HIGH-TEMPERATURE NUTRITION OF LAYING HENS

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Summary

The major effect of high temperatures on the performance of laying hens is exerted through a reduced feed consumption although the effects of heat stress per se vary with different measures of output. Attempts to define nutritional requirements at high temperatures have concentrated on energy and protein (amino acids) because of their economic importance. The results of studies involving the self-selection feeding of separate energy-rich and protein-rich feeds balanced for other nutrients, or feeding complete diets containing increased concentrations of protein, indicate that protein intake rather than energy intake is the most important factor in maintaining optimum egg production at high temperatures. Fats and oils are important energy sources with low heat increment and, in addition, their linoleic acid content can be used to manipulate egg weight. Although plasma phosphorus levels are reduced at high temperatures, increases in dietary phosphorus concentrations adversely affect egg shell quality. However, egg shell quality is improved by dietary supplementation with sodium bicarbonate as long as hens have access to the bicarbonate during the period of egg shell formation. Dietary ascorbic acid supplementation has been shown to counteract the adverse effects of heat stress on liveability, egg production, egg weight and shell quality.

I. INTRODUCTION

High temperature stress impacts adversely on all aspects of laying hen performance, including increased mortality as well as reduced appetite, egg production, egg weight and egg shell quality. The primary effect is exerted through reduced feed consumption but the relative importance of reduced nutrient intakes and heat stress per se varies with different measures of performance (Smith, 1972; Emery et al., 1984; Picard, 1985).

The effects of heat stress can be ameliorated in a number of ways. These include procedures which induce the bird to increase its intake of water and, thereby, maintain more efficient respiratory evaporative heat loss, as shown with broilers by Belay and Teeter (1993). The use of cyclical daily temperatures, in which the bird is able to dissipate heat at low temperatures during part of the 24 h cycle, is also useful although the mean temperature and the amplitude of the temperature cycle are important factors to consider (Harris et al., 1974; De Andrade et al., 1977; Deaton et al., 1981). However, since reduced appetite is the major factor associated with reduced performance at high temperatures, efforts continue to be made to define more accurately the nutrient requirements of laying hens under heat stress conditions.

II. ENERGY AND PROTEIN

The economic importance of feed ingredients supplying energy and protein has meant that the majority of nutritional studies at high temperatures have centred on examining the requirements for these nutrients.

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It is normally assumed that a limitation in energy intake is the most important factor contributing to reduced laying performance at high temperatures (Smith, 1973; Picard, 1985). Data, such as those reported by Smith and Oliver (1972) and El Jack and Blum (1978) showed large reductions in metabolizable energy (ME) intakes at high temperatures which were associated with corresponding reductions in bodyweight, egg production and egg weight. Furthermore, El Jack and Blum (1978) concluded that the decrease in egg production was not related to a protein or amino acid deficiency since the daily protein intake remained above 15 g/d. In addition, improving protein intake by increasing the dietary protein concentration of complete, isoenergetic diets only partially overcame the adverse effects of high temperatures on egg output in short-term studies of a few weeks duration (Valencia et al., 1980; Scott and Balnave, 1988a).

Although feeding high-nutrient density diets to laying hens at high temperatures has not proved to be a completely successful strategy there is evidence to indicate that substantial benefits can sometimes accrue from adjustments to dietary protein and energy concentrations. De Andrade et al. (1977), in a short-term study of 12 weeks duration, maintained similar egg production when hens were fed a high nutrient density diet containing 10 percent additional ME and 25 percent additional protein at constant 21°, constant 31° or fluctuating 26°-36°C temperatures. Lin et al. (1993) reported that at ambient temperatures of 17°-25°C protein and ME intakes were the major factors influencing egg production whereas at 29°-33°C the major factors were protein and total phosphorus intakes. Further support for the suggestion that protein rather than energy intake is the most crucial factor in maintaining optimum egg production at high temperatures has been derived from self-selection studies.

(a) Self-selection feeding

An attempt by Blake et al. (1984) to improve the performance of 34-week old laying hens at high temperatures by self-selection feeding using three diets high in energy, protein or calcium proved unsuccessful. The authors assumed the lack of response was due to an inability of the hens to satisfy daily nutrient requirements from three separate diets. However, it is more likely that the problem was associated with a failure to acclimatize the hens to self-selection feeding prior to the onset of lay. Therefore, a reduction in egg output during the time the hens were defining their selection requirements probably impacted on feed consumption which, in turn, reinforced the lower egg output. It is interesting to note that the lower rate of lay at 30°C with the self-selection hens was associated with a reduced protein, rather than ME, intake.

The importance of acclimatising hens to self-selection feeding prior to the onset of lay was clearly shown in a series of studies by Scott and Balnave (1988b, 1989). Hens were allowed to select from two feeds, these being an energy-rich and a protein-rich feed, balanced for other nutrients. These studies found that laying hens introduced to self-selection feeding about five weeks prior to sexual maturity were subsequently able to accurately select nutrients to maintain normal rates of egg production in a diurnally cycling 25°-35°C environment. These hens showed an increased preference for protein commencing about three weeks prior to sexual maturity and this elevated intake plateaued approximately six weeks after the production of the first egg. The nature of this response is shown in Figure 1, which is taken from a 20-week study by Balnave and Murtisari Abdoellah (1990). Even with the low feed intakes prevalent at high temperatures this procedure substantially improves protein intakes without any major changes in ME intake (Scott and Balnave, 1988b, 1989: Balnave and Murtisari Abdoellah, 1990). Egg mass output is improved by up to 10 percent and appears to be associated with the ability of the self-selection fed hens to gain bodyweight at high
temperatures and not to draw on body reserves to maintain egg production. Similar responses to self-selection feeding are observed at cool temperatures but the increased energy requirements make the protein intakes uneconomically high without any improvement in egg mass output (Scott and Balnave, 1988b). In a similar way Picard (1985) reported that, whereas allowing hens to self-select calcium from a separate feeder improved egg output at 33°C, no such response was obtained at 20°C where nutrient intakes were excessive.

![Graph showing Protein:ME ratio (g/MJ) against Age (weeks) for laying hens.]

Figure 1. Response of laying hens to self-selection feeding in a 25°C-35°C diurnal cycling temperature regimen (Balnave and Murtisari Abdoellah, 1990).

Long-term studies conducted by Balnave and Murtisari Abdoellah (1990) confirmed the advantages of using self-selection feeding with laying hens at high temperatures. In addition, when these workers fed a complete diet based on the ME and protein concentrations selected by hens at 25°C-35°C from separate energy- and protein-rich feeds they found that hens at 25°C-35°C produced an egg mass output between 19 and 40 weeks of age which was numerically superior, and non-significantly different, to that of hens housed at 10°C-20°C and fed a conventionally-formulated diet. Also, for hens fed the selected diet, egg mass output at 25°C-35°C was numerically less than, but not significantly different from, 10°C-20°C (Table 1). The conventional diet contained 150 g crude protein and 12.0 MJ of ME/kg and the self-selection diet contained 236 g crude protein and 10.78 MJ of ME/kg. This study implies that, apart from an increased dietary protein concentration, a reduction rather than an increase in dietary energy concentration is necessary to achieve optimum egg output at high temperatures, and this perhaps explains the inconsistent responses obtained with high nutrient density diets incorporating increased energy levels. Marsden et al. (1987) found that a high-energy, high-protein diet was unable to maintain egg output at 30°C. Picard et al. (1987) reported that hens at 33°C could perform equally well on pelleted diets containing either 183 g crude protein and 11.7 MJ of ME/kg or 161 g crude protein and 9.2 MJ of ME/kg. The lower energy diet increased food consumption which gave similar intakes of energy but a 17 percent increase in protein consumption between 22 and 38 weeks of age. Therefore, the feeding of
low-energy diets at high temperatures is not necessarily a liability since it can allow increased consumption of nutrients other than energy.

Table 1. Influence of feeding a concentrated complete diet from 18 to 40 weeks of age at cool (10⁰-20⁰C) and hot (25⁰-35⁰C) temperatures (Balnave and Murtisari Abdoellah, 1990).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Diet</th>
<th>Cool (g/b/d)</th>
<th>Hot (g/b/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food intake</td>
<td>Conventional</td>
<td>95.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>74.6&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Concentrated</td>
<td>107.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>94.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Protein intake</td>
<td>Conventional</td>
<td>15.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Concentrated</td>
<td>27.6&lt;sup&gt;d&lt;/sup&gt;</td>
<td>24.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>ME intake</td>
<td>Conventional</td>
<td>1.14&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.90&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Concentrated</td>
<td>1.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Egg mass</td>
<td>Conventional</td>
<td>38.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>31.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Concentrated</td>
<td>43.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.8&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a-d</sup>Means within a measurement with no common superscripts differ significantly (P<0.05).

Balnave and Muheereza (1998) have used a repetitive intermittent lighting regimen of 3h light:1h dark (3L:1D) to improve the food intake and egg mass output of laying hens at a constant high temperature of 32°C. This lighting regimen was compared with a conventional lighting regimen of 16L:8D from 20 to 62 weeks of age. Significant increases in food intake, liveweight gain and egg weight were observed with the 3L:1D regimen and, in addition, significant age x light interactions were observed for food intake, egg production and egg mass. Hens in the 3L:1D regimen ate significantly more food to 46 weeks of age which was reflected in a numerically greater rate of lay and significantly greater egg mass output to this age. After 46 weeks of age food intake, egg production and egg mass output were similar in both lighting regimens. These results suggest that the use of intermittent lighting may be more beneficial at high, compared to thermoneutral or low, temperatures since the use of intermittent lighting regimens in non-heat stress environments has been shown consistently to decrease food intake and egg production although improving egg weight. The use of intermittent lighting regimens is a relatively new concept and contrasts with lighting standards based on older studies which are reflected in some Codes of Practice for the welfare of poultry. For example, the Australian Code of Practice (Standing Committee on Agriculture and Resource Management, 1995) recommends that "Where poultry do not have access to daylight they should be given lighting over a period of at least 8 hours per day." The 3L:1D lighting regimen provides a total of 18 h light daily.

Another way of increasing nutrient intakes, and thereby improving production at high temperatures, is to rear the birds in a cool environment prior to exposure to hot conditions during lay. Kyarisima and Balnave (1996) found that rearing pullets at 10⁰-20⁰C before exposing them to 25⁰-35⁰C during lay significantly improved food intake and performance characteristics (Table 2).

Similar response trends were reported by Njoya (1995) in natural temperate and hot-dry climates in Cameroon. However, using a similar approach, Njoya and Picard (1994) found that pullets reared at 32°C were not acclimatised any better to this temperature during lay than pullets reared at 20°C. Pullets reared at 20°C and 60% RH and moved to either a hot-dry (32°C, 40% RH) or hot-humid (32°C, 90% RH) environment gained more body weight but showed little other beneficial effects compared with pullets maintained throughout life in these hot environments.
Table 2. Effect of a cool rearing environment on subsequent laying performance at high temperatures (Kyarisiima and Balnave, 1996).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Rearing period</th>
<th>10°-20°C</th>
<th>25°-35°C</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Laying period</td>
<td>25°-35°C</td>
<td>25°-35°C</td>
<td></td>
</tr>
<tr>
<td>Food intake (g/d)</td>
<td></td>
<td></td>
<td></td>
<td>***</td>
</tr>
<tr>
<td>Egg production (egg/hen d)</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Egg weight (g)</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Egg mass (g/d)</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Food conversion (g food/g egg)</td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Mortality (/100 hens)</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

*P<0.05; **P<0.01; ***P<0.001; NS - not significant.

There is now increasing evidence that feeding high energy diets does not necessarily counteract the effects of high temperatures on laying performance (Njoya, 1995), does not necessarily improve performance to the levels obtained with low energy-diets (Scott and Balnave, 1988b) and can result in increased mortality (El Jack and Blum, 1978). The interactions between food, protein and ME intakes, and the associated responses in egg mass output, in the study reported by Balnave and Murtisari Abdoellah (1990) show that hens fed the concentrated diet at the hot temperatures performed as well as hens fed the conventional diet at the cool temperatures although they consumed significantly less energy (Table 1). Egg mass output was related more to protein than to energy intake.

III. FATS AND OILS

Fats and oils are often considered ideal energy sources at high temperatures because of their low heat increment and the fact that they can be used to increase energy intake without elevating heat production. Njoku and Nwazota (1989) showed that the dietary inclusion of palm oil on an isoenergetic and isonitrogenous basis reduced the effect of heat stress and increased food intake, egg production, egg weight and feed efficiency.

The fatty acid composition of the dietary fat has an important influence on ameliorating the adverse effect of high temperatures on egg weight. In particular, the benefit of supplementing a layer diet with a source of linoleic acid is clearly evident from a study in which diets based on wheat or rice pollard, and containing 7 and 24 g/kg of linoleic acid respectively, were alternated every four weeks to laying hens maintained in a diurnally cycling 25°-35°C temperature environment (Balnave, 1987). The results of this study are shown in Table 3 and indicate that whereas egg weight declined each time the wheat-based diet was fed, egg weight was improved when the wheat diet was replaced with the rice pollard diet. Also, hens receiving the wheat diet continuously showed an immediate reduction in egg weight whereas those fed the rice pollard diet continuously maintained egg weight at the pre-experimental level.
Table 3. Influence of dietary linoleic acid on egg weight (g) from hens maintained at 25°-35°C over three 4-week periods (Balnave, 1987).

<table>
<thead>
<tr>
<th>Dietary regimen</th>
<th>Pre-experiment</th>
<th>Week 4</th>
<th>Week 8</th>
<th>Week 12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-4</td>
<td>5-8</td>
<td>9-12</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>W</td>
<td>W</td>
<td>59.0</td>
<td>56.6^b</td>
</tr>
<tr>
<td>RP</td>
<td>RP</td>
<td>RP</td>
<td>58.4</td>
<td>57.6^a</td>
</tr>
<tr>
<td>W</td>
<td>RP</td>
<td>W</td>
<td>58.4</td>
<td>56.4^b</td>
</tr>
<tr>
<td>RP</td>
<td>W</td>
<td>RP</td>
<td>58.5</td>
<td>58.0^a</td>
</tr>
</tbody>
</table>

^a-b Means within each week with no common superscripts differ significantly (P<0.05).

IV. MINERALS

The dietary concentration of minerals is normally increased in proportion to the expected reduction in food intake at high temperatures but few studies have examined actual requirements. Most attention has been given to calcium and phosphorus which are known to influence egg shell quality.

Nordstrom (1973) reported that the reduced egg shell quality observed at high temperatures was not due to a reduced residence time in the shell gland. The use of oyster shell rather than ground limestone as the dietary calcium source has sometimes been shown to improve egg shell quality at high temperatures (Sauveur and Picard, 1987). Although blood ionised calcium concentrations are reduced during heat stress (Odom et al., 1986) it is generally assumed that hyperventilation, and the associated respiratory alkalosis, is mainly responsible for inferior shell quality. The use of dietary supplements of sodium bicarbonate has generally given inconsistent results (Hughes, 1988), although ensuring that the hen consumes the bicarbonate source during the period of egg shell formation has been shown to significantly improve egg shell breaking strength (Balnave and Muheereza, 1997). In practice, this means employing repetitive intermittent lighting regimens. Advantages in egg shell breaking strength have been observed from the feeding of 10 g sodium bicarbonate/kg to hens housed in repetitive 3L:1D lighting schedules at 32°C over a 40 week laying period (Balnave and Muheereza, unpublished results) (Figure 2). Over the complete experiment the sodium bicarbonate supplement improved the mean shell breaking strength of eggs from hens in the 3L:1D regimen from 36.8 to 39.4 Newtons whereas a much smaller improvement from 32.2 to 33.2 Newtons was observed in eggs from hens in a conventional 16L:8D lighting regimen. This 7 percent improvement in the 3L:1D regimen occurred in addition to the 14 percent improvement (36.8 vs 32.2 Newtons) resulting from the use of the 3L:1D regimen.

Charles et al. (1978) observed that the available phosphorus requirements of laying hens was greatly increased during periods of heat stress. Usayran and Balnave (1995) found that although plasma phosphorus levels increased with increases in dietary phosphorus concentrations at both 18° and 30°C those of hens at 30°C were significantly lower than those of hens at 18°C. However, increases in dietary phosphorus adversely affected egg shell quality at both temperatures. The total phosphorus requirement on the wheat-based diets fed by Usayran and Balnave (1995) was determined as 3.2 g/kg, although the high intrinsic phytase content of wheat would have influenced this value. The results of these studies and that of Simons et al. (1992) show that a dietary phytase enzyme supplement of 200 phytase units/kg is sufficient to optimise the performance of laying hens fed proprietary diets.
V. VITAMINS

The effect of high temperatures on the vitamin requirements of laying hens has received little attention. Most of the interest has centred on the use of ascorbic acid (vitamin C). It appears that ascorbic acid exerts its greatest influence when poultry are exposed to either an environmental or a nutritional stress (Pardue and Thaxton, 1986). Although experimental results have not always been consistent, recent studies have shown that dietary ascorbic acid supplementation levels of 100-400 mg/kg help to counteract the adverse effects of heat stress on laying hens (Njoku and Nwazota, 1989; Cheng et al., 1990). Mortality is reduced and food intake, food utilization, egg production, egg weight and shell quality are improved. Recently, Khalafalla and Bessei (1997) have reported that the value of ascorbic acid supplements in the drinking water in preventing the decline in egg shell quality observed with saline drinking water (Balnave et al., 1991) is only observed at high temperatures.

REFERENCES