Chapter 1

GENERAL INTRODUCTION

Global feed production, including livestock products, has continued to increase during the past few decades in response to increased demand for feed caused by population growth and enhanced standards of living (Norse, 1992; Kennedy, 1993). In many developing countries there is intense competition between human beings and farm animals for high quality feedstuffs (cereal grains and protein sources), and as a consequence the production of animal protein in the forms of meat, milk and eggs is commonly below human requirements (Vohra, 1978; Scott, 1982; Raghavan, 1990).

It is well-known that animal protein is superior in quality to that from plants, and its consumption is related to the personal income of consumers (de Boer *et al.*, 1991). People from high income groups in developing countries consume a relatively higher proportion of animal products in their diet than do low income earners (Chantalakhana, 1994).

In the tropics, where many developing countries are located, poultry provide a very significant proportion of the human intake of animal protein (Bhat, 1983; Parkhurst and Mountney, 1988). Their advantages include small size, the ability to forage in village production systems, the fact that eggs are produced by each hen every several days, and the ability to respond to intensive management (feeds and housing). The author's home region, West Timor, Indonesia, for example, is typical of many such developing countries in that the increasing human population has created a demand for eggs that can no longer be met by traditional, low-input, village production systems (Fuah *et al.*, 1992).

As a consequence, small intensive egg production units are becoming more common, but in West Timor these face three particular nutritional problems, namely: (1) the high cost of processed (protein) feedstuffs (all of which are currently imported), (2) seasonal shortages of feedstuffs (particularly in the period immediately before a new harvest), and (3) seasonal shortages of drinking water (particularly during the "dry" season, April - November). These three problems are the subject of the experiments reported in this thesis.

On a world-wide basis, poultry diets have for many years contained a high quality protein source such as soyabean or fish meal, and cereal grain as the principal energy source (Farrell, 1976; Raghavan, 1990; Woolford, 1990; and Ravindran and Blair, 1992). Using these common feedstuffs, a number of developing countries has become more self-sufficient in poultry products, but a disadvantage has been the high cost of importing cereal grains and protein meals (Payne, 1981), which are typically scarce in developing as compared to developed countries (Fitzhugh and de Boer, 1981; Ranjahn, 1983; Raghavan, 1990).

As feed remains the major cost of production in all poultry systems, technology to improve the quantity or quality of feed ingredients or to improve their efficiency of utilisation could be of considerable economic benefit (Parkhurst and Mountney, 1988; Leeson and Summers, 1991; and Butterfield, 1993). These authors state that the main objective of the poultry producer is to achieve efficient economic conversion of feedstuffs into human feed. To achieve this it is necessary to recognise that feed must be used for body maintenance as well as production of meat and eggs.

Gleaves (1989) pointed out in his review that feed efficiency is of great interest to poultry producers because of the relatively high cost of feed compared with other inputs; feed comprises, on average, about 70 % of total variable costs in most systems of poultry production (McMahon *et al.*, 1974; Lee, 1977; Elson, 1979; Wilson and Emmans, 1979; Emmans and Charles, 1989; Behrends, 1990; Wei, 1992). On this basis it is essential to minimise feed costs (Leeson and Summers, 1991).

In practice, nearly all poultry rations are of the all-mash form, which simplifies feeding and is widely believed to assure a better balance of nutrients (Stadelman and Swanson, 1990). While one advantage of mash is the uniformity of the diet, one of its clear disadvantages is the need for grinding and mixing the main dietary components (Blair *et al.*, 1973).

Despite the widespread current practice of feeding hens a pre-mixed diet in mash form, free-choice feeding was common in the 1920's (Ewing, 1963), and renewed interest in this system of feeding began in the 1970's (Belyavin, 1994). This is partly due to consistent increases in cereal grain prices and fuel-energy costs, which have highlighted the need for a feeding system that will minimise feed and processing costs relative to the output of either eggs or poultry meat (Karunajeewa, 1978a, b).

Such a method, choice feeding, was widely recognised in the past (Winter and Funk, 1951), before knowledge regarding formulation of complete diets had reached its present high standard. In other words, choice feeding of laying hens offers an interesting alternative to a complete laying diet (Summers and Leeson, 1979; Leeson and Summers, 1991), particularly in developing countries. From an economic point of view, the energy costs of grinding and mixing could be saved if poultry could utilise whole grains and other feed ingredients (Karunajeewa, 1978b; Karunajeewa and Tham, 1984; Tauson *et al.*, 1991)

The main reason for choice feeding was pointed out by Blair *et al.* (1973), who stated that, since the bird has a digestive system capable of dealing with whole grain, it seems illogical and unnecessary to feed it a pre-ground diet. As well as providing dietary Ca, granular limestone or oyster-shell grit are both desirable for the bird to allow the gizzard to function properly as a grinding machine and to maximise the value of its feed (Feltwell, 1992).

Practical and economic advantages of free-choice feeding for chickens are claimed, it being a flexible feeding technique which can be constructed to meet the various needs of flocks of different breeds and in different climates (Cumming, 1984; Mastika and Cumming, 1985; Cumming *et al.*, 1987). It also offers a better way to use home-grown grain, and thus lower transport costs, and if unground grain is used, to lower grinding and mixing costs as well. In addition, simpler techniques are involved when building a feed plant on the farm (Cumming *et al.*, 1987; Mercia, 1990; Tauson *et al.*, 1991; Feltwell, 1992). The former authors all suggested that for these various reasons, a choice-feeding system has particular importance to small-holder poultry producers in developing countries.

Feed restriction also offers scope for increased efficiency of feed utilisation (Sherwood, 1959; Jackson, 1970; Polin and Wolford, 1972; Bell and Moreng, 1972). With feed prices rising rapidly in most countries, it is an attractive economic proposition to reduce the amount of feed consumed by layers (Best, 1974); savings of up to 16 % have been achieved without a substantial reduction in egg production (see Anonymous, 1971 for review). Restricted feeding of layers, instead of allowing them to consume feed *ad libitum*, may mean fewer and/or smaller eggs, but if prices for eggs are comparatively low while those for feed are high, then the loss of egg income may be smaller than the savings in feed costs (Best, 1974). This is one way the egg industry in the USA, for example, has been able to compensate for increasing feed costs (Horn, 1988).

It has been recognised for many years that to offer birds *ad libitum* feed is a wasteful process, due to spillage (for reviews, see Singsen *et al.*, 1958; Morris, 1968; Sykes, 1972; Hannagan and Wills, 1973; Kari *et al.*, 1977; Balnave, 1978; Robinson and Sheriden, 1982; Sainsbury, 1984;

Gleaves, 1989; Kwakkel *et al.*, 1991). Besides that, any excessive deposition of body fat in hens fed *ad libitum* can be considered wasteful, and this has raised the possibility that restricting feed intake to a level below *ad libitum* might increase profitability (Fisher, 1983). Hence, research on the restricted feeding of poultry has become increasingly relevant (Mbugua and Cunningham, 1983; Wilson *et al.*, 1983), and economically, any research that is successful in reducing the feed intake-egg production ratio has the potential to produce significant savings for egg producers (Hurnik *et al.*, 1977).

At the time the current work began, all information on restricted feeding had been gained under conditions similar to those in large, intensive production units, that is, based on automated feeding. As a consequence, restricted feeding regimes are commonly described on a time basis. In Australia (SCA, 1987), for example, there are three typical restricted feeding systems which have been used successfully with growing poultry: (a) 32 h on and 40 h off feed in each 72 h cycle; (b) access to feed for 6 - 8 h only in each 48 h cycle; and (c) a program giving 4 d on feed and 3 d off feed/week.

Such systems are rarely found in developing countries, where labour is cheaper and daily feeding by hand is commonly practised. The work reported in this thesis was thus designed to establish restricted feeding regimes appropriate to the latter conditions, that is, based on actual daily feed to be offered. In addition, in many developing countries, there are seasonal shortages in the supply of feedstuffs associated with time since the last harvest. In these countries, it is important for poultry producers to know how egg production and bird live weight respond to sub-optimal feed intakes.

One nutrient, water, without any doubt, is often forgotten (Perry, 1975; Lewis, 1978) or neglected (Qureshi, 1980; Hunton, 1986), because nutritionists and producers do not normally consider it when providing the bird, be it layer or broiler, with a balanced diet for maximum economic performance. From an economic point of view, perhaps because of its relatively low cost and ready availability in the majority of intensive poultry production areas in temperate climates, the concern with water intake has been much less than that with feed (Hill *et al.*, 1979; Gleaves, 1989). In fact, birds in those areas are normally provided with a continuous supply of water (McDonald *et al.*, 1988).

Nevertheless, water availability can be a serious limiting factor to animal production in some hot-dry areas of the tropics (Macfarlane, 1968; Payne, 1969). Satisfactory watering in those areas represents a fundamental requirement for good productivity and health in poultry flocks (IEMVPT, 1983), although as yet data are not available on the effects of various levels of water deprivation on productivity. An example of those areas is evident in West Timor, Indonesia, where the author lives and the availability of water for poultry (and other animals) is severely limited during eight months of the annual dry season (April - November; for reviews, see Ormeling, 1956; Fox, 1977; Barlow *et al*, 1990). From a research point of view, as Bailey (1990) stated, although there has been extensive research on the factors affecting water intake, researchers have concentrated on the practical aspects of diet and environmental temperature rather than on water intake. The current work was undertaken to redress this imbalance.

Since there is little information on the practical application of choice feeding to laying poultry in a single trough (see Emmans, 1979; Cumming *et al.*, 1987; de Guzman, 1992 for reviews) and there is no information on the effects of restricting the feed intake of layers on a daily-fed basis, nor on the effects on productivity of graded levels of water restriction, each of these aspects will be examined experimentally in this thesis. Of the three, choice feeding from a single feeder was considered to have the most immediate, and widespread application, and it thus became the focus of the current work. Before proceeding to a description of the experiments, the relevant literature will be reviewed.

Chapter 2

REVIEW OF LITERATURE

2.1. Feed intake of laying hens.

The feeding of laying hens has not given rise to many problems, but to feed layers economically is a real challenge to many poultry producers, and one that can only be met by strict attention to daily feed intake (Bell, 1993). In general, most laying hens are fed complete diets on an *ad libitum* basis, so there is little fluctuation in intake on a daily basis (Leeson and Summers, 1991). Modern hybrid laying birds in the temperate climates (16 - 24 °C) consume an average daily intake of about 110 g/bird (Feltwell, 1992; NRC, 1994).

According to Leeson and Summers (1991), a knowledge of feed intake in laying hens, and the factors that influence it, are therefore essential for any feed management program. Scott *et al.* (1982) listed twelve factors which may influence feed intake in laying hens. They are: (1) size and breed of hen; (2) environmental temperature; (3) stage of production; (4) housing (cage or floor pens); (5) feeding space per hen; (6) depth of feed in automatic feeders; (7) whether or not the hens are properly debeaked; (8) degree of crowding of hens in cages (and in floor pens); (9) availability of ample cool, clean drinking water; (10) disease level in the flock; (11) energy content of the diet; and (12) amino acid content of the diet. As regards environmental temperature, high ambient temperatures of a tropical climate commonly reduce feed intake. The high ambient temperature decreases the need for metabolic energy, and hence causes a decrease in feed intake (Vohra, 1982).

When feed intake falls due to high temperature, nutrient supply may not be sufficient for the hen to maintain her daily nutrient requirements for optimal production, and thus it will be reflected in reduced egg production (Payne, 1967). In the tropics, where day-time temperatures in the "dry" season in excess of 28 °C are common, it may be very difficult to ensure an energy intake which will enable the hen to maintain high egg production (Bushman, 1979).

In other words, the energy intake mechanisms of the laying hen are certainly sensitive to environmental temperature because daily feed intake by laying hens has been shown to decline as environmental temperature is increased (Wilson, 1949). The drop in feed intake as temperature increased was estimated by Payne (1966a) to be a 1.5 % reduction in consumption for each degree rise between 21 and 30 °C and a 4.6 % decrease/degree between 32 and 38 °C.

It is essential to compensate for the inevitable reduction in total feed consumed at high environmental temperatures (Sainsbury, 1984). Many of the deleterious effects of high environmental temperature over 30 °C appear to have been at least partially overcome by implementation of appropriate feeding practices which enable the hen to ingest an adequate level of the essential nutrients required for egg production (Charles, 1978; Bushman, 1979; Hargreave, 1982).

The suggestion is that diets for use in tropical climates should contain more protein, vitamins and Ca than normal diets in temperate zones, in order to ensure that sufficient of these nutrients are consumed in the lower total feed intake at high environmental temperature (Smith, 1973; Vohra, 1982).

From a nutritional point of view, the diets used to feed hens in high environmental temperature may be enhanced by supplying adequate, but not excessive levels of protein having a good balance of amino acids (Austic, 1985). Charles (1984) also suggested that in an optimal environment the first limiting factor for egg production is dietary protein.

This suggestion is supported by the data of Bray and Gessell (1961), who housed hens under constant temperature environments of between 6 and 30 °C. In these experiments it was shown that provided a hen's daily intake of 15 g of high quality protein contained 0.5 g of the sulphur-containing amino acids methionine and cystine, egg production was not affected at all environmental temperatures in the range, even though feed intake varied between 120 g/bird/d at 6 °C, and 90 g/bird/d at 30 °C.

When the hens were fed on a diet containing 26.5 % CP and 6.3 % Ca, egg production was not adversely affected up to 32 °C (Smith and Oliver, 1972), although the hens experienced a considerable initial loss in body weight due to a low energy intake. Therefore, the decline in egg production at high environmental temperatures was not necessarily due to environmental temperature *per se*, but may have been due to inadequate intake of certain essential nutrients in the diet (Payne, 1966a; Smith, 1973; Vohra, 1982).

Another suggestion is that a choice-feeding system is probably a valuable tool to help in solving the problem of the decreasing nutrient intake experienced by laying hens in the hot environments of the tropics (Charles, 1978; Mastika and Cumming, 1985; Cumming and Hill, 1993). The rationale behind the system is to try to use the ability of the bird to meet specific nutrient requirements (Summers and Leeson, 1979; Wilson and Emmans, 1979; Appleby *et al.*, 1992).

Economically, the use of choice feeding which involves dietary self-selection requires less processing of the feed (Petersen, 1976) and may result in a reduction in feed costs (Karunajeewa, 1978a; Kiiskinen, 1987; Tauson *et al.*, 1991). This being the case, choice feeding is of particular potential importance to small poultry producers in developing countries, especially in

South and South-east Asia (including Indonesia), who do not usually have ready access to chemical analyses of the raw ingredients offered to the birds, and who thus do not need to use a home mixing plant (Cumming *et al.*, 1987). As most poultry in Indonesia are kept by small-holding farmers (Soehadji, 1992), the practice of choice feeding has been chosen as an area for study in the current work.

In practice, poultry can generally be managed on six different feeding systems, depending on experience and the feed available. They are: (1) dry mash *ad libitum*; (2) dry mash and grain; (3) wet mash; (4) wet mash and other feeds; (5) choice feeding; and (6) restricted feeding (Feltwell, 1992). Among these feeding systems, the simplest and most foolproof approach to feeding layers is to feed a complete all-mash laying ration *ad libitum*. It is less complex, adaptable to mechanical feeding, and provides a more nearly balanced diet for the birds. It has however a disadvantage when intake declines at high temperature. It is also probably wasteful (Mercia, 1990; Smith, 1990).

In many poultry production systems, until recently, it has been normal practice to offer layers feed *ad libitum* (Payne, 1967; Smith, 1973; Slennett, 1976; Wilson and Emmans, 1979; Robinson and Sheriden, 1982; Leclercq *et al.*, 1984; Sainsbury, 1984; North and Bell, 1990). The practice of feeding layers *ad libitum* was based on the assumption that feed consumption is linearly related to egg production (Smith, 1973; Rayton and Hull, 1979; Robinson and Sheriden, 1982).

Contrary to these beliefs, results of experiments with laying hens by Balnave and Jackson (1973) showed that feeding under *ad libitum* conditions resulted in declining levels of egg production as feed intake approached the appetite level. These workers found that increasing the weight of feed offered daily significantly increased the weight of feed consumed, but had no significant effect on body weight, egg production or total egg weight.

Over-consumption is greater in heavy-bodied than light-bodied hens. The control of feed intake of light-bodied laying hens is very precise and they adjust to considerable variation in the energy levels in the diet and are able to maintain their daily intake of energy at a virtually constant level. Heavy-bodied birds, on the other hand, will consume more energy on a high energy diet than on a low energy one and thus they become obese (Morris, 1968; Smith, 1990).

Sykes (1972), Kari *et al.* (1977) and Bennett (1978) each suggested that hens fed *ad libitum* consume more energy than is required for body weight maintenance and egg production. The excess energy is deposited as fat, especially in the abdomen, which tends to increase body weight and add to the maintenance energy requirements, even though fat requires less energy per unit weight for maintenance than muscle.

Indeed, laying birds over-consume energy with high energy diets (i.e. > 11.9 MJ ME/kg; Sainsbury, 1984), and they will have difficulty maintaining normal energy intake when diets of less than 10.4 MJ ME/kg are offered (Leeson and Summers, 1991). In their study of the significance of adiposity in egg-type pullets, for example, Neill *et al.* (1977) found that obese hens utilised feed for egg production less efficiently than normal hens, and produced fewer saleable eggs. Working with broiler breeder pullets, Lilburn *et al.* (1987) and Robbins *et al.* (1988) both also found that hens fed *ad libitum* during lay had significantly more abdominal and carcass fat and became poorer producers of eggs than hens restrictedly fed. Excessive fat accumulation has been shown to be associated with high mortality in laying hens by Singsen *et al.* (1958) and Hannagan and Wills (1973). For these reasons, it is now recognised that offering feed *ad libitum* is a wasteful process (Pym and Dillon, 1974; Balnave, 1978).

In contrast, obesity in heavy-type laying hens could be reduced by controlling feed intake and dietary energy density (Singsen *et al.*, 1959).

These workers found that the physical restriction of feed intake, without creating nutritional deficiencies, improved feed conversion, reduced obesity and mortality, but did not affect egg production.

Snetsinger and Zimmerman (1974) also found that laying hens are prone to consume feed in excess of requirements and that it is possible to restrict energy intake by up to 10 % without adversely affecting performance. In view of these potential economic advantages, it was an aim in the current work to study the short-term physical restriction of feed intake in laying hens.

2.2. **Choice feeding**.

In the early days when the poultry industry was less intensive (e.g. before the 1940's), a common method of feeding layers was to provide a selection of feeds, either together or at different times of the day, from which the bird selected its diet (Hearn, 1979). This so-called "choice feeding" (self-selection), as applied to poultry, generally means that the bird is free to choose simultaneously from two or three components (split-diet) and compose its feed ration according to individual preferences and requirements (Emmans, 1975, 1977 and 1982; Karunajeewa, 1978a; Hughes, 1984; Kiiskinen, 1987; Leeson and Summers, 1991; Rose and Kyriazakis, 1991).

For this reason, Leeson and Summers (1991) concluded that choice feeding offers an interesting alternative to a complete laying diet. It may permit the hen to do a better job of meeting her daily cyclic requirement for nutrients as compared to the complete or single diet where, for example, she may have to consume extra energy and protein in the afternoon when she has a specific appetite mainly for Ca.

Added to this, there are two reasons for interest in choice feeding as a possible practical system for laying hens:

(1) Nutrient requirements (expressed as a percentage of the diet) vary between and within flocks due to differences in feed intake and egg output, and as a consequence, diet formulations based on the average nutrient requirements of a flock could result in potential high-producers being under-supplied with nutrients while poor layers would be over-supplied. Choice feeding would allow each hen to balance her intake of nutrients in relation to her metabolic needs.

(2) Since cereals constitute the bulk of a layer ration, feeding them in the form of whole grain would lead to some saving in fuel and the associated costs of milling and mixing (Emmans, 1975, 1979).

Historically, there has been interest in the free choice feeding of poultry since the early part of the 20th century when Kempster (1916) and Rugg (1925) observed that laying hens fed in this way produced more eggs than those fed a single feed, and that White Leghorns could balance their own diets. It was confirmed in the 1930's that birds could select a balanced diet from several otherwise imbalanced nutrient sources (Funk, 1932; Graham, 1934; Dove, 1935), and the feeding of energy (cereals), protein, mineral and vitamin supplements on a free-choice basis to poultry was popular until the late 1950's (Karunajeewa, 1978b).

In 1963, however, Ewing reported that the popularity of the all-mash system appeared to be increasing, possibly because of the saving it afforded in labour during feeding and as a result of the increased use of automatic feeders. This change has come about partly because complete diets are easily handled and because less skill is required in feeding (detailed nutritional decisions are taken by the feed miller), but later authors agree the main factor was automation of the feeding system (Karunajeewa, 1978b; Summers and Leeson, 1979). Consequently, previous feeding systems involving whole grain had largely been abandoned in favour of the all-mash (complete diet) form for intensive poultry production by the 1970's (Blair *et al.*, 1973; Karunajeewa, 1978b; Kiiskinen, 1987).

Since that time, however, free-choice feeding has received increasing attention, and this is partly due to the consistent increase in cereal grain prices and fuel-energy costs, which have highlighted the need for a feeding system that will minimise feed and processing costs without decreasing the output of either eggs or poultry meat (Karunajeewa, 1978b; Emmans, 1979; Hearn, 1979; Cumming *et al.*, 1987; Belyavin, 1994). From the economic point of view, the use of whole grains in choice-feeding systems 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). On top of that, each bird offered nutrients by choice feeding would hopefully select the optimum amount of each to satisfy its own requirements, and this increase in efficiency would represent an additional saving (Emmans, 1979; Hearn, 1979; Belyavin, 1994).

2.2.1. **The bird's ability to choose.**

The majority of animals in the wild are able to select a diet most suited to their needs by choosing between a wide variety of available feedstuffs (Rozin, 1976; Krebs and Davies, 1981). Under natural conditions wild birds are faced with an array of different feeds which vary widely in nutritional composition (as with source, season, stage of maturity, etc.); from these they are capable of selecting a diet which is adequate for their requirements (Summers and Leeson, 1979; Wilson and Emmans, 1979; Appleby *et al.*, 1992).

It has been claimed that the Red Jungle Fowl (*Gallus gallus*) of South-east Asia, which is considered to be the origin of modern domestic poultry as well as of native chickens, popularly known as 'ayam kampung' or village chickens (*Gallus domesticus*; Morris, 1974; West and Zhou, 1989; Smith, 1990; Anonymous, 1991), clearly demonstrates an ability to select and regulate its diet in natural situations to meet its requirements for growth, production and reproduction. Indeed, the wild ancestors of modern (hybrid) chickens possessed an ability to select nutrients appropriate to their requirements in a variety of environments, both tropical and temperate (Mastika, 1987; Shariatmadari and Forbes, 1993).

Under total self-selection, animals are allowed to regulate their ingestion of a wide variety of feedstuffs, which can be classed as either isolated nutrients or naturally occurring but incomplete feeds (Overmann, 1976). Hughes (1984) and Rose and Kyriazakis (1991) have reviewed diet selection in poultry, and report that since the early 1980's the evidence is strong that domestic birds, offered a range of different feedstuffs, have the ability to choose a diet which provides them with all the nutrients necessary for growth, maintenance and production.

In the selection of feed by birds, visual stimulation evidently plays a major role and feed preferences are clearly recognised (Fraser and Broom, 1990). Poultry have considerably better vision than swine, and depend upon it extensively in feed seeking (Moran, 1982). Considering the acuity of forward visual depth perception in poultry, it is not surprising that differing feed-particle sizes can be easily identified. Undoubtedly, this ability is important in feed selection, a fact that was confirmed by Hughes and Wood-Gush (1971), who showed that when birds were denied visual cues they were unable to identify or select the appropriate feedstuffs. Thus, domestic fowls 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.

2.2.2. **Effect of choice feeding on the bird's performance.**

Feed selection in the laying hen can be very precise; selective preference tests have shown that the bird has specific appetites for such major essential nutrients as energy (Hill *et al.*, 1956), protein (Graham, 1934; Holcombe *et al.*, 1976) and Ca (Hughes, 1972; Mongin and Sauveur, 1974; Holcombe *et al.*, 1975) Dove (1935) clearly demonstrated the precision of this mechanism with chicks that consumed an almost perfectly balanced diet when offered a free choice of several ingredients (Table 1). These reports implied that a major advantage of dietary self-selection would be to enable the hen to meet the essential nutrient requirements related to her physiological status and level of egg production.

Table 1. Dietary self-selection by chicks.

Feed ingredient offered free-choice	**Intake (As % of total)**	**Nutrient content of ration**
Yellow maize	52.8	CP 17.9 %
Oat meal	8.9	ME 11.42 MJ/kg
Wheat bran	21.3	Ca 1.3 %
Fish meal	11.4	P 1.1 %
Bone meal	2.9	
Dried skim milk	2.1	
Oyster shell	0.6	

(After Dove, 1935)

In the choice situation, laying hens consume nutrients according to their needs. Chah and Moran (1985) have demonstrated that laying hens allowed to choose from diets varying in energy, protein and Ca show a daily variation in nutrient selection directly related to the stage of egg development. Diurnal variation in feed intake by laying hens was found by Wood-Gush and Horne (1970) to be directly related to both egg formation and lighting pattern. Feed intake is highest in the early morning and during the late afternoon, probably related to an empty digestive tract in the morning and the need in the afternoon to satisfy a specific hunger for Ca and to prepare for the period of feed deprivation during the daily dark period.

Many studies have been reported on the effect of choice feeding on performance of laying hens, but the results are controversial. Among those studies, Leeson and Summers (1978) found that hens allowed to choose between a high-energy, high-protein diet and a low-energy, low-protein, high-Ca diet laid as well as those offered a complete diet. On the basis of other treatments which restricted the times of day when the high-Ca diet was available, they found that the high-Ca diet was eaten preferentially by the birds in the afternoon. In this short-term study, Leeson and Summers also found that birds offered a choice of diets *ad libitum* consumed 6.7 % less feed in total than did control birds receiving a conventional diet.

When offered a Ca source, birds also ate less feed overall than those fed a single conventional diet (Table 2). Leeson and Summers (1979) fed two diets to hens in feed troughs that were partitioned down their length, and reported that there was increased weight gain with the free-choice group even though egg production was similar and feed intake reduced. The reduction in voluntary feed intake noted was thought to be associated with a specific appetite for Ca in relation to the needs for shell calcification.

Leeson and Summers concluded that laying hens fed on a choice of diets based on Ca consumed 7.0 % less feed than those fed on the complete diet, while maintaining adequate performance. Emmans (1977) found that choice-fed hens had egg outputs not significantly different from those given a complete ground-barley based diet despite a reduced intake of nutrients.

Table 2. Performance of Leghorn hens fed a control corn - soyabean laying diet or when choice-fed (20 - 40 weeks).

Parameter	Choice feeding	Control diet	Level of significance
Feed intake (g/bird/d):	110.7	118.4	**
ME intake (Kcal/bird/d):	331	301	**
Protein intake (g/bird/d):	18.7	20.2	**
Ca intake (g/bird/d):	4.1	3.6	**
Egg production (%):	79.3	79.2	
Egg weight (g):	61.5	60.8	**
Egg shell deformation (μm):	21.9	22.3	*
Body weight (g) :			
- Week 1	1640	1620	
- Week 20	1792	1744	
- Week 40	1929	1829	

*, $P < 0.05$; **, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$; after, Leeson and Summers, 1979).

Karunajeewa (1978a) offered layers complete mash diets, either barley- or wheat-based, or a choice between the whole grains and a 31 % protein-concentrate mixture. Birds receiving barley, whether incorporated in the mash or as whole grains, laid less well than those receiving wheat. However, the hens receiving a choice laid as well as those on a complete diet (both groups averaging a rate of lay of 70 % over 25 weeks on a hen-day basis), and consumed 11.0 % less feed overall.

Blair *et al.* (1973) also showed that laying hens ate 6.7 % less feed when given cereal grain, a 41 % protein-concentrate pellet and oyster-shell grit in the ratio 70 : 23 : 7. Their egg output was similar to that of hens given the conventional mash diet (74.5 vs 74.8 %). However, when the Ca supplement, in the form of ground limestone, was incorporated in the concentrate and fed to the hens in the afternoon and the cereal grain given in the morning, there was an increase of 7.9 % in total feed intake. This result indicates that the hens should be able to select the Ca supplement separately from the other dietary components or else they would over-consume other nutrients in trying to satisfy their requirement for Ca. These same workers, nevertheless, did not measure separately the intake of grain, protein pellets and shell grit. Thus, it is not known whether the reduction in feed intake on the grain-concentrate-grit regime was due to the hens eating less of one or all three components of the diet.

In contrast, caged hens offered a choice in a split trough, with a whole grain/crushed pea mixture in the trough nearer to them and a protein balancer further away, gave good results (Tauson *et al.*, 1991). The birds produced a greater egg mass but ate more feed, so the feed conversion ratio was slightly poorer.

It is clear from the current review that egg production is not always increased by choice feeding, but that there is convincing evidence that birds offered a choice between diets generally perform or lay as well as those given a single complete diet. The reasons for some of the conflicting results reported may be related to the use of different grains, strain of bird, source of Ca, period of training to choice feeding, structure of feed and feeding techniques, feed trough installation (Tauson *et al.*, 1991; Roberts *et al.*, 1995) and environmental temperature (Blake *et al.*, 1984; Scott and Balnave, 1985, 1988, 1989 and 1991).

2.2.3. **Economic advantages of choice feeding.**

Since feed still represents the major cost (70 %) of production for most classes of poultry (Behrends, 1990; Leeson and Summers, 1991), many efforts have been made to reduce feed costs and increase the efficiency with which birds convert feed to eggs and meat. Among these approaches, free-choice feeding of unground grain and protein-concentrate mixture is one of the alternatives which may have application, as 50 - 75 % of a modern complete diet consists of grain (Summers and Leeson, 1979; Parkhurst and Mountney, 1988; de Boer and Todorov, 1991).

As a matter of fact, as the grinding process requires 20 kW h/tonne of grain, while processing feeds to pellets requires another 20 kW h/tonne of feed, plus the energy expenditure for the steam generation necessary for these procedures (Petersen, 1976), the use of whole grains will save the considerable energy used for grinding and pelleting (Karunajeewa, 1978a). Thus, a choice-feeding system may be economically favourable to farmers who have access to inexpensive cereal grains and a suitable protein concentrate (Tauson *et al.*, 1991), and who thus do not need to use a grinding machine (Blair *et al.*, 1973; Feltwell, 1992).

Emmans (1977) has also suggested that self-selected diets, reflecting the nutritional requirement of the bird, would have appreciable economic benefits by avoiding excessive intakes of expensive components of the diet. Holcombe *et al.* (1976) have shown that when layer chickens were offered a choice of diets with either low or adequate protein contents, they chose a higher proportion of the latter, whereas when the choice was between adequate and higher protein diets, they chose more of the former.

Rose and Kyriazakis (1991) and Forbes and Covasa (1995) claim that the major economic advantage of a choice-feeding regime in a commercial poultry system is through a reduction in the bird's protein intake. In their latest review, Forbes and Shariatmadari (1994) concluded that the three major possibilities for using choice feeding to benefit the economic efficiency of poultry production are: (1) its use on a small scale to find the mixture of feeds which best meets the requirements of birds so that these results can be used to formulate complete single feeds to be used on a large scale; (2) its use on a commercial scale to reduce feed costs and minimise nitrogenous waste; and (3) to extend the principles and practices worked out for protein to other nutrients and to discover the conditions under which diet selection can be successful when offering a choice of three or more feeds.

It seems probable, however, that choice-feeding system will only become financially attractive to large poultry enterprises at times when the cost of protein is high relative to the cost of energy (Rose and Kyriazakis, 1991). This is a situation which occurs regularly in the author's home country, West Timor, Indonesia because of both the high basic cost of protein supplements and the added costs of transporting them to Timor (a non-producer). For this reason, choice feeding has been chosen as an area for study in the work reported in this thesis.

2.2.4. **Effect of environmental temperature on choice feeding.**

The inverse relationship between environmental temperature and feed intake in laying birds fed complete diets is well documented (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 general, increasing the environmental temperature to above the thermoneutral range (i.e. 18 to 26 °C; Oluyemi and Roberts, 1979) depresses feed intake in laying hens given a single, complete diet. However, little is reported on the reaction of laying hens when they are offered a choice of diets in different environmental temperatures.

With self-selection feeding using a protein concentrate and a separate cereal-based, energy-rich mixture (Scott and Balnave, 1988), pullets showed an increased preference for protein just before sexual maturity. Protein intake increased from approximately 14 g/MJ of ME two weeks before sexual maturity to 21 g/MJ of ME at sexual maturity, presumably associated with an increase in egg protein output. The ratio remained relatively constant thereafter. Pullets at cold temperatures (6 to 16 °C) ate significantly more feed than those at hot temperatures (25 to 35 °C). However, the pullets maintained an identical protein : energy intake ratio at both temperatures, so that 4 weeks after the onset of egg production the pullets at cold temperatures actually consumed 30 g protein daily compared with 19 g daily for pullets at hot temperatures. Egg production from pullets self-selecting their feeds was higher than that from conventionally fed pullets at high temperatures, and similar at low temperatures. Self-selection feeding at the cool temperatures resulted in excessive protein consumption whereas at the warmer temperatures this feeding system gave substantial improvements in egg mass output and body weight gain compared with pullets fed on complete diets.

Kiiskinen (1987) studied the effect of choice feeding on the performance of laying hens at 17 °C. He fed 22-week-old White Leghorn hens (Strain SK 51) to 48 weeks of age according to one of the following four treatments: 1) a complete diet in pelleted form (15 % CP, 10.5 MJ ME/kg, 3.2 % Ca); 2) a choice between low Ca diet (16.1 % CP, 11.2 MJ ME/kg, 0.9 % Ca) and limestone grit; 3) a choice between diets which were widely different in each of protein, energy and Ca (7.2 vs 17.5 % CP; 7.7 vs 11.5 MJ ME/kg; 12 vs 0.5 % Ca respectively); and 4) a choice between a protein concentrate (37 % CP, 8.65 MJ ME/kg, 2.4 % Ca), whole grain (barley and oats in the ratio 80 : 20) and limestone grit. Kiiskinen concluded that choice feeding provides as good a production level as does a complete diet (Table 3). Self-selection improves feed and energy efficiency if there is a balance between the requirements of the birds and palatability of the alternative diets.

The effect of high temperature on feed selection by layers was studied by Blake *et al.* (1984). They suggested that if laying hens do have the ability to self-select diets to meet their nutrient requirements then the results could be used to demonstrate what diet would best meet needs at high temperatures. Over a 28-d period, thirty-two individually penned 34-week-old Hy-Line W-36 laying hens were offered three feeds (high in energy, protein or Ca) while kept at either 21 or 30 °C (Table 4). Blake *et al.* concluded that dietary self-selection did not enable hens to regulate nutrient intake for performance comparable to that of hens provided a balanced diet; in addition, laying hens were unable to overcome the detrimental effects (reduced egg number and weight, protein and energy intake) of high environmental temperatures by choice feeding.

Table 3. Performance of laying hens at 17 °C.

Parameter	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Level of Significance
Feed intake (g/hen/d):	137[ab]	130[a]	132[a]	145[b]	0.001
ME intake (MJ/hen/d):	1.44	1.34	1.36	1.41	
Protein intake (g/hen/d):	19.3[b]	18.3[a]	19.3[b]	24.9[c]	0.001
Ca intake (g/hen/d):	4.1[c]	3.9[b]	3.4[a]	4.9[d]	0.001
Egg production (%):	76.2	77.4	75.9	78.3	
Egg output (g/hen/d):	47.7[ab]	48.2[ab]	47.7[a]	49.8[b]	0.032
Egg weight (g):	62.6[ab]	62.3[a]	62.8[ab]	63.6[b]	0.012
Final body weight (kg):	2.00	2.00	2.03	2.05	

1- 4: Experimental treatments (see page 23). [a-d]: Means with a different superscript letter within a row are significantly different ($P < 0.05$). If no letters are used differences are non-significant ($P > 0.05$; after Kiiskinen, 1987).

Shariatmadari and Forbes (1993) have subsequently suggested that it is important to train birds to recognise the differences between diets or diet constituents by allowing them access to each one alone on alternate days so that the birds can learn to associate the sensory characteristics of each feedstuff and its nutritional value. Blake *et al.* (1984) did not provide for any such training in their experiment, and Mastika (1987) and Forbes and Shariatmadari (1994) suggest that this could be a reason for those birds being unable to successfully select favourable diets. More research is needed in this area; some has been undertaken by the current author.

Table 4. Performance of laying hens as affected by environmental temperatures and dietary treatments.

Parameter	Environmental temperatures (°C)	Choice feeding	Control diet
Feed intake (g/bird/d):	21 30	97.6^{a} 82.2^{b}	93.8^{a} 78.5^{b}
ME intake (Kcal/bird/d):	21 30	233.5^{a} 171.2^{c}	274.0^{b} 174.2^{c}
Protein intake (g/bird/d):	21 30	10.2^{a} 8.9^{a}	16.3^{b} 17.6^{b}
Ca intake (g/bird/d):	21 30	5.4^{ab} 6.3^{a}	3.3^{b} 2.7^{b}
Egg production (%):	21 30	60.1^{a} 67.8^{a}	88.4^{b} 83.9^{b}
Egg weight (g):	21 30	53.5^{a} 50.4^{b}	57.2^{b} 50.4^{b}
Egg shell breaking strength (kg/cm^{2}):	21 30	8.6^{ab} 9.2^{a}	9.7^{a} 7.6^{b}
Body weight change (g/d):	21 30	-2.03^{a} -7.03^{b}	- .03^{a} -6.34^{b}

a, b, c: Means within same parameter followed by different letters differ significantly ($P < 0.05$). If same letters are used differences are non-significant ($P > 0.05$; after Blake *et al.*, 1984).

2.2.5. **The number of containers required to present feedstuffs.**

As Tauson and Elwinger (1986) have reported, most choice-feeding experiments have been carried out basically from the point of view of poultry nutrition. Such work requires accurate measurement of feedstuffs offered and rejected, and as a result the research has mostly involved feeding by hand in either short lengths of troughing with internal dividers, or in small, separate containers (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). Among these authors, Karunajeewa, for example, reported greater efficiency in feed conversion, larger eggs, and lower protein, energy and Ca intakes in birds which were given a choice between protein-pellet concentrate, whole-grain and shell-grit components as compared with others on an all-mash diet.

From a practical viewpoint, however, such feeding techniques are very expensive (Forbes and Covasa, 1995) and unnecessary because birds have the ability to identify and pick up small, individual feed ingredients from a mixture (Cumming *et al.*, 1987; Mastika, 1987). In his review, Hochstetler (1992) considered that research could best be conducted using feeds and feeding systems that approximate good industry practice. Clearly work on choice feeding does not yet satisfy those requirements, which were based mainly on acceptance by industry. Hearn (1979) advocated the development of a modified trough fitted with separate hoppers to enable several feeds to be offered to birds simultaneously, but the additional costs involved have so far prevented a practical solution from being developed. As proposed in the present studies, an obvious, cheap and practical alternative is to apply choice feeding by offering the several feedstuffs mixed together in a single trough of the type currently used by the intensive industry.

The information on such a practical application of choice feeding is limited to the report of Cumming (1984). He conducted a trial involving 4000 laying hens of three different strains (WL x Australorp crossbred, commercial WL x New Hampshire cross and non-commercial cross WL x New Hampshire) to compare the performance of birds from 1 d-old choice feeding on whole wheat and protein-pellet concentrate with that of similar birds on complete commercial rations. Half of the birds of each strain were fed the commercial laying ration (17 % CP) and the other half were choice-fed whole wheat and protein concentrate in pellet form in a single trough. Oyster-shell grit was provided on the top of the feed in both feeding regimes. When the birds were eleven months of age, the grain was changed from whole wheat to whole sorghum over a 13-d period. Cumming reported that the egg production and both the number of eggs and number of large eggs from choice-fed hens were as great as from the complete-fed ones. The choice-fed birds were marginally more efficient in converting their diet than those fed the complete diet.

The main reason for this lack of information on choice feeding under a practical feeding regime is probably related to technical difficulties in the separation (for measurement purposes) of the feed refusals. Hence, exploitation of the concept of choice feeding in the field is more difficult because of the technical problems of presenting the different feeds in a way which allows the hens to express their preferences (Emmans, 1979; Fisher, 1983).

For these reasons, numerous workers (e.g., Blair *et al.*, 1973; Karunajeewa, 1978b; Emmans, 1982; and de Guzman, 1992) have highlighted the need for technical development of feeders for practical application of choice feeding to laying poultry It has been suggested that application of choice feeding on a commercial scale is possible but needs considerable research and development, especially to help in the understanding of the causes of individual variation which might simply be a reflection of different requirements for energy and protein (Forbes and Shariatmadari, 1994). For layers, de Guzman (1992) and Hochstetler (1992) suggested that choice feeding commercial layers requires joint attention from nutritionists, animal behaviourists and agricultural engineers to develop the necessary equipment.

However, in many small-holder situations (in both developed and developing countries) the availability of labour suggests that a simple, manually-filled trough would suffice, at least in the initial stages of development. The study reported in this thesis was thus based on such a system. To accommodate the need (in research) to separate and weigh the individual feed refusals, a set of sieves with appropriately graded apertures was developed and used. The main aim of the study reported was to examine the effects of environmental temperature on the ability of hens to meet their requirements by self-selection from a single feeder. The basic hypothesis was that as ambient temperature rises, the hens' energy intake (i.e. whole grain) would decline, and that her intakes of protein pellets and Ca would be maintained.

2.3. **Feed restriction**.

Since feed input represents an average of 70 % of variable production costs in most systems of poultry production (McMahon *et al.*, 1974; Lee, 1977, Elson, 1979; Wilson and Emmans, 1979; Behrends, 1990), it is accepted in the poultry industry that tight control over feed input is required. This control over feed input to the production system is maintained directly by the use of feed restriction (Wilson and Emmans, 1979).

A similar suggestion is made by Robinson and Sheriden (1982), who concluded that any increase in the cost of feed emphasises the need to minimise the consumption of feed by all types of livestock. In general birds, and indeed all livestock, tend to consume rather more feed than they need, a tendency which prevents them from producing as efficiently as they should (Sainsbury, 1984). Balnave (1978) pointed out in his review that a considerable amount of effort had been devoted during the preceding decade to studying and developing practical methods of restricting the feed intake of poultry. This has proved very successful in that it is now recognised that to offer birds *ad libitum* feed is a wasteful process (Pym and Dillon, 1974; Balnave 1978)

Thus, the research on the restricted feeding of poultry has become increasingly relevant in more recent years (Mbugua and Cunningham, 1983; Wilson *et al.*, 1983). Economically, any research that is successful in reducing the feed intake-egg production ratio of laying hens has the potential to produce significant savings for egg producers (Hurnik *et al.*, 1977). The literature relating to the practice of controlling the feed intake of poultry has recently been reviewed by Gleaves (1989). He pointed out that feeding on a limited basis is a nutritional approach that uses feed intake principles to more accurately supply the birds' nutrient needs.

The practice of limiting feed intake is synonymous with the term "feed restriction" as applied to birds and is usually interpreted to mean an actual restriction of nutrient intake by the birds for optimum performance in order to achieve a desirable goal such as improved efficiency of feed utilisation for egg production (Singsen *et al.*, 1959). The use of some form of feed restriction in various types of poultry production has been a common practice for many years (Wilson and Emmans, 1979; Pinchasov and Jensen, 1989). The means used to restrict intake included limiting the bird's time of access to feed, *ad libitum* feeding of a low energy diet, *ad libitum* feeding of a protein-deficient diet, intermittent lighting and restricting the quantity of feed offered (Lee *et al.*, 1971a; Balnave, 1973; Robinson, 1976; Washburn and Bondari, 1978).

In addition, according to Adams (1981), one form or another of limiting feed intake is used extensively to "force moult" laying hens. The method most often practised with commercial layers employs feed withdrawal for 10 d followed by a recovery period in which a low-protein ration (often cracked grain) is fed for about 3 weeks. Pope (1962, cited by Ewing, 1963) demonstrated the effectiveness of a forced-moult program as a means of consistently improving peak production, length of production and egg quality, which he attributed to the reproductive rest of the birds. Indeed, the practice of physically restricting feed intake to overcome the problem of over-eating in poultry has been popular since the late 1960's (Gleaves, 1989). Numerous reports have appeared during the last twenty years relating to the effect of restricted feeding of chickens during both the growing and laying periods (see Lee *et al.*, 1971a; Balnave, 1973; Robinson, 1976; Balnave, 1978; Pearson and Shannon, 1979; Leclercq *et al.*, 1984 for reviews).

The major aims of these investigations on hens were to reduce feed costs by restricting feed, without loss of productivity, and to prevent excessive increases in body weight resulting from fat deposition. In fact, restriction in the laying period by as little as 6 % of *ad libitum* feed intake was found by McMahon *et al.* (1974) to be more profitable than no laying restriction, and this increased profitability was further enhanced if the birds were also restricted during growth. Without any doubt, feed represents the major, and ever-increasing, cost item in the production of eggs (Hurnik *et al.*, 1977; Kari *et al.*, 1977), and one which is influenced by increasing prices of feed ingredients (Behrends, 1990). With feed prices rising rapidly in most countries, it is an attractive proposition to cut down the amount of feed consumed by layers to reduce feed costs (Best, 1974); savings of up to 16 % can be achieved without a substantial reduction in egg production (see Anonymous, 1971 for review). The potential for feed cost savings in layers is greater in the heavier strains than in the lighter ones (Sainsbury, 1984).

Restricted feeding of layers instead of allowing them to eat *ad libitum* may mean fewer or smaller eggs, but if prices for eggs are comparatively low while those for feed are high, the loss of egg income may be small in relation to the savings achieved in feed cost (Best, 1974). This is one way in which the egg industry in the USA has been able to compensate for increasing feed costs (Horn, 1988). According to Horn, who studied the latest developments in layer-farm management and cost analyses under commercial conditions in the USA, restricted feeding of layers is a profitable management practice in that country when feed prices are high and egg prices are low.

As well as reducing feed costs, restricted feeding in the laying period may improve laying performance (McMahon *et al.*, 1974; Robinson, 1976; Leclercq *et al.*, 1984). These advantages include healthier birds late in the laying period, a longer period of lay, lower mortality, reduced risk of an early rapid decline in the rate of lay, prevention of fatty liver haemorrhagic syndrome and greatly increased resistance to heat stress. Another advantage, the prevention of the so-called 'wet-droppings' problem, is reviewed by Robinson (1976), who reports that feed restriction invariably results in an increase in the dry matter content of layers' droppings. Early reports by McFarland (1965) with Barbary doves, and Anderson and Hill (1968) with laying hens, indicated that birds drink less when their feed intake is restricted; that too could help reduce the incidence of wet droppings.

Sherwood (1959) reported cases of improved efficiency of feed utilisation as a result of restricting feed intake; this effect apparently being the result of lowered feed wastage (Sherwood and Milby, 1961). Connor *et al.* (1977) confirmed that restricting the bird's intake during lay gave additional improvements in feed efficiency over and above those produced by restriction during the growing period alone. Attempts have also been made to improve the nutrient utilisation of laying hens by restricting feed intake by either limiting the amount of feed offered or by restricting feeding time (Robinson, 1976; Gerry and Muir, 1976; Balnave, 1978; Sainsbury, 1984).

Gerry and Muir (1976) concluded that much of the research that had been done to that time was with heavy strains of hen (i.e. > 2000 g; Sainsbury, 1984). To date, relatively little effort has been put into studying the effect of feed restriction on hens with body weights less than 2000 g (Robbins *et al.*, 1986). An example of such a strain is the lightweight White Leghorn by Australorp crossbred (Robinson and Sheriden, 1982).

Although a considerable amount of work has been done with heavy strains, the results have been conflicting. Examples of these have been reported by the following authors. Thus, while Titus (1929) restricted the feed intake of White Leghorn hens and observed marked decreases in egg production, and Heywang (1940) reported that restricting feed intake to 87.5 or 75 % of the *ad libitum* level reduced egg production significantly by 32.5 % and 53.7 % respectively (but without effect on egg weight and body weight), Temperton and Dudley (1948) found that limiting feed intake to 90 % of that of a fully fed group resulted in no loss in egg production.

Singsen *et al.* (1959) also demonstrated that the physical restriction of feed intake, without creating nutritional deficiencies, improved feed conversion, reduced obesity and mortality. These workers restricted feed intake of heavy meat type

White Rock hens to approximately 84 % of *ad libitum* levels and found that restriction resulted in lower body weight gains but did not affect egg production. Similarly, Combs *et al.* (1961) reported that restriction of the feed intake of heavy-type hens to 81 and 87 % of *ad libitum* intake did not affect egg production and mortality. Walter and Aitken (1961) also found that feed restriction in the laying period had no influence on egg weights, while Sherwood *et al.* (1964) reported that feed restriction improved the fertility and hatchability of eggs. Auckland and Fulton (1973), citing data from Jalaludin (1969), showed a reduction in body weight, but no concomitant effect on either rate of lay or egg weight, when hens were restricted for a 3-week period. Al-Khazarji *et al.* (1970) restricted feed intake of laying hens to 97.5, 95, 90 and 85 % of *ad libitum* fed controls and reported lighter body weights.

Indeed, Jackson (1970), Peterson (1971) and Sykes (1972) have shown that medium weight hybrid and White Leghorn hens can have their feed intake restricted to approximately 75 % of normal *ad libitum* intake without the number of eggs produced by them being reduced. Jackson noted in his study that feed conversion efficiency was improved in the restricted groups. Polin and Wolford (1972) restricted feed intake by limiting the quality of feed given and by restricting feed time. Restricting feed intake to 80 % of the quantity consumed by the control group or restricting feeding time to one 4-h period or two 2.5-h periods/d resulted in a significantly improved conversion of feed into eggs over that of full-fed controls.

Other researchers have also studied limited-time feeding programs. Bell and Moreng (1972) compared 10 min feeding periods every 4 h with *ad libitum* feeding in two trials. This limitation of feeding time resulted in a 20 % reduction in feed intake with a non-significant reduction in egg production in Trial 1 and a highly significant (9.4 %) reduction, in Trial 2. The conversion of feed into eggs was improved by 10 % in Experiment 1 and 5.5 % in Experiment 2.

Snetsinger *et al.* (1973) restricted the feeding time of nine producing strains and found that restriction to 94 % of the intake of full-fed controls gave a higher livability and improved feed efficiency with no loss in egg production. Andrews (1973) also found that limited-time feeding improved egg-shell quality. Watkins *et al.* (1973) reported that restricting the feeding time of layers did not affect rate of lay but feed utilisation was improved and feed consumption significantly reduced.

The reasons for these conflicting results may be differences in the strains and genotypes of birds used (Robinson and Sheriden, 1982). Similarly, restricted feeding in the laying period has produced diverse results, not only because of differences in the type of bird used, the feed restriction method, the extent of restriction, and the environmental temperatures in the experiments (MacIntyre and Aitken, 1959; Robinson, 1976; Kari *et al.*, 1977; Lee, 1987), but apparently also because of differences in a wide variety of other husbandry factors, e.g., housing system and feeder design (Robinson, 1976). In view of these potential advantages, conflicting reports and the limited information available on lightweight White Leghorn strain cross hens, the effect of short-term feed restriction on the utilisation of feed by laying hens requires further study.

2.4. **Water intake of laying hens**.

Water is one of the essential nutrients that must be supplied in adequate amounts for the laying hen to meet acceptable performance standards (Goan, 1977). It represents between 56 and 70 % of total body weight in the mature hen and may be as much as 75 % in the chick (Maynard and Loosli, 1969; Leeson *et al.*, 1976; Nesheim *et al.*, 1979; Ruckebusch *et al.*, 1991). Indeed, Medway and Kare (1959) found that the total body water content of the chick gradually decreases from 85 % at one week of age to about 55 % in the mature hen at 32 weeks of age.

Holroyd (1967), in a review of water requirements, pointed out that water is essential for the normal body functions of laying hens, acting as a spreading medium for digestive enzymes and nutrients, a transport mechanism, a physiological temperature regulator and metabolic activator. Emphasising the importance of water, Scott *et al.* (1982) in their review of the literature concluded that hens are able to survive much longer without feed than without water. Thus, the average survival time of producing hens at an ambient temperature of 29 °C was 6 d without both feed and water, 10 d without water but with feed and 38 d without feed but with water (Bierer *et al.*, 1965a).

When the effects of water deprivation were compared in productive and non-productive hens at an ambient temperature of 14 °C, Bierer *et al.* (1966a) found the average survival time to be 8 d for the former and more than 23 d for the latter. Gee and Huston (1965) also reported that the average survival time of White Leghorn hens consuming feed but not water was 22 d when at 9 °C and 11 d at 30 °C, whereas without feed but with water it was 39 d at 30 °C.

Generally speaking, the survival time of chickens at 42 °C has also been positively correlated with the persistency with which birds continued to drink (Fox, 1951). Therefore, an adequate supply of water is important for optimum productivity and well-being in laying hens (Gernat and Adams, 1990). Various workers (e.g., Leeson *et al.*, 1976; Hill *et al.*, 1979; NRC, 1981; Scott *et al.*, 1982) who have reviewed the available literature, report that the total water intake of laying hens is obtained from three sources: (1) drinking water or free water, (2) feed water or water contained in feed and (3) metabolic water.

2.4.1. **Drinking water**.

Most of the water intake of hen comes from the drinking water; this is in contrast to other animals that eat a very succulent diet (Medway and Kare, 1959). This water represents about 75 % of the total daily intake (NRC, 1981). Under normal conditions, according to Medway and Kare (1959), a week-old chick drinks about 27 ml/d ($^{\phi}$). This increases steadily so that in a 32-week-old laying hen, the

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$^{\phi}$ Water intake is normally expressed as ml/bird/d when free water is involved, and g/bird/d when the reference is to metabolic water derived from feed. Throughout this thesis, ml has been adopted as the standard measure of water intake, and where appropriate, other units quoted in the literature have been converted to ml on the basis of 1 g = 1 ml).

intake is about 480 ml/d. The drinking water intake of laying hens has been reported by a number of workers over many years (e.g., Heywang, 1941; Dixon, 1958; Medway and Kare, 1959; Kendler and Taylor, 1966; Lintern-Moore, 1972; Raffel *et al.*, 1976; Okumura *et al.*, 1977; Vo and Boone, 1977; Savory, 1978; Van Kampen, 1981a; Gernat and Adams, 1990). The results of these workers indicate that there is a wide variation in the water intake of layers, with mean values ranging from 169 to 483 ml/bird/d (Table 5).

The differences between the drinking water intakes observed in the above trials may be due to such factors as genotype, age of bird, body weight, feed intake and environmental temperature. Thus, Hillerman and Wilson (1955) reported there were significant differences ($P < 0.01$) between breeds in the water intakes of White Leghorns, Jungle fowls, and a group of heavy-breed hens (i.e. New Hampshires and Barred Rocks). At the level of strains within breeds, Malik (1965), Hill and Powell (1977) and Bordas *et al.* (1978) have all reported significant differences. Malik, for example, examined three inbred strains of commercial laying stock, and although he reported significant differences in water intake, he did not present any data or statistical detail. Hill and Powell (1977) similarly reported differences in water intake between a brown and a white strain of laying hen.

Within breed, strain and individual, variation in drinking water has also been extensively investigated by Bordas *et al.* (1978), who found, for example, water/feed intake ratios varied from 0.5 to as high as 4.5/1. With regard to age, Medway and Kare (1959) found that the water intake of White Leghorns gradually increased from about 27 ml/chick/d at one week of age to about 480 ml/hen/d at 32 weeks. However, body weight would be expected to increase from about 60 g to at least 2000 g over the same age span. Expressing water intake on a body weight basis, the 1-week-old chicks of Medway and Kare (1959) can be calculated to have consumed an average of 0.43 ml/g body weight, whereas the 32-week-olds consumed only 0.24 ml/g body weight. These figures indicate, in fact, that young chickens drink more, on a body-weight basis, than older ones.

Nesheim *et al.* (1979), Scott *et al.* (1982) and Ruckebusch *et al.* (1991), have reviewed the available literature and report that younger birds also have a greater proportion of body water than mature birds (e.g. 85 % in the chick compared to 55 % in the mature bird) and the fact that most of the decrease in water content of the chicken's body as it grows is replaced by fat.

Table 5. Daily water intake of laying hens.

Reference	**Stock**	**Age**	**Body weight (g)**	**Mean free water intake (ml/bird/d)**	**Mean free water intake/body weight (ml/g)**
Vo and Boone (1977)	White Leghorn	30 - 36 months	1,717	168.8	0.10
Okumura *et al.* (1977)	White Leghorn	6 months	*	189	*
Gernat and Adams (1990)	White Leghorn	10 - 70 weeks	*	192.4	*
Savory (1978)	Brown Leghorn	12 - 18 months	*	214.6	*
Heywang (1941)	White Leghorn	1st year of lay	1,556	227	0.15
Van Kampen (1981a)	White Leghorn	1 - 2 years	*	243	*
Kendler and Taylor (1966)	Rhode Island Red	2 - 2.5 years	*	257	*
Lintern-Moore (1972)	Brown Leghorn	2nd year of lay	2,017	312	0.15
Dixon (1958)	White Leghorn	1 year	1,607	334	0.21
Raffel *et al.* (1976)	White Leghorn	1 year	*	337.2	*
Medway and Kare (1959)	White Leghorn	32 weeks	2,035	483.5	0.24

(*) Data not available.

Feed intake is one of the most important factors which affect water intake (Hill *et al.*, 1979). Dixon (1958) and Ibarbia (1968) found that under *ad libitum* conditions the quantity of water drunk by hens is related to the amount of feed eaten. Hill and Powell (1977) also indicated that there is a close relationship between feed and water intake in the hen, but the quantitative relationship between the two variables differs substantially between birds. In other words, hens consume about 1.5 to 2.3 ml of water for every g of feed consumed during the laying period (Medway and Kare, 1959; Mongin, 1976; Scott *et al.*, 1982). Duke (1986), in his review, concluded that as less feed is consumed, less water is drunk, except when the ambient temperature is high.

It is well recognised that the water intake of hens is affected by environmental temperature. The relationship between the two variables has been fully reviewed by Smith and Oliver (1971), who found that there is a significant positive correlation between water intake and ambient temperature in laying hens. The amount of water intake increases by 100 % for a rise in environmental temperature from 21 to 32 °C (Wilson, 1948). An example in this range is reported by Van Kampen (1981b): up to 27 °C, the water intake of layers increased by about 3 ml/d/°C, but above 29 °C the increase was as great as 11 ml/d/°C. Similarly, Austic (1985) found that the daily water intake of laying hens increased very little as environmental temperature increased from 2 to 22 °C, but then increased sharply above 30 and 35 °C (Figure 1). The reason for this increase is that more water is needed by hens for evaporative cooling (Wilson, 1949; Wilson *et al.*, 1957).

In other words, the survival time of laying hens at high temperatures is dependent upon water intake (Fox, 1951). As temperature progressively increases there is an increase in the amount of water consumed by hens but also a marked reduction in feed intake (Wilson, 1948), so that the ratio of water to feed intake ingested greatly increased (Table 6).

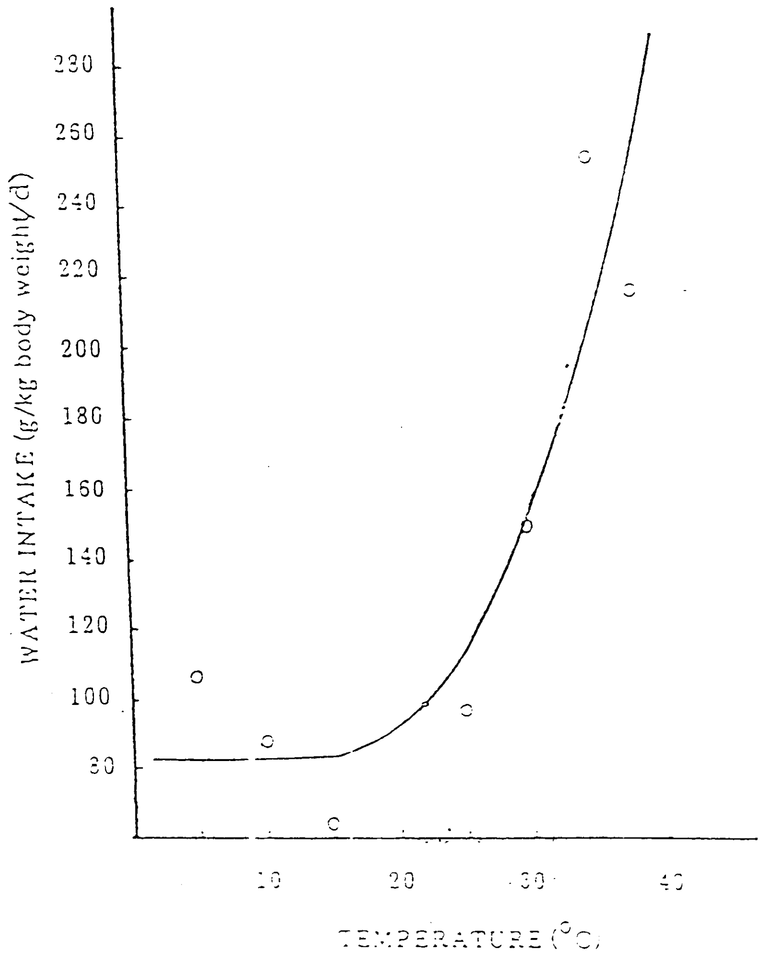

Figure 1. **Influence of environmental temperature on the daily water intake of laying hens (open circles; after Austic, 1985).**

Table 6. Water to feed intake ratios of laying hens at different ambient temperatures.

Reference	Temperatures (°C)	Water intake as a proportion of feed intake
Wilson *et al.* (1957)	1	1.7
	8	2.0
	13	2.2
	18	2.0
	23	2.2
	29	2.6
	35	4.7
Van Kampen (1981a)	5	1.8
	20	3.3
	35	10.4
Wilson (1949)	21.2	2.6
	26.6	3.0
	32.2	4.6
	38.7	8.3
Smith (1972)	24	2.6
	32	3.5
	38	15.2

The increase in the ratio of water to feed indicates that water provides internal cooling and thus aids in temperature regulation in hens as reported by Wilson *et al.* (1957). Indeed, the variability in water/feed intake ratio of laying hens is essentially due to such factors as ambient temperature, feed intake, feed ingredients, size of feed particles, egg production and strain of bird (Wilson, 1949; Bordas *et al.*, 1978).

2.4.2. **Feed water**.

The water content of feed is extremely variable (McDonald *et al.*, 1988). While the water content of the feed ingredients varies between 5 and 15 %, most complete diets for layers contain about 10 % water by weight (Leeson *et al.*, 1976; Scott *et al.*, 1982). Medway and Kare (1959) and Van Kampen (1981a) are the authors who have considered the water content of feed as contributing to the total water intake of hens. These authors reported that the mean feed water intake of hens ranged from 4.4 to about 5.6 ml/hen/d.

2.4.3. **Metabolic water**.

Metabolic water is produced as a result of the oxidation of protein, carbohydrates and fats. The oxidation of 1 g of each of these three nutrients produces 0.5, 0.6 and 1.18 ml of water, respectively (Leeson *et al.*, 1976). They estimated that metabolic water represents about 15 % of the total water intake in the typical hen. Another estimate is given by NRC (1981), who reported that a hen consuming 100 g of feed/d produces about 40 ml of metabolic water/d. On the other hand, the mean metabolic water production of hens, according to Van Kampen (1981a), is about 24 ml/bird/d.

2.5. **Water restriction**.

The water content of the faeces is one of the contributing factors as far as wet litter in poultry houses is concerned (Medway and Kare, 1959). The amount of water in the faeces was found by Hart and Essex (1942) to be about 10 % of the water intake. Lifschitz *et al.* (1967) observed a highly significantly greater water ingestion by mature females when compared to males of similar age.

Leeson *et al.* (1976), citing data from Kerstens (1964), showed that broiler chickens produce excreta containing about 60 - 70 % water, while that produced by the laying hen normally contains about 80 % water (Anderson and Hill, 1968). Medway and Kare (1959) and Longhouse *et al.* (1960) also reported that laying hens produce excreta containing about 75 to 87 % water, possibly due to a number of mechanisms : a decreased feed intake, and hence small amount of faecal materials; a low capacity of the kidney to concentrate urine and insufficient reabsorption of water in the cloaca (Osbaldiston, 1969; Lintern-Moore, 1972), or passage of an excessive amount of water directly through the digestive system (Van Kampen, 1983). Unquestionably, wet droppings in layer houses have been a problem of considerable economic and pathological importance in poultry-litter management (Charles *et al.*, 1942; Okumura *et al.*, 1977).

Despite this, wet droppings can be effectively prevented by the restriction of water intake (Maxwell and Lyle, 1957; Wilson *et al.*, 1965; and Al-Khazarji *et al.*, 1970). Maxwell and Lyle (1957) provided hens with three 15-min watering periods/d and Wilson *et al.* (1965) provided one 2-h watering period/d; both found that restricted watering increased the dry matter content of the faeces. Similarly, Al-Khazarji *et al.* (1970) found that restricting the availability of water to 15 min at 1, 2 and 3 h intervals resulted in drier droppings. While birds producing wet droppings drank much water, restriction of these birds to a normal water intake did not lead to bodily dehydration (Listern-Moore, 1972). For this reason, Lintern-Moore concluded that wet droppings are the direct result of a primary polydipsia rather than an obligatory loss of body water followed by an increased in water intake.

In developing a restricted watering program for laying hens, Goan (1977) suggested that consideration must be given to the type of drinkers, the volume of water, the temperature inside the laying house; and water requirements of the hens are related to environmental temperature. Similar considerations were reported by Sainsbury (1984), who recommends that great care must be taken not to overdo the water restriction, and states that very serious consequences can result if the temperature inside the laying house increases above 30 °C and there is insufficient water available to allow the birds to pant and evaporate excess heat.

In other words, the economic implications of restricting water intake of hens are to prevent wet droppings and to save water in layer operations (Maxwell and Lyle, 1957). Restricted watering has also been shown to improve the cleanliness of waterers: Salverson (1959), Hill (1969), Hill and Richards (1969) and Knight (1970) each found that the water troughs of intermittently watered layers were easier to keep clean. In addition Hill and Richards (1969) concluded that intensity of odours due to wet droppings in the poultry shed could be reduced by restricting the water supply to laying stock.

Besides the above, water restriction has consistently resulted in an improved feed utilisation (Maxwell and Lyle, 1957; Hill, 1969; Hill and Richards, 1969, 1975;

Spiller *et al.*, 1976). Van Kampen (1983) concluded that there are four likely reasons for this effect, namely: (1), less water intake requires less energy to raise the temperature of ingested water to that of the body; (2), there is more recovery of spilled feed from the water troughs; (3), a restriction in water intake may restrict body fat deposition due to over-eating and (4), a restriction in water intake may improve the digestibility of feed.

Although water restriction programs applied to layers consistently give good results in terms of feed utilisation (Maxwell and Lyle, 1957; Hill and Richards, 1969, 1975; Spiller *et al.*, 1976), their effects on egg production are less clear. Maxwell and Lyle (1957), who provided three 15-min watering periods/d, and Wilson *et al.* (1965), who provided two 2-h periods/d, both reported increased egg production in hens offered a restricted amount of water. Spiller *et al.* (1973) similarly found that restricting water to hens which had reached 25 % production resulted in a slight increase in subsequent egg production.

In contrast, restricting water to laying hens for 6 d reduced egg production on the 3rd and 4th d without water (Bierer *et al.*, 1965a), reduced shell weight and shell strength of eggs (Bierer *et al.*, 1965b) and adversely affected egg production for 7 - 8 weeks (Adams, 1973) after the normal watering schedule was resumed. Hill (1969), Hill and Richards (1969), Al-Khazarji *et al.* (1970) and Spiller *et al.* (1973, 1976) all reported similar results: decreased egg production as a result of water restriction; a significant decline in feed intake was also noted. In other instances (Salverson, 1959; Knight, 1970; Muir and Gerry, 1976 and Goan, 1977), it has been reported that restricted watering had no effect on egg production.

From what was stated earlier, the disparity in these results from restricted watering can probably be explained in terms of different methods used in the various experiments (Bailey, 1990). Even so, there is little information available on the performance of layers after short-term water restriction (Adams, 1973; Summers and Leeson, 1976), and in view of this and the conflicting reports outlined above, it was an aim of the current work to further investigate the effects of short-term water restriction on the laying performance of hens.

2.6. **Conclusion**.

The foregoing review has identified the following areas related to choice feeding and feed and water restriction which have potential to affect the productivity and well-being of laying hens in dry areas such as West Timor, Indonesia, and which will be investigated in the experiments which follow:

a) the effect of ambient temperature on the performance of laying hens, specifically:
   - intakes of feed components;
   - total intakes of ME, protein and Ca;
   - intake of water;
   - egg number, egg size and egg-shell quality;
   - FCR, water : feed intake ratios and
   - body weight gain

   on different feeding and watering systems, and

b) the effect of short-term feed and water restriction on the laying performance (as above) of hens fed on a complete diet.