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Australian Journal of Agricultural Research

Volume 49, 1998

A journal for the publication of original contributions towards the understanding of an agricultural system

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the Australian Academy of Science

Aust. J. Agric. Res., 1998, **49**, 279–84

Intermittent lighting and dietary sodium bicarbonate supplementation for laying hens at high temperatures

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Abstract. Point-of-lay pullets were housed in 2 temperature-controlled rooms maintained at a constant 32°C with either a conventional 16 h light : 8 h dark (16L : 8D) or an intermittent 3L : 1D lighting regimen. They were fed either a conventional layer diet (12·0 MJ of ME and 199 g crude protein/kg) or this diet supplemented with 1% sodium bicarbonate ($NaHCO_3$). Production and egg shell quality measurements were made at 8-week intervals from 22 to 62 weeks of age. All measures were influenced by age. The 3L : 1D regimen significantly increased feed intake ($P < 0{\cdot}001$), weight gain ($P < 0{\cdot}01$), egg weight ($P < 0{\cdot}001$), egg shell breaking strength ($P < 0{\cdot}001$), and shell thickness ($P < 0{\cdot}01$). Significant age×light interactions were observed for feed intake, egg production, and egg mass. Hens in the 3L : 1D regimen ate significantly ($P < 0{\cdot}001$) more food and produced significantly ($P < 0{\cdot}01$) greater egg mass to 46 weeks of age. No significant differences were observed after 46 weeks. Although not significant, $NaHCO_3$ consistently improved shell breaking strength. The response was small in the 16L : 8D regimen (3%) compared with the 3L : 1D environment (7%), the latter being additional to the 14% improvement resulting from the use of the 3L : 1D regimen. The results indicate advantages from the use of intermittent lighting and dietary $NaHCO_3$ supplementation at high temperatures.

Additional keywords: egg shell quality, egg production, egg weight, shell breaking strength.

Introduction

Poor egg shell quality from hens housed at high temperatures continues to be a major source of economic loss to egg producers and attempts to improve shell quality by nutritional or management procedures have had only limited success. However, the results of studies on the use of alternative lighting regimens at non-heat stress temperatures and recent evaluation of dietary sodium bicarbonate ($NaHCO_3$) supplementation at high temperatures suggest that these two procedures may offer some hope of success. Nys and Mongin (1981), von Torges *et al.* (1981), and Sauveur and Mongin (1983) have reported that intermittent lighting improves egg shell quality at non-heat stress temperatures. Although Sauveur and Picard (1987) concluded that the incorporation of a 1- or 2-h light period during the normal daily dark period in conventional lighting regimens (e.g. 16 h light : 8 h dark; 16L : 8D) does not increase egg shell deposition, this procedure has sometimes, but not always, improved shell quality (Grizzle *et al.* 1992; Harms *et al.* 1996). Likewise, the use of sodium bicarbonate ($NaHCO_3$) supplements in the diet or drinking water sometimes, but not always, improves shell quality (see Balnave and Muheereza 1997). Makled and Charles (1987) reported that increasing the daily photoperiod from 16 to 24 h significantly improved shell quality in laying hens, the improvements being similar to those observed in the 16L : 8D regimen when 5 g $NaHCO_3$/kg was added to a diet containing ground limestone as the calcium source. However, although Grizzle *et al.* (1992) found that supplying an additional 2 h light during the normal dark period improved egg specific gravity, a 10 g $NaHCO_3$/kg dietary supplement had no effect.

Although the results of studies incorporating $NaHCO_3$ supplements in the diet or drinking water of laying hens have been equivocal, Howes (1966) and Ernst *et al.* (1975) reported beneficial responses in shell quality at high temperatures. More recently, Balnave and Muheereza (1997) observed that the shell breaking

10.1071/AR97101 0004-9409/98/020279$05.00

strength of eggs from hens housed at 30° and 35°C was improved when 10 g $NaHCO_3$/kg was added to the diet of hens maintained in continuous light. These workers concluded that at high temperatures, supplementation of diets with $NaHCO_3$ improves shell quality as long as hens have access to feed during the period of shell formation. When hens are housed in a conventional 16L : 8D regimen the bicarbonate is not consumed during the dark period, the time during which shell formation normally occurs. In this regimen no benefits accrue from the $NaHCO_3$ unless the hens are laying late in the day and, therefore, can eat during the period of shell formation.

Since continuous lighting over an extended period of lay is unacceptable from an animal welfare point of view the present study was carried out using a repetitive 3L : 1D lighting schedule which allowed the hens a total of 6 h darkness daily. Hens fed a conventional diet with or without a 10 g $NaHCO_3$/kg supplement were compared in conventional (16L : 8D) and intermittent (3L : 1D) lighting regimens from 22–62 weeks of age.

Materials and methods

Husbandry

Pullets (192, SuperBrown, Inghams Enterprises Pty Ltd, Casula, NSW) were purchased at 19 weeks of age and placed in double bird cages in 2 temperature-controlled rooms. Three adjacent cages comprised a replicate and in each room 8 replicates were randomly allocated to each of 2 diets consisting of a basal diet (Table 1) and the basal diet containing a supplement of 10 g $NaHCO_3$/kg in lieu of solka floc, an indigestible cellulose filler. The birds were initially housed at a constant 32°C temperature in a 16L : 8D lighting environment. From 20 weeks of age, birds in one room were continued on the 16L : 8D regimen and birds in the other room were changed to a 3L : 1D regimen. Production parameters were measured between 22 weeks of age, when the birds attained 10% rate of lay, and 62 weeks of age.

Table 1. Composition (g/kg, unless otherwise indicated) of basal diet

Ingredient		Nutrient	
Wheat	155·2	*Calculated analysis*	
Sorghum	524·1	ME (MJ/kg)	12·0
Fish meal	79·6	*Determined analysis*	
Soyabean meal	129·7	Crude protein	199
Soyabean oil	3·6	Lysine	9·2
Dicalcium phosphate	3·9	Methionine	4·8
Limestone	86·2	TSAA	7·9
Sodium chloride	1·3	Calcium	38·5
DL-methionine	1·0	Total P	6·3
L-lysine HCL	0·4		
Solka floc or $NaHCO_3$	10·0		
Layer premix[A]	5·0		

[A] Supplied (per kg diet): vitamin A, 6000 IU; vitamin D_3, 1200 IU; vitamin E adsorbate, 4 mg; vitamin K_3, 2 mg; riboflavin, 5 mg; calcium pantothenate, 6 mg; niacin, 15 mg; pyridoxine, 2 mg; folic acid, 0·5 mg; vitamin B12, 5 μg; Mn, 50 mg; Zn, 50 mg; Fe, 30 mg; Cu, 2 mg; I, 2 mg; Co, 0·2 mg; ethoxyquin, 125 mg.

Production measurements

Egg numbers were recorded daily, and during the final 3 days of each 28-day period all eggs were weighed. Egg shell breaking strength was measured using a cantilever system (Balnave and Muheereza 1997) on all eggs laid over a period of 3 consecutive days every 8 weeks commencing at 30 weeks of age. Shell thickness and shell weight percentage were determined on the final day's collection in each case.

Statistical analysis

The data for the laying performance and egg shell quality, measured over five 8-week periods corresponding to the times of shell quality assessment, were analysed as a 2×2 factorial ANOVA with repeated measures (BMDP 2V; BMDP Statistical Software, Sepulvede Boulevard, Los Angeles, USA). The effects of light, diet, and age and the interactions between these factors were examined.

Results

Mortality was generally low on all treatments: 6 and 4% in hens in the 16L : 8D lighting and fed the control and $NaHCO_3$ diets, respectively; and 6 and 10% in hens in the 3L : 1D lighting and fed the control and $NaHCO_3$ diets, respectively. The main effects of age, light, and diet on feed intake, weight gain, egg production, egg weight, egg mass, and feed conversion are shown in Table 2.

Age had a significant effect on all measures. Maximum feed intake was attained between 30 and 46 weeks of age after which there was a significant decrease. Weight gain increased significantly with age. Rate of lay and egg mass output showed continuing declines in each period after 38 weeks of age, although egg weight continued to increase until 54 weeks of age. Feed conversion was poor during the first 8 weeks of lay when overall egg production and egg mass were low. Feed conversion improved significantly between 30 and 38 weeks of age, the period associated with improved egg production and egg mass output. Thereafter, there was a continuous decline in feed conversion efficiency with increasing age.

The 3L : 1D light regimen significantly improved feed intake, with hens on this lighting regimen eating 6·4 g more feed per day than those on the 16L : 8D conventional lighting. Hens in the 3L : 1D lighting regimen gained significantly more weight and produced significantly larger eggs and 2·0 g more egg mass daily, which was near the significance level (P = 0·062). No significant differences were observed between the 16L : 8D and 3L : 1D lighting regimens with respect to rate of lay and feed conversion. Also, there were no significant differences due to diet.

Table 2. Main effects of age, light, and diet on production measures from 22 to 62 weeks of age

Values within a main effect not followed by the same letter are significantly different at the level of significance shown

Main effect	Treatment	Feed intake (g/day)	Weight gain (g)	Egg production (%)	Egg weight (g)	Egg mass (g/day)	Feed : gain (g : g)
Age (weeks)	22–30	89·6b	11·6d	69·9c	50·1c	35·9c	2·52ab
	30–38	93·7a	93·6c	83·4a	52·3b	43·7a	2·15d
	38–46	95·3a	180·4b	76·2b	54·1a	41·3a	2·31cd
	46–54	88·9b	197·2ab	67·2c	55·1a	37·1c	2·42bc
	54–62	85·0c	229·0a	58·4d	55·0a	32·4d	2·65a
s.e.m.		0·60	9·28	0·89	0·25	0·55	0·039
Significance		***	***	***	***	***	***
Light	16L : 8D	87·3b	111·2b	70·9	51·9b	37·1	2·46
	3L : 1D	93·7a	174·6a	71·0	54·7a	39·1	2·54
s.e.m.		1·11	15·78	1·17	0·34	0·73	0·048
Significance		***	**	n.s.	***	n.s.	n.s.
Diet	Control	89·8	130·4	70·6	53·4	38·0	2·64
	$NaHCO_3$	91·2	154·4	71·3	53·3	38·2	2·66
s.e.m.		1·11	15·78	1·17	0·34	0·73	0·048
Significance		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$; n.s. non significant.

Table 3. Interaction effects of age and lighting regimen on feed intake (g/day), egg production (%), and egg mass (g/day) from 22 to 62 weeks of age

Values within a main effect not followed by the same letter are significantly different at the level of significance shown

Age (weeks)	Light	Feed intake	Egg production	Egg mass
22–30	16L : 8D	85·4d	71·1de	35·3ef
	3L : 1D	93·9bc	68·8de	36·5de
30–38	16L : 8D	89·9cd	81·8ab	41·7bc
	3L : 1D	97·4ab	85·1a	45·8a
38–46	16L : 8D	89·8cd	74·1cd	39·0cd
	3L : 1D	100·8a	78·2bc	43·6ab
46–54	16L : 8D	87·1d	67·9e	36·6de
	3L : 1D	90·7cd	66·6e	37·7de
54–62	16L : 8D	84·4d	60·6fg	32·8f
	3L : 1D	85·5d	56·2g	32·0f
s.e.m.		0·84	1·26	0·77
Significance		***	**	**

** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$.

The only significant interactions were age×light effects on feed intake, egg production, and egg mass (Table 3). The feed intake of hens in the 3L : 1D lighting regimen was significantly greater to 46 weeks of age; thereafter, there was no significant effect of light. The maximum improvement achieved in the 3L : 1D regimen was 11 g/day between 38 and 46 weeks of age. Although no significant differences in egg production were observed at any age, there was a tendency for more eggs to be laid in the 3L : 1D lighting regimen between 30 and 46 weeks of age and in the 16L : 8D lighting regimen between 46 and 62 weeks of age. Hens in the 3L : 1D regimen produced significantly more daily egg mass than hens in the 16L : 8D regimen between 30 and 46 weeks of age but differences due to lighting regimen at other times were small and non significant.

The main effects of age, light, and diet on the egg shell quality measures are shown in Table 4 and Fig. 1. All egg shell quality measures were affected significantly by age. Egg shell quality was best during early lay at 30 and 38 weeks of age but declined thereafter. Eggs from hens in the 3L : 1D regimen, had a significantly greater shell breaking strength and shell thickness than eggs from hens in the 16L : 8D regimen, and the shell weight percentage effect approached significance ($P = 0{\cdot}057$). Dietary supplementation with $NaHCO_3$ had no significant effect on the shell quality measures. However, supplementation with $NaHCO_3$ consistently improved shell breaking strength (Fig. 1). This response was greater in the 3L : 1D than in the 16L : 8D regimen, although no significant interactions were observed. The shell breaking strength of eggs

Table 4. Main effects of age, light, and diet on egg shell quality measures from 22 to 62 weeks of age

Values within a main effect not followed by the same letter are significantly different at the level of significance shown

Main effect	Treatment	Shell strength (N)	Shell weight (%)	Shell thickness (μm)
Age (weeks)	30	36·95ab	9·71a	372a
	38	37·29a	9·69a	375a
	46	33·87b	9·64ab	368ab
	54	34·08ab	9·29bc	361b
	62	34·87ab	8·93c	349c
s.e.m.		0·712	0·081	1·9
Significance		***	***	***
Light	16L : 8D	32·70b	9·33	360b
	3L : 1D	38·13a	9·58	372a
s.e.m.		0·787	0·091	2·2
Significance		***	n.s.	**
Diet	Control	34·51	9·46	366
	$NaHCO_3$	36·32	9·45	366
s.e.m.		0·787	0·091	2·2
Significance		n.s.	n.s.	n.s.

** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$; n.s. non significant.

from hens in the 16L : 8D regimen was improved by 1·0 N, from a mean overall value of 32·2 N to 33·2 N, by the use of the $NaHCO_3$ supplement, whereas the improvement was much greater in eggs from hens in the 3L : 1D regimen (36·8 to 39·4 N). This 7% improvement in the 3L : 1D regimen occurred in addition to the significant 14% improvement (36·8 *v*. 32·2 Newtons) resulting from the use of the 3L : 1D regimen.

Discussion

Apart from a significant increase in the feed intake of these heat-stressed hens in the 3L : 1D regimen, the only other overall significant effects of light or diet on the production responses were the improved egg weight and increased weight gain of hens in the 3L : 1D regimen. In fact the body weight gains of the hens in both lighting regimens were more than satisfactory considering the constant high temperature used in the study. However, significant age×light interactions were observed on feed intake, egg production, and egg mass. Hens in the 3L : 1D regimen ate significantly more food to 46 weeks of age and this was reflected in a numerically greater rate of lay and significantly greater egg mass output. However, after 46 weeks of age, feed intake, egg production, and egg mass output were similar in both lighting environments. These results at heat-stress temperatures contrast with the results obtained by others who have examined the effects of intermittent lighting on layer performance in non-heat stress environments. The results of these latter studies have consistently found intermittent lighting to decrease feed intake and egg production (Nys and Mongin 1981; von Torges *et al*. 1981; Leeson *et al*. 1982; Sauveur and Mongin 1983; Morris and Butler 1995). However, no significant differences in feed intake or egg production were observed when hens were maintained for part of their time at 32°C in a long-term study involving the provision of 2 h additional lighting during the conventional dark period (Grizzle *et al*. 1992). The current study also recorded improved egg weight from hens on intermittent lighting, which is in agreement with previous findings (Nys and Mongin 1981; von Torges *et al*. 1981; Sauveur and Mongin 1983; Morris and Butler 1995).

The use of intermittent lighting at non-heat stress temperatures has been shown to improve egg shell quality (Nys and Mongin 1981; von Torges *et al*. 1981; Sauveur and Mongin 1983). In addition, Grizzle *et al*. (1992) reported a significant improvement in egg specific gravity when 2 h additional lighting was provided to hens in a long-term study during which the ambient temperature reached 32°C for part of the time. The present results extend these observations to the prolonged use of intermittent lighting at heat stress temperatures and have shown the benefits of a 3L : 1D regimen on the maintenance of egg weight and body weight as well as on shell breaking strength, shell thickness, and shell weight percentage. In fact, as far as the current authors are aware, this is the first time that the effect of repetitive intermittent lighting on production and egg shell quality has been evaluated at high ambient temperatures. Although temperature comparisons were not conducted in the present study the results suggest that the use of intermittent lighting may be more beneficial at high, compared with thermoneutral or low, temperatures.

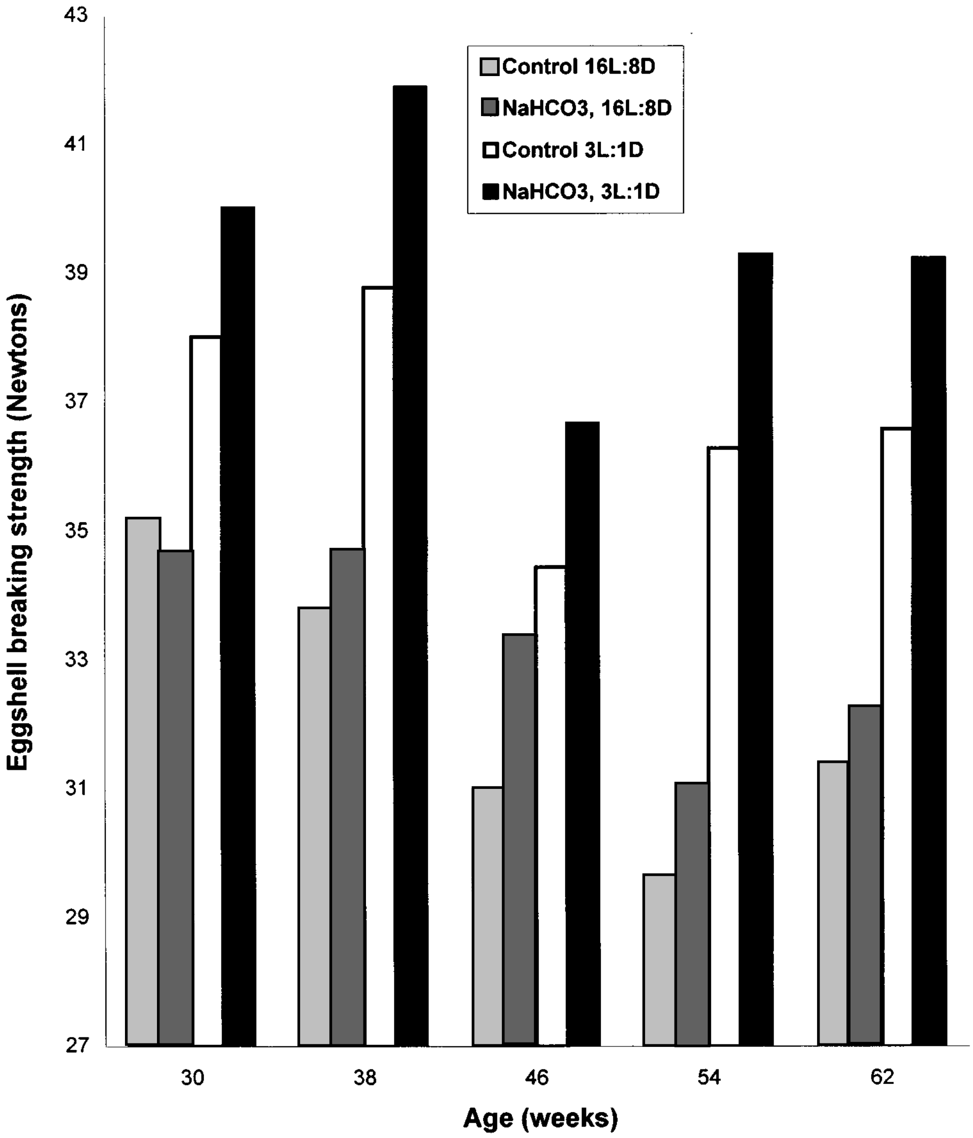

Fig. 1. Effect of light regimen and diet on shell breaking strength; s.e.m. = 1·424.

It is generally accepted that dietary $NaHCO_3$ supplementation should play an important role in maintaining good egg shell quality. However, attempts to improve egg shell quality in this way have been equivocal (see Balnave and Muheereza 1997). Howes (1966) and Balnave and Muheereza (1997) appear to be the only researchers to have obtained a beneficial response at high temperatures, although Ernst *et al.* (1975) reported that in hot weather hens receiving $NaHCO_3$ produced significantly fewer rough-shelled eggs. In the current experiment no significant differences in egg shell quality were observed between the dietary treatments. However, the $NaHCO_3$ supplement given to hens in the 3L : 1D lighting regimen consistently improved shell breaking strength (overall mean 7%) in addition to the 14% improvement resulting from the use of the 3L : 1D regimen. Providing the $NaHCO_3$ to the hens in the 16L : 8D regimen only induced a 3% improvement in shell breaking strength. These improvements in shell breaking strength at 32°C in the 3L : 1D regimen are similar in extent to those reported previously for hens maintained in continuous light at 30–35°C (Balnave and Muheereza 1997). In this earlier work, improvements of 15% resulting from feeding hens a supplement of 10 g $NaHCO_3$/kg at the same time as increasing the daylength from 16 to

24 h, and improvements of 9% due to feeding 10 g $NaHCO_3$/kg to hens acclimated to continuous light, were significant. Therefore, it appears that feeding a supplement of 10 g $NaHCO_3$/kg to laying hens at high temperatures is a means of improving egg shell quality as long as hens consume the additional bicarbonate during the period of active shell formation. The use of a repetitive intermittent lighting regimen such as the 3L : 1D used in the current study provides that access in a more consistent way than supplementary lighting of 1 or 2 h duration during the dark period of a conventional 16L : 8D regimen. It also allows for desynchronisation of ovulation patterns (Nys and Mongin 1981; Sauveur and Mongin 1983), which may be important to the improvements noted in egg weight and shell breaking strength.

Finally, it is worth noting that the intermittent lighting regimen improved shell breaking strength through increases in shell deposition as shown by improvements in shell thickness and shell weight percentage. These latter measures were not affected by dietary $NaHCO_3$ supplementation, implying that in this case the numerical improvement in shell breaking strength was associated with changes in shell ultrastructure (van Toledo *et al*. 1982; Roberts and Brackpool 1994).

Acknowledgments

This work was supported by The Poultry Research Foundation and The Australian Egg Industry Research and Development Committee of the Rural Industries Research and Development Corporation. Ms Melinda Hayter and Mr Darren Mulley helped with diet preparation and the conduct of the experiment.

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Manuscript received 24 June 1997, accepted 18 September 1997