Effect of High Ambient Temperature on Feed Digestibility in Broilers

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ABSTRACT The effect of chronic heat exposure on feed digestibility of broilers was investigated. Eighty 4-wk-old male chickens were brooded in individual battery cages in two controlled-environment rooms at a constant ambient temperature (22 or 32 C) until 6 wk of age. They were equally distributed into three treatments: 22 C, ad libitum feed consumption (22AL); 32 C, ad libitum feed consumption (32AL), and 22 C, pair-feeding on the daily feed intake of heat-exposed chickens (22PF). Broilers were fed either a standard corn-soybean meal diet (control diet) or a practical seasonal diet containing several ingredients including wheat, spring pea, and animal fat (summer diet). Digestibility of energy, dry matter, protein, fat, starch, and nitrogen, and total mineral balances were measured between 38 and 42 d of age.

Apparent metabolizable energy content of summer diet was significantly decreased in 32AL compared to 22AL, whereas AME of the control diet did not change. Nitrogen retention was significantly reduced in 32AL birds compared to 22AL and 22PF birds, irrespective of the diet. Taking into account these differences in nitrogen balance, AMEn was reduced under hot exposure: ±72 and ±155 kcal for control and summer diets respectively, in 32AL compared to 22PF chickens. This reduction could be explained by a significant decrease of nutrient digestibility: protein: ±4.2 percentage units irrespective of the diet, fat: ±1.7 and ±5.2 percentage units for control and summer diets respectively, and starch: ±4.2 percentage units for summer diet. It thus appears worthwhile to take into account such reduction in digestibility to formulate practical diets for brooding under hot conditions. High quality oil and protein sources should also be used instead of low quality feedstuffs, like animal sources, in such conditions.

(Key words: chronic heat exposure, feed digestibility, metabolizable energy, protein, broiler)

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INTRODUCTION

Conditions of high ambient temperature are causing increasing concern in poultry due to the rapid development of the poultry industry in countries having hot climates and to the reduced performance of poultry during summer months in countries having temperate climates. Drastic decreases of feed intake and growth have been reported under such conditions (Austic, 1985; Howlider and Rose, 1987) and feed efficiency appears to be significantly reduced. Indeed, Geraert et al. (1996a) showed that about half of the growth reduction in hot environments was due to a direct effect of high temperature. This reduction of efficiency was partly explained by decreased metabolic utilization of nutrients, increased heat production, reduced protein retention, and enhanced lipid deposition (Am Baziz et al., 1996; Geraert et al., 1996a). The reduction in feed efficiency might also be due primarily to lower feed digestibility, the first step of feed utilization.

The effect of high temperature on dietary ME appears rather controversial. Slightly increased or even unchanged ME in heat-exposed chickens have been reported (El Husseiny and Creger, 1980; Keshavarz and Fuller, 1980; Wallis and Balnave, 1984; Geraert et al., 1992). However, Yamazaki and Zi-Yi (1982) found a decreased ME content of the diet when birds were exposed to high environmental temperature. Such discrepancies might be attributed to various factors, among these: feed intake, age, genotype, sex, and type of diet. For example, ME increased more in the experiment reported by El Husseiny and Creger (1980), in which the feed reduction was about 10% than in the experiment reported in Keshavarz and Fuller (1980), in which feed intake was reduced by 20%. Moreover, up to 4 wk of age, high temperature did not affect AMEn in broilers (Lei and Slinger, 1970). Using raw materials, Zuprizal et al. (1993) reported a significant decrease of AMEn due to high temperature with rapeseed meal (either dehulled or not), whereas there was no decrease with soybean meal in hot environments. Dietary ME content was significantly increased in chickens with genetically lean genotypes than in chickens with more
potential for fat deposition (Geraert et al., 1992). Wallis and Balnave (1984) observed a tendency for increased 
ME in male chickens but not in females when birds were 
exposed to high temperature.

Fewer results are available on protein digestibility in 
hot environments. Studies reveal a consistent decrease of 
protein and amino acid digestibilities of complete 
diets (Wallis and Balnave, 1984) and individual feed 
ingredients (Zuprizal et al., 1993). Digestibilities of other 
nutrients have not been measured, although the following 
studies suggest possible effects on digestibility. Amylase and 
maltase activities were reported to change under acute heat stress conditions, but not under 
chronic exposure to heat (Osman and Tanios, 1983). The 
absorption of glucose or galactose by the small intestine 
in vitro (Dibner et al., 1992; Mitchell and Carlisle, 1992) 
was enhanced in chickens reared at 35 C compared to 22 
C. Wolfenson et al. (1987) found a slight increase in fatty 
sugar absorption in 8-wk-old heat-exposed turkeys. Mineral retention was decreased under hot conditions 
(Smith and Teeter, 1987). In addition to these effects on 
specific nutrients, gastrointestinal size was reported to 
decrease in heat-exposed chickens (Savory, 1986; Mitchell 
and Carlisle, 1992).

In all of these studies, the effect of high temperature 
was not separated from the effect of the reduction of 
feed intake. The present study was thus designed to 
estimate the direct effect of high ambient temperature on dietary ME value (AME and AMEn), feed digestibility 
and nitrogen and total mineral retentions in 6-wk 
broilers exposed for 2 wk to 32 or 22 C.

**MATERIALS AND METHODS**

**Birds and Management**

Day-old male Vedette (ISA) broiler chicks were 
brooded in battery cages. They received a standard starter 
diet containing 3,040 kcal ME and 221 g crude protein/kg 
(Table 1). Ambient temperature was progressively 
decreased from 32 C at 1 d to reach 22 C at 3 wk of age. At 4 
wk of age, 80 birds of similar body weight were 
transferred to individual battery cages and distributed 
into three treatments until 6 wk of age: ad libitum food 
consumption at 22 C (22AL), ad libitum feed consumption 
at 32 C (32AL), and pair-feeding chicks reared at 22 C on 
the feed intake of the 32AL (22PF). The 22PF birds were 
fed four times a day to avoid the “large meal effect”2 
usually observed in feed-restricted birds. The relative 
humidity was maintained at 55 ± 5%. The lighting 
program was 23 h light:1 h dark.

Chicks on each treatment were fed a control diet based on 
corn and soybean meal or a more complex diet 
containing wheat, corn, rapeseed meal, spring pea, meat 
meal, and animal fat (Table 1). The latter diet (a summer 
diet) corresponded to practical diets used in France during 
the summer season. Both diets were presented in pellets. 
Birds had free access to water.

**Measurements**

The birds were weighed at 4 and 6 wk of age after an 
overtight period without feed (16 h). Daily feed intake 
was measured during the experimental period. Only 60 
cages were available for daily water intake measurements.

Feed digestibility was measured from Day 38 to 42 by 
total collection of excreta (Lessire, 1990). The modified 
procedure was characterized by 2 d prefeeding, 13 h 
without feed, 2 d feeding, and 13 h without feed periods. 
The digestive tracts of the birds on different treatments 
were assumed to contain the same amounts of residues at 
the end of the two feed withdrawal periods. Excreta were 
collected twice a day, pooled, and freeze-dried. They were 
then ground (0.5 mm).

The 22PF birds were fed 10 times a day during the 
digestibility assay, from 38 to 42 d (between 0700 to 2200 
h) to avoid the “large meal” effect.

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2The large meal effect corresponds to the total daily intake ingested 
over a short period of time, i.e., about 2 h.
Chemical Analysis

Dry matter of diets and excreta was determined by oven-drying 4 h at 103 C and ash by complete combustion (550 C for 24 h). Gross energy was measured using a C700 IKA-Calorimeter.3 The AME content of the diets was then calculated. Nitrogen content was determined by a macro-Kjeldahl method in order to correct AME values to AMEn according to Hill and Anderson (1958). In order to estimate protein digestibility, fecal and urinary N were chemically separated according to the method of Terpstra and de Hart (1974). Total lipids of diets and excreta were extracted using 2:1 (vol/vol) chloroform-methanol according to Folch et al. (1957). Starch was determined with the dimethyl sulfoxide procedure (Boehringer Mannheim, 1980) as described previously (Carré et al., 1991).

Statistical Analysis

Results are presented as means with their standard errors. All data were analyzed by analysis of variance, after testing homogeneity of variance between treatments by Bartlett’s test. Treatment means were compared by the Tukey test (Snedecor and Cochran, 1980, using a Systat software program.4

RESULTS

Growth Performance

Final body weight, daily feed intake, weight gain, and feed conversion data are presented in Table 2. The 32AL chickens weighed approximately 500 g less than the 22AL chickens. Feed consumption decreased by 34 and 30% on a daily basis with control and summer diets, respectively. Significantly more of the summer diet was consumed than the control diet under high temperature exposure: 113 vs 105 g/d. Weight gain was reduced by 50% in heat-exposed chickens compared to 22AL birds. Feed to gain ratio was thus significantly higher in 32AL chickens: 0.88 and 0.62 units higher with control and summer diets, respectively. Irrespective of the diet, heat exposure enhanced water intake (Table 3). The water to feed ratio nearly doubled for 32AL chickens compared to 22AL chickens: 3.0 vs 1.6 g/g.

Metabolizable Energy and Feed Digestibility

The AME of the summer diet was significantly decreased by 132 kcal/kg in chronically heat-exposed chickens compared to 22AL birds (Table 4). There was no significant effect of high temperature with the control diet. The effect of high temperature exposure was further enhanced when compared at the same feed intake 32AL vs 22PF. Indeed, AME was decreased by 96 and 179 kcal/kg with control and summer diets, respectively.

Nitrogen retention was decreased in 32AL birds compared to both 22 C groups, whereas feed restriction had no effect (Table 4). Taking into account nitrogen balance reduced the effect of high temperature exposure on energy digestibility; however, AMEn was still decreased by 72 and 155 kcal/kg for control and summer diets, respectively.

Dry matter, protein, fat, and starch digestibilities were decreased in 32AL birds compared with 22AL birds receiving the summer diet, whereas only protein digestibility was significantly reduced in 32AL chickens receiving the control diet (Table 5). When compared at the same feed intake (32AL vs 22PF), dry matter, protein, fat, and starch digestibilities measured with both diets were significantly decreased under exposure of chickens to high temperature. This decrease was, however, more important with the summer diet (Table 5). Whatever the variables, the summer diet was less digested than the control diet, irrespective of the ambient temperature or the feeding level. Total mineral retention appeared significantly decreased under high temperature exposure, particularly with the summer diet (Table 6).

DISCUSSION

After only 2 wk of chronic heat exposure, feed intake decreased by more than 3% per degree increase between 22 and 32 C. The reduction was greater than previously reported results: 1.7% (Autic, 1985) and 2.1% (Geraert et al., 1996a) per degree increase from 18 to 22 C, which could be due to the fact that birds were heavier at the beginning of exposure. Such a result underlines the greater susceptibility of modern broilers to hot conditions. The drastic drop in feed consumption justifies taking into account this effect in determining feed digestibility in birds reared at high temperature. When compared to pair-fed control-exposed birds, heat-exposed chickens showed lower weight gain and higher feed to gain ratio (Dale and Fuller, 1979; Geraert et al., 1996a and present experiment). Such reduced growth due to the direct effect of high ambient temperature needs to be explained. A reduction of feed digestibility might contribute to a decrease in the amounts of nutrients available for growth.

The effect of high temperature on the ME value depends on the diet, which could explain discrepancies reported in the literature. Indeed, when birds were fed a corn-soybean meal diet, energy digestibility did not significantly change when birds were exposed to high temperature, as observed by El Husseiny and Creger (1980), Wallis and Balnave (1984), and Geraert et al. (1992). On the other hand, AME decreased when birds were exposed to 32 compared to 22 C, with the summer diet containing more lipids (116 vs 81 g total lipids/kg). Keshavarz and Fuller (1980), also using a high fat diet, reported a lower ME in hot conditions. The originality of

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1IKA-Analysentechnik GmbH, D-7843 Heitersheim, Germany.
2Systat Inc., Evanston, IL 60201.
## TABLE 2. Average final body weight, daily feed intake, weight gain, and feed conversion of ad libitum fed 32 °C exposed (32AL), ad libitum fed 22 °C exposed (22AL), and pair-fed 22 °C exposed (22PF) male chickens from 4 to 6 wk of age

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control diet</th>
<th>Summer diet</th>
<th>Probabilities</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>22AL</td>
<td>22PF</td>
<td>32AL</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>Body weight, (6 wk), g</td>
<td>13</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Feed intake, g/d</td>
<td>159 ± 3a</td>
<td>110 ± 1b</td>
<td>105 ± 2b</td>
</tr>
<tr>
<td>Weight gain, g</td>
<td>1,084 ± 5a</td>
<td>642 ± 9b</td>
<td>515 ± 28c</td>
</tr>
<tr>
<td>Feed conversion, g:g</td>
<td>2.06 ± 0.04c</td>
<td>2.40 ± 0.03b</td>
<td>2.94 ± 0.13a</td>
</tr>
</tbody>
</table>

aMeans ± SE in a row within a diet with no common superscript differ significantly (P < 0.05).

Initial 4-wk liveweight of all groups was 1,215 ± 11 g.

## TABLE 3. Water and feed consumptions and water to feed ratio of ad libitum fed 32 °C exposed (32AL), ad libitum fed 22 °C exposed (22AL), and pair-fed 22 °C exposed (22PF) male chickens from 4 to 6 weeks of age

<table>
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<td>22AL</td>
<td>22PF</td>
<td>32AL</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>Water consumption, g</td>
<td>249 ± 11a</td>
<td>227 ± 15a</td>
<td>322 ± 19b</td>
</tr>
<tr>
<td>Feed consumption, g</td>
<td>155 ± 4a</td>
<td>110 ± 1b</td>
<td>105 ± 2b</td>
</tr>
<tr>
<td>Water:feed, g:g</td>
<td>1.61 ± 0.04b</td>
<td>2.05 ± 0.14b</td>
<td>2.99 ± 0.18a</td>
</tr>
</tbody>
</table>

aMeans ± SE in a row within a diet with no common superscript differ significantly (P < 0.05).

## TABLE 4. Apparent metabolizable energy content, AMEn, and nitrogen retention of ad libitum fed 32 °C exposed (32AL), ad libitum fed 22 °C exposed (22AL), and pair-fed 22 °C exposed (22PF) male chickens measured between 38 and 42 d of age

<table>
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<tbody>
<tr>
<td></td>
<td>22AL</td>
<td>22PF</td>
<td>32AL</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>AME, kcal/kg</td>
<td>3.205 ± 15b</td>
<td>3.272 ± 13a</td>
<td>3.176 ± 11b</td>
</tr>
<tr>
<td>AMEn, kcal/kg</td>
<td>3.065 ± 13b</td>
<td>3.130 ± 13a</td>
<td>3.058 ± 9b</td>
</tr>
<tr>
<td>Nitrogen intake, g</td>
<td>16.7 ± 0.4a</td>
<td>10.4 ± 0.1b</td>
<td>9.8 ± 0.4b</td>
</tr>
<tr>
<td>Nitrogen excretion, g</td>
<td>8.2 ± 0.3a</td>
<td>5.0 ± 0.1b</td>
<td>5.5 ± 0.2b</td>
</tr>
<tr>
<td>Nitrogen retention, %</td>
<td>51.1 ± 0.9a</td>
<td>51.9 ± 1.3a</td>
<td>43.2 ± 2.0b</td>
</tr>
</tbody>
</table>

a,bMeans ± SE in a row within a diet with no common superscript differ significantly (P < 0.05).
### TABLE 5. Dry matter, protein, lipid, and starch digestibility of *ad libitum* fed 32 C exposed (32AL), *ad libitum* fed 22 C exposed (22AL), and pair-fed 22 C exposed (22PF) male chickens measured between 38 and 42 d of age

<table>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22AL</td>
<td>22PF</td>
<td>32AL</td>
</tr>
<tr>
<td>n</td>
<td>13</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Dry matter</td>
<td>70.2 ± 0.3 b</td>
<td>71.6 ± 0.3 a</td>
<td>69.1 ± 0.4 c</td>
</tr>
<tr>
<td>Proteins</td>
<td>83.2 ± 0.8 a</td>
<td>84.6 ± 0.3 a</td>
<td>80.7 ± 0.7 b</td>
</tr>
<tr>
<td>Fats</td>
<td>89.1 ± 0.7 a</td>
<td>91.7 ± 0.4 a</td>
<td>88.0 ± 1.3 b</td>
</tr>
<tr>
<td>Starch</td>
<td>95.3 ± 0.2 b</td>
<td>96.7 ± 0.2 a</td>
<td>95.5 ± 0.2 b</td>
</tr>
</tbody>
</table>

*a*bMeans ± SE in a row within a diet with no common superscript differ significantly (*P* < 0.05).

### TABLE 6. Total mineral balance of *ad libitum* fed 32 C exposed (32AL), *ad libitum* fed 22 C exposed (22AL), and pair-fed 22 C exposed (22PF) male chickens from 4 to 6 wk of age measured from ash content of feed and excreta between 38 and 42 d of age

<table>
<thead>
<tr>
<th>Variable</th>
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<tr>
<td></td>
<td>22AL</td>
<td>22PF</td>
<td>32AL</td>
</tr>
<tr>
<td>n</td>
<td>13</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Total mineral intake, g</td>
<td>29.6 ± 0.7 a</td>
<td>18.4 ± 0.1 b</td>
<td>17.4 ± 0.7 b</td>
</tr>
<tr>
<td>Total mineral excreted, g</td>
<td>21.8 ± 0.7 a</td>
<td>14.1 ± 0.1 b</td>
<td>13.5 ± 0.5 b</td>
</tr>
<tr>
<td>Total mineral retention, g/100 g</td>
<td>26.6 ± 0.9 a</td>
<td>23.7 ± 0.7 b</td>
<td>22.1 ± 1.2 b</td>
</tr>
</tbody>
</table>

*a,b*Means ± SE within a diet with no common superscript differ significantly (*P* < 0.05).
the present experiment lies on the comparison of the three treatments allowing to separation of the direct effect of heat from the effect associated with reduction of feed intake. When compared at the same feed intake, AME as well as feed digestibility was significantly decreased at high temperature, irrespective of the diet. Moreover, nitrogen retention was significantly reduced at high ambient temperature by 8 to 9 percentage units justifying the use of AMEn. However, the correction for nitrogen balance lowered the reduction of AME under hot conditions.

Lipid digestibility appeared decreased with the summer diet irrespective of the ambient temperature and could be related to the increased saturated to unsaturated fatty acid ratio. Indeed, Annison (1974) and Kussaibati et al. (1982) reported, in young chickens reared at thermoneutrality, a decreased lipid digestibility with saturated fats. The decrease was probably related to insufficient secretion of biliary salts. The summer diet contained animal fats, representing about 20% of total dietary lipids. The decrease of fat digestibility in heat-exposed chickens was further enhanced in chickens receiving the summer diet, and this result suggests that it may be beneficial to use more vegetable fat sources instead of animal sources in order to limit decreases of fat digestibility and AME value under hot conditions.

In agreement with the results of Zuprizal et al. (1993) and Wallis and Balnave (1984), chronic heat exposure significantly decreased protein digestion, particularly with the summer diet. Zuprizal et al. (1993) also observed a greater decrease at high temperature compared to control temperature with uncommon ingredients (rapeseed either hulled or dehulled) than with soybean meal. The greater decrease in protein digestion with the summer diet compared to the control diet could be due to the quality of protein. Indeed, the summer diet contained 5.7% meat meal, known to be less well digested than soybean protein sources, which could decrease the overall protein digestibility by 0.6 percentage units. Thus, the use of practical diet containing highly digestible protein materials may attenuate the effect of high temperature on protein digestibility.

The ME decrease at high temperature was only partly explained by decreased protein and fat digestibilities. Indeed, starch digestibility was also reduced in heat-exposed chickens receiving the summer diet but not in those fed the control diet. Such results could suggest that the effect of temperature on starch digestibility depends on the starch origin: mainly from corn in the control diet and from wheat, corn, and peas in the summer diet.

The decreased total mineral retention under heat exposure was partly due to a reduction of feed intake and confirmed previous results showing reduced potassium retention (Smith and Teeter, 1987) and increased Cu and Mg excretion (Belay et al., 1992). Improvement of digestive ability, particularly absorption, might come from mineral balance adjustment through mineral supplementation.

At thermoneutrality, feed restriction tended to improve protein, fat, and starch digestibilities irrespective of the diet. Such a trend has also recently been reported at a lower level of feed restriction (Lessire et al., unpublished data). However, in heat-exposed chickens, feed digestibility was reduced, particularly when birds were fed the summer diet. Such results suggest a higher direct effect of heat on feed digestion. These changes in digestibility of all feed components (protein, lipid, or starch) might be explained by physiological modifications under heat exposure. First, water consumption dramatically increased at 32°C, which could reduce absorption through an enhanced feed passage rate. However, Wilson et al. (1980) demonstrated a longer feed passage time in heat-exposed male ducklings. Chronic heat exposure has also been shown to reduce the size of the gastrointestinal tract. Savory (1986) reported lower proventriculus and gizzard weights which could explain part of the reduction in protein digestibility. However, Savory (1986) and Mitchell and Carlisle (1992) did not show any significant decrease of duodenal length. Moreover, these authors, as well as Wolfenson et al. (1987), observed a decrease in intestinal villosity surface that could further reduce absorption capacity at high temperature. In growing heat-exposed pigs, Dauncey et al. (1983) also reported a reduction in alanine absorption capacity by the enterocytes probably related to delayed cell maturation. Changes in vascular characteristics might also contribute to reduced digestive capacity. Indeed, Wolfenson et al. (1987) reported reduced blood flow in the upper gastrointestinal tract after chronic heat exposure.

The decrease in feed digestibility of the different components of the diet (starch, fats, and proteins) after heat exposure was accentuated by the complexity of the raw materials used in the diet. The decrease of feed digestibility explains a part of the decrease of growth performance of broilers exposed to high temperature and justifies the use of a feed formulation adapted for hot periods of the year. Moreover, whereas the experimental diets were not similar in ME, lipid, or protein contents, growth performance was improved under heat exposure with the summer diet. However, dry matter, protein, fat, and starch digestibilities were surprisingly reduced with the summer diet. Thus, the growth improvement might be explained by a higher net energy content of the summer diet, which contains more lipids than the control diet. Metabolic utilization of nutrients also changes under heat exposure in response to endocrine control (Geraert et al., 1996b).

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