IS BROILER BREEDER WELFARE IMPROVED BY USING QUALITATIVE RATHER THAN QUANTITATIVE FOOD RESTRICTION TO LIMIT GROWTH RATE?

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Abstract *Animal Welfare 1996, 5:* 105-127

Possible welfare benefits of qualitative rather than quantitative food restriction were investigated with growing female broiler breeder chickens (Ross 1). In Experiment 1, body-weight gains from 2 to 6 weeks of age were compared among different diet dilution, appetite suppression and low protein treatments, with free access to food at all times, to identify qualitative treatments causing weight gains similar to that recommended in the Ross 1 Parent Stock Management Manual. *Based on these results, four diet dilution (400g kg^{-1} unmolassed sugar-beet pulp, 300 and 600g kg^{-1} oat hulls, 500g kg^{-1} softwood sawdust) and one appetite suppression (50g kg^{-1} calcium propionate) treatments were compared with two quantitative restriction (the recommended daily ration and twice that amount) and one* ad libitum *control treatments, from 2 to 10 weeks of age, in Experiment 2. As well as growth, food intake, excreta production and digestibility, measurements were also made of behaviour and blood indices of stress. Several conclusions were drawn. Different methods of qualitative food restriction can be used to control growth rate within desired limits. Problems with these methods include reduced uniformity in weight gain, increased excreta production and/or increased cost. Although they appear to suppress abnormal oral behaviours, they do not alter the increased general activity which is correlated with suppression of growth rate, and which may more accurately reflect associated hunger. Suppression of abnormal oral behaviours may only rarely correspond with reduction in blood indices of stress, and so cannot be taken to indicate improved welfare. Some of these methods can add to physiological stress. Finally, there was insufficient evidence of improved welfare, based on both behavioural and physiological criteria, to justify advocating the suitability of any of these methods for commercial use.*

Keywords: *animal welfare, behaviour, chickens, hunger, qualitative and quantitative food restriction, stress*

Introduction

The parent stock (breeders) of meat-type chickens (broilers) are subjected to severe quantitative food restriction during rearing in order to limit their body-weight at sexual maturity, thereby reducing food costs and the incidence of skeletal and metabolic disease, while also improving reproductive performance (Hocking *et al* 1987; Katanbaf *et al* 1989;

Mench 1993). The need for this restriction stems directly from genetic selection for faster growth in the progeny. In the UK there are around seven million broiler breeders, at least 90 per cent of which are females, sexes are reared separately, and food rations are provided once a day from the second week onwards.

Typically, females reared to 18–20 weeks on a commercial programme of restriction gain about a third as much weight as unrestricted control birds; they eat a quarter to a half as much food as unrestricted birds, depending on age and on whether birds of the same age or weight are compared (Katanbaf *et al* 1989; Hocking 1993; Savory *et al* 1993a). After the first few weeks of restriction they eat their daily ration in about 10min. Operant feeding tests showed that their motivation to eat is consistently high, and was 3.6 times greater than that of unrestricted birds subjected to 72h food deprivation (Savory *et al* 1993a). They also tend to show behaviour characteristic of undernourishment and frustration of feeding motivation, in the form of hyperactivity and abnormal oral behaviour (Kostal *et al* 1992; Savory *et al* 1992; Savory & Maros 1993). Some of the latter is expressed as overdrinking, and in commercial conditions the water supply is often removed a few hours after feeding to prevent wetting of floor litter. This does not appear to compromise the birds' welfare (Hocking *et al* 1993), presumably because the water is removed after food-related thirst has been satisfied. Finally, there is evidence that blood indices of stress (heterophil/lymphocyte ratio, basophil and monocyte frequencies, plasma corticosterone concentration) are higher in restricted-fed broiler breeders than in unrestricted birds (Katanbaf *et al* 1988; Maxwell *et al* 1990, 1992; Hocking *et al* 1993; Savory *et al* 1993b).

Taken together, these facts indicate that current commercial food restriction of broiler breeders contravenes the first of the UK Farm Animal Welfare Council's 'five freedoms' (freedom from hunger and thirst, Farm Animal Welfare Council 1992). The broiler breeder industry is thus caught in a welfare dilemma, because on the one hand stock may be suffering through chronic hunger, while on the other hand less severe restriction leads to defects in health and reproduction.

The purpose of the present study was to test the suggestion (Mench 1993; Savory *et al* 1993a) that qualitative restriction of nutrient intake, by appropriate dietary dilution or appetite suppression, with free access to food, might be a less stressful alternative to quantitative restriction for limiting growth rate. A similar approach has been tried with pregnant sows, which are also subjected to (less severe) chronic food restriction, and which also show abnormal oral behaviour and consistently high levels of feeding motivation (Rushen 1985; Appleby & Lawrence 1987; Lawrence *et al* 1988). It was found that providing chopped straw in their rations reduced general activity, but not the incidence of oral stereotypies during time spent active (Fraser 1975), or motivation to eat in operant tests (Lawrence *et al* 1989). In other studies, however, it was reported that diet dilution with wheat bran and corn cobs, oat hulls or unmolassed sugar-beet pulp suppressed both general activity and the occurrence of oral stereotypies (Robert *et al* 1993; Brouns *et al* 1994), and reduced eating rate observed with the sugar-beet pulp diet was taken to reflect lower feeding motivation (Brouns *et al* 1992).

From these latter trials it was proposed that the welfare of restricted-fed sows may be improved by dietary dilution with fibre, through its effects in promoting satiety and reducing the incidence of stereotypies (Robert *et al* 1993; Brouns *et al* 1994). There was no attempt in either study to test this proposal by comparing physiological indices of stress among

different treatments. Such supporting evidence is necessary because the behavioural data are open to varying interpretation. Robert *et al* (1993) did recognize, however, that although greater dietary bulk can promote short-term satiety through increased stomach distension, this effect is not involved in the long-term regulation of nutrient intake (McHugh & Moran 1986). Hence, an animal fed on a diluted diet could still be 'metabolically hungry' despite having a full stomach.

In a recent study with female broiler breeders, quantitative and qualitative food restriction were combined by diluting the recommended daily ration with ground oat hulls. This extended the time spent feeding to about one hour, but otherwise had no significant effect on behaviour during the rearing period. It was, however, associated with an apparent reduction in the heterophil/lymphocyte ratio at 12 weeks of age (Zuidhof *et al* 1995).

There were two experiments with growing female broiler breeders in the present investigation. The purpose of the first was to identify suitable qualitative restriction treatments for testing in more detail in the second. Thus, in the first, body-weight gains from 2 to 6 weeks of age were measured with six diet dilution, three appetite suppression and three low protein treatments, with free access to food at all times, and were compared with the recommended weight gain on conventional quantitative restriction. Fillers tested in the dilution treatments were unmolassed sugar-beet pulp (Brouns *et al* 1994), oat hulls (Hill & Dansky 1954; Waldroup *et al* 1966; Robert *et al* 1993) and softwood sawdust (Davis & Briggs 1948; Savory & Gentle 1976a), each at two inclusion levels. Anorectic agents tested in the appetite suppression treatments were monensin sodium (Oyawoye & Krueger 1986, 1990) and calcium propionate (Pinchasov & Jensen 1989; Pinchasov *et al* 1993), at two and one concentrations, respectively. The low protein treatments (Waldroup *et al* 1966; Pinchasov *et al* 1993) were based on rolled wheat (104g kg^{-1} crude protein, Bolton & Blair 1974), with and without vegetable oil to supplement dietary energy.

In the second experiment, four diet dilution and one appetite suppression treatments were compared with two levels of quantitative restriction and one *ad libitum* control treatment. These were applied from 2 to 10 weeks of age, and as well as measuring growth and nutritional parameters, systematic observations of behaviour were made and blood samples were taken to determine indices of stress. It was thus intended to assess welfare implications of the various treatments and, where appropriate, their possible commercial applicability.

Experiment 1

Methods

Subjects, husbandry and feeding treatments

Sixty female broiler breeder chicks (Ross 1, Ross Breeders Ltd, Midlothian, UK) were kept in a multi-unit brooder (GH Elt Ltd, Worcester, UK) for their first 2 weeks of life, with continually available supplies of water and a conventional 'starter' mash diet (196g kg^{-1} crude protein and 11.5MJ kg^{-1} metabolizable energy). From 2 weeks of age they were housed individually in cages measuring 31x46x36cm (width x depth x height) in two identical rooms measuring 4.5x3.0m. The cages were in pairs separated by wire mesh, but each had one solid side, a solid back, and a front with vertical bars through which the bird could feed and drink from food and water containers on the outside (adjacent birds could not reach each other's food). There were five blocks of 12 cages, each consisting of two tiers of three pairs, and these were situated along the sides of the rooms, three blocks in one room and two in

the other. Within each block birds were allocated at random to the following 12 feeding treatments:

1 Starter mash + 300g kg^{-1} unmolassed sugar-beet pulp.
2 Starter mash + 600(450 after 3 days)g kg^{-1} unmolassed sugar-beet pulp.
3 Starter mash + 300g kg^{-1} oat hulls.
4 Starter mash + 600g kg^{-1} oat hulls.
5 Starter mash + 300g kg^{-1} softwood sawdust.
6 Starter mash + 600(450 after 3 days)g kg^{-1} softwood sawdust.
7 Starter mash + 200ppm monensin sodium (Elanco Products Ltd, Basingstoke, UK).
8 Starter mash + 300ppm monensin sodium.
9 Starter mash + 50g kg^{-1} calcium propionate (Sigma, Poole, UK).
10 Rolled wheat + vitamin and mineral supplement.
11 Rolled wheat + vitamin and mineral supplement + 100g kg^{-1} vegetable oil.
12 Rolled wheat + vitamin and mineral supplement + 200g kg^{-1} vegetable oil.

These treatments were applied from 2 weeks until the experiment ended at 6 weeks. Food and water were supplied *ad libitum*, lights were on for 8h each day (0800h to 1600h), and ambient temperature was maintained at about 28°C (range 26–30°C) in both rooms.

Body-weight gain and food intake

All birds were weighed at 2 weeks and at weekly intervals thereafter until the experiment ended. They were also weighed 3 days after the first weighing, when the diet dilution levels in treatments 2 and 6 were changed from 600g kg^{-1} to 450g kg^{-1} because those birds had lost weight. One bird was removed from treatment 12 then because it had lost weight. Single birds were also removed from treatments 6 and 10 after two weeks for the same reason, and treatment 12 was terminated at the same time because those birds were gaining very little weight.

Food containers were weighed and refilled every 2 or 3 days, and amounts eaten during the day (0800h to 1600h) and night (1600h to 0800h) were measured over two days and four nights at 3 and 5 weeks of age. As the aim of this experiment was simply to identify treatments for subsequent testing, no statistical comparisons were made here.

Results

Body-weight gain

The expected gain in body-weight of female broiler breeders (Ross 1) between 2 and 6 weeks, when fed according to the recommended (Ross 1988) programme of quantitative food restriction, is 410g. In Experiment 1, treatments 4, 6 and 9 produced mean weight gains that were closest to this desired level (Figure 1, Table 1). Weight gains were about twice as high with treatments 3, 7 and 8, one and a half times as high with 1 and 5, lower than the desired level with 2, and very low with the low protein treatments 10, 11 and 12.

It is recommended in the Management Manual (Ross 1988) that the coefficient of variation (standard deviation divided by the mean) in body-weight (and weight gain) in commercial flocks should be less than 0.08. However, only treatments 7 and 8 came close to that level (Table 1).

Food intake and food conversion ratio

Mean total food intakes from 2 to 6 weeks were highest with treatments 1, 3, 4, 5, 6, 7 and 8, lower with 2 and 9, and lowest with 10, 11 and 12 (Table 1). Food conversion ratios (weight gain : food intake) were highest with 7 and 8, lower with the high diet dilutions (2, 4 and 6) than with the low dilutions (1, 3 and 5) and treatment 9, and lowest with 10, 11 and 12.

From the measurements of food intake during the day and night at 3 and 5 weeks, mean proportions of total 24h intake that were eaten during the 16h dark period varied from 10 to 44 per cent on different treatments (overall mean 24 per cent, Table 1). Coefficients of variation in intake during the night were consistently (2.0–5.5 times) greater than those during the day.

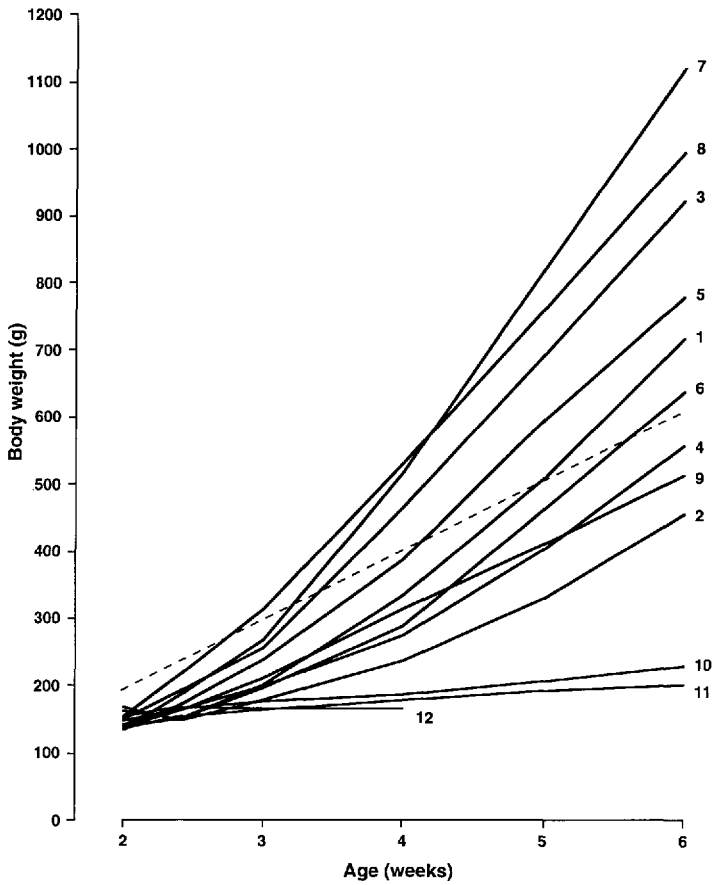

Figure 1 **Mean (n = 5) body-weight at different ages of birds fed according to 12 treatments in Experiment 1 (see Methods section).**
Treatments are indicated by the numbers after each line. Treatment 12 ended at 4 weeks. The dashed line represents the target growth rate in the Management Manual (Ross 1988).

Table 1 **Mean (n = 5) body weight gain, total food intake and food conversion ratio from 2 to 6 weeks of age, and proportion of food eaten at night at 3 and 5 weeks[1], on 12 feeding treatments (see Methods section) in Experiment 1.**

Treatment	1	2	3	4	5	6[2]	7	8	9	10[2]	11	12[3]
Weight gain (g)	578	299	770	406	642	474	983	837	373	84	62	(13)
CV	0.18	0.30	0.21	0.33	0.19	0.28	0.04	0.13	0.44	0.29	0.21	(0.94)
Food intake (g)	1709	1220	2214	1854	2000	1854	2063	1939	1075	705	575	(205)
CV	0.09	0.10	0.16	0.22	0.20	0.23	0.04	0.10	0.28	0.05	0.15	(0.07)
Gain: intake ratio	0.34	0.24	0.35	0.22	0.32	0.25	0.48	0.43	0.34	0.12	0.11	(0.06)
CV	0.12	0.21	0.05	0.13	0.05	0.06	0.04	0.09	0.18	0.24	0.14	(0.94)
Night intake as per cent of total	44	30	30	28	25	38	22	12	29	10	10	(12)

[1] From measurements of food intake over two days (0800 to 1600h) and four nights (1600h to 0800h)

[2] In treatments 6 and 10, n = 4

[3] In treatment 12, n = 4, and the values shown are for the period from 2 to 4 weeks

CV coefficient of variation (standard deviation divided by the mean)

Discussion

Judging from the weight gains and growth curves obtained with the diet dilutions in Experiment 1, it was decided (with modification of concentration where necessary) to use 400g kg^{-1} sugar-beet pulp, 600g kg^{-1} oat hulls and 500g kg^{-1} sawdust treatments in Experiment 2 for achieving growth rates similar to the desired one in the Management Manual (Ross 1988). The 50g kg^{-1} calcium propionate appetite suppression treatment (9) was also chosen for the same purpose.

This concentration of propionate, which appeared to be suitable here in combination with a high protein and energy diet, was 32 per cent greater than the 38g kg^{-1} found to be insufficient when combined with a lower protein and energy diet in a previous study (Pinchasov *et al* 1993). The 200 and 300ppm concentrations of monensin sodium, an ionophore anticoccidial drug, were lower than the 400ppm previously associated with increased mortality (Oyawoye & Krueger 1986). These monensin treatments were relatively ineffective here, but might well have suppressed appetite and growth rate more if they had been tested in combination with a lower protein diet (Oyawoye & Krueger 1986, 1990). By contrast, the rolled wheat low protein diets were too effective at suppressing growth, particularly when combined with vegetable oil, and they appeared to be much less palatable than corn- and barley-based diets with similar low protein contents tested in earlier studies (Waldroup *et al* 1966; Pinchasov *et al* 1993).

In Experiment 2, the three diet dilution and one appetite suppression treatments identified above were compared with two levels of quantitative food restriction (the recommended daily ration and twice that amount), a lower level of diet dilution (300g kg^{-1} oat hulls), and one *ad libitum* control treatment. Welfare implications of these were assessed by comparing birds' responses in terms of growth, nutritional parameters, behaviour and blood indices of stress.

Although considerable amounts were eaten at night in Experiment 1, and variation in intake between birds at night was greater than during the day, it was decided to continue with free access to food at all times (except for the quantitative restriction treatments) in Experiment 2. This was mainly because growth responses to selected qualitative restriction treatments would (presumably) have been altered in an unpredictable way if food access had been limited to daylight hours only.

Experiment 2

Methods

Subjects, husbandry and feeding treatments

Ninety six female broiler breeder chicks (Ross 1) were treated as in Experiment 1 for the first 2 weeks of life, and were then moved to the same individual cages in the same two rooms as before. In Experiment 2 there were twelve blocks of eight cages, each consisting of four pairs in either the upper or lower tier, and each room containing three blocks in each tier. Within each block birds were allocated at random to the following eight feeding treatments:

1 Starter mash + 400g kg^{-1} unmolassed sugar-beet pulp.
2 Starter mash + 300g kg^{-1} oat hulls.
3 Starter mash + 600g kg^{-1} oat hulls.
4 Starter mash + 500g kg^{-1} softwood sawdust.

5 Starter mash + 50g kg^{-1} calcium propionate.
6 Starter mash; the recommended ration (Ross 1988).
7 Starter mash; twice the recommended ration.
8 Starter mash; *ad libitum*.

These treatments were applied from 2 to 6 weeks of age, when the basal diet was changed from starter mash to 'grower' mash (146g kg^{-1} crude protein and 11.0MJ kg^{-1} metabolizable energy). The same treatments (1–8) then continued with this new basal diet until the experiment ended at 10 weeks. As well as treatment 8, food was also supplied *ad libitum* in treatments 1–5, water was supplied *ad libitum* in all treatments, and the weighed rations in treatments 6 and 7 were provided daily at 0900h. Lights were on for 8h each day (0800h to 1600h), and ambient temperature was maintained at about 27°C (23–30°C) from 2 to 6 weeks and 23°C (20–27°C) from 6 to 10 weeks, in both rooms.

Body-weight gain and food intake

All birds were weighed at 2 weeks and at weekly intervals thereafter until the experiment ended. Single birds died after two weeks in treatments 1 and 4, but there was no mortality or removal of birds thereafter.

With treatments 1–5 and 8, food containers were weighed every two or three days, and amounts eaten during one day and night were measured at 9 weeks of age.

Digestibility and metabolizable energy

Approximate digestibilitys of food eaten on all treatments were measured at 5 and 9 weeks, when the basal diet was starter and grower mash, respectively. This was done by collecting each bird's total excreta produced over 24h, from trays under the cages, and expressing the difference between the dry weight of food eaten in the same 24h and the dry weight of excreta as a fraction of the dry weight of food eaten. Each bird's excreta were weighed before and after oven-drying at 80°C for 72h, so wet weights and water contents of excreta were also obtained for each treatment.

The dried excreta collected at 9 weeks were used for calculating apparent metabolizable energy (AME) values for all treatments, after measuring their gross energy contents and those of the grower mash-based diets. Fibre and crude protein contents of all the diets in Experiment 2 were also measured.

Behaviour observations

Birds were observed in eight blocks of 12 in each of the 8 weeks of the experiment. Each block was observed in random order for 10min on Thursday and 10min on Friday, between 1400h and 1600h, and each bird's behaviour was recorded every minute from a single 'on the dot' (Slater 1978) observation, according to one of eight mutually exclusive categories. These were feeding, drinking, standing (only), pacing, sitting (only), preening (while standing or sitting), pecking at the empty feeder (treatments 6 and 7 only), and pecking at parts of the cage. Each bird was thus observed for 80min between 2 and 6 weeks and 80min between 6 and 10 weeks. From the recordings were calculated mean proportions of time (between 1400h and 1600h) that each bird spent in the various activities in these two periods.

Blood indices of stress

A 1.5ml blood sample was taken by wing vein from each bird on one day at 6 and 10 weeks of age, between 0930h and 1200h. Sampling in both rooms was done simultaneously, and each bird was removed from its cage, sampled and returned to its cage before moving on to the next. Total handling time before and during blood removal was less than 2min, and any effect of this on corticosterone concentration should have been both minimal (Beuving & Vonder 1978) and consistent among birds. The blood samples were put in plastic tubes coated with ethylene diamine tetra-acetic acid (EDTA) anticoagulant.

One drop from each sample was smeared on a slide for counting blood cell frequencies, and the remainder was centrifuged to obtain plasma in which corticosterone concentration was measured with a radioimmunoassay kit (Biogenesis Ltd, Bournemouth, UK), modified as described by Mitchell *et al* (1986). The smears were air-dried and stained according to Robertson & Maxwell (1990), and with each slide, 100 white blood cells were examined and frequencies of the various types (heterophils, lymphocytes, basophils, monocytes, eosinophils) were recorded. All of these (and corticosterone) have been shown to respond to at least some types of stressor in birds (Maxwell 1993).

Statistical analyses

With data based on measurements of body-weight gain, food intake, digestibility and metabolizable energy, statistical comparisons across feeding treatments were done by one-way ANOVA. Significant ($P < 0.05$) differences among mean values were determined by Tukey's multiple comparison procedure (Maxwell & Delaney 1990). With the behaviour observations and blood cell counts, measured as percentages, analyses were done with angular (arcsine root) transformed data (Bartlett 1947) to give approximately equal variances to all treatments. Heterophil/lymphocyte ratios and corticosterone concentrations were log transformed for the same reason. Transformed data were compared by split-plot ANOVA, with birds as plots, to measure the significance of effects of treatment, age and their interaction. With feeding and pecking at the empty feeder, which were not seen in all treatments, ANOVA tests were applied only to those treatments where they were seen. Differences among treatment means were determined by Tukey's procedure, as before, and the mean values presented in Tables 4 and 5 are in the observed scale, from back transformations. Also shown in Tables 4 and 5 are values and formulae for estimating standard errors of these back-transformed means (after Kendall & Stuart 1963).

Results

Body-weight gain

From 2 to 10 weeks, the mean weight gain of birds fed the recommended ration (treatment 6, 823g, Table 2) was about the same as that (800g) expected from the Management Manual (Ross 1988), and they also grew at the expected rate (Figure 2).

Those fed twice the recommended ration (treatment 7) and *ad libitum* (treatment 8) gained nearly two and three times as much weight as treatment 6, respectively. The qualitative restriction treatments 1, 3 and 5 produced weight gains closest to treatment 6, while treatment 2 was intermediate between 7 and 8, and 4 was only half as great as 6. Apart from treatments 1 and 6, and 1, 3 and 5, all the means differed significantly from each other (Table 2).

Table 2 **Mean (n = 12) body weight gain, total food intake and food conversion ratio from 2 to 10 weeks of age, and proportion of food eaten at night at 9 weeks[1], on eight feeding treatments (see Methods section) in Experiment 2.**

Treatment	1[2]	2	3	4[2]	5	6	7	8	SED	Significance
Weight gain (g)	882^{de}	1892^{b}	1132^{d}	433^{f}	1089^{d}	823^{c}	1452^{c}	2350^{a}	84	***
CV	0.17	0.13	0.27	0.31	0.19	0.05	0.09	0.12		
Food intake (g)	4825^{b}	7137^{a}	6410^{a}	3742^{c}	3998^{bc}	2494^{d}	4988^{b}	7067^{a}	343	***
CV	0.13	0.12	0.21	0.30	0.14	-	-	0.14		
Gain: intake ratio	0.18^{c}	0.27^{b}	0.18^{c}	0.12^{d}	0.27^{b}	0.33^{a}	0.29^{b}	0.33^{a}	0.01	***
CV	0.11	0.05	0.09	0.14	0.09	0.05	0.09	0.05		
Night intake as per cent of total	35^{ab}	24^{b}	22^{b}	24^{b}	42^{a}	(0)	(0)	29^{ab}	7	*

[1] From measurements of food intake over one day (0800 to 1600h) and night (1600h to 0800h)

[2] In treatments 1 and 4, n = 11

SED Standard error of the difference between means, with 86 (64 for night intake) degrees of freedom

CV coefficient of variation (standard deviation divided by the mean)

Within rows, means with the same superscript do not differ significantly ($P > 0.05$, by Tukey's multiple comparison procedure)

* $P < 0.05$, *** $P < 0.001$ (by ANOVA)

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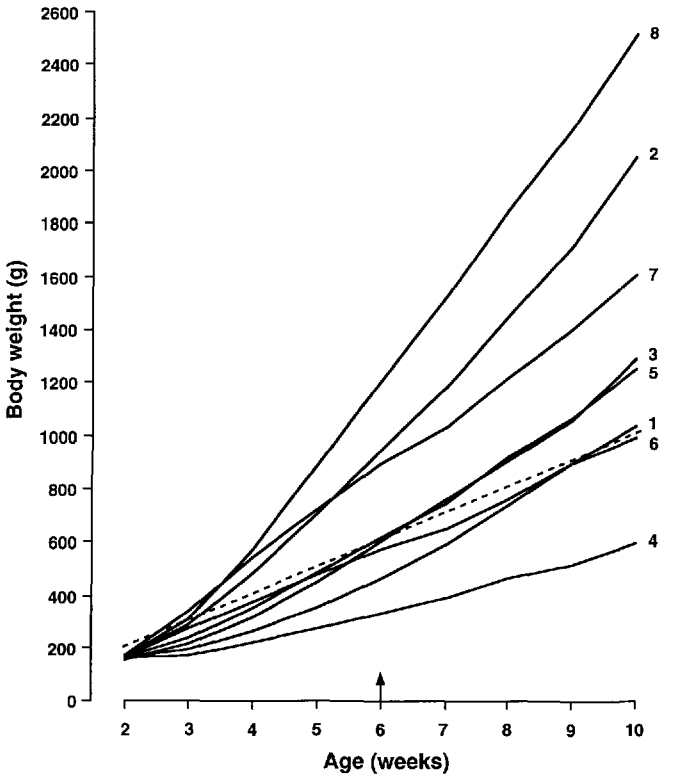

Figure 2 **Mean (n = 12) body-weight at different ages of birds fed according to eight treatments in Experiment 2 (see Methods section).** Treatments are indicated by the numbers after each line. The dashed line represents the target growth rate in the Management Manual. The arrow indicates the change from starter to grower based diets.

As in Experiment 1, coefficients of variation in weight gain with most qualitative restriction treatments in Experiment 2 were at least twice as great as the recommended maximum level of 0.08 (Table 2).

Food intake and food conversion ratio

From 2 to 10 weeks, mean total food intakes were highest with treatments 2, 3 and 8, intermediate with 1, 4, 5 and 7, and lowest with 6 (Table 2). Food conversion ratios were highest with treatments 2 and 5–8, intermediate with 1 and 3, and lowest with 4. In the treatments with *ad libitum* access to food (1–5 and 8), coefficients of variation in food intake were consistently (1.2–2.8 times) greater than those in food conversion ratio.

In treatments 1–5 and 8, mean proportions of total 24h food intake that were eaten during the 16h dark period at 9 weeks varied from 22 to 42 per cent (overall mean 29 per cent, Table 2). A greater proportion was eaten at night with the appetite suppression treatment 5 than with dilution treatments 2, 3 and 4. As before, coefficients of variation in intake at night were consistently (1.6–3.8 times) greater than those during the day.

Digestibility and metabolizable energy

Approximate digestibilitys of both starter and grower mash-based diets, and apparent metabolizable energy (AME) values of the latter, were highest with the undiluted treatments 5–8, intermediate with the sugar-beet pulp and oat hulls treatments 1–3, and lowest with the sawdust treatment 4 (Table 3). Across all treatments and both basal diets, mean digestibilitys were highly correlated ($P < 0.001$) negatively with (neutral detergent) fibre content and positively with crude protein content; the same was true with AME values across grower mash-based treatments.

Production and water content of excreta

Mean wet weights of excreta produced during the 24h collection periods were higher with the grower treatments, at 9 weeks, than with the starter treatments at 5 weeks (Table 3). With both basal diets, they were highest with the sugar-beet pulp treatment 1, intermediate with 2, 3 and 8, and lowest with 4–7. Mean water contents of excreta were also higher with grower than with starter treatments. With both basal diets, they were highest with treatment 1, intermediate with 5–8, and lowest with 2–4.

When the recommended ration treatment 6 is compared with 1, 3 and 5, where weight gains were closest to it (Table 2), treatment 1 caused much greater production of wetter excreta, 3 caused greater production of drier excreta, and 5 caused similar production of drier excreta (Table 3).

Behaviour observations

There was no feeding with treatment 6 during the afternoon observation sessions because those birds had finished their daily (recommended) ration by then. With the larger ration in treatment 7, some feeding was observed between 2 and 6 weeks but not between 6 and 10 weeks (Figure 3). With the remaining treatments, the proportion of time spent feeding was highest with 4, intermediate with 1, 2, 3 and 8, and lowest with 5 (Table 4).

Drinking increased with age with all treatments, particularly 1 and 6, and was highest with 6, intermediate with 1, 3, 4, 5 and 7, and lowest with 2 and 8. Standing decreased with age with all except treatment 7, and was highest with 6, intermediate with 1, 3, 4, 5 and 7, and lowest with 2 and 8. Pacing decreased with age, and was similarly low with all treatments. Sitting tended to increase with age, and was highest with 2, 7 and 8, intermediate with 5, and lowest with 1, 3, 4 and 6. Preening did not change with age, and was highest with 6 and 7, intermediate with 1, 2, 3, 5 and 8, and lowest with 4. Pecking at the empty feeder and at parts of the cage were absent or rare with all except 6 and 7.

To summarize the behaviour data, the quantitative restriction treatments 6 and 7 caused most drinking (6 only), preening and object pecking. Treatments 2 and 8, with the highest weight gains, caused most sitting and least drinking and standing. Of treatments 1, 3 and 5, with weight gains closest to 6, 1 and 3 reduced sitting while 5 reduced feeding. Lastly, treatment 4, with the lowest weight gain, caused most feeding and least sitting and preening.

Table 3 **Fibre and crude protein contents, and mean (n = 12) approximate digestibility, metabolizable energy, and production and water content of excreta with starter and grower diets on eight feeding treatments (see Methods section) in Experiment 2.**

Treatment	1[1]	2	3	4[1]	5	6	7	8	SED	Significance
NDF[2] (g kg^{-1})										
starter	203	226	349	430	86	91	91	91		
grower	212	271	363	495	112	118	118	118		
Crude protein (g kg^{-1})										
starter	149	158	120	110	190	196	196	196		
grower	122	120	100	77	138	146	146	146		
Approximate digestibility (g kg^{-1})										
starter	648^{cd}	640^{cd}	614^{d}	578^{d}	772^{a}	693^{bc}	726^{ab}	723^{ab}	23	***
grower	513^{bc}	563^{b}	493^{bc}	435^{c}	693^{a}	741^{a}	756^{a}	686^{a}	30	***
AME[3] (MJ kg^{-1})										
grower	8.5^{bc}	9.7^{b}	8.1^{c}	7.4^{c}	12.0^{a}	12.2^{a}	12.5^{a}	11.4^{a}	0.5	***
24h excreta production (g wet wt)										
starter	164^{a}	120^{abc}	92^{bcd}	67^{d}	50^{d}	48^{d}	86^{cd}	135^{ab}	15	***
grower	494^{a}	221^{b}	202^{bc}	150^{bcd}	115^{cd}	91^{d}	120^{cd}	183^{bcd}	30	***
Excreta water content (g kg^{-1})										
starter	828^{a}	632^{cd}	557de	545^{e}	654^{c}	737^{b}	747^{b}	732^{b}	25	***
grower	895^{a}	702de	637^{f}	685^{ef}	761^{cd}	849^{ab}	799^{bc}	738^{cde}	20	***

[1] In treatments 1 and 4, n = 11

[2] NDF, neutral detergent fibre (hemicellulose, cellulose and lignin)

[3] AME, apparent metabolizable energy, measured with the grower diet only

SED Standard error of the difference between means, with 86 degrees of freedom

Within rows, means with the same superscript do not differ significantly ($P > 0.05$, by Tukey's multiple comparison procedure)

***$P < 0.001$ (by ANOVA)

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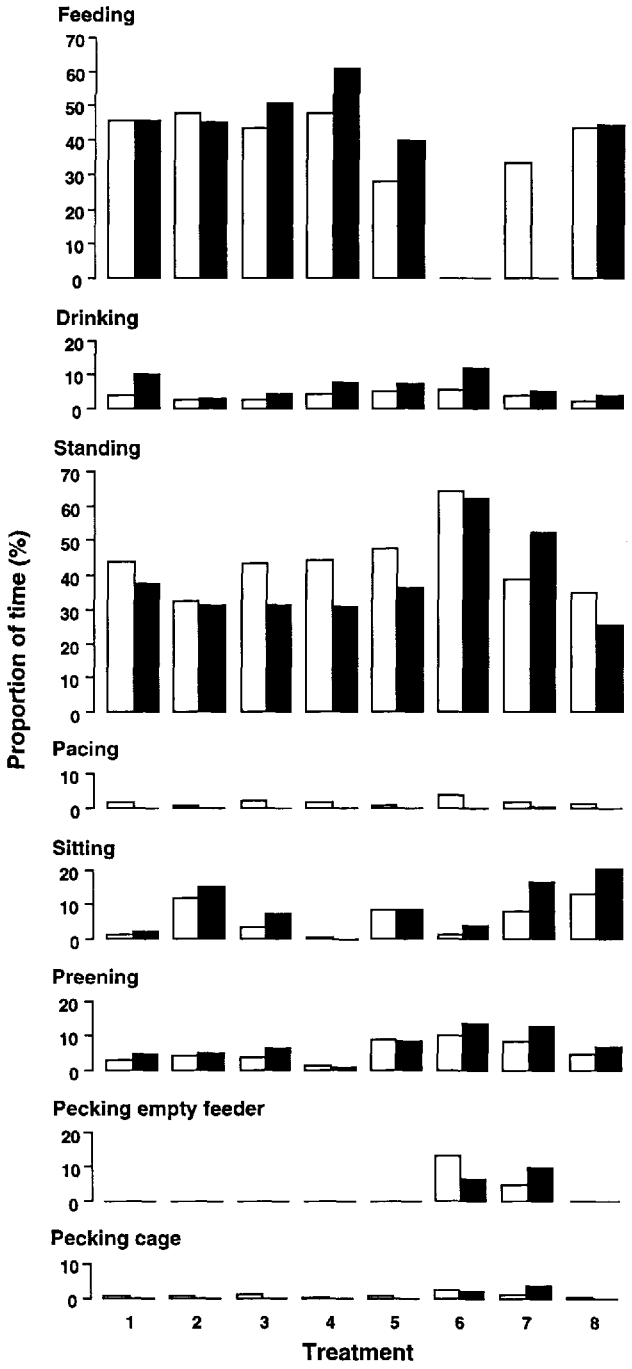

Figure 3 **Mean (n = 12) proportions of time spent in different activities by birds fed according to eight treatments in Experiment 2 (see Methods section), during afternoon observation periods at 2–6 (white columns) and 6–10 (black columns) weeks of age.**

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Table 4 **Overall mean[1] (n = 12) proportions (%) of time spent in different activities on eight feeding treatments (see Methods section) in Experiment 2, and significance of effects of treatment (T), age (A, 2–6 weeks versus 6–10 weeks) and their interaction, from ANOVA.**

										Significance of effects		
Treatment	**1[2]**	**2**	**3**	**4[2]**	**5**	**6**	**7**	**8**	**SEM[3]**	**T**	**A**	**TxA**
Feeding	45.5^{ab}	46.3^{ab}	47.0^{ab}	54.5^{a}	32.5^{b}	-	10.2^{c}	43.3^{ab}	2.1	***	*	***
Drinking	5.9^{ab}	1.9^{b}	2.9^{ab}	5.1^{ab}	4.6^{ab}	7.2^{a}	3.2^{ab}	2.3^{b}	1.5	**	***	ns
Standing	40.5^{b}	31.5^{c}	37.0^{bc}	37.0^{bc}	41.7^{b}	63.2^{a}	45.3^{b}	29.8^{c}	1.3	***	***	***
Pacing	0.3	0.1	0.4	0.2	0.2	0.7	0.5	0.2	0.8	ns	***	ns
Sitting	0.4^{c}	12.1^{a}	2.7^{bc}	0.0^{c}	6.3^{ab}	1.2^{bc}	10.2^{a}	14.0^{a}	2.0	***	***	ns
Preening	3.0^{bc}	4.3^{b}	4.4^{b}	0.7^{c}	7.3^{ab}	10.2^{a}	10.0^{a}	4.6^{b}	1.4	***	ns	ns
Pecking empty feeder	-	-	-	-	-	8.2	4.7	-	1.6	ns	ns	**
Pecking cage	0.2^{b}	0.1^{b}	0.2^{b}	0.1^{b}	0.2^{b}	2.0^{a}	1.6^{a}	0.1^{b}	0.7	***	**	***

[1] Analyses of variance were done on transformed data (see Methods section), and the values shown are in the observed scale (from back transformations)

[2] In treatments 1 and 4, n = 11

[3] The standard error of any one of the means (in the observed scale) is approximately equal to this SEM value multiplied by $2\pi/180\times\sqrt{p(100-p)}$, where p is the respective mean

Within rows, means with the same superscript do not differ significantly ($P > 0.05$, by Tukey's multiple comparison procedure)

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, ns not significant ($P > 0.05$)

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Blood indices of stress

Mean ratios of heterophil to lymphocyte white blood cells were lower at 10 than at 6 weeks, and were significantly higher with treatment 1 than with all other treatments (Figure 4, Table 5).

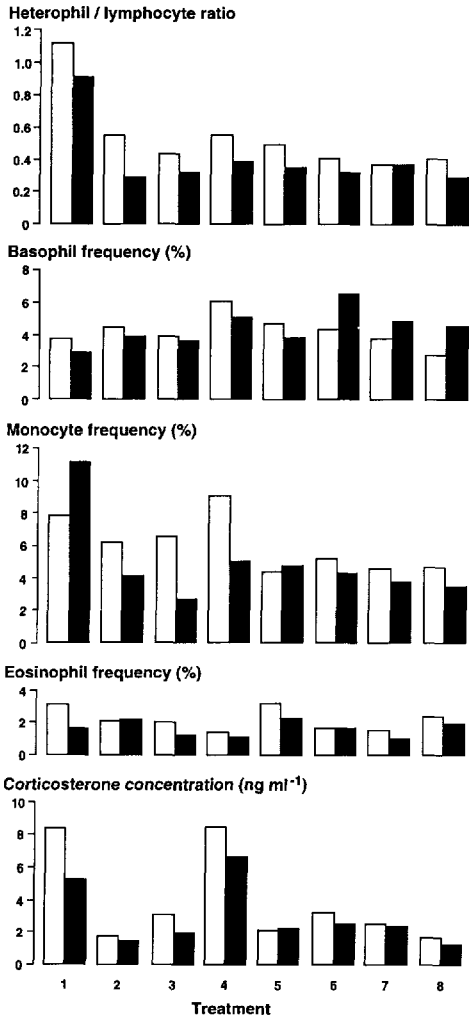

Figure 4 **Mean (n = 12) blood indices of stress in birds fed according to eight treatments in Experiment 2 (see Methods section), from samples taken at 6 (white columns) and 10 (black columns) weeks of age.**

Basophil frequencies did not differ with age, and were highest with 4 and lowest with 1. Monocyte frequencies decreased with age with all treatments except 1 and 5, and were higher with 1 and 4 than with other treatments. Eosinophil frequencies tended to decrease with age, and were highest with 5 and lowest with 4. Plasma corticosterone concentrations also decreased with age, and were highest with 1 and 4, intermediate with 3, 5, 6 and 7, and lowest with 2 and 8.

Table 5 **Overall mean[1] (n = 12) heterophil/lymphocyte ratio, differential frequency (%) of basophils, monocytes and eosinophils, and plasma corticosterone concentrations (ng ml^{-1}) on eight feeding treatments (see Methods section) in Experiment 2, and significance of effects of treatment (T), age (A, 6 weeks versus 10 weeks) and their interaction, from ANOVA.**

										Significance of effects		
Treatment	**1[2]**	**2**	**3**	**4[2]**	**5**	**6**	**7**	**8**	**SEM[3]**	**T**	**A**	**TxA**
Heterophil/lymphocyte	0.74^{a}	0.34^{b}	0.31^{b}	0.43^{b}	0.38^{b}	0.34^{b}	0.33^{b}	0.32^{b}	0.11	***	***	ns
Basophils	2.83^{b}	4.04^{ab}	3.32^{ab}	5.33^{a}	3.73^{ab}	4.99^{ab}	4.04^{ab}	3.31^{ab}	0.79	*	ns	ns
Monocytes	8.87^{a}	4.80^{b}	3.89^{b}	6.52^{ab}	3.95^{b}	4.39^{b}	3.95^{b}	3.61^{b}	0.98	***	**	**
Eosinophils	1.99^{ab}	1.68^{ab}	1.21^{ab}	0.56^{b}	2.10^{a}	1.28^{ab}	0.67^{ab}	1.85^{ab}	0.88	**	*	ns
Corticosterone	5.17^{a}	1.35^{c}	2.38^{bc}	6.59^{a}	1.87^{bc}	2.55^{b}	2.24^{bc}	1.34^{c}	0.13	***	***	*

[1] Analyses of variance were done on transformed data (see Methods section), and the values shown are in the observed scale (from back transformations)

[2] In treatments 1 and 4, n = 11

[3] The standard error of any one of the means (in the observed scale) is approximately equal to this SEM value multiplied either by the respective mean (for heterophil/lymphocyte and corticosterone) or by $2\pi/180\times\sqrt{p(100-p)}$, where p is the respective mean (for basophils, monocytes and eosinophils)

Within rows, means with the same superscript do not differ significantly ($P > 0.05$, by Tukey's multiple comparison procedure)

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, ns not significant ($P > 0.05$)

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Hence, increased stress was indicated by three blood indices with treatments 1 and 4. When treatment 6 is compared with 1, 3 and 5, where weight gains were closest to it, 1 caused a higher heterophil/lymphocyte ratio, monocyte frequency and corticosterone concentration, and there were no significant differences with either 3 or 5 (Table 5).

Discussion

The two- and threefold increases in body-weight gain with treatments 7 and 8, compared with 6, were like those reported previously for penned broiler breeders fed on the same three treatments to 20 weeks of age (Savory *et al* 1993a). Here, the qualitative restriction treatments 1, 3 and 5 produced weight gains closest to that with the recommended ration in 6. However, when the experiment ended at 10 weeks, the birds on 1, 3 and 5 were all gaining weight at rates greater than those on 6 (Figure 2), so presumably these qualitative treatments would be inadequate for achieving target body-weights in broiler breeders at sexual maturity (23 weeks). A likely solution would be to increase the concentration of the dietary diluent or appetite suppressant to prevent growth rate increasing. This could be done at 6 weeks, at the change from starter to grower diets, and 400g kg^{-1} sugar-beet pulp (1) could be increased to, say, 450g kg^{-1}, 600g kg^{-1} oat hulls (3) to 700g kg^{-1}, or 50g kg^{-1} calcium propionate (5) to 60g kg^{-1}, with further increases if necessary. In Experiment 1, 450g kg^{-1} softwood sawdust (6) produced a growth rate that appeared to be too high (Figure 1), yet the 500g kg^{-1} sawdust treatment (4) in Experiment 2 was clearly too much (Figure 2); perhaps 450g kg^{-1} would be suitable to 6 weeks, and 500g kg^{-1} thereafter.

Birds are able to compensate adequately for substantial diet dilutions without much loss in body-weight, as seen here with treatment 2 and also in other studies (Hill & Dansky 1954; Van Hemel & Myer 1969; Waldroup *et al* 1966, 1976; Savory 1984). However, there comes a point with every diluent where the rate of assimilation of digested nutrients is no longer sufficient to sustain growth (or maintenance of body-weight in adults). Variation in appropriate inclusion levels of different diluents depend on properties such as their digestibility, nutrient content, density and absorbency. Here, the sugar-beet pulp and oat hulls in treatments 1–3 had apparent metabolizable energy values of 1.1 and 1.7MJ kg^{-1} respectively, and crude protein values of 93 and 46g kg^{-1} (World's Poultry Science Association 1989; National Research Council 1994; J McNab unpublished data), whereas the sawdust in treatment 4 presumably had minimal digestibility (Halnan 1949). Densities of these diluents are similar when dry, but sugar-beet pulp is much more absorbent than oat hulls or sawdust, as reflected by the high water content of excreta (Table 3) and relatively high level of drinking (Table 4) with treatment 1, so its increased bulk when wet in the alimentary tract is a further constraint on the amount that can be processed. The ability of birds to adapt to different forms of diet dilution depends also on adjustments in gastrointestinal morphology and function (Savory & Gentle 1976b; Moss & Trenholm 1987; Savory 1992).

The results here confirm that calcium propionate (treatment 5) is a potent appetite suppressant, but its mechanism of action is uncertain (Pinchasov & Jensen 1989; Pinchasov & Elmaliah 1994). When treatment 5 birds were given a choice between the 50g kg^{-1} propionate (grower) diet and grower mash at the end of Experiment 2, they ate a total of 178 ± SEM25g in 24h, of which 65 ± 6 per cent was grower mash ($P < 0.05$ by paired t test). Treatment 8 (*ad libitum* control) birds given the same choice ate 195 ± 23g, of which 81 ± 5

per cent was grower mash ($P < 0.001$). Hence, both groups preferred grower mash, but not exclusively so. Both acidic and neutralized solutions of propionic acid suppress food intake in a dose-related way when intubated into the crop, implying a post-ingestional mechanism of action not attributable to acidity (Pinchasov & Jensen 1989), but one which nevertheless could cause conditioned reduction in palatability.

With regard to commercial applicability, the problems with treatments 1, 3 and 5 are that they were all associated with reduced uniformity in body-weight gain, 1 and 3 caused greatly increased production of excreta (which were very wet with 1), and 5 would be expensive to use on a large scale (calcium propionate circa £700 per ton). There might also be a health risk associated with handling large amounts of the acidic propionate in its powder form. Perhaps uniformity in weight gain could be improved by closing food hoppers at night, to prevent the consistently greater variability in food intake then, but this would mean that new inclusion levels for the qualitative treatments would have to be identified, to allow for only daytime (8h) access to food. Even then, it seems unlikely that this uniformity could be as high with *ad libitum* feeding as with ration feeding, and the other problems would remain.

With increasing levels of quantitative restriction, from treatments 8 to 7 to 6, there were reductions in feeding and sitting, and increases in drinking, standing, preening and object pecking (at the cage and empty feeder) (Table 4). These trends in behaviour are broadly similar to those found previously with penned broiler breeders fed on the same three treatments (Savory & Maros 1993), which were associated with corresponding variation in feeding motivation (Savory *et al* 1993a). The tendency for increasing food restriction to cause increases in general activity and in oral stereotypies has also been reported with pigs (Appleby & Lawrence 1987; Terlouw *et al* 1991). Here, birds on different treatments could see and hear each other within the two rooms, and may have influenced each others' behaviour through social facilitation (Savory 1975). This may have reduced some effects of treatment on behaviour.

With the qualitative restriction treatments 1–5, times spent feeding, drinking, pacing and object pecking did not differ significantly from those with the control *ad libitum* treatment 8. Standing was increased with 1 and 5, and preening reduced with 4. Treatment 2, with the highest growth rate of the qualitative treatments, was like 8 in all aspects of behaviour. Hence, the qualitative treatments here suppressed the abnormal oral behaviours characteristic of quantitative restriction, just as they have been shown to do with pregnant sows (Robert *et al* 1993; Brouns *et al* 1994). However, the other characteristic of quantitative restriction, increased general activity, was not suppressed with treatments 1, 3 and 4, judging from times spent sitting (the only index of consistent inactivity). Of the treatments with body-weight gains closest to 6, therefore, only 5 appeared to show reductions in both types of behaviour. In fact, weight gains with 3 and 5 were greater than with 6 (Table 2), and times spent sitting with different treatments (Table 4) were correlated closely ($P < 0.001$) with corresponding weight gains. The level of activity observed may thus reflect the suppression of growth rate, and hence, presumably, an associated level of chronic hunger (cf Baumeister *et al* 1964). By contrast, diet dilution with fibre did reduce general activity in restricted-fed sows (Fraser 1975; Robert *et al* 1993; Brouns *et al* 1994), but these were adults whose level of restriction was only half as great as that with the recommended ration (treatment 6) here (Savory *et al* 1993a).

Effects of quantitative food restriction on blood indices of stress have not always been consistent in previous work with broiler breeders. Thus, although the heterophil/lymphocyte ratio, frequencies of basophils and monocytes, and plasma corticosterone concentration have all been shown to be higher in restricted than in unrestricted birds (Maxwell *et al* 1990, 1992; Hocking *et al* 1993; Savory *et al* 1993b), only the basophil increase was found in all four studies. Some of this variation may be due to the time of day when samples were taken (Maxwell 1981; Honma *et al* 1986). Here, samples were taken in the morning, and only corticosterone concentration increased significantly in response to quantitative restriction, judging from treatments 6, 7 and 8 in the multiple comparisons in Table 5. There were, however, parallel but non-significant trends across these three treatments with the heterophil/lymphocyte ratio and basophil and monocyte frequencies. With the qualitative treatments where weight gains were closest to 6, 1 was much higher than 6, 7 and 8 in three of the stress indices, whereas 3 and 5 did not differ significantly from 6, 7 and 8 in any of them.

These data strongly suggest that physiological stress was caused by the 400g kg^{-1} sugar-beet pulp treatment 1, perhaps associated with its high absorbency, and by the 500g kg^{-1} sawdust treatment 4, where growth rate was reduced most severely. There appeared to be no evidence of stress associated with the 50g kg^{-1} calcium propionate appetite suppression treatment 5, where the mechanism of action was unknown, or with the 300 and 600g kg^{-1} oat hulls treatments 2 and 3. The sugar-beet results may have implications for previous work with pigs (Brouns *et al* 1994), where it was suggested that suppression of stereotypies with an *ad libitum* diet containing 500g kg^{-1} unmolassed sugar-beet pulp may indicate improvement in welfare, but where no assessment of physiological stress was made.

Animal welfare implications

Several conclusions concerning broiler breeders can be drawn from these experiments. First, controlled reduction of growth rate within desired limits can be achieved qualitatively, with free access to food, by means of appropriate diet dilution or appetite suppression. Second, problems with these methods that may preclude commercial application include reduced uniformity in weight gain, increased excreta production and/or increased financial cost. Third, although these methods appear to suppress abnormal oral behaviours, they do not alter the increased general activity which is correlated with suppression of growth rate, and which may more accurately reflect associated chronic hunger. Fourth, suppression of abnormal oral behaviours by these methods may only rarely correspond with reduction in blood indices of stress, and so cannot be taken to indicate improved welfare. Fifth, some of these methods can add to physiological stress. Sixth, there is insufficient evidence here, based on both behavioural and physiological welfare criteria, to justify advocating the suitability of any of these methods for commercial use. There are, however, indications that further work should be done in this area.

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