Chapter 3

# EXPERIMENTAL

## STUDIES ON EGG PRODUCTION OF CAGED HENS EXPOSED TO DIFFERENT REGIMES OF FEEDING, WATERING AND TEMPERATURE.

### 3.1. General introduction.

The seven experiments reported in this chapter were conducted (1) to obtain information on the practical application of choice feeding to laying hens in a single feeder at different environmental temperatures; and (2) to study the effect of short-term feed and water restriction programs on the laying performance of hens fed on a complete diet. As discussed in Chapter 1, these are particular problems of egg production in West Timor, Indonesia, the author's home country.

### 3.2. Choice feeding experiments.

#### 3.2.1. Introduction.

Recently, there have been several suggestions that study of the practicality of offering laying hens separate dietary ingredients in a single trough is needed (Emmans, 1979; Cumming *et al.*, 1987; Forbes and Covasa, 1995). This system, referred to as a "choice feeding" or "split-diet" regime, has been known for at least sixty years (Funk, 1932; Graham, 1934; Dove, 1935). Currently, there has been a number of studies in which hens were allowed to exercise dietary self-selection, and in most cases two or more separate feed troughs with internal dividers, or small, separate containers have been used (Cowan *et al.*, 1978; Cowan and Michie, 1979; Emmans, 1977, 1978; Karunajeewa, 1978a; Karunajeewa and Bagot, 1978; Leeson and Summers, 1978, 1979; Summers and Leeson, 1979; Desmayati *et al.*, 1983;

Blake *et al.*, 1984; Karunajeewa and Tham, 1984; Savory, 1986; Kiiskinen, 1987; Scott and Balnave, 1985, 1988, 1989 and 1991).

From a practical viewpoint, however, such techniques are very expensive (Forbes and Covasa, 1995) and indeed it is perhaps unnecessary to supply various feeds in separate feed troughs because hens have the ability to identify and pick up small, individual feed ingredients from a mixture (Cumming *et al.*, 1987; Mastika. 1987). In other words, individual hens are well able to select from the various feed ingredients on offer and to compose their own diet, hopefully according to their actual needs and egg production capacity (Emmans, 1975, 1977 and 1982; Karunajeewa, 1978a; Hughes, 1984; Leeson and Summers, 1991; Rose and Kyriazakis, 1991). From the economic point of view, the use of whole grains in a choice-feeding system represents a reduction in feed cost, as grinding, mixing and many of the handling procedures associated with mash production are then unnecessary (Karunajeewa, 1978b; Kiiskinen, 1987; Tauson *et al.*, 1991).

However, information on such a feeding system to laying hens is limited to one report, that of Cumming (1984). The main reason for this lack of information is probably related to technical difficulties in the separation (for measurement purposes) of the feed refusals. In addition, there is little information on the effect of single-cereal diets in the form of whole grain plus a protein-pellet concentrate mixture with oyster-shell grit on performance of laying hens (Karunajeewa, 1978a), although such a diet appears very relevant to many developing countries, and perhaps to economic production in general.

In the present studies a set of sieves with appropriately graded apertures was developed and used in the process of separating dietary components before and after feeding. The aim of the five experiments here reported was to explore the effect of temperature on the laying performance of hens when alternative feeding systems were used. Two grains, one relatively high in protein (wheat), the other relatively low in protein (maize) were chosen in the anticipation that protein deficiency would manifest itself when a single ration based on a low protein grain was offered in conditions of high temperature. "Choice-fed" birds might be expected to overcome the problem of decreasing nutrient intake in the hot environments of the tropics by exercising preference for the most limiting nutrient.

The five experiments can thus be summarised:

* Experiment 1 = Experiment 1 at 20 °C - Free-choice of whole wheat, protein pellets and oyster-shell grit, or that of a complete diet .
* Experiment 2 = Experiment 2 at 32 °C - Free-choice of whole wheat, protein pellets and oyster-shell grit, or that of a complete diet .
* Experiment 3 = Experiment 3 at 20 °C (night) : 32 °C (day) - Free-choice of whole wheat, protein pellets and oyster-shell grit, or that of a complete diet.
* Experiment 4 = Experiment 4 at 20 °C - Free-choice of whole maize, protein meal and oyster-shell grit, or that of a complete diet.
* Experiment 5 = Experiment 5 at 32 °C - Free-choice of whole maize, protein meal and oyster-shell grit, or that of a complete diet.

This section will report the laying performance of hens fed either complete diets or by choice feeding (whole grains wheat or maize plus protein source and oyster-shell grit in a single feeder) at different environmental temperatures. The first three experiments used whole wheat whereas Experiments 4 and 5 used whole maize as a basal ingredient in order to offer birds a choice of diets in a single feeder. Maize is the dominant grain used in poultry rations in West Timor, Indonesia; wheat occupies the same position in Australia.

### 3.2.2. **Common materials and methods.**

#### 3.2.2.1. **Procedures common to Experiments 1, 2, 3, 4, and 5.**

All experiments were conducted in two separate rooms in the Animal House complex and the John Hammond Animal Climate Laboratory, University of New England. Experiments 1, 2 and 4 each lasted for 8 weeks, and 3 and 5 for 10 weeks. A 2-week period of adaptation (i.e. "acclimation"; Bligh and Johnson, 1973) was allowed between the experiments (Savory, 1986). The protocols for them, and the last two experiments (i.e. feed restriction in Experiment 6 and water restriction in Experiment 7), were approved by the University of New England Animal Care and Experimentation Ethics Committee.

All birds were kept on a constant lighting program of 16 h light and 8 h of darkness (lights on at 04.00 h and off at 20.00 h). Temperature and humidity in the rooms were controlled within narrow limits and monitored daily by thermohydrograph. The temperatures chosen for the experiments were a 'normal' or 'moderate' temperature, 20 ± 1 °C (Morris and Taylor, 1967; Savory, 1986), and 32 ± 1 °C ('warm for chickens' or 'high for layers'; Savory, 1986; Cobb, 1991). The relative humidity was 60 ± 2 % in the room at 20 °C dry bulb. This corresponds to an absolute humidity of 7 mm Hg w.v.p, and to achieve a similar absolute humidity level at 32 °C dry bulb, a wet bulb temperature of 20 °C was maintained.

#### 3.2.2.2. **Experiments 1, 2 and 3.**

The experiments each used 68 light hybrid pullets of White Leghorn x Australorp genotype (Tegel Tint, Hy-Line 300), and each consisted of two treatment groups of 34 hens each. The hens were 24 weeks old at the beginning of Experiment 1 and they were re-randomised before re-use at the beginning of Experiments 2 and 3.

The birds, which had been leg-banded and kept from 20 to 22 weeks of age in two separate rooms in an animal house, were brought into two environmentally-controlled rooms in the John Hammond Animal Climate Laboratory, University of New England, on January 29, 1993. All the birds were kept in individual wire cages measuring 45 cm wide, 30 cm long and 40 cm high. The cages were placed back to back and were fitted with individual feeders and waterers. An example of an individual feeder used in all experiments is shown in Plate 1.

Plate 1. An example of a single feeder used in all experiments.

At 22 weeks of age, the birds in each room were randomly divided into two treatment groups for Experiment 1 before being randomly allocated to individual cages within rooms. Both rooms were air-conditioned and maintained at 20 ± 1°C . In each room two replicates of 17 birds were fed *ad libitum* on either a complete diet (diet A; Table 7) or on the basis of self-selection of whole wheat and a layer protein-pellet concentrate (33.2 % CP, 11. 6 MJ ME/kg and 3.5 % Ca) in the ratio 60 : 40 (diet B; Table 8). Oyster-shell grit was provided *ad libitum* and was mixed with the other feeds.

Sorghum and maize meal were used interchangeably as protein sources (Tables 7, 8and 9), depending on availability, and assuming similar particle size.

All birds, which had been trained to choice feeding at 20 weeks of age, were allowed two weeks to adapt to the experimental diets. After this preliminary period, Experiment 1 began on February 11, 1993, and continued for 8 weeks before terminating on April 14, 1993. During the 8-week experimental period, each feeder was inspected each day to ascertain whether all ingredients in the feeder were available *ad libitum*. In Experiment 2, one of the two rooms was adjusted from 20 ± 1 °C to 32 ± 1 °C while the other one was maintained at 20 ± 1°C. The experiment commenced as soon as the 2-week acclimation period was complete (April 28, 1993) and continued for 8 weeks before concluding on June 24, 1993. All basic procedures in this experiment were the same as those described previously.

Table 7. Composition of the complete diet (diet A) used in Experiments 1, 2 and 3.

| **Ingredients** | **% composition** |
|---|---|
| Wheat (13 %) | 34.0 |
| Sorghum (8 %) | 34.0 |
| Meat meal (50 %) | 9.0 |
| Canola meal (37 %) | 4.40 |
| Cotton meal (37 %) | 3.0 |
| Soyabean meal (45 %) | 3.3 |
| Rice pollard (12.9 %) | 5.5 |
| Limestone | 6.5 |
| Salt | 0.1 |
| Choline chloride (75 %) | 0.03 |
| Methionine | 0.05 |
| Lysine | 0.02 |
| Layer premix | 0.1 |
| Total | 100 |
| Determined analysis: | |
| - Protein (% CP) | 17.0 |
| - Energy (MJ ME/kg) | 11.6 |
| - Ca (%) | 3.5* |

* plus *ad libitum* oyster shell grit

In Experiment 3, the birds were moved to two identical environmentally-controlled rooms in the New Animal House, because of the demolition of the climate laboratory used previously. The temperatures in the rooms were adjusted to equate to typical tropical conditions in the author's home region, West Timor, Indonesia. Both rooms were thus adjusted automatically to 32 ± 1 °C during the day (9 a.m. to 5 p.m.) and 20 ± 1 °C during the night (5 p.m. to 9 a.m.). The experiment started as soon as the 2-week acclimation was complete (July 15, 1993) and continued for 10 weeks before terminating on September 23, 1993. All basic procedures in Experiment 3 were the same as those described for Experiments 1 and 2.

Table 8. Composition of the three feed components (diet B) used in Experiments 1, 2 and 3.

| **Ingredients** | |
|---|---|
| (1). Whole wheat: (Leeson and Summers, 1991) | |
| - Protein (%) | 13.0 |
| - Energy (MJ ME/kg) | 13.2 |
| - Ca (%) | 0.05 |
| (2). Protein concentrate pellet: | **% composition** |
| Wheat (13 %) | 12.30 |
| Meat meal (50 %) | 29.0 |
| Canola meal (37 %) | 14.52 |
| Cotton meal (37 %) | 9.70 |
| Soyabean meal (45 %) | 9.70 |
| Rice pollard (12.9 %) | 23.50 |
| Salt | 0.50 |
| Choline chloride (75 %) | 0.10 |
| Methionine | 0.30 |
| Lysine | 0.06 |
| Layer premix | 0.32 |
| Total | 100 |
| Determined analysis | |
| - Protein (% CP) | 33.2 |
| - Energy (MJ ME/kg) | 10.5 |
| - Ca (%) | 3.4 |
| (3). Oyster-shell grit: (Leeson and Summers, 1991) | |
| - Protein (% CP) | - |
| - Energy (MJ ME/kg) | - |
| - Ca (%) | 38.0 |

- **Feedstuff separation**.

Two types of standard sieves with different sized and shaped apertures were used in the separation of the complete diet and oyster-shell grit (diet A) and components of the choice-fed diet (whole wheat, protein-pellet concentrate and oyster-shell grit; diet B) in Experiments 1, 2 and 3. They were:

1. Laboratory test sieves (B5 4 0/ 1986) with apertures of 2.00 mm (sieve 1) and 4.00 mm (sieve 2); produced by Endecotts Ltd., London.
2. A sieve (sieve 3) hand-made from a standard round-hole perforated sheet of metal, No. 213, 4.76 mm; open area 43. 5 %; produced by Lockers Wire Weavers and Perforators Pty. Ltd., Moorabbin, Victoria.

The function of each sieve was as follows.

* Sieve 1 was used to separate off dust in the wheat before the grain was offered. It was also used to separate dust from protein pellets.
* Sieve 2 was used to separate wheat from protein pellets and oyster-shell grit.
* Sieve 3 was used to separate oyster-shell grit from mash, wheat and protein pellets. It was also used to separate small pieces of oyster-shell grit from the sample before the grit was offered to the birds.
* Sieve 4 was used to separate whole maize and oyster-shell grit in Experiments 4 and 5 (Plate 2).


Plate 2. All sieves used in Experiments 1 - 5.

- **Measurements.**

The following performance data were collected from all hens in each experiment:

(1). Body weight was recorded to the nearest 1 g at the commencement of each experiment and at 2-week intervals thereafter.

(2). Individual daily intakes of the complete diet, and of each of whole wheat, protein pellets and oyster-shell grit offered by choice feeding were calculated as the simple means of individual intakes totalled over successive 14-d periods.

(3). Water intake was measured daily, to nearest 10 ml, every 2nd week (i.e., d 15-21; 29-35 etc.) by subtracting individual refusals measured at 8.30 h from the amounts offered *ad libitum*.

(4). Eggs were collected daily. Egg production in each group was calculated on a weekly basis as a hen-day egg production (the total number of eggs in a week multiplied by 100 divided by the number of birds in each treatment) as described by Sainsbury (1984) and North and Bell (1990).

(5). Average egg weight was determined each week by weighing all eggs collected on four consecutive days. The procedure was a modification of that adopted by Karunajeewa (1978a) and Karunajeewa and Tham (1984) who determined average egg weight each fortnight by weighing all eggs collected on four consecutive days.

(6). Data concerning weekly FCR were determined as g of feed intake/g of egg weight (Hurwitz and Plavnik, 1989; Feltwell, 1992; Hunton, 1992; Katle, 1992).

(7). Water : feed intake ratios were expressed as ml of water drunk/g of feed

consumed (Medway and Kare, 1959).

(8). Specific gravity of eggs was determined on one egg/bird each week by using the suspension weighing technique described by Pym (1969).

- **Statistical analysis.**

All performance data were statistically analysed by using analysis of variance for a complete factorial experiment according to the procedure described by Burr (1982); regression analyses were run using the Minitab system (Ryan *et al.*, 1985).

3.2.2.3. **Experiments 4 and 5.**

These two experiments were conducted each using 76 light hybrid pullets of White Leghorn x Australorp genotype (Tegel Tint, Hy-Line 300). Both experiments consisted of two treatment groups of 38 hens each. The hens were 24 weeks old at the beginning of Experiment 4. The birds had been weighed, leg-banded and trained to choice feeding from 12 weeks (December 17, 1993) to 22 weeks of age (February 28, 1994) in two rooms in the John Hammond Animal Climate Laboratory, University of New England. On February 28, 1994, the birds were re-weighed and randomised on the basis of body weight to one of two feeding regimes and to one of the two available rooms.

Both rooms were air-conditioned at 20 ± 1 °C and in each room two replicates of 19 birds were fed *ad libitum* on either diet A (Table 9) or diet B (Table 10), which provided for self-selection from a single feeder from a mixture of 67.7 % whole maize. 24.004 % of the protein meal used in diet A (but without any limestone), and 8.3 % oyster-shell grit (the same proportions as in diet A). The protein meal was mixed by machine whereas maize meal was machine-ground.

The ME values of the diets were calculated using published values for the basic nutrient composition of normal commercial poultry feedstuffs (Leeson and Summers, 1991). Birds fed the choice-fed diet (diet B) were provided with granite grit *ad libitum* in an additional feeder fitted at the front of each in order to maintain normal function of the gizzard (Balloun and Phillips, 1956; Karunajeewa and Tham, 1984; Tauson and Elwinger, 1986; Mercia, 1990; Feltwell, 1992).

Table 9. Composition of the complete diet (diet A) used in Experiments 4 and 5.

| **Ingredients** | **% composition** |
|---|---|
| Maize meal | 67.7 |
| Soyabean meal (45 %) | 11.2 |
| Sunflower meal (38 %) | 10.1 |
| Dicalcium phosphate | 1.9 |
| Limestone | 8.3 |
| DL-Methionine | 0.1 |
| Lysine HCL | 0.2 |
| Salt | 0.3 |
| Layer vitamin mix | 0.1 |
| Layer mineral mix | 0.1 |
| Tryptophane | 0.004 |
| Total | 100.004 |
| Calculated analysis: | |
| - Protein (% CP) | 16.5 |
| - Energy (MJ ME/kg) | 11.4 |
| - Ca (%) | 3.5 |

Table 10. Composition of the three feed components (diet B) used in Experiments 4 and 5.

| **Ingredients** | |
|---|---|
| (1). Whole maize: (Leeson and Summers, 1991) | |
| - Protein (% CP) | 8.6 |
| - Energy (MJ ME/kg) | 13.9 |
| - Ca (%) | 0.01 |
| (2). Protein meal: | **% composition** |
| Soyabean meal (45 % CP) | 11.2 |
| Sunflower meal (38 % CP) | 10.1 |
| Dicalc. phosphate | 1.9 |
| DL-Methionine | 0.1 |
| Lysine HCL. | 0.2 |
| Salt | 0.3 |
| Layer vitamin | 0.1 |
| Layer mineral | 0.1 |
| Tryptophane | 0.004 |
| Calculated analysis: | |
| - Protein (% CP) | 16.5 |
| - Energy (MJ ME/kg) | 11.4 |
| - Ca (%) | 3.5 |
| (3). Oyster-shell grit: (Leeson and Summers, 1991) | |
| - Protein (% CP) | - |
| - Energy (MJ ME/kg) | - |
| - Ca (%) | 38.0 |

The cages were fitted with the same individual feeders as used previously in Experiments 1, 2 and 3. Every six cages had a communal water trough at the back. Each feeder was regularly inspected each day to ascertain whether all feeds were available *ad libitum*. Free access to water was allowed to the birds throughout the experiments. After two weeks acclimation, Experiment 4 began on March 8, 1994 and continued for 8 weeks before terminating on May 13, 1994.

In Experiment 5, one of the two rooms was adjusted to 32 ± 1 °C. The same birds used in Experiment 4 were re-weighed and re-randomised on the basis of body weight and also randomly re-allocated to one of the two rooms and one of the two feeding regimes. Experiment 5 started as soon as a 2-week acclimation period was complete, i.e. on May 27, 1994, and continued for 10 weeks before concluding on August 5, 1994. All basic procedures in Experiments 4 and 5 were the same as described previously for Experiments 1, 2 and 3.

- **Feedstuff separation**.

The same sieves as shown in Plate 2 were used in Experiments 4 and 5, except that an additional sieve (4) was used for the separation of whole maize and oyster-shell grit. It had diamond-shaped apertures which measured 13.9 mm in length and 4.4 mm in width.

- **Measurements**.

The following performance data were collected.

(1). Body weight was recorded to the nearest 1 g at the commencement of each of Experiments 4 and 5 and at weekly intervals throughout.

(2). The individual intakes of a maize meal mixture, whole maize, protein meal and oyster-shell grit were measured separately for each week during the experimental period.

(3). Eggs were collected daily. Egg production in each group was calculated on a weekly basis as a hen-day egg production (the total number of eggs in a week multiplied by 100 divided by the number of birds in each treatment as described by Sainsbury (1984) and North and Bell (1990).

(4). Average egg weight was determined each week by weighing all eggs collected daily.

(5). Data concerning weekly FCR were determined as g of feed intake/g of egg weight (Hurwitz and Plavnik, 1989; Feltwell, 1992; Hunton, 1992; Katle, 1992).

(6). Specific gravity of eggs was determined on one egg/bird each week by using the suspension weighing technique described by Pym (1969).

(7). Yolk colour was determined on one egg/bird each week by using the 'Roche Yolk Colour Fan' described by Vuilleumier (1969).

(8). Albumen quality was determined on one egg/bird each week by following the method of Haugh (1937).

(9). Shell thickness was determined on one egg/bird each week by using a a Mitutoyo Model 2109-10 gauge mounted on a frame as used by Roberts and Balnave (1992).

- **Statistical analysis**.

All performance data collected were statistically analysed using analysis of variance for a complete factorial experiment according to the procedure described by Burr (1982); regression analyses were run using the Minitab system (Ryan *et al.*, 1985).

### 3.2.3. Experiment 1 at 20 °C - Free-choice of whole wheat, protein pellets and oyster-shell grit, or that of a complete diet (mash).

#### 3.2.3.1. Introduction.

Complete diets are predominant today because of the prevalent cage-housing system and automation of the feeding system (Blair *et al.*, 1973; Karunajeewa, 1978b; Summers and Leeson, 1979; Kiiskinen, 1987). The last author further suggests that diets are most commonly formulated to meet the requirement of the average bird and ignore individual variations in dietary requirements.

In contrast, if the individual bird has any ability to select the feed it needs for maintenance and production, a feeding system that permits some choice may result in a more efficient use of feedstuffs than a single compounded diet (Robinson, 1985). Undoubtedly, individual hens have an innate ability to self-select from the various feed ingredients on offer and compose their own diet, hopefully according to their actual needs and production capacity (Emmans, 1975, 1977 and 1982; Karunajeewa, 1978a; Hughes, 1984; Leeson and Summers, 1991; Rose and Kyriazakis, 1991).

Published evidence concerning the hen's ability to regulate her own major nutrient intake is available for energy (Hill *et al.*, 1956), protein (Graham, 1934; Holcombe *et al.*, 1976) and Ca (Hughes, 1972; Mongin and Sauveur, 1974; Holcombe *et al.*, 1975). Thus, laying hens have effective feed-selection mechanisms and it has been argued (Emmans, 1975) that this ability to choose an appropriate diet can be exploited to increase dietary efficiency under commercial conditions.

The beneficial effects of allowing laying birds some self-selection are that it not only saves the energy costs of grinding, mixing and other feed-handling procedures, but also hopefully prevents over-consumption of energy and other nutrients (Karunajeewa, 1978a; Kiiskinen, 1987; Tauson *et al.*, 1991).

Indeed, hens offered a choice of diets have been shown to eat less feed overall than those fed or a complete diet while maintaining adequate performance (Blair *et al.*, 1973, Karunajeewa, 1978a; Leeson and Summers, 1978, 1979). However, very few investigations have considered the practical application of choice feeding to laying poultry in the single troughs which are currently used by the intensive industry (see Emmans, 1979; Cumming *et al.*, 1987; de Guzman, 1992; Hochstetler, 1992 for reviews).

The effect of offering whole wheat plus a protein-pellet concentrate mixture with oyster-shell grit on a free-choice basis in a single feeder on the laying performance of hens kept at a constant ambient temperature has not been reported and will be studied here Another aim of this study was to compare the laying performance of hens given a choice between whole wheat, protein pellets and oyster-shell grit with that of those fed a complete diet. All birds had been trained to choice feeding at 20 weeks of age. At 22 weeks of age, they were randomised to treatments and cages. Then, they were re-trained to their new feeding regime for 2 weeks before Experiment 1 started when the birds were 24 weeks old.

3.2.3.2. **Experimental hypothesis and design**.

The hypothesis developed was that the mean nutrient intake and egg-laying performance of birds given a choice of nutrient sources *ad libitum* in a single feeder at 20 °C would not differ from that of the birds offered an all-mash diet. In order to test this hypothesis, a randomised block design with choice feeding and complete diet as the main factors. Birds were blocked within treatment and individual hens were treated as replicates.

3.2.3.3.

**Results**.

The treatment means and results of the statistical analyses for the duration of Experiment 1 are summarised in Table 11. Over the 8-week laying period, birds offered choice feeding *ad libitum* in a single feeder consumed significantly ($P < 0.05$) less feed in total than did those on the complete diet. This intake differential was associated with highly significant ($P < 0.01$) reductions in the intakes of grain, mash and Ca. The mean egg-shell quality of the choice-fed hens as assessed by using the suspension weighing technique was highly significantly ($P < 0.01$) less strong than that of the hens fed on the complete diet (Table 13).

Table 11. Effects of feeding treatments on the nutrient intake and laying performance of hens from 24 to 32 weeks of age in Experiment 1.

| Parameter | Choice feeding | Complete diet | SEM | Level of significance |
|---|---|---|---|---|
| Grain intake (g/bird/d): | 68.7[1)] | 83.2[2)] | 0.3 | ** |
| Protein-pellets intake (g/bird/d): | 41.3 | 39.1[3)] | 0.2 | |
| Oyster-shell-grit intake (g/bird/d): | 4.6 | 4.2 | 0.1 | |
| Mash intake (g/bird/d): | 110.0[4)] | 122.3 | 0.5 | ** |
| Total feed intake (g/bird/d): | 114.6 | 126.5 | 0.9 | * |
| ME intake (kJ/bird/d): | 1368 | 1413 | 6.9 | |
| Protein intake (g/bird/d): | 22.6 | 20.8 | 0.1 | |
| Ca intake (g/bird/d): | 3.1 | 5.8 | 0.1 | ** |
| Water intake (ml/bird/d): | 233.7 | 236.9 | 2.3 | |
| Egg production (%): | 91.6 | 91.4 | 0.2 | |
| Egg weight (g): | 57.0 | 56.8 | 0.03 | |
| Egg specific gravity (g/ml): | 1.083 | 1.084 | 0.0004 | ** |
| FCR (g feed intake/g egg weight): | 2.0 | 2.2 | 0.01 | ** |
| Water : feed intake ratios (ml water drunk/g feed intake): | 2.0 | 1.9 | 0.01 | |
| Body weight (g): | 1839 | 1786 | 1.6 | ** |

1) whole wheat; 2) calculated value of 34 % wheat + 34 % sorghum in the mash portion of the diet; 3) estimate based on protein sources in the complete diet; 4) whole wheat + protein pellets *, $P < 0.05$; **, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$).

In the same period, birds on choice-feeding treatment utilised feed more efficiently ($P < 0.01$) and gained more weight ($P < 0.01$) than those fed the complete diet (Table 11). However, protein-pellet intake, oyster-shell-grit intake, ME intake, protein intake, water intake, egg production, egg weight and water : feed intake ratios were not significantly ($P > 0.05$) affected by the feeding treatments.

3.2.3.4. **Discussion**.

Results obtained over the 8-week laying period in Experiment 1 agree well with previous results (Blair *et al.*, 1973; Karunajeewa, 1978a; Leeson and Summers, 1978, 1979) in that birds which were choice-fed consumed significantly less feed in total than did conventionally fed birds while maintaining adequate performance. The results indicate that birds offered choice feeding *ad libitum* consumed 10.4 % less feed in total than did control birds offered the complete diet. This figure is higher than the values (6.7, 6.7 and 7.0 %) reported by Blair *et al.* (1973) and Leeson and Summers (1978, 1979) and is in closer agreement with those of Karunajeewa (1978a), in which hens receiving choice feeding consumed 11.0 % less feed overall.

The largest reduction in daily total feed intake occurred in weeks 3 - 4 (Table 12) when the choice-fed birds consumed 15 % less feed in total than those given the complete diet. This saving in feed intake associated with the choice-feeding system in Experiment 1 has an estimated economic value similar to that recommended by Snetsinger and Zimmerman (1974) for a conventional restricted feeding program.

Table 12. Mean ± SEM daily intakes of feed components, intake of water, FCR, water:feed intake ratios and body weight of hens as affected by feeding treatments during the successive fortnightly periods in Experiment 1.

| Parameter | Weeks 1 - 2 | Weeks 3 - 4 | Weeks 5 - 6 | Weeks 7 - 8 |
|---|---|---|---|---|
| Grain intake (g/bird/d): | | | | |
| - Choice feeding[1] | 69.0 ± 2.3* | 66.4 ± 2.0** | 69.5 ± 1.8* | 69.9 ± 0.8* |
| - Complete diet[2] | 82.9 ± 2.0* | 85.2 ± 1.5** | 83.4 ± 1.4* | 81.2 ± 2.9* |
| Protein-pellets intake (g/bird/d): | | | | |
| - Choice feeding | 39.5 ± 1.7 | 42.5 ± 2.2 | 40.4 ± 2.0 | 42.7 ± 2.9 |
| - Complete diet[3] | 39.0 ± 1.0 | 40.1 ± 0.7 | 39.3 ± 0.7 | 38.2 ± 2.5 |
| Oyster-shell-grit intake (g/bird/d): | | | | |
| - Choice feeding | 4.8 ± 0.4 | 4.6 ± 0.4 | 4.5 ± 0.4 | 4.6 ± 0.4 |
| - Complete diet | 4.4 ± 0.3 | 4.9 ± 0.3 | 4.8 ± 0.3 | 2.5 ± 1.0 |
| Mash intake (g/bird/d): | | | | |
| - Choice feeding[4] | 108.5 ± 0.2* | 108.9 ± 3.0* | 109.9 ± 1.6 | 112.6 ± 4.9 |
| - Complete diet | 121.9 ± 3.0* | 125.3 ± 5.5* | 122.7 ± 2.8 | 119.4 ± 7.3 |
| Total feed intake (g/bird/d): | | | | |
| - Choice feeding | 113.3 ± 0.1 | 113.5 ± 1.2* | 114.5 ± 0.4 | 117.3 ± 0.9 |
| - Complete diet | 126.3 ± 1.3 | 130.2 ± 0.9* | 127.2 ± 0.6 | 121.9 ± 1.6 |
| ME intake (kJ/bird/d): | | | | |
| - Choice feeding | 1316 ± 11.4 | 1362 ± 10.1 | 1384 ± 9.0 | 1414 ± 8.1 |
| - Complete diet | 1415 ± 12.6 | 1430 ± 10.1 | 1423 ± 8.8 | 1385 ± 12.3 |
| Protein intake (g/bird/d): | | | | |
| - Choice feeding | 22.0 ± 0.3 | 22.7 ± 1.2 | 22.4 ± 1.1 | 23.2 ± 1.2* |
| - Complete diet | 20.7 ± 0.5 | 21.3 ± 1.1 | 20.8 ± 1.1 | 20.3 ± 1.3* |
| Ca intake (g/bird/d): | | | | |
| - Choice feeding | 2.7 ± 0.1* | 3.2 ± 0.1* | 3.1 ± 0.2* | 3.2 ± 0.2 |
| - Complete diet | 5.9 ± 0.2* | 6.3 ± 0.2* | 6.1 ± 0.2* | 5.0 ± 0.2 |
| Water intake (ml/bird/d): | | | | |
| - Choice feeding | 237.5 ± 1.8 | 237.5 ± 2.1 | 227.5 ± 2.2 | 232.5 ± 2.0 |
| - Complete diet | 250.0 ± 2.6 | 250.0 ± 2.1 | 240.0 ± 2.1 | 207.5 ± 2.8 |
| FCR (g feed intake/g egg weight): | | | | |
| - Choice feeding | 2.0 ± 0.02 | 2.0 ± 0.02 | 2.0 ± 0.02 | 1.9 ± 0.02 |
| - Complete diet | 2.2 ± 0.02 | 2.3 ± 0.02 | 2.2 ± 0.02 | 2.0 ± 0.02 |
| Water : feed intake ratios (ml water drunk/g feed intake): | | | | |
| - Choice feeding | 2.1 ± 0.02 | 2.1 ± 0.02 | 1.9 ± 0.02 | 2.0 ± 0.02 |
| - Complete diet | 2.0 ± 0.02 | 2.1 ± 0.02 | 1.8 ± 0.03 | 1.7 ± 0.03 |
| Body weight (g): | | | | |
| - Choice feeding | 1790 ± 0.5* | 1830 ± 6.0* | 1854 ±3.7* | 1881 ± 7.1 |
| - Complete diet | 1729 ± 3.3* | 1764 ± 6.4* | 1804 ±5.1* | 1845 ± 11.0 |

1) whole wheat; 2) calculated value of 34 % wheat + 34 % sorghum in the mash portion of the diet; 3) estimate based on protein sources in the complete diet; 4) whole wheat + protein pellets; *, $P < 0.05$; **, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$).

When the feed cost of choice feeding was calculated according to the average monthly feed prices prevailing in Australia throughout 1995, it cost 1.86 ¢/hen/d. The price of the complete diet was 3.16 ¢/hen/d. The fact that there was a big saving in feed cost is a considerable advantage for the self-selection program, and the cost estimate quoted does not take into account savings on transportation, handling, grinding and mixing that would not be required in a choice-feeding system.

Table 13. Mean ± SEM weekly egg production, daily egg weight and weekly egg specific gravity of hens as affected by feeding treatments during the successive weeks in Experiment 1.

| Week | Egg production (%) | | Egg weight (g) | | Egg specific gravity (g/ml) | |
|---|---|---|---|---|---|---|
| | Choice feeding | Complete diet | Choice feeding | Complete diet | Choice feeding | Complete diet |
| 1 | 94.1 ± 0.6 | 92.0 ± 0.4 | 54.9 ± 0.02 | 54.1 ± 0.2 | 1.085 ± 0.002 | 1.086 ± 0.002 |
| 2 | 89.1 ± 0.5 | 91.6 ± 0.5 | 55.2 ± 0.2 | 55.8 ± 0.2 | 1.085 ± 0.002 | 1.084 ± 0.003 |
| 3 | 85.6 ± 0.7 | 93.4 ± 0.7 | 55.3 ± 0.2 | 56.7 ± 0.2 | 1.085 ± 0.003 | 1.085 ± 0.002 |
| 4 | 95.8 ± 0.7 | 90.3 ± 0.8 | 55.6 ± 0.2 | 56.3 ± 0.2 | 1.082 ± .003* | 1.084 ± 0.003* |
| 5 | 92.4 ± 0.7 | 93.2 ± 0.7 | 57.7 ± 0.2 | 57.3 ± 0.2 | 1.083 ± 0.003 | 1.084 ± 0.003 |
| 6 | 91.6 ± 0.7 | 88.6 ± 0.7 | 57.0 ± 0.2 | 57.0 ± 0.2 | 1.081 ± 0.003 | 1.082 ± 0.003 |
| 7 | 91.6 ± 0.6 | 92.0 ± 0.7 | 58.5 ± 0.3 | 57.9 ± 0.3 | 1.081 ± 0.003 | 1.083 ± 0.003 |
| 8 | 92.4 ± 0.6 | 89.9 ± 0.6 | 59.0 ± 0.3 | 58.8 ± 0.3 | 1.080 ±.004** | 1.083 ±.004** |

*, $P < 0.05$; ** $P < 0.01$; no asterisk, non-significant result ($P > 0.05$). For method of calculation of each parameter, see page 53.

It is interesting to note that although hens on choice feeding consumed some 10.4 % less feed in total than those fed the complete diet, they produced eggs at a similar rate of lay and of a similar size of egg (Tables 11 and 13). This is probably due to their similar ME intakes (the ME content of the complete diet was less than that of the choice-fed diet), since Summers and Leeson (1989) indicated that there is a good correlation between ME intake and egg production and egg weight, and indeed it was one of the main factors influencing egg numbers and egg weight in laying hens.

Since there was a significant (P < 0.05) reduction in total feed intake of hens on the choice feeding, a highly significant overall improvement (P < 0.01) was observed for the conversion of feed to eggs as compared to the complete diet. The results of Experiment 1 agree well with most previous reports in so far as the choice-fed birds were marginally more efficient in converting their diet than those fed the complete diet (e.g., Blair *et al.*, 1973; Karunajeewa, 1978a; Cumming, 1984).

Although the mean water : feed intake ratios of hens in the present study were not significantly affected by the feeding treatments, birds on choice feeding tended to have higher values of the water : feed intake ratio than those fed on the complete diet. It has been suggested that hens with a high water : feed intake ratio have an improved feed utilisation (Van Kampen, 1983). Thus, the results from the present experiment strongly suggest that dietary self-selection appears to offer an advantage for laying hens in terms of consuming less feed, and greater efficiency in feed conversion.

It has been shown by Heywang (1941) and Jull (1949) that normally the water intake of laying hens is closely related to their egg production when the birds are fed on an all-mash diet. The results of Experiment 1 support this finding, since the feeding treatments had no significant effects on egg production, egg weight or water intake.

Sugandi *et al.* (1975) and Gleaves *et al.* (1977) found that laying hens which consumed significantly more protein tended to have a significantly higher egg production. The current results were unable to confirm these observations since no significant (P > 0.05) differences were observed in either protein intake or egg production (Tables 11 and 13).

It is of interest that although the daily intakes of ME and protein were similar for both groups, the choice-fed birds (Tables 11 and 12) gained more body weight and were heavier than those fed the complete diet. This was probably due to the type of cereal used in Experiment 1. These results do agree with those of Karunajeewa (1978a), who used a similar type of cereal for laying hens. In his study, the choice-fed hens given whole wheat were able to gain more body weight than those given ground wheat in mash diets, even though their ME and protein intakes were similar and total feed intake was reduced. A similar increase in body weight from birds on choice feeding was also reported by Karunajeewa and Tham (1984), who found that laying hens offered whole wheat gained more weight than those offered crushed wheat.

The mean daily intakes of Ca in Experiment 1 were 3.1 and 5.8 g/bird for the choice-fed and control birds, respectively. This finding is consistent with the results of Leeson and Summers (1978, 1983), who noted that hens on choice feeding consumed significantly less Ca than controls, and with observations that birds on complete diets tend to overconsume protein in order to obtain Ca.

In general, the Ca intakes in Tables 11 and 12 show that under the conditions of this experiment the choice-fed hens consumed a diet which was slightly deficient in Ca and that the control birds consumed a slight excess of Ca as compared to the daily recommended intake value of 3.8 g/hen for laying hens housed in a moderate climate (16 - 24 °C) and fed a complete diet (SCA, 1987; Woolford, 1990; NRC, 1994).

However, the observed Ca intakes were still in the range of the daily values (3.0 - 3.8 g/hen) recommended by the ARC (1975) in the U.K., were in excess of the daily calculated values of 2.7 to 2.8 g/hen reported in America by Scott *et al.* (1971) and de Andrade *et al.* (1976, 1977), and were similar to the value of 3.13 g/hen/d reported by Reid and Weber (1973) to be adequate for hens housed at a constant temperature of 21 °C and fed a complete diet.

Petersen (1965), Wolford and Tanaka (1970) and Washburn (1982) are among those who have concluded that a low dietary-Ca intake in laying hens leads to a reduction in the thickness of egg shells, and Horn (1988) considers that a specific gravity of eggs of 1.080 g/ml represents the boundary between those with good (> 1.080 g/ml) and poor (< 1.080 g/ml) shells.

In the current work the specific gravity (and hence egg-shell quality) of eggs declined significantly with time during the experiment (Table 13) in both groups, but the rate of decline was greater in the choice-fed group. By the 8th week the specific gravity of the eggs from choice-fed birds had declined to 1.080 g/ml, a level which Horn (1988) has indicated to be the lower level for "good" egg-shell quality. The current experiment was of 8 weeks' duration, so in the longer term of production under commercial conditions it can be concluded that the egg-shell quality of choice-fed birds would have declined still further and may have become of commercial significance.

The decline in egg specific gravity in choice-fed hens was associated with a mean Ca intake of only 3.1 g/hen/d (despite their being fed *ad libitum* oyster shell grit), compared to the 3.8 g/hen/d recommended by SCA (1987), Woolford (1990) and NRC (1994). Leeson and Summers (1978, 1983) also reported sub-optimal Ca intakes in choice-fed birds. Together, these results indicate the need for further studies of Ca intake in choice-fed birds, and in particular of means of increasing that intake, and of Ca availability from different sources.

It is concluded that laying hens offered a choice-feeding diet *ad libitum* in the one trough will consume about 10 % less feed and show a greater efficiency in feed conversion, while producing a comparable number of eggs to those fed a complete diet. Egg-shell quality, however, appears to be inferior to that on a complete diet, and the fact that choice-fed hens consumed less Ca than controls in Experiment 1 suggests that the intake of Ca by hens choice-fed in a single trough requires further investigation.

### 3.2.4. Experiment 2 at 32 °C - Free-choice of whole wheat, protein pellets and oyster-shell grit, or that of a complete diet (mash).

#### 3.2.4.1. Introduction.

It is well recognised that the feed intake of laying birds fed complete diets *ad libitum* declines exponentially as environmental temperature is increased. As a consequence, a reduction occurs in the number of eggs produced, and egg weight and egg-shell strength are also reduced. The main cause of these reductions in egg characteristics has been identified as the reduction in energy intake at high ambient temperature (Payne, 1966a, 1967; Smith and Oliver, 1971; Smith, 1972, 1973 and 1990; Emmans, 1974; Sykes, 1977; Marsden and Morris, 1981; Vohra, 1982; Austic, 1985; Emmans and Charles, 1989).

Many attempts have been made to overcome this problem, by such means as increasing the dietary energy concentration (Payne, 1967; Marsden *et al.*, 1973; de Andrade *et al.*, 1977), increasing the protein content of the diet (Bray and Gessell, 1961; Smith and Oliver, 1972), changing the light intensity (Wilson *et al.*, 1972b; Zimmerman *et al.*, 1973) and cycling the temperatures (Marsden and Morris, 1975; Vohra *et al.*, 1979). All previous reports dealt with conventional, complete diets, and from their reviews of them, Marsden and Morris (1981) and Van Kampen (1981b) concluded that the deleterious effect of high temperature on laying hens can indeed be overcome, at least in part, by dietary manipulation.

Despite this, choice feeding offers an interesting alternative to complete diets because laying hens fed in this way have the opportunity to balance their own nutrient intakes appropriately to their environments (Mastika, 1987; Forbes and Shariatmadari, 1994). Choice feeding is thus probably a valuable tool to help in solving the problem of the decreasing nutrient intake of laying hens in hot environments (Charles, 1978; Mastika and Cumming, 1985; Cumming and Hill, 1993).

The rationale behind the choice-feeding system is that it uses the hens' innate ability to meet its nutrient requirements for growth, maintenance and production (Summers and Leeson, 1979; Wilson and Emmans, 1979; Appleby *et al.*, 1992). The present experiment was thus carried out to study the effects of exposure to 32 °C on the ability of hens to meet their nutrient requirements by self-selecting from three feed components in a single feeder. The same comparisons will be made as in Experiment 1, between both feeding regimes and aspects of feed intake and laying performance. The birds were re-randomised to treatments and cages on the day Experiment 1 concluded. They were trained to their new feeding regime for 2 weeks before Experiment 2 commenced when the birds were 34 weeks old.

3.2.4.2. **Experimental hypothesis and design.**

The hypothesis was that at 32 °C the hens' energy intake would decline, relative to that observed at 20 °C in Experiment 1, but that in those birds which were choice-fed the intake of protein concentrate and Ca would be maintained, and that as a consequence there would be little change (relative to 20 °C) in egg production. The experimental design was as described for Experiment 1. Unfortunately, a lack of climate-chamber accommodation meant that the 20 °C (Experiment 1) and 32 °C (Experiment 2) treatments could not be run concurrently. They were, however, run consecutively (with only a 2-week gap between), and in combining the two the results of the control group (mash diet) were used as a linkage.

3.2.4.3. **Results**.

The treatment means and results of the statistical analyses for the duration of Experiment 2 are summarised in Table 14. Over the 8-week laying period, hens on the choice-feeding regime based on a single feeder had similar mash or whole wheat plus protein-pellet intakes, and total feed intakes, to the hens fed the complete diet, but their grain and Ca intakes were significantly (P < 0.01) reduced. Egg weight, egg specific gravity and FCR of the hens were similar in both feeding treatments.

Table 14. Effects of feeding treatments on the nutrient intake and laying performance of hens from 34 to 42 weeks of age in Experiment 2.

| Parameter | Choice feeding | Complete diet | SEM | Level of significance |
|---|---|---|---|---|
| Grain intake (g/bird/d): | 64.0 1) | 72.7 2) | 0.3 | ** |
| Protein-pellets intake (g/bird/d): | 42.4 | 34.2 3) | 0.3 | ** |
| Oyster-shell-grit intake (g/bird/d): | 4.3 | 3.0 | 0.05 | ** |
| Mash intake (g/bird/d): | 106.4 4) | 106.9 | 0.4 | |
| Total feed intake (g/bird/d): | 110.7 | 109.9 | 0.3 | |
| ME intake (kJ/bird/d): | 1329 | 1239 | 2.3 | * |
| Protein intake (g/bird/d): | 22.4 | 18.2 | 0.01 | ** |
| Ca intake (g/bird/d): | 3.1 | 4.9 | 0.01 | ** |
| Water intake (ml/bird/d): | 308.7 | 251.9 | 0.2 | ** |
| Egg production (%): | 88.1 | 85.7 | 0.03 | * |
| Egg weight (g): | 59.1 | 59.4 | 0.008 | |
| Egg specific gravity (g/ml): | 1.077 | 1.079 | 0.0004 | |
| FCR (g feed intake/g egg weight): | 1.8 | 1.8 | 0.02 | |
| Water : feed intake ratios (ml water drunk/g feed intake): | 2.9 | 2.3 | 0.1 | * |
| Body weight (g): | 1969 | 1912 | 0.7 | ** |

1) whole wheat; 2) calculated value of 34 % wheat + 34 % sorghum in the mash portion of the diet; 3) estimate based on protein sources in the complete diet; 4) whole wheat + protein pellets; *, P < 0.05; **, P < 0.01; no asterisk, non-significant result (P > 0.05).

In the same period, choice-fed birds consumed more (P < 0.05) ME through high consumption of protein pellets (P < 0.01), and as a result the mean protein intake and body weight were significantly higher (P < 0.01) than for hens on the complete diet. Hens offered choice feeding also ate more (P < 0.01) oyster-shell grit, drank more (P < 0.01) water, produced a greater ($P < 0.05$) number of eggs and experienced a higher ($P < 0.05$) water : feed intake ratio than those offered the complete diet.

3.2.4.4. **Discussion**.

As reported earlier, the feed intake of laying birds fed complete diets *ad libitum* declines exponentially as environmental temperature is increased (Payne, 1966a, 1967; Smith and Oliver, 1971; Smith, 1972, 1973 and 1990; Emmans, 1974; Sykes, 1977; Marsden and Morris, 1981; Vohra, 1982; Austic, 1985; Emmans and Charles, 1989).

In contrast, it was interesting to note that hens offered choice feeding *ad libitum* in single feeder at 32 °C in the present study did not appear to experience a marked drop in feed intake as compared to that of hens offered the complete diet (Tables 14 and 15). Results obtained over the 8-week laying period in Experiment 2 agree well with the previous short-term study of Blake *et al.* (1984) in that the feed intake and egg weight of the choice-fed hens were similar to those of hens fed a complete diet at high temperatures.

The significantly higher mean daily oyster-shell-grit intake of the choice-fed hens (Tables 14 and 15) was probably due to the need for the nutrient in the grinding of the whole wheat as well as to meet Ca requirements for egg-shell formation. This conclusion is supported by the findings of Scott *et al.* (1971), Karunajeewa and Tham (1984), Tauson and Elwinger (1986) and Taylor *et al.* (1995). It is also possible that the capacity of the gizzards of these hens was not sufficient to enable them to consume enough oyster shell grit to meet their requirement for Ca.

Table 15. Mean ± SEM daily intakes of feed components, intake of water, FCR, water : feed intake ratios and body weight of hens as affected by feeding treatments during the successive fortnightly periods in Experiment 2.

| Parameter | Weeks 1 - 2 | Weeks 3 - 4 | Weeks 5 - 6 | Weeks 7 - 8 |
|---|---|---|---|---|
| Grain intake (g/bird/d): | | | | |
| - Choice feeding[1)] | 55.7 ± 3.0* | 69.3 ± 0.1* | 62.3 ± 12.6 | 58.7 ± 14.0* |
| - Complete diet[2)] | 76.8 ± 3.7* | 76.9 ± 3.9* | 68.5 ± 6.2 | 68.4 ± 7.0* |
| Protein-pellets intake (g/bird/d): | | | | |
| - Choice feeding | 43.5 ± 5.4* | 47.4 ± 14.0* | 40.2 ± 7.0* | 38.2 ± 6.1 |
| - Complete diet[3)] | 36.1 ± 4.8* | 36.2 ± 6.0* | 32.2 ± 6.2* | 32.2 ± 6.3 |
| Oyster-shell-grit intake (g/bird/d): | | | | |
| - Choice feeding | 4.6 ± 1.0 | 4.3 ± 0.7* | 4.3 ± 0.9* | 4.0 ± 0.9 |
| - Complete diet | 3.5 ± 0.8 | 2.7 ± 0.9* | 2.7 ± 0.9* | 3.3 ± 0.8 |
| Mash intake (g/bird/d): | | | | |
| - Choice feeding[4)] | 112.1 ± 6.5 | 113.8 ± 12.0 | 102.5 ±21.1* | 97.0 ± 14.3* |
| - Complete diet | 112.9 ± 4.2 | 113.1 ± 10.1 | 100.7 ±14.2* | 100.6 ± 12.7* |
| Total feed intake (g/bird/d): | | | | |
| - Choice feeding | 116.7 ± 1.3 | 118.1 ± 1.4 | 106.8 ± 1.6 | 101.0 ± 1.7 |
| - Complete diet | 116.4 ± 0.8 | 115.8 ± 0.5 | 103.4 ± 1.6 | 103.9 ± 1.6 |
| ME intake (kJ/bird/d): | | | | |
| - Choice feeding | 1364 ± 10.1 | 1456 ± 18.9 | 1282 ± 20.3 | 1212 ± 21.2 |
| - Complete diet | 1310 ± 10.8 | 1312 ± 6.5 | 1169 ± 20.2 | 1167 ± 20.9 |
| Protein intake (g/bird/d): | | | | |
| - Choice feeding | 23.0 ± 1.4* | 24.7 ± 5.3* | 21.4 ± 4.5* | 20.3 ± 2.3* |
| - Complete diet | 19.2 ± 0.6* | 19.2 ± 0.6* | 17.1 ± 1.6* | 17.1 ± 1.9* |
| Ca intake (g/bird/d): | | | | |
| - Choice feeding | 3.2 ± 0.2** | 3.2 ± 0.2** | 3.0 ± 0.2** | 2.9 ± 0.2** |
| - Complete diet | 5.2 ± 0.2** | 4.9 ± 0.2** | 4.5 ± 0.2** | 4.7 ± 0.2** |
| Water intake (ml/bird/d): | | | | |
| - Choice feeding | 305.0±17.0** | 282.5±15.2** | 320.0 ±19.4** | 327.5±22.4** |
| - Complete diet | 250.0±14.5** | 232.5±12.9** | 260.0 ±16.0** | 265.0±18.2** |
| FCR (g feed intake/g egg weight): | | | | |
| - Choice feeding | 1.9 ± 0.02 | 1.9 ± 0.02 | 1.7 ± 0.03 | 1.7 ± 0.03 |
| - Complete diet | 1.9 ± 0.02 | 1.8 ± 0.02 | 1.7 ± 0.03 | 1.7 ± 0.03 |
| Water : feed intake ratios (ml water drunk/g feed intake): | | | | |
| - Choice feeding | 2.6 ± 0.06 | 2.5 ± 0.08* | 3.1 ± 0.11 | 3.4 ± 0.14* |
| - Complete diet | 2.2 ± 0.06 | 1.9 ± 0.08* | 2.6 ± 0.12 | 2.6 ± 0.14* |
| Body weight (g): | | | | |
| - Choice feeding | 1964 ± 8.6* | 1973 ±21.9* | 2019 ± 5.4* | 1918 ± 10.6 |
| - Complete diet | 1908 ±10.9* | 1905 ± 4.6* | 1950 ±10.7* | 1885 ± 5.1 |

[1)] whole wheat; [2)] calculated value of 34 % wheat + 34 % sorghum in the mash portion of the diet; [3)] estimate based on protein sources in the complete diet; [4)] whole wheat + protein pellets; *, P < 0.05; **, P < 0.01; no asterisk, non-significant result (P > 0.05).

Although the mean total feed intake of hens was not significantly affected by the feeding treatments, the apparent increase in ME intake by choice-fed hens in the present study is of interest and may be reflected in their high egg production relative to controls (Summers and Leeson, 1989). Such results are apparently due to the form of grain used in Experiment 2, since McIntosch *et al.* (1962) reported that whole wheat tends to yield more ME than pelleted or ground wheat. Reid and Weber (1973) reported that ME intake is the major limiting factor for egg production at higher temperatures. This was confirmed by the choice-fed hens in the present study.

Table 16. Mean ± SEM weekly egg production, daily egg weight and weekly egg specific gravity of hens as affected by feeding treatments during the successive weeks in Experiment 2.

| Week | **Egg production (%)** | | **Egg weight (g)** | | **Egg specific gravity (g/ml)** | |
|---|---|---|---|---|---|---|
| | Choice feeding | Complete diet | Choice feeding | Complete diet | Choice feeding | Complete diet |
| 1 | 92.8 ± 0.6 | 90.3 ± 0.4 | 58.5 ± 0.2 | 58.9 ± 0.1 | 1.079 ± 0.004 | 1.081 ± 0.004 |
| 2 | 90.7 ± 0.5 | 89.4 ± 0.5 | 59.3 ± 0.1 | 59.0 ± 0.1 | 1.076 ± 0.005* | 1.083 ± .005* |
| 3 | 87.8 ± 0.7 | 86.9 ± 0.7 | 59.4 ± 0.2 | 59.7 ± 0.2 | 1.083 ± 0.005 | 1.080 ± 0.005 |
| 4 | 89.9 ± 0.7 | 86.5 ± 0.8 | 60.8 ± 0.2 | 62.2 ± 0.3 | 1.078 ± 0.005 | 1.081 ± 0.005 |
| 5 | 89.5 ± 0.7 | 87.8 ± 0.7 | 59.2 ± 0.3 | 59.0 ± 0.3 | 1.078 ± 0.005 | 1.082 ± 0.005 |
| 6 | 86.9 ± 0.7 | 79.4 ± 0.7 | 59.4 ± 0.4 | 59.3 ± 0.4 | 1.073 ± 0.006 | 1.074 ± 0.006 |
| 7 | 85.7 ± 0.65 | 84.4 ± 0.7 | 58.2 ± 0.4 | 59.1 ± 0.4 | 1.071 ± 0.007 | 1.074 ± 0.007 |
| 8 | 81.5 ± 0.6 | 81.1 ± 0.6 | 57.7 ± 0.4 | 57.9 ± 0.4 | 1.072 ± 0.007 | 1.076 ± 0.007 |

*, $P < 0.05$; no asterisk, non-significant result ($P > 0.05$). For method of calculation of each parameter, see page 53.

Normally the water intake of laying hens fed on an all-mash diet is closely related to their egg production (Heywang, 1941; Jull, 1949), so it is very likely that the highly significant increase ($P < 0.01$) in water intake of the choice-fed hens in Experiment 2 was associated with the increase in their egg production. Another possible reason for the increase in water intake of the choice-fed hens s their highly significant increase ($P < 0.01$) in body weight, since Bordas *et al.* (1978) found that water intake is positively and highly correlated with body weight in laying hens.

It is of interest that hens on choice feeding consumed more protein than hens fed the complete diet (Tables 14 and 15); the mean daily protein intake of choice-fed hens was 22.4 g/bird as compared to 18.2 g/bird for those on the compete diet. The present results support those of Valencia *et al.* (1980) who found that the protein intake of 22 g/d achieved by hens fed a complete diet when housed at 32 °C was adequate to support egg production at a level of 89 %. The protein intakes recorded in Experiment 2 satisfy the daily recommendation of 18 g of CP for hens producing a mean daily egg output of 50 g (ARC, 1975; SCA, 1987; Woolford, 1990).

A likely explanation for the significant difference in protein intake between feeding treatments is that the choice-fed hens selectively consumed protein rather than energy. Reid and Weber (1973) indicated that ME intake became the first limiting nutrient at high temperatures and that increased protein intakes were likely to only partially overcome the adverse effects of high temperature. This was not the case in the current work : choice-fed birds virtually maintained their ME intake at 32 °C as opposed to 20 °C, while those fed the complete ration suffered a decline of 14 % (from 1413 to 1239 kJ/bird/d; Tables 11 and 14).

Sugandi *et al.* (1975) also found that a higher protein intake induced a significantly greater ($P < 0.01$) water intake in caged hens fed a complete diet. This was essentially the same finding as in the present study except that the method of offering feed to the birds and the ambient temperatures were different. The direct association between protein and water intakes is probably related to the well known fact that a greater amount of water is required for the metabolism of protein than for that of carbohydrates or fats (James and Wheeler, 1949).

The increased intake of protein by choice-fed hens at 32 °C may, however, prove uneconomical, as it did not improve egg weight but rather appeared to be used for maintenance of body weight. The relationship established here between protein intake and body weight supports the results of Valencia *et al.* (1980), who also found that hens which consumed more protein at 32 °C showed a positive change in body weight, while hens fed a lower protein diet lost weight.

The present results are, however, contrary to those of Blake *et al.* (1984), who reported that dietary self-selection did not enable hens to regulate nutrient intake to a comparable level as achieved by hens fed a balanced diet, and as a consequence hens on the self-selected treatment utilised body reserves in order to maintain egg production at high temperature. This difference may be due to differences in the experimental approaches adopted and in the duration of the studies. In their study, for example, Blake *et al.* used three diets, each being high in either energy, protein, or Ca. These diets were provided *ad libitum* for laying hens in three feeders for an experimental period of only 28 d (compared to one feeder and 56 d in the current work). In addition, they did not train their birds to recognise these diets until the experiment actually started. The current results are thus consistent with the suggestions of Mastika (1987) and Forbes and Shariatmadari (1994) that the poor results reported by Blake *et al.* were possibly due to the fact that the hens used by them were not experienced in choice feeding.

The mean daily intakes of Ca in Experiment 2 were 3.1 and 4.9 g/bird for choice-fed and control birds, respectively. By way of comparison, these Ca intakes for choice-fed hens appear to be slightly higher than those reported by de Andrade *et al.* (1976, 1977), who found that the average daily Ca intakes of laying hens housed at constant high temperatures of 31 or 32 °C and fed a complete diet were 2.7 and 2.4 g/hen respectively. Although the Ca intakes of choice-fed hens were significantly lower than those of control birds (Tables 14 and 15), the actual Ca intakes were in excess of the mean daily value of 2.7 g/hen reported by Scott and Balnave (1991) to be adequate for hens on choice feeding and housed at high temperature (25 to 35 °C).

As in Experiment 1, the specific gravity of eggs in Experiment 2 declined progressively with time and once again this decline was greater in the choice-fed hens. Mongin and Sauveur (1979) reported that laying hens given free access to a Ca source consume sufficient Ca to meet their needs. However, the results of Experiments 1 and 2 of the current work cast doubt on the universality of this concept, and point to the need for further studies of, and the need to improve Ca intake in choice-fed hens. The specific gravity figures reporyted in Table 14 (and subsequently in Tables 16, 17 and 19) are at the low end of the normal range, a fact which is attributed to the advanced age of the hens.

Although the mean FCR values of hens in the present study were similar in both feeding treatments, choice-fed birds tended to have higher ($P < 0.05$) water : feed intake ratios than those fed the complete diet. These results when taken in conjunction with the earlier report of Van Kampen (1983), suggest that hens with a high water : feed intake ratio experience improved feed utilisation. In accordance with the present findings, Valencia *et al.* (1980) reported that feed efficiency measured as g of egg/g of feed consumed showed a significant improvement for laying hens fed on a complete diet and housed at 32 °C over those at 21 °C. Thus, the results from the present experiment indicate that dietary self-selection offers laying hens an advantage in terms of feed-conversion efficiency at high temperatures.

In conclusion, hens allowed to self-select nutrients from whole wheat, protein pellets and oyster-shell grit *ad libitum* in a single feeder at 32 °C were able to increase ME intake, protein intake, water intake, egg production, body weight and feed efficiency while maintaining similar total feed intake, egg weight and egg specific gravity as compared to hens fed on a complete diet.

### 3.2.5. Experiment 3 at 20 °C (night) : 32 °C (day) (8 hours : 16 hours) - Free-choice of whole wheat, protein pellets and oyster-shell grit, or that of a complete diet (mash).

#### 3.2.5.1. Introduction.

As Vohra (1982) has reported, most studies on the effects of high environmental temperature on the productivity of laying hens have been conducted in constant-temperature environmental chambers. In general, the production rate, egg size and egg-shell strength are reduced when laying hens are subjected to constant high emperature (Payne, 1966a, 1967; Smith and Oliver, 1971; Smith, 1972, 1973 and 1990; Emmans, 1974; Sykes, 1977; Marsden and Morris, 1981; Vohra, 1982; Austic, 1985; Emmans and Charles, 1989).

In contrast, laying hens exposed to varying temperatures lay more eggs than those in a constant thermal environment (Mueller, 1961; Payne, 1966b; Wilson *et al.*, 1972a). The beneficial effects of fluctuating temperatures on the productivity of laying hens appears to be largely dependent on the mean temperature (Smith, 1990). Laying hens in cycling environments of 10 to 34 °C, 26 to 38 °C, and 26.7 to 35.6 °C, with average temperatures of 22, 32, and 31 °C, respectively, produced more eggs and had better feed efficiency than hens kept in constant environments corresponding to those average temperatures (Wilson *et al.*, 1972a; Miller and Sunde, 1975; de Andrade *et al.*, 1977).

Marsden and Morris (1975) reported a series of experiments in which fluctuating temperatures were compared with constant temperatures at the same mean (12 h at 18 °C, 12 h at 24 °C and 12 h at 24 °C, 12 h at 30 °C). They concluded that there was no difference between constant and fluctuating regimes when the mean was below the panting threshold. Similar results have been reported by Zimmerman and Snetsinger (1977, cited by Marsden and Morris, 1981), bu their results suggest that where the mean temperature (31 °C) was above the panting threshold there may be a slight advantage in favour of fluctuation, especially where the low point of the fluctuation is below 29 °C during daylight hours.

In the natural environment, there are wide fluctuations in temperature between day and night, with non-equatorial regions also having seasonal variations (Marsden and Morris, 1981; Vohra, 1982). The last author further stated that temperatures in regions between the Tropics of Cancer and Capricorn are also not uniform. As the temperatures fluctuate throughout the day, the energy requirement of chickens also fluctuates (Mastika and Cumming, 1985). They suggested that by offering chickens a choice of grain (as a source of energy) and protein pellets, the birds should be able to adjust their energy intakes under varying environmental conditions.

However, very little information is available about the relative effects of diurnally variable (cycling) temperatures on the intakes and performance of laying hens offered choice feeding or complete diets. The present experiment was thus carried out to study the effects of exposure to a regime of 16 h at 20 °C (night) and 8 h at 32 °C (day) on the ability of laying hens to meet their nutrient requirements by self-selecting from three feed components in a single feeder.

The same comparisons were made as in Experiments 1 and 2, between both feeding regimes and aspects of feed intake and laying performance. Experiment 3 followed on 2 weeks after Experiment 2 ended and the same birds were used. As before, the birds were re-randomised to treatments and cages on the day Experiment 2 terminated, and for the rest of 2 weeks were trained to their new feeding regime. Experiment 3 started when the birds were 44 weeks old.

3.2.5.2. **Experimental hypothes s and design**.

The hypothesis develope l was that the mean nutrient intake and egg-laying performance of hens giv en a choice of nutrient sources *ad libitum* in a single feeder at a 20 °C (n ght) : 32 °C (day) temperature regime would not differ from those of hens fed a complete diet. The same experimental design was used as in Experiments 1 and 2. Unfortunately, because of limited climate-chamber ava lability it was not possible to conduct Experiment 3 concurrently with the other experiments.

3.2.5.3. **Results**.

The treatment means and results of the statistical analyses for the duration of Experiment 3 are summarised in Table 17. Over the 10-week laying period, hens on the choice-feeding treatment had similar mash and total feed intakes as compared to those of the hens fed the complete diet, but their grain and Ca intakes were significantly ($P < 0.01$) reduced. Egg weight and FCR of the hens were also similar in both feeding treatments.

Birds on choice feeding consumed more ($P < 0.01$) ME than controls on the complete diet, due largely to significantly increased consumption of protein pellets ($P < 0.01$), and as a result their protein intakes and body weights were significantly higher ($P < 0.01$). Hens offered the choice feeding also consumed more ($P < 0.01$) oyster-shell grit, drank more ($P < 0.01$) water, produced a greater number of eggs ($P < 0.05$), had lower ($P < 0.01$) values of egg-shell quality as assessed by the suspension weighing technique, and recorded higher ($P < 0.05$) water : feed intake ratios than those offered the complete diet.

Table 17. Effects of feeding treatments on the nutrient intake and laying performance of hens from 44 to 54 weeks of age in Experiment 3.

| Parameter | Choice feeding | Complete diet | SEM | Level of significance |
|---|---|---|---|---|
| Grain intake (g/bird/d): | 57.0[1)] | 69.7[2)] | 0.3 | ** |
| Protein-pellets intake (g/bird/d): | 44.9 | 32.8[3)] | 0.2 | ** |
| Oyster-shell-grit intake (g/bird/d): | 4.7 | 3.3 | 0.04 | ** |
| Mash intake (g/bird/d): | 101.9[4)] | 102.5 | 0.1 | |
| Total feed intake (g/bird/d): | 106.6 | 105.9 | 2.0 | |
| ME intake (kJ/bird/d): | 1259 | 1189 | 2.0 | ** |
| Protein intake (g/bird/d): | 22.3 | 17.4 | 0.04 | ** |
| Ca intake (g/bird/d): | 3.3 | 4.8 | 0.01 | ** |
| Water intake (ml/bird/d): | 323.5 | 267.5 | 1.9 | ** |
| Egg production (%): | 84.1 | 81.3 | 0.2 | * |
| Egg weight (g): | 60.1 | 59.7 | 0.03 | |
| Egg specific gravity (g/ml): | 1.074 | 1.077 | 0.0002 | ** |
| FCR (g feed intake/g egg weight): | 1.7 | 1.8 | 0.01 | |
| Water : feed intake ratios (ml water drunk/g feed intake): | 3.0 | 2.5 | 0.03 | * |
| Body weight (g): | 2033 | 1910 | 1.6 | ** |

[1)] whole wheat; [2)] calculated value of 34 % wheat + 34 % sorghum in the mash portion of the diet; [3)] estimate based on protein sources in the complete diet; [4)] whole wheat + protein pellets; *, $P < 0.05$; **, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$).

3.2.5.4. **Discussion**.

Deaton *et al.* (1981) reported that there were no significant differences in feed intake, egg weight, or feed efficiency (g of feed intake/g of egg weight) between hens kept in environments cycling from either 21.1 to 35 °C or from 15.6 to 35 °C. In a later study the same authors found no significant differences in production parameters when hens were kept either at a constant 25 °C or when cycling between 15.6 and 35 °C daily (Deaton *et al.*, 1982). The current experiment extends those observations to choice-fed birds, as the mash intake as well as total feed intake, egg weight and FCR of hens on the choice-feeding treatment (in a single feeder) were similar to those of hens fed on a complete diet.

Table 18. Mean ± SEM daily intakes of feed components, intake of water, FCR, water : feed intake ratios and body weight of hens as affected by feeding treatments during the successive fortnightly periods in Experiment 3.

| Parameter | Weeks 1 - 2 | Weeks 3 - 4 | Weeks 5 - 6 | Weeks 7 - 8 | Weeks 9 - 10 |
|---|---|---|---|---|---|
| Grain intake (g/bird/d): | | | | | |
| - Choice feeding[1] | 54.4 ± 1.0* | 56.5 ± 3.2** | 56.7 ± 3.1** | 60.9 ± 3.3* | 56.6 ± 2.2** |
| - Complete diet[2] | 63.4 ± 0.3* | 69.6 ± 2.0** | 72.1 ± 2.6** | 72.1 ± 1.3* | 71.4 ± 1.7** |
| Protein-pellets intake (g/bird/d): | | | | | |
| - Choice feeding | 39.1 ± 1.3** | 45.7 ± 6.3** | 47.1 ± 2.0** | 46.0 ± 1.5** | 46.4 ± 1.4** |
| - Complete diet[3] | 29.8 ± 0.2** | 32.7 ± 0.9** | 33.9 ± 0.6** | 33.9 ± 0.6** | 33.6 ± 0.8** |
| Oyster-shell-grit intake (g/bird/d): | | | | | |
| - Choice feeding | 4.8 ± 0.1* | 4.6 ± 0.7 | 5.1 ± 0.8* | 4.3 ± 0.7* | 4.8 ± 0.8** |
| - Complete diet | 3.6 ± 0.8* | 3.5 ± 0.7 | 3.9 ± 0.7* | 2.9 ± 0.8* | 2.7 ± 0.9** |
| Mash intake (g/bird/d): | | | | | |
| - Choice feeding[4] | 93.5 ± 0.[illegible] | 102.2 ± 5.3 | 103.8 ± 2.3 | 106.9 ± 3.3 | 103.0 ± 2.8 |
| - Complete diet | 93.2 ± 0.[illegible] | 102.3 ± 3.6 | 106.1 ± 2.9 | 106.1 ± 2.9 | 105.0 ± 2.6 |
| Total feed intake (g/bird/d): | | | | | |
| - Choice feeding | 98.3 ± 0.8 | 106.8 ± 0.9 | 108.9 ± 0.4 | 111.2 ± 0.5 | 107.8 ± 0.1 |
| - Complete diet | 96.8 ± 1.0 | 105.8 ± 0.9 | 110.0 ± 0.4 | 109.0 ± 0.4 | 107.7 ± 0.3 |
| ME intake (kJ/bird/d): | | | | | |
| - Choice feeding | 1162 ±12.1* | 1261 ± 14.4* | 1277 ± 13.4 | 1324 ± 14.3** | 1269 ± 12.9 |
| - Complete diet | 1081 ± 13.3* | 1183 ± 12.4* | 1231 ± 12.6 | 1231 ± 13.4** | 1218 ± 12.2 |
| Protein intake (g/bird/d): | | | | | |
| - Choice feeding | 20.1 ± 0.3** | 22.5 ± 2.0** | 23.0 ± 0.7** | 23.1 ± 0.9** | 22.8 ± 0.1** |
| - Complete diet | 15.8 ± 0.1** | 17.4 ± 0.5** | 18.0 ± 0.6** | 18.0 ± 0.3** | 17.8 ± 0.4** |
| Ca intake (g/bird/d): | | | | | |
| - Choice feeding | 3.2 ± 0.2** | 3.3 ± 0.2** | 3.6 ± 0.2** | 3.2 ± 0.2** | 3.4 ± 0.2** |
| - Complete diet | 4.6 ± 0.2** | 4.8 ± 0.2** | 5.2 ± 0.2** | 4.8 ± 0.2** | 4.7 ± 0.2** |
| Water intake (ml/bird/d): | | | | | |
| - Choice feeding | 345.0 ± 4.8* | 317.5 ± 1.8* | 322.5 ± 1.8* | 327.5 ± 0.6 | 305.0 ± 1.2 |
| - Complete diet | 260.0 ± 1.7* | 260.0 ± 3.6* | 265.0 ± 3.6* | 282.5 ± 3.0 | 270.0 ± 0.2 |
| FCR (g feed intake/g egg weight): | | | | | |
| - Choice feeding | 1.7 ± 0.03 | 1.5 ± 0.04 | 1.8 ± 0.04 | 1.8 ± 0.04 | 1.7 ± 0.3 |
| - Complete diet | 1.6 ± 0.03 | 1.8 ± 0.04 | 1.8 ± 0.04 | 1.8 ± 0.03 | 1.7 ± 0.3 |
| Water : feed intake ratios (ml water drunk/g feed intake): | | | | | |
| - Choice feeding | 3.5 ± 0.1* | 2.9 ± 0.1 | 2.9 ± 0.1 | 2.9 ± 0.1 | 2.7 ± 0.1 |
| - Complete diet | 2.6 ± 0.1* | 2.4 ± 0.1 | 2.4 ± 0.1 | 2.5 ± 0.1 | 2.5 ± 0.1 |
| Body weight (g): | | | | | |
| - Choice feeding | 2007 ±9.9** | 2017 ± 8.8** | 2057 ±11.8** | 2021 ±12.4** | 2060 ±11.0** |
| - Complete diet | 1900 ±8.0** | 1926 ± 3.5** | 1926 ±7.0** | 1916 ± 3.5** | 1929 ± 6.1** |

[1] whole wheat; [2] calculated value of 34 % wheat + 34 % sorghum in the mash portion of the diet; [3] estimate based on protein sources in the complete diet; [4] whole wheat + protein pellets; *, P < 0 05; **, P < 0.01; no asterisk, non-significant result (P > 0.05).

Blair *et al.* (1973) reported that the choice-feeding system gave satisfactory egg production as compared to a complete diet in mash form, but the hens ate more protein pellets and less grain. This was essentially the same finding as in Experiment 3 except that the ambient temperatures were different. Robinson (1985) found that protein pellets which contained no powdered limestone appeared to be more palatable than protein pellets with limestone to hens offered choice feeding. This finding was confirmed in the present study.

As in Experiment 2, the significantly higher mean daily oyster-shell-grit intake of the choice-fed hens in Experiment 3 was associated with the need for the grit in the grinding of the whole wheat as well as to meet Ca requirements for egg-shell formation (Scott *et al.*, 1971; Karunajeewa and Tham, 1984; Tauson and Elwinger, 1986; Taylor *et al.*, 1995), but may have been limited by the capacity of the gizzards.

Mueller (1961) reported that fluctuating daily temperatures may have had a stimulating effect on egg production. The higher egg production of the choice-fed hens (84.1 %) in Experiment 3 supports this conclusion. By way of comparison, the observed egg production of hens on choice feeding in Experiment 3 was higher than the value (82.6 %) reported by Payne (1966b), who kept the hens at 30 °C for 9 h, followed by 18 °C for 15 h, and fed them on a complete diet.

The current results are in close agreement with those of Mowbray and Sykes (1971), who found that egg production can be maintained at a high rate (86 %) by keeping hens in one of the following thermal environments: (1) environmental temperature fluctuating between 10 and 15 ° C; (2) 30 °C constantly; (3) 30 °C for 10 h and 18 °C for 14 h; (4) 35 ° C for 10 h and 13 °C for 14 h. The high egg-production rate of the choice-fed hens in the current work may have also been partly due to their greater intake of ME, since Summers and Leeson (1989) indicated that there is a good correlation between ME intake and egg production of hens on choice feeding.

The daily protein intakes in Experiment 3 were 22.6 and 17.4 g/bird for the choice-fed birds and the control birds, respectively. In general, the mean protein intake of the complete-fed birds was closer to the daily recommended allowance of 18 g of CP for hens producing a mean daily egg output of 50 g (ARC, 1975; SCA, 1987; Woolford, 1990) but the mean protein intake of the choice-fed hens was higher than these guidelines.

The fact that choice-fed hens also produced more, and slightly larger, eggs (Table 17) is consistent with the work of Sugandi *et al.* (1975) and Gleaves *et al.* (1977), who found that laying hens that consumed significantly more protein tended to have a significantly higher egg production. However, a major practical question is whether the extra protein consumed by choice-fed hens is economical. There are two aspects of this, the financial return from extra egg production (number and weight), and the estimated value (if any) of the greater body weight of choice-fed hens.

In the current work, protein meal cost approximately 40 ¢/kg and eggs were valued at A$ 2.40/kg. Using the values in Table 17, it can be calculated that choice-fed birds, as compared to those on the complete diet, consumed additional protein valued at approximately 0.5 ¢/d but produced extra egg mass valued at only 0.38 ¢/d. The choice-fed hens were heavier than control birds (2033 vs 1910 g), but the difference was small and its commercial value (as, for example, through reduced mortality or a longer period in lay) seems unlikely to have exceeded 0.12 ¢/egg (0.5 - 0.38). It can thus be concluded that in this experiment at least, the added protein intake of choice-fed hens was uneconomical.

The significantly higher mean daily water intake of the choice-fed hens in Experiment 3 might well be a response to their significantly higher mean protein intake as compared to those fed the complete diet. The results on the relationship between water and protein intakes support the conclusion of James and Wheeler (1949) that a greater amount of water is required for the metabolism of protein than for that of carbohydrates or fats.

Table 19. Mean ± SEM weekly egg production, daily egg weight and weekly egg specific gravity of hens as affected by feeding treatments during the successive weeks in Experiment 3.

| Week | **Egg production (%)** | | **Egg weight (g)** | | **Egg specific gravity (g/ml)** | |
|---|---|---|---|---|---|---|
| | Choice feeding | Complete diet | Choice feeding | Complete diet | Choice feeding | Complete diet |
| 1 | 87.3 ± 0.8 | 80.6 ± 0.8 | 58.4 ± 0.4 | 58.5 ± 0.4 | 1.073 ± 0.008* | 1.077 ±0.008* |
| 2 | 85.3 ± 0.8 | 79.4 ± 0.9 | 59.0 ± 0.4 | 59.0 ± 0.4 | 1.071±.008** | 1.074 ± 0.008 |
| 3 | 83.6 ± 0.9 | 82.3 ± 0.9 | 59.1 ± 0.3 | 58.8 ± 0.3 | 1.073 ±.008** | 1.074 ± 0.008** |
| 4 | 84.9 ± 0.9 | 76.9 ± 0.9 | 59.6 ± 0.3 | 59.8 ± 0.3 | 1.073 ± 0.008 | 1.078 ± 0.008 |
| 5 | 81.0 ± 0.9 | 81.9 ± 0.9 | 60.1 ± 0.3 | 59.2 ± 0.3 | 1.076 ± 0.008 | 1.076 ± 0.008 |
| 6 | 85.7 ± 0.9 | 81.9 ± 0.9 | 60.1 ± 0.3 | 59.6 ± 0.3 | 1.075 ± 0.008 | 1.077 ± 0.008 |
| 7 | 81.9 ± 0.9 | 79.0 ± 0.9 | 60.9 ± 0.3 | 59.8 ± 0.3 | 1.076 ± 0.008 | 1.078 ± 0.008 |
| 8 | 83.6 ± 0.9 | 86.5 ± 0.9 | 60.8 ± 0.3 | 60.5 ± 0.3 | 1.070 ± 0.008 | 1.073 ± 0.009 |
| 9 | 86.1 ± 0.9 | 83.2 ± 0.9 | 61.4 ± 0.3 | 60.0 ± 0.3 | 1.073 ± 0.009* | 1.077 ± 0.009* |
| 10 | 81.0 ± 0.9 | 81.5 ± 0.9 | 61.2 ± 0.3 | 61.8 ± 0.3 | 1.079 ± 0.009 | 1.080 ± 0.009 |

*, $P < 0.05$; ** $P < 0.01$; no asterisk, non-significant result ($P > 0.05$). For method of calculation of each parameter, see page 53.

It has also been shown by Heywang (1941), Jull (1949) and Bordas *et al.* (1978) that normally the water intake of laying hens is closely related to their egg production and body weight when the birds are fed on an all-mash diet. The results of Experiment 3 are consistent with those findings, since the choice-fed birds had significantly higher egg production, body weight and water intake than hens fed the complete diet (Tables 17 and 18).

The mean daily intakes of Ca in Experiment 3 were 3.3 and 4.8 g/bird for the choice-fed and control birds, respectively. The figure for the choice-fed hens is similar to that of Deaton *et al.* (1981), who calculated that the average daily Ca intake of laying hens exposed to temperature cycles of 21.1 to 35 °C and fed a complete diet was 3.3 g/hen. By way of comparison, the Ca intakes in Tables 17 and 18 show that under the conditions of Experiment 3 choice-fed hens consumed a similar amount of Ca as previously reported by Leeson and Summers (1978), Blair *et al.* (1973) and Karunajeewa (1978a) (i.e. 3.1, 3.3 and 3.4 g/hen/d respectively).

In contrast, control birds in Experiment 3 consumed a slight excess of Ca (4.8 g/hen/d) as compared to the values of 3.4, 3.4 and 3.5 g/hen/d reported by the above authors. Environmental conditions did vary between these experiments, and in this regard Payne (1966b) found that the average daily Ca intake of laying hens fed a complete diet and kept at 30 °C for 9 h followed by 18 °C for 15 h each day was 3.6 g/hen. In general, the observed Ca intakes of the choice-fed hens were within the range of daily values (3.0 - 3.8 g/hen) recommended by the ARC (1975) in the U.K., but below the daily value of 3.8 g/hen recommended by the SCA (1987), Woolford (1990) and NRC (1994).

It is noteworthy that although the mean Ca intakes of the choice-fed hens in Experiment 3 were higher than in Experiments 1 and 2 (3.3 > 3.1 and 3.1 g Ca/hen/d), the mean value of their egg-shell quality was lower (1.074 < 1.077 and 1.083 g/ml). This was probably due to the direct effects of heat stress on hens, since de Andrade *et al.* (1977) found that there was a significantly lower average value of both shell thickness (mm) and egg specific gravity (g/ml) in laying hens exposed to cycling (26.7 to 35.6 °C) or constant (31 °C) high temperatures as compared to those kept in a constant 21 °C (0.293 mm - 1.075 g/ml or 0.280 mm - 1.072 g/ml vs 0.320 mm - 1.080 g/ml). Emery *et al.* (1984) also found that shell thickness was significantly reduced at temperatures which cycled between 15.6 and 37.7 °C or between 21.1 and 37.7 °C as compared with a constant 23.9 °C, and concluded that the reduction in shell thickness was a direct effect of heat.

Although the mean FCR values of hens in Experiment 3 were similar in both feeding treatments, birds on choice feeding tended to have higher (P < 0.05) values of the mean water : feed intake ratios than those fed on the complete diet. This agrees with Van Kampen (1983) who suggested that laying hens with a high water : feed intake ratio experience improved feed utilisation. Wilson *et al.* (1972a) also observed an improvement in feed efficiency for hens kept in a constant 36 °C or in a cycling temperature (10 to 36 °C) compared with those kept in constant 10 or 23 °C environments. Other workers (e.g., Mueller, 1961; Payne, 1966b; and de Andrade *et al.*, 1977) also reported an improvement in feed efficiency in constant or cycling high-temperature environments.

In summary, laying hens allowed to self-select nutrients from whole wheat, protein pellets and oyster-shell grit which were provided *ad libitum* in a single feeder in a 20 °C (night) : 32 °C (day) temperature regime were able to increase ME intake, protein intake, water intake, egg production, body weight and feed efficiency while maintaining a similar total feed intake, egg weight and FCR, as compared to hens fed on a complete diet.

However, the significantly higher protein intake of the choice-fed hens would prove uneconomical if protein sources were scarce and expensive, as in developing countries. At the farm level, this slight inefficiency in protein utilisation would need to be offset against the more substantial economic gains that could be expected to come from the fact that grinding and mixing of feed constituents is not needed in the choice-feeding system.

### 3.2.6. Experiment 4 at 20 °C - Free-choice of whole maize, protein meal and oyster-shell grit, or that of a complete diet (meal).

#### 3.2.6.1. Introduction.

The commercial laying hen has demonstrated distinct appetites for energy, protein and Ca. The daily metabolic requirements of the laying hen for each of the dietary constituents varies with individual, age and over time (Robinson, 1985; Taylor *et al.*, 1995). The same authors further emphasise that feeding systems which allow no choice of diet cannot accommodate these variations. Kiiskinen (1987) also stated that the current practice of feeding compounded laying diets which are formulated to meet the requirements of the average bird ignores individual variations in dietary requirements.

From the economic point of view, the use of whole grains in a choice-feeding system offers a better way to use home-grown grain, and thus represents a reduction in feed cost, as transport, grinding, mixing and many handling procedures are then unnecessary (Karunajeewa, 1978b; Tauson and Elwinger, 1986; Kiiskinen, 1987; Cumming *et al.*, 1987; Mercia, 1990; Tauson *et al.*, 1991; Feltwell, 1992). For these various reasons, Cumming *et al.* (1987) suggested that a choice-feeding system has particular importance to small poultry producers in developing countries.

However, there is little information on the effect of feeding hens a choice of whole grains which are grown extensively in tropical countries (Karunajeewa and Tham, 1984). Besides that, the response of laying hens to choice feeding has been shown to be influenced by several factors such as type of cereal offered (Karunajeewa, 1978a; Desmayati *et al.*, 1983), source of Ca, strain of bird, period of training (Roberts *et al.*, 1995) and environmental temperature (Blake *et al.*, 1984; Scott and Balnave, 1985, 1988, 1989 and 1991).

Since maize is the dominant grain used in poultry rations in the author's home region, West Timor, Indonesia, and no information is available on the choice feeding of this grain in a single feeder, the present experiment was designed along the same lines as Experiment 1. That is, to study the effect of offering whole maize grain plus a protein-meal mixture with oyster-shell grit on a free-choice basis in a single feeder on the laying performance of hens kept at a constant ambient temperature of 20 °C.

All basic aims in this experiment were the same as described for Experiment 1. All birds had been trained to choice feeding at 12 weeks of age. At 22 weeks of age, they were randomised to treatments (on body weight) and to cages. They were re-trained to their new feeding regime for 2 weeks before Experiment 4 started when the birds were 24 weeks old.

3.2.6.2. **Experimental hypothesis and design.**

The hypothesis developed was the same as in Experiment 1 that the mean nutrient intake and egg-laying performance of birds given a choice of nutrient sources *ad libitum* in a single feeder at 20 °C would not differ from that of the birds offered a complete diet in a meal form. The experimental design was the same as described for Experiment 1; that is a randomised block design with choice feeding and a complete diet as the main factors and individual hens serving as replicates.

3.2.6.3. **Results and discussion.**

The treatment means and results of the statistical analyses for the duration of Experiment 4 are summarised in Table 20. Over the 8-week laying period, birds offered the choice feeding *ad libitum* in a single feeder consumed highly significantly ($P < 0.01$) less feed in total than did those on the complete diet. This intake differential was associated with highly significant (P < 0.01) reductions in the intakes each of grain, protein meal and oyster-shell grit.

Table 20. Effects of feeding treatments on the nutrient intake and laying performance of hens from 24 to 32 weeks of age in Experiment 4.

| Parameter | Choice feeding | Complete diet | SEM | Level of significance |
|---|---|---|---|---|
| Grain intake (g/bird/d): | 81.4[1)] | 83.8[2)] | 0.1 | ** |
| Protein-meal intake (g/bird/d): | 28.9 | 29.7[3)] | 0.02 | ** |
| Oyster-shell-grit intake (g/bird/d): | 10.0 | 10.3[4)] | 0.01 | ** |
| Total feed intake (g/bird/d): | 120.3 | 123.8 | 0.1 | ** |
| ME intake (kJ/bird/d): | 1463 | 1503 | 0.8 | ** |
| Protein intake (g/bird/d): | 19.8 | 20.4 | 0.02 | ** |
| Ca intake (g/bird/d): | 3.8 | 3.9 | 0.03 | |
| Egg production (%): | 93.3 | 94.2 | 0.2 | |
| Egg weight (g): | 54.3 | 53.8 | 0.03 | * |
| Albumen quality (Haugh units): | 98.6 | 97.4 | 0.1 | |
| Yolk colour (Roche Fan score): | 11 | 11 | 0.02 | |
| Egg-shell thickness (μm): | 365 | 358 | 0.3 | ** |
| Egg specific gravity (g/ml): | 1.083 | 1.082 | 0.0001 | |
| FCR (g feed intake/g egg weight): | 2.2 | 2.3 | 0.003 | ** |
| Body weight (g): | 1719 | 1693 | 1.5 | * |

[1)] whole maize; [2)] calculated value of 67.7 % maize meal in the complete diet; [3)] estimate based on protein sources in the complete diet; [4)] estimate based on Ca source in the complete diet; *, P < 0.05; **, P < 0.01; no asterisk, non-significant result (P > 0.05).

In the same period, birds on the choice-feeding treatment consumed less (P < 0.01) ME and protein, utilised feed more efficiently (P < 0.01), laid larger (P < 0.05) eggs and gained more (P < 0.01) in body weight than those fed the complete diet. The mean egg-shell thickness of the choice-fed hens was significantly greater (P < 0.01) than that of the hens fed on the complete diet. However, the mean Ca intake, egg production, albumen quality, yolk colour and egg specific gravity of the hens were similar in both feeding treatments.

Results obtained over the 8-week laying period in Experiment 4 agree well with previous results (Blair *et al.*, 1973; Karunajeewa, 1978a; Leeson and Summers, 1979) in that birds offered choice feeding consumed significantly less feed in total than did control birds, while maintaining adequate performance. Unlike Experiment 1, the results of the present study indicate that there was only a small saving in the mean total feed intake of the choice-fed hens compared to control birds (10.4 vs 2.9 %; Tables 11 and 20).

On a week by week basis, significant reductions in daily total feed intake occurred only in weeks 2, 3, 7 and 8 (Table 23), when the choice-fed hens consumed respectively 3.5, 3.3, 3.8 and 3.9 % less feed than controls. The above figures are indeed lower than the values (6.7, 6.7, 7.0 and 11.0 %) reported by Blair *et al.* (1973), Leeson and Summers (1978, 1979) and Karunajeewa (1978a). A likely cause of the observed difference of saving in feed intake associated with choice-feeding system appears to be the use of different grains, since Desmayati *et al.* (1983) indicated that the response of laying hens to choice feeding was different for corn, rice bran, wheat pollard and corn + rice bran (1:1) as compared with mixed diets.

Table 21. Mean ± SEM daily intakes of grain, protein meal and oyster-shell grit of hens as affected by feeding treatments in Experiment 4.

| Week | Grain intake (g/bird/d) | | Protein-meal intake (g/bird/d) | | Oyster-shell-grit intake (g/bird/d) | |
|---|---|---|---|---|---|---|
| | Choice feeding[1] | Complete diet[2] | Choice feeding | Complete diet[3] | Choice feeding | Complete diet[4] |
| 1 | 80.4 ± 0.6 | 82.4 ± 1.3 | 28.5 ± 0.1 | 29.2 ± 0.4 | 9.8 ± 0.1* | 10.1 ± 0.2* |
| 2 | 84.0 ± 1.7 | 87.0 ± 2.6 | 29.8 ± 0.6* | 30.8 ± 0.9* | 10.3 ± 0.2* | 10.7 ± 0.3* |
| 3 | 81.8 ± 1.8* | 84.5 ± 2.1* | 29.0 ± 0.9* | 29.9 ± 0.8* | 10.0 ± 0.3* | 10.3 ± 0.3* |
| 4 | 84.0 ± 2.1 | 83.8 ± 2.7 | 29.7 ± 0.9 | 29.7 ± 0.8 | 10.2 ± 0.3 | 10.3 ± 0.3 |
| 5 | 80.4 ± 2.7 | 82.1 ± 2.5 | 28.5 ± 0.8 | 29.1 ± 0.8 | 9.8 ± 0.3 | 10.1 ± 0.3 |
| 6 | 80.7 ± 2.4 | 83.1 ± 2.3 | 28.6 ± 0.7* | 29.5 ± 0.7* | 9.9 ± 0.3* | 10.2 ± 0.3* |
| 7 | 80.8 ± 2.2* | 83.8 ± 2.1* | 28.6 ± 0.7* | 29.7 ± 0.7* | 9.9 ± 0.3* | 10.3 ± 0.3* |
| 8 | 80.2 ± 2.1* | 83.3 ± 2.1* | 28.4 ± 0.7* | 29.5 ± 0.7* | 9.8 ± 0.3* | 10.2 ± 0.3* |

1) whole maize; 2) calculated value of 67.7 % maize meal in the complete diet; 3) estimate based on protein sources in the complete diet; 4) estimate based on Ca source in the complete diet; *, $P < 0.05$; no asterisk, non-significant result ($P > 0.05$).

From the results shown in Tables 20, 21 and 22, the consequence of birds on choice feeding consuming less grain is a decrease in the ME intake. In fact, the choice-fed birds consumed about 2.9 and 2.7 % less grain and ME as compared to those fed the complete diet (Table 20). This result is in agreement with that of Leeson and Summers (1978, 1979), who found that birds on choice feeding consumed significantly less ME than did control birds.

It is of interest that hens on choice feeding consumed less protein than hens fed the complete diet (Tables 20 and 22); the mean daily protein intake of choice-fed hens was 19.9 g/bird as compared to 20.8 g/bird for those on the control diet. This finding is similar to results of Blair *et al.* (1973), Karunajeewa (1978a) and Leeson and Summers (1978, 1979), each of whom found that hens on choice feeding consumed significantly less protein than did the control birds (17.5 vs 19.2, 17.9 vs 19.0, 18.7 vs 19.6, 18.7 vs 20.2 %), while producing the same quantity of eggs.

Table 22. Mean ± SEM daily intakes of ME, protein and Ca of hens as affected by feeding treatments in Experiment 4.

| Week | ME intake (kJ/hen/d) | | Protein intake (g/bird/d) | | Ca intake (g/bird/d) | |
|---|---|---|---|---|---|---|
| | Choice feeding | Complete diet | Choice feeding | Complete diet | Choice feeding | Complete feeding |
| 1 | 1442 ± 9.2* | 1480 ± 13.4 | 19.6 ± 0.5 | 20.1 ± 0.5 | 3.7 ± 0.1 | 3.8 ± 0.1 |
| 2 | 1508 ± 7.1 | 1561 ± 43.3* | 20.4 ± 0.5* | 21.2 ± 0.5* | 3.9 ± 0.1 | 4.0 ± 0.1 |
| 3 | 1467 ± 33.2* | 1516 ± 40.0* | 19.9 ± 0.5* | 20.6 ± 0.5* | 3.8 ± 0.1 | 3.9 ± 0.1 |
| 4 | 1506 ± 49.5 ** | 1504 ± 50.3 | 20.4 ± 0.5 | 20.4 ± 0.6 | 3.9 ± 0.1 | 3.9 ± 0.1 |
| 5 | 1443 ± 7.1** | 1473 ± 47.9 | 19.6 ± 0.6 | 20.0 ± 0.5 | 3.7 ± 0.1 | 3.8 ± 0.1 |
| 6 | 1449 ± 11.3* | 1492 ± 43.9 | 19.7 ± 0.5 | 20.2 ± 0.5 | 3.7 ± 0.1 | 3.8 ± 0.1 |
| 7 | 1449 ± 10.6 | 1503 ± 40.4* | 19.7 ± 0.5* | 20.4 ± 0.5* | 3.7 ± 0.1 | 3.9 ± 0.1 |
| 8 | 1439 ± 18.3 | 1493 ± 37.8* | 19.5 ± 0.5* | 20.3 ± 0.5* | 3.7 ± 0.1* | 3.9 ± 0.1* |

*, P < 0.05; **, P < 0.01; no asterisk, non-significant result (P > 0.05).

In accordance with the present study, Karunajeewa (1978a) indicated that hens given whole grains were able to utilise dietary protein more efficiently than those given ground grain in mash diets. Although the protein intake of the choice-fed hens was significantly lower than that of the control birds, these actual protein intakes were slightly higher than the daily recommended allowance of 18 g of CP for hens producing a mean daily egg output of 50 g (ARC, 1975; SCA, 1987; Woolford, 1990).

A likely explanation for the significant difference in protein intake between feeding treatments lies in the duration of training the birds (to recognise their diets) were allowed before the experiments actually started. Roberts *et al.* (1995) indicated that after only a short period of training (i.e.: 2-3 weeks; compared to 10-12 weeks in the current work), the birds adapted to choice feeding by over-consuming protein in comparison to those fed a complete diet. Hughes (1984) also concluded that birds selected protein through a learning process resulting from positive ingestional feedback. The present study is thus consistent with the suggestion of Forbes and Shariatmadari (1994) that laying hens can balance their diet for protein when they are given appropriate training for choice feeding, although it must be acknowledged that the birds may also have been selecting the protein concentrate for nutrients such as energy, vitamins and minerals.

Since there was a highly significant ($P < 0.01$) reduction in the total feed intake of hens on choice feeding, a significant overall improvement ($P < 0.01$) was observed in the conversion of feed to eggs as compared to those on the complete diet (Tables 20 and 23). This substantiates the findings of Blair *et al.* (197[illegible]), Karunajeewa (1978a) and Cumming (1984) that hens on choice feeding are marginally more efficient in converting their diet than those fed the complete diet.

A more plausible explanation for the significant difference in the mean FCR values of hens in the present study lies in the role of oyster-shell and insoluble grit in the diets. Balloun and Phillips (1956) indicated that laying hens fed grit experienced improved feed utilisation compared to those not receiving grit. This improvement was greater when a mash and whole grain diet was fed as compared with an all-mash diet.

Table 23. Mean ± SEM daily total feed intake, egg weight and FCR of hens as affected by feeding treatments in Experiment 4.

| Week | Total feed intake (g/bird/d) | | Egg weight (g) | | FCR (g feed intake/g egg weight) | |
|---|---|---|---|---|---|---|
| | Choice feeding | Complete diet | Choice feeding | Complete diet | Choice feeding | Complete feeding |
| 1 | 118.7 ± 0.8 | 121.7 ± 2.0 | 51.8 ± 1.1 | 51.7 ± 0.8 | 2.3 ± 0.04 | 2.3 ± 0.05 |
| 2 | 124.1 ± 2.5* | 128.5 ± 3.9* | 52.4 ± 0.8 | 52.7 ± 0.7 | 2.4 ± 0.05 | 2.4 ± 0.04 |
| 3 | 120.8 ± 3.7* | 124.7 ± 3.5* | 53.7 ± 1.0 | 53.0 ± 1.0 | 2.2 ± 0.1 | 2.3 ± 0.05 |
| 4 | 123.9 ± 3.4 | 123.8 ± 3.8 | 54.4 ± 1.0 | 53.5 ± 1.0 | 2.3 ± 0.1 | 2.3 ± 0.1 |
| 5 | 118.7 ± 3.9 | 121.3 ± 0.2 | 55.3 ± 1.2 | 54.1 ± 1.2 | 2.1 ± 0.1 | 2.2 ± 0.1 |
| 6 | 119.2 ± 1.1 | 122.8 ± 1.4 | 54.9 ± 1.2 | 54.6 ± 1.2 | 2.2 ± 0.1 | 2.2 ± 0.1 |
| 7 | 119.3 ± 1.5* | 123.8 ± 1.9* | 55.6 ± 1.2 | 54.6 ± 1.2 | 2.1 ± 0.1* | 2.3 ± 0.1* |
| 8 | 118.4 ± 2.1* | 123.0 ± 2.1* | 56.1 ± 1.3 | 55.8 ± 1.3 | 2.1 ± 0.1 | 2.2 ± 0.1 |

*, $P < 0.05$; no asterisk, non-significant result ($P > 0.05$).

Table 24. Mean ± SEM weekly egg production, albumen quality and yolk colour of hens as affected by feeding treatments in Experiment 4.

| Week | Egg production (%) | | Albumen quality (Haugh units) | | Yolk colour (Roche Fan score) | |
|---|---|---|---|---|---|---|
| | Choice feeding | Complete diet | Choice feeding | Complete diet | Choice feeding | Complete feeding |
| 1 | 91.0 ± 9.0 | 95.5 ± 12.6 | 94.0 ± 2.8 | 94.5 ± 2.1 | 9.0 ± 0.8 | 9.0 ± 0.8 |
| 2 | 93.2 ± 14.6 | 96.2 ± 16.3 | 97.5 ± 2.3 | 97.0 ± 2.1 | 11.0 ± 0.9 | 11.0 ± 0.9 |
| 3 | 91.7 ± 17.1 | 92.5 ± 17.8 | 98.0 ± 2.1 | 98.5 ± 2.1 | 11.5 ± 1.1 | 12.0 ± 1.3 |
| 4 | 97.3 ± 18.7 | 93.2 ± 19.1 | 100.5 ± 2.4* | 95.0 ± 3.0* | 11.0 ± 1.3 | 11.5 ± 1.3 |
| 5 | 92.8 ± 19.4 | 93.2 ± 19.6 | 98.5 ± 2.9 | 97.5 ± 2.1 | 10.5 ± 1.2 | 10.5 ± 1.1 |
| 6 | 92.4 ± 19.7 | 94.3 ± 19.9 | 98.0 ± 1.5 | 96.5 ± 1.4 | 11.5 ± 1.1 | 12.0 ± 1.2 |
| 7 | 95.6 ± 20.0 | 95.5 ± 20.2 | 101.0 ± 2.0 | 100.5 ± 2.0 | 12.0 ± 1.2 | 12.0 ± 1.2 |
| 8 | 92.5 ± 20.2 | 92.8 ± 20.1 | 101.0 ± 2.1 | 100.0 ± 2.0 | 13.0 ± 1.3 | 13.0 ± 1.3 |

*, $P < 0.05$; no asterisk, non-significant result ($P > 0.05$).

An interesting fact was that although consuming less total feed (grain, protein and ME; Tables 20, 21 and 22), birds offered choice feeding gained more in body weight than those fed the control diet (Tables 10 and 15).

This increase in body weight was probably due to the form of grain used in Experiment 4. These results agree with those of Karunajeewa (1978a), who found that hens given whole grains were able to utilise dietary energy more efficiently and thus they gained more body weight than those given ground grain in mash diets. In a later study the same author and his co-worker also reported that laying hens offered whole wheat gained more weight than those offered crushed wheat (Karunajeewa and Tham, 1984).

From a consideration of egg weight (Tables 20 and 23), the increase in body weight of the choice-fed hens appeared to be associated with the increase in their egg weight, since Summers and Leeson (1983) found that body weight appeared to be the main factor controlling egg weight for young hens fed a complete diet. Working with feed-restricted hens, in addition, Kwakkel *et al.* (1991) concluded that egg weight is dependent primarily on body weight.

Table 25. Mean ± SEM weekly body weight, egg-shell thickness and egg specific gravity of hens as affected by feeding treatments in Experiment 4.

| Week | Body weight (g) | | Egg-shell thickness (μm) | | Egg specific gravity (g/ml) | |
|---|---|---|---|---|---|---|
| | Choice feeding | Complete diet | Choice feeding | Complete diet | Choice feeding | Complete feeding |
| 1 | 1653 ± 18.4 | 1659 ± 19.5 | 354.0 ± 5.6* | 341.5 ± 23.3* | 1.080 ± 0.001 | 1.080 ± 0.009 |
| 2 | 1669 ± 17.2 | 1666 ± 16.2 | 363.0 ± 19.4 | 359.5 ± 15.9 | 1.081 ± 0.001 | 1.081 ± 0.009 |
| 3 | 1708 ± 24.3 | 1693 ± 28.7 | 365.5 ± 14.3 | 356.5 ± 12.7 | 1.084 ± 0.002 | 1.083 ± 0.002 |
| 4 | 1738 ± 38.3 | 1680 ± 37.5 | 375.5 ± 13.6* | 359.5 ± 13.0* | 1.082 ± 0.002 | 1.080 ± 0.002 |
| 5 | 1745 ± 40.5 | 1688 ± 42.1 | 356.5 ± 12.7 | 355.0 ± 12.3 | 1.085 ± 0.002 | 1.086 ± 0.001 |
| 6 | 1713 ± 40.9 | 1698 ± 40.8 | 372.0 ± 12.3 | 365.0 ± 11.8 | 1.085 ± 0.001 | 1.083 ± 0.001 |
| 7 | 1747 ± 41.8 | 1699 ± 41.6 | 373.0 ± 11.8 | 366.0 ± 11.4 | 1.084 ± 0.001 | 1.084 ± 0.001 |
| 8 | 1778 ± 47.4 | 1758 ± 49.7 | 362.5 ± 11.0 | 357.5 ± 10.9 | 1.081 ± 0.002 | 1.079 ± 0.002 |

*, $P < 0.05$; no asterisk, non-significant result ($P > 0.05$).

It is noteworthy that although the mean specific gravities of eggs in Experiment 4 (Tables 20 and 25) were similar in both feeding treatments (1.083 vs 1.082 g/ml), birds on choice feeding tended to have slightly higher egg-shell thickness than did the control birds (365 vs 358 μm). The increased egg-shell thickness of hens receiving oyster-shell grit may have resulted from the greater solubility of oyster-shell grit as compared with limestone (78 vs 47 %; Keshavarz *et al.*, 1993). These results agree with those of Roberts *et al.* (1995), who used similar sources of Ca as in the current study, and found that the egg-shell thickness of choice-fed hens was significantly greater for birds given oyster-shell grit than for those given limestone (369 vs 363 μ m), even though egg specific gravity was similar (1.085 vs 1.084 g/ml). In accordance with these authors, oyster-shell grit proved to be a better Ca source than limestone.

In conclusion, laying hens allowed to self-select nutrients from whole maize, protein meal and oyster-shell grit *ad libitum* in a single feeder at 20 °C consumed about 2.9 % less feed in total, 2.7 and 3.0 % less protein and ME, and showed a greater increase in body weight, egg weight, egg-shell thickness and improved feed efficiency while maintaining similar Ca intake, egg production, albumen quality, yolk colour and egg specific gravity as compared to hens fed on a complete, meal diet compounded from the same ingredients.

### 3.2.7. **Experiment 5 at 32 °C - Free-choice of whole maize, protein meal and oyster-shell grit, or that of a complete diet (meal).**

#### 3.2.7.1. **Introduction.**

The main concern under the conditions of high environmental temperatures is the layer's ability to consume feed. As poultry house temperature increases above the thermoneutral range (i.e. 18 to 26 °C; Oluyemi and Roberts, 1979), then less heat is required by laying hens to maintain body temperature and so the birds given a complete diet consume less feed (Leeson and Summers, 1991; Forbes and Shariatmadari, 1994).

Payne (1966a) and Van Kampen (1981b) also reported that feed intake of laying hens is depressed in hot environments in order to reduce the metabolic rate and hence body heat load. The drop in feed intake as temperature increased was estimated by Payne (1966a) to be a 1.5 % reduction in appetite for each degree rise between 21 and 30 °C, and about 4.6 % decrease/degree rise between 32 and 38 °C. Concomitant with reduced feed intake in laying hens given complete diets at constant high temperatures were reductions in egg production, egg weight and egg-shell quality (Payne, 1966a, 1967; Smith and Oliver, 1971; Smith, 1972, 1973, and 1990; Emmans, 1974; Sykes, 1977; Marsden and Morris, 1981; Vohra, 1982; Austic, 1985; Emmans and Charles, 1989).

By contrast, choice feeding offers an interesting alternative to complete diets because laying hens fed in this way have the opportunity to balance their own nutrient intakes appropriately to their environments (Mastika, 1987; Shariatmadari and Forbes, 1993). In their latest review, Forbes and Shariatmadari (1994) further proposed that if laying hens are given a choice between high-protein and low-protein feeds at high environmental temperatures it might be expected that protein intake would be maintained while energy intake was reduced to relieve the heat stress. Thus, choice feeding is probably a valuable tool to help in solving the problem of decreasing nutrient intake experienced by laying hens in the hot environments of the tropics (Charles, 1978; Mastika and Cumming, 1985; Cumming and Hill, 1993).

This suggestion is supported by the data of Scott and Balnave (1988), who found that when feed intake is limited at high temperatures hens trained to self-select nutrients from energy- and protein-rich feeds are better able to sustain egg output and body weight at sexual maturity than those fed complete diets. In an early study the same authors also found that when pullets were introduced to self-selection at 12 weeks of age they learned to consume an accurate balance of their essential nutrients at high environmental temperatures (Scott and Balnave, 1985). In other words, the rationale behind the choice-feeding system is that it uses the hens' innate ability to meet its nutrients requirements for growth, maintenance and production (Summers and Leeson, 1979; Wilson and Emmans, 1979; Appleby *et al.*, 1992).

However, very few investigations have introduced choice feeding to laying hens at an early age (before the commencement of lay) and then kept them at a constant high environmental temperature. Besides that, there is no information available on the choice feeding of whole maize grain plus a protein meal mixture with oyster-shell grit in a single feeder. The present experiment was thus designed along the same lines as Experiment 2, that is, to study the ability of laying hens to meet their nutrient requirements by self-selecting from three feed components in a single feeder, but in this case at an environmental temperature of 32 °C.

All basic aims in this experiment were the same as described for Experiment 2. All birds had been trained to choice feeding for 2 weeks, beginning at 12 weeks of age. The birds were re-randomised to treatments and cages on the day Experiment 4 terminated. Then, they were trained to their new feeding regime for 2 weeks before Experiment 5 started when the birds were 34 weeks old.

3.2.7.2. **Experimental hypothesis and design**.

The hypothesis developed was similar to that in Experiment 2: that at 32 °C the hens' energy intake would decline, relative to that at 20 °C in Experiments 1 and 4, but that in those birds which were choice-fed the intake of protein meal and Ca would be maintained, and that as a consequence there would be little change (relative to 20 °C) in egg production. The experimental design was as described for Experiment 4.

3.2.7.3. **Results**.

The treatment means and results of the statistical analyses for the duration of Experiment 5 are summarised in Table 26. There were no significant differences ($P > 0.05$) between the hens' intakes of grain, protein meal, oyster-shell grain and total feed, nor consequently their intakes of ME, protein and Ca.

Table 26. Effects of feeding treatments on the nutrient intake and laying performance of hens from 34 to 44 weeks of age in Experiment 5.

| Parameter | Choice feeding | Complete diet | SEM | Level of significance |
|---|---|---|---|---|
| Grain intake (g/bird/d): | 78.4[1)] | 78.3[2)] | 0.06 | |
| Protein-meal intake (g/bird/d): | 27.8 | 27.8[3)] | 0.05 | |
| Oyster-shell-grit intake (g/bird/d): | 9.6 | 9.6[4)] | 0.06 | |
| Total feed intake (g/bird/d): | 115.8 | 115.7 | 0.02 | |
| ME intake (kJ/bird/d): | 1406 | 1405 | 1.2 | |
| Protein intake (g/bird/d): | 19.1 | 19.1 | 0.04 | |
| Ca intake (g/bird/d): | 3.6 | 3.6 | 0.03 | |
| Egg production (%): | 82.8 | 81.9 | 0.02 | ** |
| Egg weight (g): | 56.8 | 56.3 | 0.07 | ** |
| Albumen quality (Haugh units): | 99.4 | 99.3 | 0.02 | |
| Yolk colour (Roche Fan score): | 11.5 | 11.6 | 0.02 | |
| Egg-shell thickness (µm): | 342.5 | 342.7 | 0.08 | |
| Egg specific gravity (g/ml): | 1.078 | 1.078 | 0.0001 | |
| FCR (g feed intake/g egg weight): | 2.0 | 2.0 | 0.001 | |
| Body weight (g): | 1711 | 1685 | 1.3 | * |

1) whole maize; 2) calculated value of 67.7 % maize meal in the complete diet; 3) estimate based on protein sources in the complete diet; 4) estimate based on Ca source in the complete diet *, $P < 0.05$; **, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$).

Over the 10-week laying period, the feeding treatments had no significant effects ($P > 0.05$) on the hens' performance characteristics except that the choice-fed birds laid more ($P < 0.01$) eggs of a larger ($P < 0.01$)