light treatments) = 32 pens holding a total of 3200 birds for each experiment.

Table 1. *Determined analyses of the diets used for both experiments*

	Units	Starter crumbs	Grower pellets	Finisher pellets
Metabolizable energy*	MJ/kg	12·5	12·8	12·6
Crude protein	g/kg	210	207	193
Ether extract	g/kg	43	91	67
Total ash	g/kg	54	63	49
Calcium	g/kg	8·8	14·2	9·2
Phosphorus	g/kg	7·3	7·0	5·5
Methionine	g/kg	4·5	4·4	4·0
Methionine + cystine	g/kg	7·4	7·5	7·2
Lysine	g/kg	9·9	10·5	10·2

* Calculated.

Table 2. *Mean* (± S.E.) *intensity of light at three ages in both experiments*

	Intensity (lux)		
Treatment	Day old	8 days	56 days
0·7 lux	28·57 ± 1·49	0·78 ± 0·04	0·65 ± 0·05
3·0 lux	28·77 ± 1·52	3·17 ± 0·18	2·99 ± 0·19
15·0 lux	31·04 ± 0·76	15·29 ± 0·74	14·79 ± 0·57
46·5 lux	28·32 ± 1·51	45·99 ± 1·11	47·04 ± 2·19
Blue	4·77 ± 0·15	1·05 ± 0·04	0·63 ± 0·04
Green	4·78 ± 0·11	3·18 ± 0·13	1·80 ± 0·14
Red	5·08 ± 0·31	1·82 ± 0·10	0·94 ± 0·07
White	4·73 ± 0·14	1·65 ± 0·04	0·93 ± 0·06

Each value is the mean of 8 intensities (2 sexes × 4 replicates), each of which is the average of 13 readings.

Table 1 shows the calculated or determined analyses of the common starter, grower and finisher diets. 500 g of the starter diet was allocated to each bird, while 770 and 930 g of the grower diet were fed to the female and male birds respectively. Food was available *ad libitum*. Details of the ventilation and heating system of the rooms are given by Charles, Groom & Bray (1981). Other husbandry practices followed recognized procedures (Ministry of Agriculture, Fisheries and Food, 1978). The temperature at three points in each room was recorded every 2 h. Within each experiment there were no differences between rooms in the mean daily post-brooding temperature (14–56 days), which were 21·3 ± 0·05 °C and 21·6 ± 0·05 °C for the wavelength and illuminance experiments respectively. In addition more detailed recordings of the temperature at two locations in each pen in one room of each experiment were made every hour. These measurements showed no appreciable difference between the temperatures within different pens. The food consumption of all birds and the body weights of 25 birds, sampled at random, of each pen in each room were recorded weekly. At the beginning and end of the experiments all birds in all pens were weighed.

The light illuminance for the first 7 days was the same for all pens in each experiment and the light treatments were introduced on the 8th day. Measurements of the light illuminance at 13 locations in each pen were made with a photometer (Model Minilux 2, Salford Electrical Instruments) at days 1, 8 and 56. Table 2 shows the mean illuminances recorded 200 mm above floor level. The change in intensity with time was due to ageing of the luminaires. Light was provided by incandescent bulbs in the illuminance experiment, at nominal illuminances of 3·0, 15·0 and 46·5 lux respectively, except for the lowest illuminance treatment of 0·7 lux, for which the background illumination of the room supplied the necessary level of light. In the colour experiment blue, green, pink-red and white (Northlite, Thorn Lighting) 20 W fluorescent tubes were used; white tubes were employed for all treatments for the first 7 days. Figure 1 shows the spectral compositions of the light sources, measured with a spectrophotometer, and the relative spectral luminosity of the photopic human eye (from List, 1966) and of the photopic chicken eye (from Bowmaker & Knowles, 1977). The peak spectral wavelengths were 425, 525 and 610 nm for the blue, green and red lights respectively; the

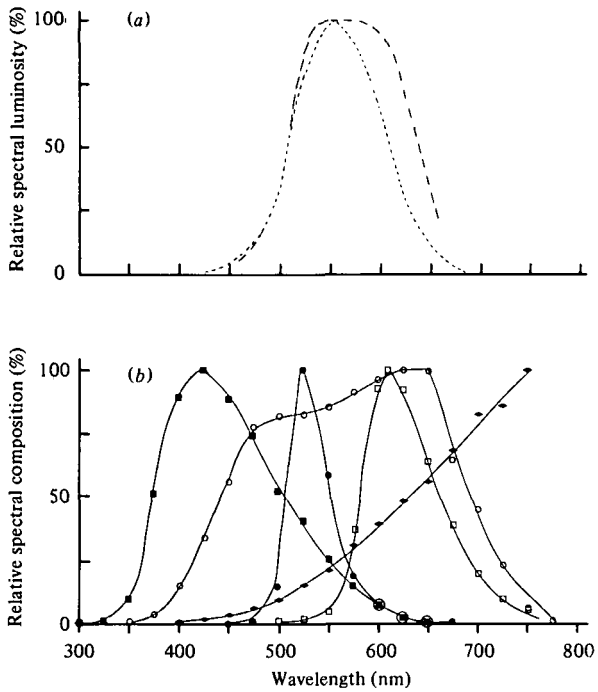

Fig. 1. (*a*) The relative spectral luminosity of the photopic human eye (····) (from List, 1966) and of the photopic chicken eye (– – –) (from Bowmaker & Knowles, 1977). (*b*) The relative spectral compositions of the light sources used in the wavelength experiment: ■, blue, ●, green, □, red and ○, white; and ◆, in the intensity experiment. The spectral compositions and luminosities are given on a quantum basis.

median wavelength of the white light was 560 nm. A photoperiod of 23·5 h light in each 24 h was used throughout the experiments.

RESULTS

Figures 2 and 3 show the mean cumulative food intake and body-weight change of the male and female birds at 42, 49 and 56 days for the light illuminance and wavelength experiments respectively. Two analyses were performed in which the data for the two sexes were either combined or separated. The separate analyses were carried out to test if the residual variances were homogeneous for males and females. The variances were homogeneous for all variates except food intake per pen to 56 days in the light illuminance trial. The combined analyses were performed to investigate the sex × treatment interactions but they did not reveal additional trends in the data from those found in the separate analyses.

Neither body-weight change nor cumulative food intake was corrected for the small numbers of the inevitable errors in bird sexing which occurred at the hatchery. Sexing errors could be detected after the birds had reached 6 weeks of age, and from observations at a later age we found that about 5 % of all birds were incorrectly sexed. Accurate calculation of food intake for the male and female birds separately was therefore not possible since the intake of birds whose sex was wrongly identified at hatching is not known. However, the estimate of body-weight change can account for these mistakes. To ensure consistency with other workers and to allow estimation of food conversion efficiencies we calculated weight change from the final weights uncorrected for sexing errors.

The data in Figs 2 and 3 are presented on a per-pen rather than a per-bird basis because the food intake of birds which died during the trial and of those whose sex was wrongly identified is unknown since the birds were fed as a group. Furthermore, the food was weighed weekly while carcasses were collected daily. For advisory purposes, however, we express the results in the conventional manner as 'per bird allocated at the start of the trial'; summaries of these data calculated on this basis are available from the authors.

The variate body-weight change referred to in this paper has been calculated as the difference in

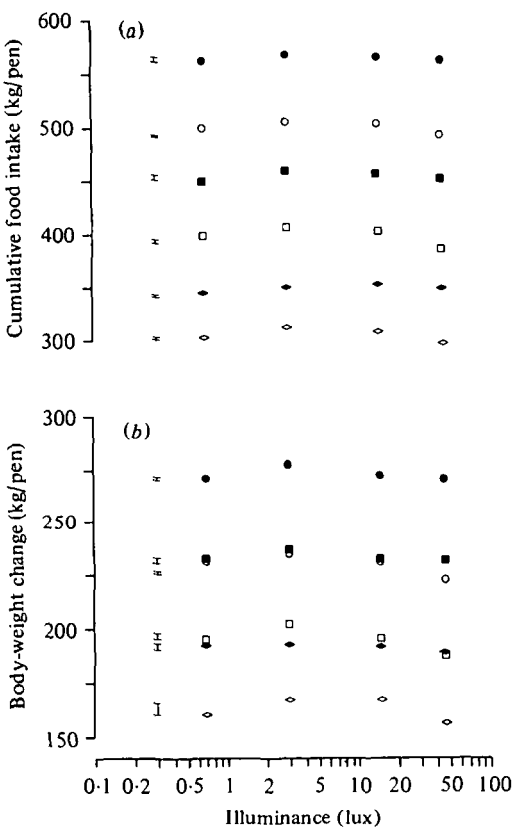

Fig. 2. (*a*) Cumulative food intake to and (*b*) body-weight change at 42 (◇), 49 (□) and 56 (○) days for male and female broilers at four light illuminances. Closed symbols, males; open symbols, females. I, S.E. of the difference between treatment means.

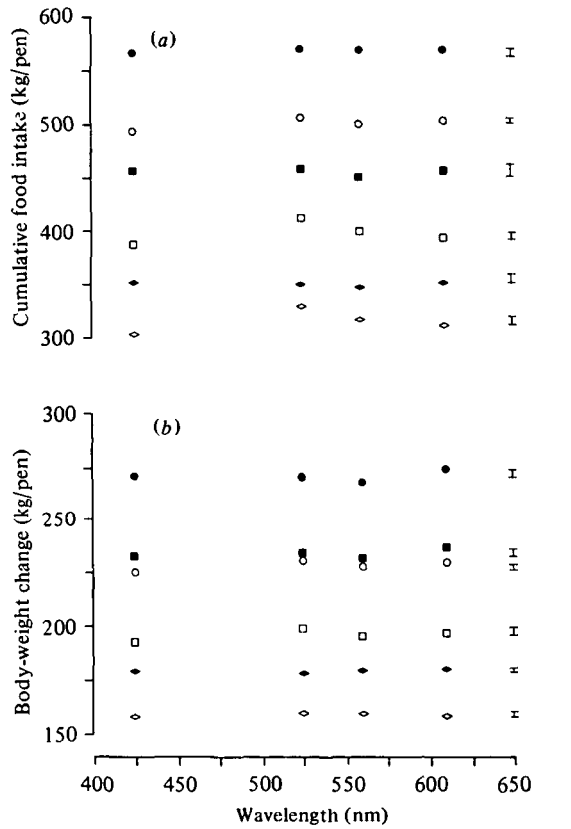

Fig. 3. (*a*) Cumulative food intake to and (*b*) body-weight change at 42 (◇), 49 (□) and 56 (○) days for male and female broilers at four light wavelengths. Closed symbols, males; open symbols, females. I, S.E. of the difference between treatment means.

live weight measured at day-old and at a particular age plus the carcass weight of birds dying at that specified age, all on a pen basis. In addition to the usual performance indices, body-weight change was adjusted by covariance analysis to a constant value of cumulative food intake at a given age. This provides complementary information on the extent to which treatment effects on body weight occurred by way of improved food conversion as compared with effects through increased stimulation of food intake. Covariance analysis applied in this way can reveal the mechanism of treatment effects when two independent but associated variates (in this case body weight and food intake) are jointly influenced by an independent factor, such as light illuminance or wavelength.

The effects of light illuminance and wavelength on performance (body-weight change and cumulative food intake) were determined from an analysis of variance using GENSTAT (Rothamsted Experimental Station, Harpenden, Herts.). This showed no significant effect of wavelength on performance at 42, 49 or 56 days, apart from food intake at 49 days for the females ($P < 0{\cdot}05$). Body-weight change at 49 days and cumulative food intake to 42 and 49 days of the females were both influenced by light illuminance. At 56 days light of high illuminance significantly depressed the body weights of both sexes and decreased the food intake of the females. Body-weight change, when adjusted by covariance regression for cumulative food intake, showed no influence of either light illuminance or wavelength at 42 or 49 days. Nevertheless there was a trend for birds kept at 3·0 lux to be heavier than those housed under higher or lower intensities. At 56 days the adjusted body-weight change was progressively depressed at illuminances above 3·0 lux for the females ($P \leqslant 0{\cdot}01$), but not for the males.

The treatment sum of squares was partitioned by polynomial regression into linear, quadratic and

higher order terms for the light illuminance experiment. This was done in order to define the shape of the response curve when birds are subjected to a range of light illuminances. In addition to the nominal levels, the effect of transforming the measured light illuminances to a logarithmic scale (base 10) was also examined, following a suggestion of Morris (1968). This procedure did not reveal any additional dependence of performance on light illuminance. In general such trends as were significant were linear for the untransformed data and both linear and quadratic for the transformed data.

Bird mortality was analysed both by analysis of variance (assuming a normal distribution of the errors) and by an analysis of deviance using GLIM (Baker & Nelder, 1978) in which a binomial error distribution was specified. The latter analysis assumes that the risk of death for individual birds is constant and that birds do not affect each other's survival. For group-penned poultry these assumptions may not be true if the birds are diseased. However, the GLIM analysis gave a residual deviance which closely approximated the residual degrees of freedom, indicating that the binomial model provided a good fit to these mortality data. Neither type of analysis showed any effect of either light illuminance of wavelength on bird mortality, which was in the range from 1·5 to 4·5 % for both experiments.

DISCUSSION

Although the anatomy of their eyes differs, the cones of the human and the fowl are both trichromatic (Cornsweet, 1970). In contrast, the visual pigments in the rods cannot distinguish between quanta of different wavelengths, and vision in the dim light is monochromatic (Cornsweet, 1970). The visual response of the scotopic human eye, and presumably also of the chicken eye, is to the number of quanta received at the retina and not to the energy flux or irradiance (Hecht, Shlaer & Pirenne, 1942). In ducks, and probably fowls, between 1 and 5 lux are necessary for photostimulation of the gonads via the retina, although the minimum light illuminance for visual function is probably much lower (Benoit, 1964). The relative spectral luminosities of the chicken, pigeon and man are similar (Bowmaker & Knowles, 1977; Blough, 1957), with the corollary that photometers, which measure illuminance and not irradiance and which are calibrated in units of lux, can be used to assess the quality and quantity of light reaching a bird. If two light sources of different spectral composition each provide the same level of illuminance then the luminous energy fluxes at the retina will also be the same. Morris (1968) observed that most workers confuse the separate effects of light intensity and colour, although if the illuminance is specified the two influences should be readily distinguishable.

Light wavelength

The results of early experiments showed that bird growth was unaffected by light wavelength (Barott & Pringle, 1951; Kondra, 1961). Cherry & Barwick (1962) compared red and white lights at the same two illuminances (1·1 and 101 lux) and found no effect of wavelength. A similar result was reported by Proudfoot & Sefton (1978) for incandescent white and green lights at 0·5 lux. In an experiment involving 216 cockerels, Foss *et al.* (1972) studied the birds' physiological development at six different wavelengths, with peak transmissions at 450, 545, 650 and 750 nm and in the dark and in broad-spectrum white light. They specified an irradiance of 800 mW/m^2, 70 mm above floor level, whereas a constant illuminance would have been more appropriate. Although the combs and testes were heavier and gonadotrophic hormone levels were higher under red (650 nm) and white lights, weight gain was greatest at 545 nm (green), while food consumption was unaffected by light colour. These two findings appear contradictory as testosterone normally acts as a growth stimulant. The enhancement of body weight under green light was confirmed by Osol *et al.* (1980). These authors also studied the role of the pineal and thyroid glands. Cockerels which had undergone pinealectomy had a lower body weight than either sham-operated or control birds. They suggested that some spectral components of white light depressed growth via an inhibition of pineal activity.

In the present study there were no differences between wavelength treatments in either room temperature or bird activity. The sensitivity of the current experiment was high; the standard error of the difference between two light wavelength treatments was 3·19 kg for the body-weight change of 100 male birds from hatching to 56 days and 3·24 kg for female birds. Wabeck & Skoglund (1974) also conducted a highly sensitive experiment. They distinguished between illuminance and irradiance but preferred to standardize their light treatments to an irradiance of 2 W/m^2 at bird height. The combined bird weights of males and females at 63 days were greater under blue (470 nm) and green (530 nm) lights than under yellow (580 nm), red (650 nm) and white lights. In contrast, our results showed that food intake and growth at 56 days were unaffected by coloured lights of similar illuminance. Both Foss *et al.* (1972) and Osol *et al.* (1980) suggested that certain wavelengths inhibit bird growth by some endocrine mechanism. Our findings contradict this. Different wavelengths and, by inference, spectral compositions had no significant effects on bird growth in our experiment.

Furthermore, a comparison between the performances of the birds in the wavelength and illuminance experiments reveals little difference between the two light sources: either fluorescent tubes or incandescent bulbs may be used with little detrimental effect provided that the light illuminance is held constant.

Light illuminance

Previous studies on the influence of light intensity showed that high illuminances (33 lux and higher) depress growth (Barott & Pringle, 1951; Cherry & Barwick, 1962; Beremski, 1976). In reviewing these experiments and that of Skoglund & Palmer (1962), Morris (1968) showed that the response of live weight is linearly related to the logarithm (base 10) of the illuminance. The transformation of the scale to logarithms in the present experiment failed to reveal such a dependence for males, even though the light treatments were equally spaced on a logarithmic base. However, for females both linear and quadratic terms were significant. When birds were given a choice of 11, 53 or 127–138 lux, 75% preferred the lowest illuminance at 7 days (Haller & Sunde, 1973). The results of Bacon & Touchburn (1976) using male turkeys suggest that behavioural patterns adopted in the 1st week endure to 22 weeks, even if the light illuminance is changed abruptly at 11 weeks. Altering the light did not affect growth. They also observed that birds kept at 0·1 lux were less prone to feather pecking than those at 1·1, 11 or 33 lux. These findings may not apply to fowls because of inter-specific differences in imprinting during the first weeks of life.

When body-weight change and cumulative food intake are considered separately, the present results are consistent with those of other workers: live weight is greatest at 3·0 lux at 56 days. In growing animals, however, body weight and food intake are interdependent traits and neither should be considered in isolation (Wilson, 1977). A covariance analysis helps to elucidate these interdependencies, albeit it assumes a linear relationship between the two variates. Other more complex relationships in terms of a growth model are described by Wilson (1977). In this experiment, consideration of the adjusted body-weight changes revealed no significant biological effect of light illuminance on males, while females were lightest at 46·5 lux. As in the wavelength experiment there were no measurable differences between the environmental temperatures of either plots within a room or between rooms. A preliminary analysis showed that activity was unaffected by treatment although males were less active than females, especially at 6 weeks (unpublished observations). The reasons for the differences between males and females in their response to illuminance are unclear. One possible explanation is that the synthesis and release of growth hormone may be influenced by some photostimuli, the action of which differs between the sexes (Siegel, 1977). Birds kept at the same illuminance but under intermittent lighting regimes (6 days light; 1 day dark) were heavier than those in continuous light (Proudfoot & Sefton, 1978), although Cherry, Beane & Weaver (1978) found no such effect. There may be an interaction between sex, light intensity, photoperiod and the degree of sexual maturity (Siegel, 1977). Such an interaction warrants further investigation since the results of this study show evidence of a small but significant sex interaction in the response to light illuminance *per se*.

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