REVIEW OF LITERATURE
II. REVIEW OF LITERATURE

Research reports on the effect of variation in dietary profile and early feed restriction in broilers on various growth parameters and carcass yields are presented in brief under the following paragraphs.

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2.1 Compensatory growth in the broiler chicken

Compensatory growth is defined as abnormally rapid growth relative to age within a breed of animal (Wilson and Osbourn, 1960). Uninterrupted growth of animals follows a predetermined growth curve. Temporary conditions unfavourable for growth, such as under nutrition or illness, make the animal deviate from its original growth path. When favourable conditions are restored, the animal often exhibits accelerated growth. In animal production, most classical studies in compensatory growth have involved sheep and cattle (O'Donovan, 1984).

Two hypotheses have been put forward to explain the mechanisms that govern compensatory growth. The first is the ‘central control’ hypothesis, which suggests that the body has a set point for body size appropriate for a particular age and that this control mechanism resides in the central nervous system (Wilson and Osbourn, 1960). After a period of under nutrition, the body tries to attain size that is appropriate for age in the shortest possible time. The second is the ‘peripheral control’ hypotheses, which suggests that control of body size is determined by the tissues where cell number or, more accurately, DNA determines the extent of growth following a period of under nutrition or illness (Pitts, 1986).

A schematic representation of different growth curves of broiler chickens as described by Leeson and Summers (1991) is given in Fig. 1. Lines A, B and C represent three potential growth curves of broilers that reach approximately 2 kg body weight at 42 days of age. If birds grow at a uniform rate, growth will be as depicted by line B and represents perhaps a biological ideal as far as minimizing stress is concerned i.e., continual steady growth with no major period of slow or rapid growth. However, few animals grow with such ‘statistical’ precision. Birds which grow through lines A and C both reach 2 kg weight at 42 days, yet
Fig. 1: Schematic representation of growth curves of broiler chickens

(Leeson and Summers, 1991)

A: More rapid initial growth and subsequently slower growth approaching market weight
B: Continual steady growth with no slow or rapid growth
C: Initially slower rate of growth, followed by an accelerated growth towards market weight
the routes they take are quite dissimilar. Bird A has more rapid initial growth and subsequently, a slower growth approaching market weight. Bird C initially has a slower rate of growth, followed by an accelerated growth towards market weight.

Bird C will probably exhibit a superior feed conversion because it will have a lower maintenance requirement especially at early age. The reason for this reduced maintenance requirement is that, at any specific age, before reaching point X, the bird has a smaller body mass to maintain and so will need less feed nutrients for this purpose. Smaller birds have proportionately higher maintenance requirements, but if C is sufficiently different from A, there will be a reduction in the absolute quantity of nutrients going towards maintenance. Totaling these reduced maintenance needs, while still achieving the desired body weight X (Fig. 1), must result in more feed directed to growth and so improved feed efficiency. Nevertheless, this theory should assume that the carcass composition is unaltered.

Early studies of feed restriction programmes in broilers have been primarily concerned with lowering body fat and improving the feed efficiency (Fisher, 1984), which in many cases were attained at the expense of final body weight. Osbourn and Wilson (1960) and Auckland and Morris (1971) demonstrated the feasibility of compensatory growth with chickens and turkeys subjected to feed restriction during early life so that final body weight is not compromised. Other workers, however, failed to show complete growth compensation under similar nutritional regimen (Jones and Farrell, 1992; Zubair and Leeson, 1996b). The variability in results of studies is obviously due to a number of factors that influence the response of broiler chickens to a short-term or prolonged under nutrition.
2.2 Factors that influence compensatory growth

Factors that influence the ability of animals to exhibit compensatory growth during the period of re-alimentation following nutritional deprivation were identified by Osbourn and Wilson (1960). These factors include the nature, severity and duration of under-nutrition as well as the age at the commencement of under-nutrition and the degree and pattern of re-alimentation.

2.2.1 Duration and timing of restricted nutrition

Many studies have shown that the longer the period of under-nutrition, the more difficult it is for broilers to compensate for the reduction in weight gain (Yu and Robinson, 1992). Feed restriction for a period of six days allowed for complete body weight recovery, while recovery was not seen when restriction was more prolonged at 12 days (Plavnik et al., 1986). Most workers recommended feed restriction of not more than seven and five days for male and female broilers, respectively, to allow for full body weight recovery (McMurtry et al., 1988; Plavnik and Hurwitz, 1991; Shariatmadari and Hosseni, 2001).

Mollison et al. (1984) restricted the feed intake of birds to 90 per cent of that of control birds from 7 to 49 days of age and reported a significantly lower final body weight at 56 days of age. The lack of recovery in body weight by the restricted birds was likely to have been caused by the prolonged period of restriction, giving no time for the birds to exhibit complete growth compensation. On the other hand, a feed restriction period of four days for female broilers allowed for full recovery in a much shorter time (Jones and Farrell, 1992; Lippens et al., 2000). It is not clear whether milder restriction programmes of shorter duration would have any effect on reducing body fat deposition, which is one of the primary objectives of feed restriction.
Initiation of 6 days feed restriction at any age between 3 and 11 days of age seems to permit complete body weight recovery by 8 weeks of age in male broilers (Plavnik and Hurwitz, 1988). Similarly, other workers have recommended the commencement of restriction at 5 to 7 days of age (Rosebrough et al., 1986). On the other hand Washburn and Bondari (1978) initiated their feed restriction programme at 3 weeks of age, and reported very little evidence of compensatory growth, probably because very little time was allowed for recovery.

2.2.2 Nature and severity of restricted nutrition

The level of restriction imposed is usually calculated to meet the maintenance energy requirement of the birds, based on the recommendations of Plavnik and Hurwitz (1989). These workers estimated the metabolizable energy (ME) requirement for maintenance of male broilers to be 6.3 KJ/kg W^{0.67}. More severe restriction tends to compromise the ability of the bird to recovery. The level of feed restriction which estimated just to meet maintenance energy requirements is equivalent to about 167 KJ ME/bird/day in the 6 to 12 day period (approximately 35% of normal intake). This maintenance energy level, however, must have been over estimated because the feed restricted birds gained 2 to 4 g body weight each day during the restriction period. It is also possible, as suggested by some workers, that the birds, even though in negative energy balance were able to gain weight due to change in body composition i.e., used fat reserve and deposited more lean tissue (Lesson et al., 1991: Yu and Robinson, 1992: Zhong et al., 1995). However, other workers were unable to demonstrate complete compensatory growth of boilers, which had been subjected to similar degrees of feed restriction (Plavnik et al., 1986: Robinson et al., 1992). Later studies by Plavnik and Hurwitz (1991) showed that milder
restriction, which allowed 60 to 70 per cent of normal growth, permits more realistic recovery.

2.2.3 Condition of re-alimentation

There is at present very limited information about energy and protein requirements during the re-feeding period. Plavnik and Hurwitz (1989) re-evaluated the amino acid requirements of broilers during re-alimentation. Based on the expected growth rate and body composition, their model calculations showed higher requirements for most of the essential amino acids, especially during the first two weeks of re-feeding.

Jones and Farrell (1992) demonstrated that dietary supplementation with lysine and/or methionine during the re-feeding period resulted in higher final body weight and leaner carcasses. More consistent results of compensatory growth have been obtained in studies that have extended the growth period to 7 weeks or more (Upendra kumar et al., 1997; Nirmala et al., 2005).

2.2.4 Genetic factors

Male broilers have a greater ability to exhibit compensatory growth following a period of under nutrition than females (McMurty et al., 1988; Plavnik and Hurwitz, 1991). The results of studies by Plavnik and Hurwitz (1990) showed that males were able to exhibit complete compensatory growth when subjected to similar conditions but not females. The lack of consistency in the response of broilers to early under nutrition programmes has been attributed by many workers to differences in strains of birds used (Yu et al., 1990). Cherry et al. (1978) showed that fast growing broiler strain exhibit little compensatory growth when compared with slower growing strains. Alsobayel et al. (1989) and
Attia et al. (1998) reported broiler females had higher abdominal fat than males when subjected to early feed restriction.

Diet dilution resulted in a significant reduction in body weight at 11 days of age in broilers, although by 42 days there was complete recovery of body weight with no change in overall efficiency of feed utilisation in both sexes (Leeson et al., 1991).

Saleh et al. (1996) subjected the broilers to feed restriction by 20, 30 or 40 per cent of the fully fed group on day 8, 9, 12 and 13 followed by *ad libitum* feeding showed males had higher final body weight than females.

The feed restriction either in male, female or combined sex broilers during 2nd and 3rd week of age by 10, 20 and 30 per cent to that of *ad libitum* control feeding showed the male broilers attained early compensatory growth compared to females (Nirmala et al., 2005).

### 2.2.5 Adipose development and fat deposition

Studies suggesting that fatness at an early age may affect adiposity at adulthood led to the initiation of studies intended to elucidate whether nutrition at an early age might have subsequent inductive effects (Nir et al., 1988). Nutritional studies have indicated that the ages at which the different processes involved in adiposity (hyperplasia and hypertrophy) occur can be altered by level of feeding, especially at early ages (Fontana et al., 1993). Feed restriction treatments are, therefore, mostly imposed during the second to third week of age in broiler chickens, as an attempt to alter hyperplastic growth of adipocytes which, at this age, accounts for most of the growth of the adipose tissue. It is hypothesized that this will suppress or delay adipocyte proliferation, and this is expected to be accompanied by lower adiposity in older broilers.
The application of early under nutrition to reduce carcass fat content in the broiler chickens has met with varying degrees of success. Reduction in body fat and abdominal fat as a result of early feed restriction was achieved by a number of workers (Plavnik and Hurwitz, 1985; Nirmala et al., 2005), although a comparable number of studies showed no real effect (Summers et al., 1990; Zubair and Leeson, 1996b).

Results of number of studies showed that, even though growth of adipose tissue is controlled during feed restriction, adipose tissue is, however, capable of hyperplasia during re-feeding. Such adipocyte hyperplasia continues until the cell number appropriate for the body mass is attained (Zubair and Leeson, 1996b). A very strong positive relationship has been reported between development of body mass and adipocyte hyperplasia in broilers (Cartwright, 1991). These workers suggested that adipose tissues from larger birds are hypoplastic relative to tissues from birds of smaller body size.

2.3 Methods of feed restriction

2.3.1 Physical feed restriction

Various methods of under nutrition have been used to retard or even stop growth during the under nutrition period. The most commonly used method of feed restriction is simple physical restriction, which provides a calculated quantity of feed per bird, this often being just enough to provide for maintenance requirement. This method of feed restriction has the disadvantage of requiring frequent weighing of feed. There is the additional problem of feeder space, which if limiting, leads to non-uniform distribution of the small feed supply, thereby causing uneven body weight distribution within a flock. Many workers have used physical methods of feed restriction because birds can adapt to the
feeding of high fibre diets. Such adaptation enables them to digest, to some extent, the otherwise indigestible fibre, thereby getting more energy (and possibly other nutrients) than is required to achieve the desired growth retardation during the under nutrition period. Leeson et al., (1991) reported more than expected growth for broilers fed a diet containing 55 per cent rice hulls, based on the calculated expected nutrient intake. They suggested that the ingredients used for diet dilution, such as rice and oat hulls, are assumed to contain little digestible energy, but may actually provide substantial amounts of nutrients. Such a situation will obviously interfere with the total energy intake of the birds during under nutrition, there by changing the growth pattern.

**2.3.2 Diet dilution and chemical methods of feed restriction**

While physical feed restriction is the most common technique used to achieve under nutrition, in practical situations it is very difficult to distribute feed evenly. With physical feed restriction programmes there is also the problem of even distribution of micro-nutrients and anti-coccidial chemicals among the birds in a flock. An alternative system of achieving uniform under nutrition within a flock is by diet dilution or the use of other chemical means to restrict intake of specific nutrients or feed.

Leeson et al. (1991) replaced 25 to 55 per cent of conventional broiler starter diet with rice hulls during a period of 7 to 16 days and showed recovery of body weight by 42 days of age. In this study, vitamin and mineral sources were not affected by the diet dilution.

Jones and Farrell (1992) who fed diets diluted up to 65 per cent with rice hulls and also obtained growth compensation relative to the control birds at 48 days of age.
Restriction of feed intake of broilers by chemical means was suggested by Fancher and Jensen (1988) as an alternative to diet dilution. These authors used glycolic acid which is naturally occurring compound in many foods and has been reported to depress feed intake in a dose dependent manner in broiler chicks. Pinachasov and Jensen (1989) used glycolic acid as a chemical means of restricting feed intake of broilers, and compared this with the traditional feed restriction method. During the restriction period (7-14 days) the feed intake of birds, given diets supplemented with 1.5 per cent and 3 per cent glycolic acid was depressed by 17 per cent and 45 per cent, respectively. These reductions of feed intake due to glycolic acid supplementation resulted in growth retardation during the under nutrition period to 71 per cent and 41 per cent respectively, relative to the growth of control birds. Male broilers exhibited complete body weight recovery at 49 days of age, with no difference between the birds restricted by the dietary glycolic acid addition or those subjected to physical feed restriction. Due to its natural occurrence, glycolic acid may serve as a safe and useful anorectic compound for restricting feed intake in poultry (Harris and Richardson, 1980). This method of feed restriction has the advantage of ensuring even distribution of the feed and giving the birds appropriate intake of micro-ingredients such as anti-coccidials.

2.3.3 Use of low protein or low energy diets

Achieving growth retardation by under nutrition may require extra labour or mechanization to apply physical feed restriction or the use of non-digestible materials to dilute the feed. An alternative method of retarding early growth is the restriction of intake of specific nutrients, such as protein (Moran, 1979). Broilers require 220, 200 and 180 g/kg dietary crude protein during the starting, growing and finishing periods,
respectively for optimal growth (NRC, 1994). They tend to increase their feed intake to make up for deficiencies when fed with diets that are marginally deficient in crude protein (Fisher, 1984). However, feed intake is depressed by feeding diets that are severely deficient in crude protein (Plavnik and Hurwitz, 1990; Michel Picard et al., 1999).

Studies by Plavnik and Hurwitz (1990) showed that *ad libitum* feeding of a diet containing only 94 g/kg crude protein from 8 to 14 days decreased the feed intake of broilers by some 57 per cent. This decrease in feed intake resulted in 41 per cent growth retardation, which was not recovered after six weeks of re-alimentation. Deaton et al. (1973) utilized a low energy diet to reduce body weight of broilers by four weeks of age. By eight weeks of age males fed a high-energy diet were able to compensate for the weight loss occurring during the preliminary feeding of low energy diets. Females required less energy to recover from the lost body weight than did males.

Calvert et al. (1987) used two levels of diet ME (13.0 and 14.2 MJ/kg) during an under-nutrition period 6 to 12 days of age and fed birds 167 KJ ME/bird/day. All growth retarded birds observed complete growth compensation by 56 day of age.

## 2.4 Effect of dietary variation and feed restriction on performance

Variation in nutrient profile and early feed restriction have been reported to influence the body weight, feed consumption, feed conversion ratio and livability of birds which are reviewed as under.

### 2.4.1 Body weight

Deaton et al. (1973) demonstrated that broilers fed a diet containing 3141 Kcal of ME/kg (0-4 weeks) had a four per cent reduction
in body weight at four weeks of age as compared to birds fed a diet containing 3306 Kcal for ME/kg. By eight weeks of age, the birds were able to compensate for the four per cent reduction in 4th week body weight, when fed a high energy diet containing 3372 Kcal of ME/kg from five to eight weeks.

Washburn and Bondari (1978) studied the effects of timing (duration of 1, 2, 3 and 5 weeks between the ages of 3 to 8 weeks) and duration (3 to 5 weeks) of skip-a-day restricted feeding on compensatory growth of broilers and reported a significant (P<0.05) reduction in eight week body weight of males but not in females in comparison to control groups.

Broilers fed low level of protein (20%) during growing phase (2 to 5 weeks) exhibited reduced body weight than high protein (24%) and intermediate protein (22%) fed groups. By 7 weeks of age, compensatory growth of those groups that had previously experienced poor performance was recorded when common finishing rations were fed (Moran, 1979).

Hargis and Creger (1980) studied the effects of varying dietary protein and energy levels on growth rate and reported that high dietary protein levels were detrimental to growth during the starting period (0-14 days), but beneficial in maximizing weight gain during the finishing period (28-49 days).

Body weight of broilers on quantitative feed restriction at levels of 95, 90 and 85 per cent of ad libitum for two weeks (6-8 weeks) and three weeks (6-9 weeks of age) were not significantly different from those fed ad libitum at slaughter at the end of tenth week. However, the birds kept on restricted diets for four weeks on all levels of restriction showed lower live weights at slaughter time as compared to those fed ad lib (Sunaria and Sharda, 1981).
Restriction of feed intake in broilers to 90 per cent of ad libitum intake in early life significantly (P<0.01) reduced the 49th day body weight (Mollison et al., 1984).

Plavnik and Hurwitz (1985) studied the performance of broiler chicks due to feed restriction by way of providing energy from 30 to 45 Kcal per day for different periods ranging from 6 to 28 days started at the age of one week and found that the body weight gain in feed restricted birds was lowered during the first two weeks of refeeding but later exceeded that of control.

The effects of early nutrition alternations upon market age broiler performance was demonstrated by Bryan and Leo (1986) and observed that chicks fed diets containing 2850 Kcal ME/kg with either 18, 23 or 28 per cent crude protein for the first week, did not differ significantly in the 7th week body weight among treatments.

The initiation of six days feed restriction at any age between 3 and 11 days of age seems to permit complete body weight recovery by eight weeks of age in male broilers (Plavnik and Hurwitz, 1988).

Victoria et al. (1988), found that ad libitum fed broilers were at least 41 per cent heavier throughout the trial period compared to those on the 25 per cent restricted diet during 5 to 39 days of age.

Feed restriction in broilers by 76 and 85 per cent or 69 and 75 per cent of ad libitum at second and third weeks followed by ad libitum feeding until seven to eight weeks of age showed no significant difference in weight gain between the control and restricted birds (Alsobayel et al., 1989).

Calvert et al. (1989) studied the effect of three levels of feed intake, ad libitum, 40 Kcal ME/d from 6 d through 12 d and 40 Kcal ME/d from
6 d through 18 d post-hatching, on weight gain and found that there was no effect of restriction on weight gains from 21 to 56 days of age.

Oporta and Rubio (1989) found that the body weight of broilers was not affected when subjected to 20 and 30 per cent feed restriction during the fourth and fifth week of age. They concluded that it was possible to restrict feed up to 30 per cent without affecting other production characteristics.

Feed regimen that restricted the growth of male broilers severely between 6 and 11 or 6 and 12 days old followed by increase in dietary nutrient density resulted in an enhanced growth rate (Plavnik and Hurwitz, 1989).

The effect of different nutrient restriction programs in early life of broilers was studied by Cabel and Waldroup (1990) and found that the compensatory gain was not observed consistently in the experiment.

Summers et al. (1990) reported no significant difference in 42 day body weights between ad libitum fed birds and birds either restricted in feed intake or fed diluted diets between 7 and 14 days or between ad libitum fed birds and birds fed higher levels of dietary protein between 36 and 42 days of age.

Yu et al. (1990) studied the growth and body composition of broiler chickens in response to different regimes of feed restriction (Ad libitum, skip-a-day, daily or hourly) between 8 and 14 day post hatch and observed that on day 56, body weight of restricted chicks was not significantly different from one another, but was significantly less than that of full-fed birds.

Ballay et al. (1992) studied the initiation and the length of different feed restriction programs on broilers and reported that chicks restricted for only 6 days during first 18 days of age reached body weight
equivalent to those of chicks eating *ad libitum* at 39 days of age, whereas, chicks fed on restricted feed for more than six days during the first 18 days after hatch were lower in body weight than those of *ad libitum* fed chicks.

Fontana *et al.* (1992) reported that the broilers subjected to 5 or 6 or 7 days of early feed restriction commencing at 4 days of age, had significantly lower mean final body weight than control for all duration.

Feed regimen which restricted the growth of male broilers by about 58 per cent between 6 and 12 days old followed by *ad libitum* feeding had no significant effect on body weight at 47 days of age (Plavnik and Balnave, 1992).

Robinson *et al.* (1992) studied the growth performance in full fed and feed restricted broilers and roaster chicken and reported that the time taken for attaining the market weight delayed by 2 or 3 days in the early short term (7 days) feed restricted birds. Also, the optimum timing for feed restriction was during the second week rather than later.

Feed restriction in broilers by 50 and 65 per cent of *ad libitum* at 6 to 14 days and 8 to 14 days of age, respectively exhibited compensatory growth at 21, 35 and 45 days of age equivalent to that of *ad libitum* fed groups (Scheideler, 1993).

Broilers fed with reduced nutrient density (175 g protein/kg) between 7 and 14 day of age, causing a uniform reduction in body weight of 15 to 16 per cent at 14 day of age, which was fully recouped by compensatory growth between 15 and 49 days of age (Carter *et al.*, 1994).

Susbilla *et al.* (1994) demonstrated that broilers restricted in intake to 50 or 75 per cent of *ad libitum* from 5 to 11 days of age showed higher *(P<0.05)* relative growth rate from 12 to 39 days of age in 50 per
cent restricted group compared to 75 per cent restricted group and control group.

Feed restriction by 50 per cent diet dilution with oat hulls for six days starting at 6 days of age in male broilers showed complete growth compensation by 35 days of age (Zubair and Leeson, 1994a). Again they demonstrated that the lower metabolic rate in ‘restricted re-fed’ broilers does not a part in growth compensation (Zubair and Leeson, 1994b).

Broiler chicks reared from 1 to 56 days of age under feed restriction from 8 to 56 days of age with 8 hours per day of access to feed had 11.2 per cent reduction in growth rate when compared to control (Arce Menocal et al., 1995).

Deaton (1995) conducted a study on feeding of 90, 75 and 60 per cent of previous 24 hour feed consumption of full fed controls from 7 to 14 days of age or 80 and 60 per cent from 8 to 16 days of age and concluded that the body weight of broilers equated the control at 41 days of age in 90 per cent feed restriction.

The effects of feed restriction was studied by Santoso et al. (1995) by way of providing 50 per cent of ad libitum for 5, 10 and 15 days starting from 5 days old followed by ad libitum up to 56 day old and reported that body weight of broiler chickens fed 50 per cent ad libitum for 10 and 15 days had significantly lower body weight than those of ad libitum fed chickens.

Zhong et al. (1995) found that feed restriction of 1.49 Kcal/g body weight$^{2/3}$ daily from 7 to 12 days of age showed no difference in mean body weight between the full fed and restricted males and combined sex broilers at 49 days of age.

A broiler experiment was conducted by Ramlah et al. (1996) by way of providing feed ad libitum, restricted to 75 per cent of ad libitum
intake from 8 to 14 days old or restricted to 50 per cent of ad libitum intake from 15 to 21 days old and concluded no compensatory gain in restricted groups.

Saleh et al. (1996) subjected the broilers to feed restriction by 20, 30 or 40 per cent of the fully fed group on Day 8, 9, 12 and 13 followed by ad libitum feeding. They concluded that final body weight did not differ among those restricted to 20 or 40 per cent and those fully fed.

The effect of early life feed restriction in male broilers was demonstrated by Zubair and Leeson (1996b) by way of providing 50 per cent physical feed restriction during the period of 6 to 12 days of age followed by gradual refeeding until 42 days of age and reported that complete compensatory growth was not achieved by 42 days by feed restricted birds relative to control.

The effect of different restricted feeding programmes was studied by Cristofori et al. (1997) and they concluded that feed restricted chicken had a good but not complete compensatory growth when compared with the control.

Qualitative feed restriction by diluting the diet with 0, 20, 40 and 60 per cent of rice hulls between 7 and 14 days of age in broilers, had significantly (P<0.05) reduced the body weight and weight gain at 15 days of age as compared to the control. However, there was complete recovery in body weight by 42 days of age (Upendrakumar et al., 1997).

Attia et al. (1998) studied the effect of broilers subjected to feed restriction during 2nd week by 50 per cent of feed consumed by ad libitum controls or 50 per cent of ad libitum during 2nd and 3rd week of age and reported that body weight of one week restricted chickens did not differ from those of controls whereas, two weeks restricted chickens showed the lowest body weight at 7 weeks of age.
Benyi and Habi Habi (1998) conducted an experiment consisted of broiler chicks fed with 85 or 70 per cent of *ad libitum* or *ad libitum* for 5 days per week with 3rd and 5th days of food withdrawal for 28 days and reported a significantly reduced final body weight and rate of growth in quantitative feed restriction to 85 and 70 per cent of *ad libitum* and reduction in feeding time by two days per week.

Diets diluted with 50 and 20 per cent wheat bran between 0 to 5 days and 5 to 11 days of age, respectively followed by control diet showed lower body weight in restricted broilers compared to control at 41 day of age (Michel Picard *et al.*, 1999).

Vargas *et al.* (1999) studied four levels of quantitative feed restriction (0, 15, 30 and 45%) and two periods (from 8 to 14 and from 8 to 17 days of age) in broilers and reported that the body weight and weight gain reduced in higher levels of feed restriction.

Lippens *et al.* (2000) restricted the feed to broilers to 80 or 90 per cent of *ad libitum* feed intake for 4 days or 80 per cent for 8 days started from 4th day of age followed by *adlibitum* feeding and observed that the final body weight in broilers kept on 90 per cent of *adlibitum* intake for 4 days did not differ significantly but lower than that of controls.

The effects of early life under nutrition in broilers was studied by Lee and Leeson (2001) by providing 0.75 Kcal ME/g b.wt.⁰.⁶⁷ for 4 days, 1.5 Kcal ME/g b.wt.⁰.⁶⁷ for 5 days or 2.25 Kcal ME/g b.wt.⁰.⁶⁷ for 6 days started from 6th day of age and found that restricted birds were smaller following feed restriction although growth compensation occurred and at 49 days all restricted birds were heavier than full fed control birds.

Shariatmadari and Hosseni (2001) studied the effects of feed restriction during the early stage of growth (7 to 14 days) and later period (42 to 49 days), with three levels of restriction (90, 80 and 70%) on
broiler performance and found that the birds on feed restriction at the beginning of the growth period (7-14 days) took 2.5 days longer to reach the same body weight as the control group. The birds on late restriction (42 to 49 days) reached this weight 3.5 days later.

The effects of energy and protein dilution (adding rice hulls at 0, 100, 150, 200, 250 and 300 g/kg) between 6 and 12 days of age in broilers was demonstrated by Yussefi Kelaricolaii et al. (2001) and they found that diet dilution reduced the weight gains between Day 6 and 12. Due to compensatory growth, no significant differences between treatments were observed at 42 days of age.

Lippens et al. (2002) reported broilers restricted to 80 per cent of the *ad libitum* intake of the previous 24 hours of the control group from Day 4 to 7. After the period of restriction all birds were fed *ad libitum* up to 42 days of age and found that compensatory growth was substantial. They were also concluded that a retardation of the early growth of fast growing broiler chickens can, in certain circumstances increases performance and nitrogen retention.

Santoso (2002) studied the effect of early feed restriction by providing 25 per cent of *ad libitum* for 4 to 6 days, 50 per cent of *ad libitum* for 4 to 6 days and 75 per cent of *ad libitum* for 4 to 6 days and reported that restricted broilers exhibited compensatory growth and the level of feed restriction significantly influenced the body weight but duration of feed restriction had no effect.

Broilers restricted to 90 per cent of *ad libitum* intake of control group during different intervals showed non-significant differences across treatments in the body weight at 42 days of age (Urdaneta Rincon and Leeson, 2002).
Camacho *et al.* (2004) carried out an experiment by restricting feed to the broilers for 8 hours/day for 14 days at 21 or 28, 14 or 21 and 7 or 14 day of age and concluded that the quantitative feed restriction at 7 day of age was permitted compensatory growth sufficient to equal the production characteristics of the control group at 49 day of age.

The effect of meal time feeding (food was withdrawn from 9 am to 3 pm) and low protein diet (19.5% protein) feeding from 7 to 21 days of age in broilers was studied by Konca *et al.* (2004) and they found that compensatory growth at 45 days of age was not observed either for meal time fed broilers or low protein fed broilers from 7 to 21 days.

Shariatmadari and Vaeztorshizi (2004) studied the effect of three feeding levels (control, 15% and 30% below *ad libitum*) from 7 to 14 days of age on male and female broilers performance and observed that male broilers had better compensatory growth ability as judged by significantly (*P*<0.05) higher growth rates than females.

Broiler chicks subjected to *ad libitum* feed from 7 to 13 days of age or given 25 and 50 per cent of *ad libitum* intake on a daily basis (physical restriction) or 100 per cent of *ad libitum* intake on a daily basis, when the diets were diluted with 25 and 50 per cent rice hulls (dilution restriction) showed physically restricted birds gained significantly more weight than their diet diluted counterparts. Birds in all of the restricted groups gained weight similar to the full fed birds at 49 day of age (Toghiani *et al.*, 2004).

The feed restriction either in male, female or combined sex broilers during second and third week of age by 10, 20 and 30 per cent to that of *ad libitum* control feeding did not affect the final 7th week body weight between treatments (Nirmala *et al.*, 2005).
2.4.2 Feed consumption and feed conversion ratio

Washburn and Bondari (1978) studied the effects of timing (duration of 1, 2, 3, 4 and 5 weeks between the ages of 3 to 8 weeks) and duration (3 to 5 weeks) of skip-a-day restricted feeding and reported a reduction of as much as 10 per cent feed consumption and higher feed conversion ratio (FCR) in all restricted groups than the control.

Broiler fed lowest level of protein (20%) during growing period (2 to 5 weeks) exhibited poorer utilization of feed than high protein (24%) and intermediate protein (22%) fed groups. By 7 weeks of age, groups which had received the lowest protein and exhibited the poorest feed conversion (between 2-5 weeks), now made the best use of their feed when common finishing rations (5-7 weeks) were fed (Moran, 1979).

The effects of varying dietary protein and energy levels on growth rate was studied by Hargis and Creger (1980) and reported that high dietary protein levels were detrimental to growth during the starting period (0-14 days) but beneficial in maximising feed efficiency during the finishing period (28 to 49 days).

Starrjackson et al. (1982) reported broilers fed varying levels of dietary protein (16, 20, 24, 28, 32 and 36%) and energy (2600, 2800, 3000, 3200, 3400 and 3600 Kcal ME/kg) to determine the effect of alteration in nutrient density on performance and observed that feed efficiency improved with increased dietary protein or energy.

Restriction of feed intake to 90 per cent of ad libitum intake in early life of broilers had significantly improved the feed intake compared to groups fed ad libitum diet (Mollison et al., 1984).

Plavnik and Hurwitz (1985) studied the performance of broiler chicks due to feed restriction by way of providing energy from 30 to 45 Kcal per day for different periods ranging from 6 to 28 days started at the
age of one week and found that cumulative feed efficiency was improved over the control.

The effect of age, duration and sex on early feed restriction in broiler chicks was demonstrated by Plavnik and Hurwitz (1988) and found that early feed restriction in males for seven days resulted in improved feed efficiency on age basis or on body weight basis after body weight has reached 0.7 to 1.0 kg, but with females little benefit in feed efficiency when compared with ad libitum fed birds on body weight basis.

Victoria et al. (1988) found that feed efficiency was better in the ad libitum fed group up to 11 days of age and then became similar to those on the 25 per cent restricted diet during 5 to 39 days of age.

Calvert et al. (1989) studied the effect of three levels of feed intake: ad libitum, 40 Kcal ME/day from 6 through 12 day and 40 Kcal ME/day from 6 through 18 day posthatching and found that feed: gain improved (P<0.05) in both restricted groups.

Feed intake (5005, 5002 and 5004 g) and feed efficiency (0.451, 0.430 and 0.455) in broilers were not affected by feed restriction (ad libitum 20% and 30%) during 4th and 5th week (Oporta and Rubio, 1989).

Feed regimen, which affects the feed efficiency of male broilers between 6 and 11 or 6 & 12 days old followed by increase in nutrient density resulted in an improved feed efficiency (Plavnik and Hurwitz, 1989).

Shyamsunder et al. (1989) studied the performance of broilers fed continuously 17 or 19 per cent protein diet for 8 weeks or birds fed 17 or 19 per cent protein diet for 3, 4 and 5 weeks and reported cumulative feed intake in all restricted group was similar to that of control group. The feed efficiency of birds maintained on restriction for 3 to 5 weeks was comparable to those fed control diet, but the groups kept continuously
on 17 or 19 per cent protein diet for 8 weeks had significantly poor feed conversion efficiency than the control group.

Cabel and Waldroup (1990) studied the effect of different nutrient restriction programmes in early life of broilers and they reported a general improvement in feed efficiency by nutrient restriction.

Low-sodium, low-protein or a control diet fed *ad libitum* to 8-day-old male broiler chickens for 6 days showed lowest weight gain in low protein diet feed groups and did not recover at 56 days old, however feed efficiency was improved significantly (Plavnik and Hurwitz, 1990).

Summers *et al*. (1990) reported no significant difference in feed: gain ratios was noticed between *ad libitum* fed birds and birds either restricted in feed intake or fed diluted diets between 7 and 14 days or between *ad libitum* fed birds and birds fed higher levels of dietary protein between 36 and 42 days of age.

Attia *et al*. (1991) conducted a study on broilers subjected to *ad libitum* feeding or feed restriction to 50 per cent of control feed intake between 1 and 3 weeks or given 20 per cent dried chicken excreta during 5 and 6 weeks old and found that cumulative FCR for control and feed restricted birds were the same.

Leeson *et al*. (1991) used conventional starter diets, which had been diluted with 25, 40 or 55 per cent rice hulls from 7 to 16 days of age and reported no change in overall feed efficiency.

Skip-a-day feed restriction programmes during the starting period in broilers can effectively reduced the incidence of ascites syndrome without severely compromising body weight gain or feed conversion (Arce *et al*., 1992).

Ballay *et al*. (1992) studied the initiation and the length of different feed restriction programs on broilers and reported that chicks restricted
for the whole experiment had superior feed efficiency with low body weights.

A broiler experiment was carried out by Fontana et al. (1992) by providing 40 Kcal of ME/bird/day, commencing at 4 days of age for the duration of 5, 6 or 7 days and found that feed conversion ratio for restricted broilers were significantly lower at 28 and 49 days of age than for birds consuming feed *ad libitum*.

The growth performance in full fed and feed restricted broilers and roaster chicken was observed by Robinson et al. (1992) and reported that the feed efficiency was not affected by short term feed restriction.

A period of short term feed restriction and subsequent refeeding in broiler chickens is sometimes, but not always, marked by catch-up growth and it is accompanied by a corresponding increase in feed intake (Yu and Robinson, 1992).

Roth et al. (1993) studied the feed restriction in broilers at 5 days old to 50, 60 or 70 per cent of free intake for 2 weeks, 70 per cent for 2, 3 and 4 weeks and at 65 per cent of free intake for 4 or 12 days and concluded that increasing the duration of feed restriction decrease the cumulative feed conversion ratio.

Dietary restriction in broiler chickens (175 g protein/kg between 7 and 14 day of age) caused a uniform reduction in body weight at 14 days of age, which was fully recouped by compensatory growth on day 49. However, food intake was not significantly affected (Carter et al., 1994).

Susbilla et al. (1994) reported non-significant difference among different groups in feed conversion ratio of broilers restricted to 50 or 75 per cent of *ad libitum* intake for 5 to 11 days of age.

Feed restriction by 50 per cent diet dilution with oat hulls for six days starting at 6 days of age showed superior feed efficiency
(P<0.05) in feed restricted male broilers relative to control birds (Zubair and Leeson, 1994a).

Deaton (1995) conducted a study in broilers on feeding of 90, 75 and 60 per cent of previous 24 hour feed consumption of full fed controls from 7 to 14 days of age or 80 and 60 per cent from 8 to 16 days of age and concluded that early feed restriction improved the feed conversion ratio.

Broilers subjected to varying dietary protein levels (20 and 22% CP) and restricted feeding (0,10 & 20%) showed 20 per cent CP fed groups and 10 per cent feed restriction groups had superior feed efficiency than that of control (Hirwade et al., 1995).

Santoso et al. (1995) studied the effects of feed restriction by way of providing 50 per cent *ad libitum* for 5, 10 and 15 days starting from 5 days old followed by *ad libitum* feeding up to 56 days old and reported a better feed conversion ratio in broiler chicks fed 50 per cent *ad libitum* for 10 and 15 days than those of *ad libitum* fed birds.

Zhong et al. (1995) reported feed conversion was better (P<0.05) for restricted broilers than full fed broilers.

A broiler experiment was conducted by Ramlah et al. (1996), which consisted of providing feed *ad libitum*, restricted to 75 per cent of *ad libitum* intake from 8 to 14 days of age and restricted to 50 per cent of *ad libitum* intake from 15 to 21 days of age and they observed that the feed conversion efficiency was generally improved by feed restriction.

Saleh et al. (1996) conducted a study on broilers subjected to feed restriction by 20, 30 or 40 per cent of the fully fed group on day 8, 9, 12 and 13 followed by *ad libitum* feeding and reported an initial improvement in feed conversion ratio, but insignificant final values in restricted feeding when compared with control group.
The effect of early life feed restriction in male broilers was studied by Zubair and Leeson (1996b) by way of providing 50 per cent physical feed restriction during the period of 6 to 12 days of age followed by gradual refeeding until 42 days of age and reported consistent improvement in feed efficiency among treatment groups.

Upendra Kumar et al. (1997) studied the effects of diets diluted with 0, 20, 40 and 60 per cent of rice hulls between 7 and 14 days of age in broilers and concluded that overall feed intake was significantly increased with increase in diet dilution with no change in overall feed efficiency.

Broilers subjected to 50 per cent of ad libitum feed intake on daily basis from 6 to 11 days of age were more efficient in overall energy intake: body weight gain (P<0.01) (Leeson and Zubair, 1997).

Attia et al. (1998) studied the effect of broilers subjected to feed restriction during 2nd week by 50 per cent of feed consumed by ad libitum controls or 50 per cent of ad libitum during 2nd and 3rd week of age and reported a better feed to gain ratio in two weeks feed restricted chickens than that of controls at 7 weeks of age.

Low feed intake was recorded in broilers fed with low nutrient density diet (16% CP, 2800 Kcal ME/kg) between 0 to 70 days of age. Feed efficiency was poorer in the starter period. However, after this time, feed efficiency for this group normalized and these birds had the numerically lowest efficiency in the 49 to 70 day finisher period when compared to high density diet fed groups (Leeson et al., 1999).

Vargas et al. (1999) studied four levels of feed restriction (0, 15, 30 and 45%) and two periods (8 to 14 and 8 to 17 days of age) in broilers and reported a improved feed : gain ratio in feed restricted groups.
Broilers restricted to 80 or 90 per cent of *ad libitum* feed intake for 4 days or 80 per cent for 8 days starting from 4th day of age followed by *ad libitum* feeding revealed no significant differences in feed conversion among treatment groups (Lippens *et al.*, 2000).

Lee and Leeson (2001) studied the effects of early life under nutrient in broilers by providing 0.75 Kcal ME/g BW\(^{0.75}\) for days, 1.5 Kcal ME/g BW\(^{0.75}\) for 6 days starting from 6th day of age and found an improved feed conversion in restricted birds than full-fed control birds.

The effects of feed restriction (90, 80 and 70 per cent of *ad libitum* intake) during the early stage of growth (7-14 days) and later period (42-49 days) in broilers was studied by Shariatmadari and Hosseni (2001) and they found that the feed conversion efficiency of the birds given the early feed restriction was better than the control group when considered at the same age and on the same body weight basis. Birds restricted at the late stage of their growth not only had a better feed conversion efficiency at the same age as the control group, but had a better feed conversion efficiency on the same weight basis.

The effects of energy and protein dilution (adding rice hulls at 0, 100, 150, 200, 250 and 300 g/kg) between 6 and 12 days of age in broilers was demonstrated by Yussefikelari Colaii *et al.* (2001) and they observed that feed intake following the feed restriction period tended to be less (P>0.05) for the birds that received the diluted diets as compared to control and diet dilution had no significant effect on feed conversion ratio.

Santoso (2002) studied the effect of early feed restriction by providing 25 per cent of *ad libitum* for 4 to 6 days, 50 per cent of *ad libitum* for 4 to 6 days and 75 per cent of *ad libitum* for 4 to 6 days, and reported a higher feed conversion ratio than the control.
Broilers restricted to 90 per cent of *ad libitum* intake of control group during different intervals showed significant linear improvement in feed conversion ratio at 42 days (Urdaneta Rincon and Leeson, 2002).

The effect of mealtime feeding (food was withdrawn from 9 am to 3 pm) and low protein diet feeding (19.5% protein) from 7 to 12 days of age in broilers was studied by Konca *et al.* (2004) and found that feed intake was reduced by mealtime feeding. However, better-feed conversion was achieved by mealtime feeding.

Shariatmadari and Vaeztorshizi (2004) studied the effect of three feeding levels (Control, 15% and 30% below *ad libitum*) from 7 to 14 days of age on male and female broiler performance and observed that male broilers had a better-feed efficiency ratio than females.

Broiler chicks subjected to *ad libitum* feed from 7 to 13 days of age or given 25 and 50 per cent of *ad libitum* intake on a daily basis (physical restriction) or 100 per cent of *ad libitum* intake on a daily basis, when the diets were diluted with 25 and 50 per cent rice hulls (dilution restriction) showed feed intake was increased after restriction period and there was no difference in the feed conversion after restriction period (13 to 40 days) between different groups (Toghiani *et al.*, 2004).

The feed restriction either in male, female or combined sex broilers during second and third week of age by 10, 20 and 30 per cent to that of *ad libitum* control feeding did not affect the final seventh week cumulative feed consumption and feed efficiency between treatments (Nirmala *et al.*, 2005).

### 2.4.3 Livability of birds

Peter *et al.* (1972) studied the influence of restricted feed intake on the response of chickens to Marek’s disease and reported no mortality in
groups restricted to 70 or 60 per cent *ad libitum* intake prior to 7\textsuperscript{th} week. Whereas, mortality was seen as early as the 27\textsuperscript{th} day in full fed groups.

The mortality due to ascites in broiler chicks may be reduced when feed was restricted up to 30 per cent without affecting other production characteristics (Oporta and Rubio, 1989).

The role of growth of commercial broilers and its relation to the ascites syndrome was studied by Palos Rodriguez *et al.* (1991) and reported restricted feeding (75.0 or 82.5\%) up to 28 days of age followed by *ad libitum* feeding up to 56 days reduced the ascites mortality without affecting the final body weight.

Ballay *et al.* (1992) studied the initiation and the length of different feed restriction programs on broilers and reported overall mortality was less in restricted groups.

The control of ascites syndrome by feed restriction techniques was demonstrated by Arce *et al.* (1992) and found that skip-a-day feed restriction programs during the starting period can effectively reduce the incidence of ascites syndrome without severely compromising body weight gain or feed conversion.

The mortality of broiler chicks reared from 1 to 56 days of age under feed restriction from 8 to 56 days of age with 8 hours per day of access to feed were 88 per cent less when compared to control (Arcemenocal *et al.*, 1995).

Ramlah *et al.* (1996) conducted an experiment in broilers (0-42 days) consisted of providing feed *ad libitum*, restriction to 75 per cent of *ad libitum* intake from 8 to 14 days old and restricted to 50 per cent of *ad libitum* intake from 15 to 21 days old and concluded that the mortality rate in the restricted groups was lower than the full fed groups.
Broilers subjected to feed restriction by 20, 30 or 40 per cent of the fully fed group on day 8, 9, 12 and 13 followed by *ad libitum* feeding showed decreased mortality rate in restricted feeding group than the control group (Saleh *et al*., 1996).

A significantly lower mortality was recorded in the feed restricted flocks (12 hours feed/day at 15-35 days of age) than in the fully fed flock aged from 3 to 7 weeks (Tottori *et al*., 1997).

The broilers subjected to quantitative feed restriction of 0, 10, 20, 30 and 50 per cent from 8 to 14 days had decreased mortality rate than the control. Also, birds fed *ad libitum* had highest sudden death syndrome (SDS) against feed restricted birds (Gonzales *et al*., 1998).

The broilers restricted to 80 or 90 per cent of *ad libitum* feed intake for 4 days or 80 per cent for 8 days followed by *ad libitum* feeding revealed reduction in mortality rate and sudden death syndrome in restricted groups than the control group (Lippens *et al*., 2000).

Lippens *et al.* (2002) in their study, the broilers were restricted to 80 per cent of *ad libitum* intake of previous 24 hours of the control group from 4th to 7th day of age followed by *ad libitum* feeding and concluded that the retardation of early growth of fast growing broiler chickens could reduce mortality and increase performance.

The effect of early feed restriction was studied by Santoso (2002) by providing 25 per cent of *ad libitum* for 4 to 6 days, 50 per cent of *ad libitum* for 4 to 6 days and 75 per cent of *ad libitum* for 4 to 6 days and reported inconsistent mortality rate in early feed restricted broiler groups.

Camacho *et al.* (2004) carried out an experiment by restricting feed to the broilers for 8 hours/day for 14 days at 21 or 28 day, 14 or 21 day
and 7 or 14 day of age and concluded that the quantitative feed restriction at 7 days of age reduced the mortality from ascites.

The feed restriction either in male, female or combined sex broilers during 2nd and 3rd week of age by 10, 20 and 30 per cent to that of ad libitum control feeding showed hundred per cent livability in female broilers up to 7th week of age both in feed restricted groups and in ad libitum fed control group, such livability was recorded in male and combined sex broilers up to 5th week of age (Nirmala et al., 2005).

### 2.5 Effect of dietary variation and feed restriction on carcass characteristics

Dressed carcass percentage tended to increase with increasing dietary energy level (Farrell et al., 1973).

Moran (1979) reported percentage apparent carcass yield was not affected when broilers fed with lowest level of protein (20%) during growing phase (2 to 5 weeks) followed by normal finishing ration (6 to 7 weeks).

Significantly higher dressing percentage was recorded in broilers subjected to quantitative feed restriction at levels of 95, 90 and 85 per cent of ad libitum for 2 and 3 weeks as compared to those fed ad libitum (Sunaria and Sharda, 1981).

The effect of early protein restriction on the meat quality of broilers was studied by Choudhary and Aggarwal (1986) and found that the per cent protein content of meat increased with increase in age, however with a decrease in protein in feed, the per cent protein content of meat also decreased.

Leeson et al. (1991) used conventional broiler starter diets, which had been diluted with 25, 40 or 55 per cent ground rice hulls, from 7 to
16 days of age and reported diet dilution had no effect on carcass characteristics at 42 days of age.

Broilers subjected to either *ad libitum* access or restricted to alternate day access to feed initiated at different ages and lasted for different durations showed feeding regimens had little effect on organ weights (Ballay *et al.*, 1992).

Fontana *et al.* (1993) carried out an experiment by restricting the feed to broilers by providing 40 Kcal of ME/bird/day, commencing at 4 days of age for the duration of 6 or 7 days and observed that early feed restriction minimally affects organ weights.

Organ weights taken during realimentation showed significantly (P<0.05) heavier liver and pancreas for feed restricted broilers (50% of *ad libitum* between 6-12 days of age) compared to those fed *ad libitum* (Zubair and Leeson, 1994b).

The increased weight of the empty digestive tract may have contributed to the ability of the broiler chickens to achieve compensatory growth after the early food restriction period (Susilla *et al.*, 1994).

Broilers subjected to varying dietary protein levels and restricted feeding showed higher edible meat per kg live weight in restricted groups than the control birds (Hirwade *et al.*, 1995).

Palo *et al.* (1995) reported absolute and relative weights of supply organs (proventriculus, gizzard, small intestine, liver and pancreas) were less affected by feed restriction and responded more quickly to refeeding than the whole body.

The effect of energy and protein restriction on carcass characteristics of broilers was studied by Ramarao *et al.* (1996) and found that dietary regimen had no significant effect on blood and feather loss and ready-to-cook yields.
Ramlah et al. (1996) concluded that there was no effect on dressing percentage due to early feed restriction in broilers. But, the weights of liver and gizzard were affected due to restriction.

Saleh et al. (1996) studied on broilers subjected to feed restriction by 20, 30 or 40 per cent of the fully fed group on Day 8, 9, 12 and 13 followed by *ad libitum* feeding and found that the dressing percentage of most severely restricted groups was higher than that of corresponding controls.

The effect of different restriction feeding programs was studied by Cristofori et al. (1997) and they concluded that broilers subjected to feed restriction by daily amount to satisfy their metabolic requirements in early stage from 7 to 21 days showed the best carcass visual scores.

Diet dilution with 0, 20, 40 and 60 per cent of rice hulls between 7 and 14 days of age in broilers had no effect on per cent dressed and eviscerated weight at 56 days of age (Upendrakumar et al., 1997).

The gut development could not be stimulated by diluting the starter diet with wheat bran during 11 days after hatch in broilers (Michel Picard et al., 1999).

Vargas et al. (1999) studied four levels of feed restriction in broilers (0, 15, 30 and 45%) and two periods (from 8 to 14 and from 8 to 17 days of age) and reported a decrease in total carcass yield and breast yield and increase in edible viscera up to level of 22.29 per cent in feed restriction.

The broilers restricted to 80 or 90 per cent of *ad libitum* feed intake for 4 days or 80 per cent for 8 days followed by *ad libitum* feeding revealed 80 per cent of *ad libitum* intake for 8 days had a significant lower carcass yield than that of control (Lippens et al., 2000).

The effects of early life under nutrition in broilers was studied by Lee and Leeson (2001) by feeding 0.75 Kcal ME/g BW$^{0.67}$ for 4 days, 1.5
Kcal ME/g BW$^{0.67}$ for 5 days or 2.25 Kcal ME/g BW$^{0.67}$ for 6 days started from 6th day of age and they observed decline in carcass yield for birds fed with 0.75 Kcal ME/g BW$^{0.67}$ for 4 days. Whereas, superior breast meat yield was recorded in birds fed with 1.5 Kcal ME/g BW$^{0.67}$ for 5 days.

Urdaneta Rincon and Leeson (2002) reported broilers restricted to 95, 90 or 85 per cent of ad libitum intake of control group during different intervals showed ad libitum fed birds had the heaviest carcass weight and breast meat yields and a progressive reduction in both parameters was noted with increasing feed restriction.

The effect of three feeding levels (control, 15% and 30% below ad libitum) during 7 to 14 days of age on male and female broiler performance was demonstrated by Shariatmadari and Vaeztorshizi (2004) and they found that feed restriction had no effect on carcass components and there was no difference between carcass components of male and females.

Broiler chicks were full fed from 7 to 13 days of age or given 25 and 50 per cent of ad libitum intake on a daily basis (physical restriction) or 100 per cent of ad libitum intake on a daily basis, when the diets were diluted with 25 and 50 per cent rice hulls (dilution restriction). The results showed that method and severity of restriction had no effect on intestine and liver weight (Toghiani et al., 2004).

The carcass characteristics (pre-slaughter weight, eviscerated weight, ready-to-cook percentage, giblets weights) at 7th week of age in male, female and combined sex broilers did not differ significantly due to feed restriction at early ages (Nirmala et al., 2005).
2.5.1 Abdominal fat content

Restriction of feed intake to 90 per cent of ad libitum intake in early life had significantly reduced the abdominal fat pad size at 49 days of age in broilers (Mollison et al., 1984).

Plavnik and Hurwitz (1985) studied the performance of broiler chicks due to feed restriction by way of providing energy from 30 to 45 Kcal/day for different periods ranging from 6 to 28 days started at the age of one week and found a reduction in abdominal fat at 8 weeks of age in early energy restricted groups.

Plavnik and Hurwitz (1988) studied the effect of age, duration and sex on early feed restriction in broiler chicks and found that feed restriction reduced the amount of abdominal fat at the age of 54 to 59 days without any concomitant reduction in body weight.

Feeding strategy to reduce fat deposition in broiler chickens was studied by Jones and Farrell (1989) and they reported early feed restriction begining at 7 days old, decreased the body fat and extreme feed restriction reduced the adipocyte volume but milder restriction affected the adipocyte number.

The commercial broiler females had higher abdominal fat content than males (Alsobayel et al., 1989). The effects of severe feed restriction by providing diets containing the metabolizable energy value of 1.5X body weight (kg)$^{2/3}$ was studied by Liarn et al. (1991) and they concluded that feed restriction for 5 or 10 days at 1 or 5 weeks old reduced the fat pad weight by 31.3 to 70.8 per cent.

Ballay et al. (1992) studied the initiation and the length of different feed restriction programs on broilers and reported that feeding regimen had little effect on organ weights relative to body weight, amount of abdominal fat or percentage lipid in the abdominal fat pad.
The feed restriction significantly reduced the abdominal fat (Plavnik and Balnave, 1992). Susbilla et al. (1994) recorded non-significant difference among different groups in percentage of carcass fat and abdominal fat of broilers restricted to 50 or 75 per cent of *ad libitum* intake from 5 to 11 days old.

A study on feeding of 90, 75 and 60 per cent of previous 24 hour feed consumption of full fed controls from 7 to 14 days of age or 80 and 60 per cent from 8 to 16 days of age was conducted by Deaton (1995) and concluded that the feed restriction did not affect the abdominal fat of broilers.

The effects of feed restriction in broilers was studied by Santoso et al. (1995) by way of providing 50 per cent *ad libitum* for 5, 10 and 15 days starting from 5 days old followed by *ad libitum* feeding up to 56 days old and reported that the abdominal fat weight tended to be increased at 27th day old and was decreased at 56th day.

Zhong et al. (1995) found that feed restriction of 1.49 Kcal/g BW$^{2/3}$ daily from 7 to 12 days of age in broilers showed decreased abdominal fat level than the control. They attributed it to the reduction in adipocyte volume due to reduced lipogenesis.

A broiler experiment was conducted by Ramlah et al. (1996) by way of providing feed *ad libitum*, restricted to 75 per cent of *ad libitum* intake from 8 to 14 days old or restricted to 50 per cent of *ad libitum* intake from 15 to 21 days old and concluded no effect on the weight of abdominal fat.

The effect of long term feed restriction in broiler chicken was studied by Khantaprab et al. (1997) from 1 to 50 days old i.e., fully fed, 20 and 40 per cent reduction in feeding and reported fat deposition
included abdominal, inter muscular and other parts of the body was inhibited by feed restriction.

Attia et al. (1998) studied the effect of broilers subjected to feed restriction during second week by 50 per cent of ad libitum control for one week and 50 per cent of ad libitum during second and third week age and reported a lower abdominal fat percentages in one week feed restriction than the other two methods at 7 weeks of age. Females had higher abdominal fat percentage than the males.

Broilers chicks fed with 85 or 75 per cent of ad libitum or ad libitum for 5 days per week with 3rd and 5th days of food withdrawal for 28 days showed lower abdominal fat in 25 per cent feed restricted birds than all the other groups (Benyi and Habi Habi, 1998).

Leeson et al. (1999) recorded low abdominal fat in broilers fed with low nutrient density diets between 0 to 70 days of age compared to control.

The effects of energy and protein dilution (adding rice hulls at 0, 100, 150, 200, 250 and 300 g/kg) in broiler chickens was demonstrated by Yussefikelari Colaii et al. (2001) between 6 and 12 days of age and reported diet dilution had no significant effect on abdominal fat proportions.

Urdaneta Rincon and Leeson (2002) reported broilers restricted to 90 per cent of ad libitum intake of control group during different intervals showed no significant difference in abdominal fat pad weight across treatments.

The effects of three feeding levels (control, 15% and 30% below ad libitum) during 7 to 14 days of age on broiler performance was demonstrated by Shariatmadari and Vaeztorshizi (2004) and they found there was no effect of restriction on abdominal fat content.
Broiler chicks were full fed from 7 to 13 days of age or given 25 and 50 per cent of *ad libitum* intake on a daily basis (physical restriction) or 100 per cent of *ad libitum* intake on a daily basis, when the diets were diluted with 25 and 50 per cent rice hulls (dilution restriction). The result showed that method and severity of restriction had no effect on intestine and liver weight but 50 per cent diet diluted birds showed significantly lower abdominal fat pad compared to full fed birds (Toghiani *et al*., 2004).

The feed restriction either in male, female or combined sex broilers during 2nd and 3rd week of age by 10, 20 and 30 per cent to that of *ad libitum* control feeding showed the abdominal fat deposition is lowered by early feed restriction (Nirmala *et al*., 2005).

### 2.6 Effect of dietary variation and feed restriction on skeletal deformities

Salmon *et al.* (1983) studied the effect of starter and finisher protein on performance, carcass grade and meat yield of broilers and found that leg problems were associated with the highest starter protein level.

Short term feed restriction during early stage benefits broiler chickens by slowing early growth and allowing better skeletal development (Robinson *et al*., 1989). Similarly Leeson and Summers (1988) reported slower growth rate at early stage in broilers might also be important for optimising skeletal development.

Robinson *et al.* (1992) showed that restricting feed intake of broilers at 2nd week post-hatch significantly reduced skeletal problems associated with early fast growth.
The potential of short term feed restriction programs as a management tool, directed at decreasing the incidence of skeletal disease in broilers (Yu and Robinson, 1992).

Broilers fed with reduced nutrient density (175 g protein/kg) between 7 and 14 day of age showed feed restricted birds had consistently fewer walking defects and less ‘hock burn’ than the *ad libitum* fed birds (Carter *et al*., 1994). Feed restriction at an early age of broilers reduced the mortality, leg abnormalities and ascites (Zubair and Leeson, 1994a).

Deaton (1995) conducted a study on feeding of 90, 75 and 60 per cent of previous 24 hour feed consumption of full fed controls from 7 to 14 days of age or 80 and 60 per cent from 8 to 16 days of age and concluded that the deformed legs did not differ between any of the comparisons.

Camacho *et al*. (2004) carried out an experiment by restricting feed to the broilers for 8 hrs/day for 14 days at 21 or 28 day, 14 or 21 day and 7 or 14 day of age and concluded that the quantitative feed restriction at 7 days of age reduced the mortality from leg problems.

Feed restriction programs in broilers, both quantitative (60% of *ad libitum*) and qualitative (energy and protein) between 7 and 14 days of age did not significantly affect the Ca and P contents of tibia, femur and humerus. However, bird age influenced Ca and P contents, with levels increasing up to 28 days of age and remaining constant afterwards (Giustibruno *et al*., 2004).

The effect of mealtime feeding (food was withdrawn from 9 am to 3 pm) and low protein diet feeding (19.5% protein) between 7 to 21 days of age in broilers was studied by Konca *et al*. (2004) and found that feeding programs did not improve the gait score of broilers.
2.7 Effect of dietary variation and feed restriction on Economics

Starr Jackson et al. (1982) reported feed costs per kilogram live weight and return over feed costs per bird were significantly (P<0.01) affected by dietary protein and energy levels. Increasing dietary protein level above 20 per cent resulted in higher costs and lower returns. Despite the low cost of the 16 per cent crude protein diets, production costs were increased above those for higher protein levels, reflecting the poor body weights and feed conversion ratio achieved with these diets.

The performance of broiler chicks due to feed restriction was studied by Plavnik and Hurwitz (1985) by way of providing energy from 30 to 45 Kcal/day for different periods ranging from 6 to 28 days started at the age of one week and found an economic advantage in restricted feeding over a continuous ad libitum feeding regimen.

Attia et al. (1991) conducted a study on broilers subjected to ad libitum feeding or feed restriction to 50 per cent of control feed intake between 1 and 3 weeks or given 20 per cent dried chicken excreta during 5 and 6 weeks age and concluded that incorporating dried chicken excreta in finisher diets is economically feasible, whereas 50 per cent feed restriction is not.

Mild food restriction applied at an age of about one week and allowing for 60 to 75 per cent of normal growth, may offer an economic advantage over a continuous ad libitum feeding regimen in broilers (Plavnik and Hurwitz, 1991).

Tottori et al. (1997) reported the economic performance with restricted feeding was better than that with full feeding as a result of improvements in viability and feed conversion rates.
The effect of diets diluted with 0, 20, 40 and 60 per cent of rice hulls between 7 and 14 days of age in broilers was studied by Upendrakumar et al. (1997) and concluded that cost of production was not affected by diet dilution.

Broilers subjected to mild feed restriction (90% of *ad libitum* intake for 4 days) revealed some economic advantages as compared to control birds mainly by reducing mortality (Lippens et al., 2000).

Nirmala et al. (2005) reported the feed restriction either in male, female or combined sex broilers during 2nd and 3rd week of age by 10, 20 and 30 per cent to that of *ad libitum* control feeding showed the broilers with 20 per cent feed restriction during 8 to 14 days of age fetched the highest net profit per bird (Rs.10.08) and the highest net profit per kg live weight (Rs.4.57).