THE EFFECT OF 'rc' MUTATION ON THE PERFORMANCE OF CHICKENS UNDER DIFFERENT DENSITIES AND FLOCK SIZES

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ABSTRACT

The impact of visual contact or the lack of it on egg production was investigated by utilizing genetically blind chickens in a factorial experiment involving two genotypes (blind vs sighted), two densities (1000cm^2 per bird vs 2000cm^2 per bird), two flock sizes (1♂ 4♀♀ vs 4♂♂ 16♀♀), and two replications. Parameters measured were: number of eggs collected, egg weight, amount of feed taken from feed trough, body weight gain, fertility of eggs, feather pecking and comb damage scores, leukocyte count, plasma corticosterone level and adrenal gland weight.

During the two-month experimental period, blind hens produced 12.7% more eggs while requiring 44.1g less feed per bird per day compared to normal hens. There was no significant difference in body weight gained between the two genotypes. Thus blind hens had better feed efficiency compared to normal hens. Significant genotype x flock size and genotype x density interactions also indicated that the performance of the blind chickens was less sensitive to densities and flock sizes compared with normal chickens.

Other parameters measured provided evidence that the blind chickens were less active socially, and had better feather coverage during the experimental period. These parameters also provided circumstantial evidence that the blind chickens were under less stress than normal ones. It is therefore concluded that the blind chickens had less energy requirement for activities other than egg production. Results from this experiment indicate that the genetically blind chicken not only has good potential as an experimental animal but also may have some commercial value.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

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INTRODUCTION

The gene 'rc', an autosomal recessive mutation, causes blindness in chickens when in the homozygous state. The birds lack rods and cones in the retina and cannot perceive light (Cheng et al., 1980). After analysing the genetic background of this mutant , Cheng et al. (1978) have designated this gene as 'rc' to indicate the absence of rods and cones in the retina. Hutt (1935) also reported a case of hereditary blindness which seems to be similar to 'rc' mutation in behavior and external eye morphology. Several other forms of reported cases of hereditary blindness in chickens are evident in the literature (Clayton, 1975; Smith et al., 1977). Very little information is available on the behavior and reproductive performance of birds having vision anomalies. It is apparent, however, from the works of Hutt (1935) and Cheng et al., (1980) that blind chicks learn to eat and drink as well as normal ones when they are exposed to readily available feed and water in an enclosed battery or pen.

Under normal rearing conditions, survival rate of affected birds has not yet been determined but performances in terms of egg production, body weight gain, fertility and hatchability are thought to be in the normal range (Cheng et al., 1980).

Many environmental factors influence laying hens' performance, of which density (floor area per bird) and flock size (number of birds per flock) have received considerable attention (Adams and Jackson, 1970; Adams et al., 1978; Hill, 1977 and Cunningham and Ostrander, 1982). In modern poultry management, layers are kept, as a general rule, in a place as small as possible without lowering productivity. This has occurred to keep a balance with increasing

costs of building, equipment and labour which, as a consequence, has brought about a significant change in laying hens' environment.

In a restricted environment such as in an intensive production system, animals become dependent on each other and on the surrounding environment (Kilgour, 1972). This affects normal behavior of animals. Intensive housing is also a part of intensive animal husbandry and it demands behavioral adaptations by the animals concerned (Arbi, 1978). The question of adaptability and non-adaptability emerges under those conditions. Non-adaptability may impose stress which may appear to be greater with higher densities and large flock sizes than with lower densities and small flock sizes (Hill, 1980). Such stress will result in poor productivity per bird.

Studies concerning bird density and flock size on the performances of layers are progressively increasing in number. There is also an increasing interest to manipulate other environmental conditions to reduce the level of social interactions among birds in a flock. For example, intensity of light in poultry houses could be manipulated to reduce social interactions among the flock mates. Hughes and Black (1974) observed that bright light (55 to 80 lux) compared to dim light (17 to 22 lux) increased activity highly significantly in birds (Shaver 288) reared either in cages or pens. They also found a direct relationship between activity and pecking damages.

Therefore, under low intensity of light (dim light), probably, the birds cannot see each other well, thus, reducing agonistic encounters (social interactions) among them. Some Scientists are also attempting to restrict the vision of the birds by using spectacles to reduce social stress. In Australia, the use of 'specs' (Specs are anti-pecking devices made of a coloured flexible polyethylene

material. When fitted on the nares of the hens, they allow them to look to the side or down but not directly ahead) in commercial laying flocks has been increasing (Cumming and Epps, 1976). Several reports are available in the literature describing the effects of specs on the performance of laying hens (Cooper and Barnet, 1966; Cumming and Epps, 1976; Karunjeewa, 1977; Arbi, 1978). These works suggest that fitting specs to hens controls feather pecking by reducing visual contact and agonistic behavior, save energy from reduced social interactions and increases productivity. The use of specs also has advantage in reducing social stress by limiting visual contact and breaking down the social hierarchy. More recently, coloured contact lenses for laying hens have been introduced in the United States for reduction of cannibalism in chickens; hens fitted with red lenses (rosy glasses) appeared to be the least stressed (Time magazine, December 29, 1980, page 14).

Despite many advantages of using mechanical device to control vision in laying hens, there are some disadvantages also. The hens fitted with such devices need to adapt to them. In addition, they increase costs in terms of labour and capital investments. Furthermore, they could be a health hazard to the birds (if not fitted properly) inviting bacteria and parasites to cause disease. The genetically blind birds are obviously free from all such disadvantages. However, the opportunity to conduct investigations into the usefulness or disadvantages of genetically blind birds in this context has not presented itself until now.

This study was therefore undertaken to determine if the lack of sight affects the performances of chickens (utilizing the genetically blind birds and their sighted counterparts) under different density and flock size

conditions.

REVIEW OF LITERATURE

I. Productivity

1. Egg production

Egg production is by far the most important trait in commercial egg-laying strains and accounts for about 90% of the total farm income from commercial egg production (Oluyemi and Roberts, 1979). In the modern system of intensive husbandry practices, laying hens' genetic back-ground and its environment have been changed in many ways (Craig, 1982).

The numerous breeds of yesterday have been replaced entirely by the White Leghorn for white egg production and by the Rhode Island Red and New Hampshire breeds for brown egg production. Within the White Leghorn breed, many strains for commercial egg production have been developed. These various strains are not expected to be equally well adapted to intensive housing conditions. Genetically influenced behavioral differences existing among stocks probably bear on their relative adaptatedness to high density environment (Craig, 1982).

The response of different laying strains under intensive rearing conditions has been the subject of many investigations. Adams and Jackson (1970) conducted two experiments over two years involving 6 commercial laying strains. They observed highly significant strain effect on hen-housed egg production in one experiment but not in the other. However, when production was expressed as hen-day production, the difference between strains became non-significant in either experiment. This result indicated that strain difference in egg production was due to differences in sexual maturity of the pullets as well as

differences in mortality of laying birds. Another experiment on egg production was conducted by Marks et al. (1970). They also used 6 commercial egg laying stocks and recorded their egg production over a full year. The same experiment was repeated in the following year. In both of their trials, they observed highly significant differences among stocks in percent hen-day egg production. The number of chickens housed in the same cage also affects egg production. Emmans (1971) surveyed 11 different strains of layers kept in cages. Birds in 6 strains showed a reduction in egg production when they were housed at 4 per cage rather than 3, but the egg number of the remaining 7 strains did not show any significant decline. In another study (Anon, 1974), 4 birds at 523cm^2 per bird were compared with 5 birds at 418cm^2. Nine different strains were used, 8 of those showed a reduction in egg production under the most crowded conditions while one did not change. The reduction in egg production varied from 0.7 to 10.4%. That egg production is significantly affected by strains was also reported by Feldkamp and Adams (1973); Aitken et al. (1973) and Hill (1977). In a recent study using two strains of White Leghorn pullets, Cunningham and Ostrander (1982) reported significant strain differences for hen-day and hen-housed egg production. In their study, 1 strain averaged 4% more eggs per hen on a hen-day and hen-housed basis than the other strain.

Studies on genotypes involving single locus on the variability of egg production are not common. In one study, Bullerman (1981) observed a reduction of 17% in egg production of dwarf genotype (dw/dw) compared to non dwarfs (Dw-) under identical conditions. Merat and Bordas (1979), on the other hand, did not find any variations in pea comb genotype (Pp) compared to single comb (pp).

The effect of floor space, sometimes referred to as bird density on egg

production of laying hens has been widely investigated. Hoffman and Tomhave (1945) observed the effect of density on the egg production of New Hampshire pullets at densities of 2564, 3437 and 4320cm^2 per bird. The high density group (2564cm^2 per bird) laid about 18 eggs less (in a year) than the other two groups. Siegel (1959) compared two extreme densities (3716 vs 1239cm^2 per bird) in floor pens. The egg production rates were 48% for low-density and only 38% for high-density groups. On the other hand, Nordskog (1959), and Fox and Clayton (1960) reported only small declines in production from decreasing floor space. From the early sixties onward, most density related studies were made in cages and have demonstrated a reduction of egg production as the cage density increased (Lowe and Haywang, 1964; Moore et al., 1965; Cook and Dembnicki, 1966; Bell and Little, 1966; Owing et al., 1967; Wilson et al.1967; Champion and Zindel, 1968; Adams and Jackson, 1970; Grover et al., 1972; Foss and Carew, 1974; Hill, 1977 and Cunningham and Ostrander, 1982).

Group size or colony size also seem to significantly contribute to egg production of laying stocks. In most of the earlier studies, it has been difficult to evaluate its effect because group-size has been confounded with density (Hughes, 1975). Aitken et al. (1973) observed that compared to birds housed two per cage those housed one per cage laid 9% more eggs. Feldkamp et al. (1973) using 3 or 5 birds in small cages (41cm x 41cm) and 9 or 18 birds in large cages (72cm x 82cm) found significant effect of colony size. Highest rate of lay (78%) was from the small cage-low density and lowest rate (70%) from the large cage-high density. Adams and Jackon (1970) also observed similar responses. The effect of increased colony size on the hen-day rate of lay was studied by Wilson et al. (1977). Increased colony size depressed egg production.

Mean rate of lay was significantly higher for individually caged birds (75.59%) than for birds housed either 3 (67.39%) or 5 (67.39%) or 5 (63.54%) per cage. A review of literature indicated that all group sizes in constant area per bird did not respond in a linear order. As for example, Champion and Zindel (1968) found that 3 birds per cage had better egg production compared to 2, 4 or 6 birds per cage. In another study, Tower et al. (1967) had shown that 10 birds per cage was more productive than 2, 5 or 20 birds per cage.

The egg production of laying hens is also influenced by the behavior and social rank (according to peck order) of the individuals within a flock (Tindel and Craig, 1959). In studies involving strains differing in social dominance ability, Biswas and Craig (1970), Craig (1970) and Lowry and Abplanlp (1972) observed that, compared to their relative performance when kept separately, socially dominant strains had higher levels of egg production relative to subordinate stocks when kept together. Indirect evidence of the within flock aggressiveness on egg production was provided by Craig (1970) and by Biswas and Craig (1970). These workers reported that a strain of highly aggressive White Leghorn had higher egg production than a strain of more peaceful White Leghorn when kept in individual cages. On the other hand, their ranks for egg production were reversed when those strains were kept separately in floor pens.

McBride (1971) reported that the impact of visual contact among hens is great in crowding situations. Fitting 'specs' to the hens may reduce, to some extend, the chance of visual contact and thus reduce the social stress (Arbi, 1978) and improve productivity. Cumming and Epps (1976) in studies with spec-hens found increased egg production and feed efficiency. The spec-hens produced 11% more eggs than the control hens over 11-month laying period. Other reported

studies using spec on hens showed considerable improvement in egg production of spec-hens (Karunajeewa, 1977 and Arbi, 1978).

Among many other factors which can affect egg production of laying hens, the most important are dietary composition (Lebbie et al. 1981; Vargas and Edward, 1982), light (Odom and Harrison, 1979; Nys and Morgin, 1981) and temperature (Arad et al. 1981).

2. Egg weight

Egg size is very important in the production and marketing of eggs (Christmas et al. 1979). Romanoff and Romanoff (1949) stated that egg size could be expressed in terms of egg weight, because weight provides a basis of comparison which is more convenient than dimensions or volume. The egg weight of laying hens is influenced by numerous hereditory, environmental and physiological factors.

Earlier reports (Romanoff and Romanoff, 1949) on the egg weight of different avian species indicated large variations between species. Ostrich for example lays eggs which are on the average 1400g, Swan 285g, Canada Goose 135g, Pea Fowl 90g, Turkey 85g, Duck 80g, Leghorn Fowl 58g, Pigeon 17g and Humming Bird 0.5g.

The effect of heredity on egg weight of chickens has been investigated. Warren (1953) reported that egg weight is a highly heritable character. Numerous heritability estimates were reported for this trait. King and Handerson (1954) found that the heritability of egg weight on the basis of full-sib correlation and regression of daughter on dam were 0.48 and 0.60 respectively. Hogsett and Nordskog (1958) reported heritability estimates to be 0.36, 0.45 and 0.41 in light breeds and 1.15, 0.55 and 0.85 in heavy breeds on the basis of paternal

half-sib, maternal half-sib and full-sib correlations respectively. Kinney (1969) summarised the reported heritabilities of light and heavy breeds for early egg weight and mature egg weight. For early egg weight light breeds averaged 0.45, 0.53, 0.45 and 0.52; heavy breeds 0.57, 0.65, 0.67 and 0.63; for mature weight, light breeds 0.36, 0.45, 0.50 and 0.44; heavy breeds 0.58, 0.54, 0.58 and 0.46 respectively according to sire, dam, full-sib and regression methods. Recent reviews on the heritability estimates of egg weight are not evident in the literature.

The effect of strains on the egg weight of laying hens has been the subject of several investigations. Cunningham and Ostrander (1982) reported significant strain effects for average egg weight in two White Leghorn egg laying strains. Egg weight for one strain averaged 4g more than the other one (62g vs 58g). They also found that the strain which had the heaviest egg weight had also produced the most eggs. Akber et al. (1983) had also demonstrated differences in egg size of 7 genetic stocks of White Leghorn type chickens. On the other hand, Hill (1977) did not find such variations in two other commercial strains of White Leghorns.

Several authors reported that they found no significant influence of bird density on egg weight. Cunningham and Ostrander (1982) observed that birds housed 4 per cage compared to those housed 5 birds per cage had the same egg weight. Hill (1977) conducted two experiments with Babcock 300 and Shaver, 288 stocks. This author demonstrated that birds housed 310, 387 or 464cm^2 per bird, or 3, 6, or 12 birds per group did not have significantly different egg weights in either of the experiments. Similar results were also reported by other workers (eg. Aitken et al., 1973; Adams and Jackson, 1970).

Egg weight is reported to be significantly affected by cage size, but the results are inconclusive. Cunningham (1982) reported that White Leghorn layers housed in shallow cages laid significantly heavier eggs than birds in the deep cages (60.1g vs 58.9g). Significantly heavier average annual egg weight for birds in shallow cages compared to birds in deep cages were also reported by Hill and Hunt (1978). Contrary to the above findings, Lee and Bolton (1976) reported that White Leghorn layers housed in deep cages laid significantly heavier eggs than those housed in shallow cages. Adams and Jackson (1970), and Cunningham and Ostrander (1982) did not find such difference between shallow and deep cages with varying population sizes.

The relationship of laying hen's body weight and egg weight was investigated by several authors. Harms et al. (1982) divided Dekalb XL pullets at 28 weeks of age into light (L), medium (M) and heavy (H) body weight groups. The birds were housed in 20.3 x 45.7cm wire cages for a period of 16 weeks. They found egg weight to be related to hen's body weight. Significant differences were found between all three body weight groups. There were approximately 1 and 2g differences in egg weight between the L to M and M to H groups. In another study Bell et al. (1981) used 3 strains of SCWL pullets segregated into two weight classes (heavy and light) at 1 day of age versus 18 weeks of age. Performance records were kept to 68 weeks of age. Light pullets segregated at 1 day and 18 weeks produced significantly smaller eggs. This amounted to 2.4g for the 1 day groups and 2.8g for the 18 week groups. McClung and Jones (1973) also reported similar results.

Age of the hen is also a contributing factor to egg weight. Gilbert et al. (1978) stated that egg weight is a function of age of the hens rather

than the period of lay. Reports by previous workers (eg. Cowen et al., 1964; Saeki et al., 1967; Weatherup and Foster, 1980) indicated that egg weight increases monotonically with age and approaches an asymptote.

Many other factors also affect egg weight. Some important ones are nutrition (Lebbie et al., 1981; McDeniel et al., 1981), ambient temperature (Arad et al., 1981) and light schedule (Nys and Morgin, 1981).

3. Feed consumption

Feed cost accounts for at least two-third of the total cost of producing eggs (Wing and Nordskog, 1982) or 70% of total cost for producing broilers (Pym and Nicholls, 1979). Any improvement in the efficiency of feed utilization would be of economic benefit. The amount of feed that a bird consumes is related to its energy requirements which in turn is affected by genetics and environment. One way of comparing feed consumption is by means of analysing the 'residual feed component' (Bordas and Merat, 1981). The residual component was defined as the amount of feed consumption remaining after statistical adjustments for body weight and egg mass. Expected feed consumption was estimated from a multiple regression equation using independent variables such as mean body weight, body weight change during the test period, and egg mass produced. The residual was then calculated as observed feed consumption minus expected feed consumption. Using this measurement, Merat and Bordas (1979) demonstrated that pea comb (Pp) hens consumed about 2% less feed than single comb (pp) hens. They suggested that with the smaller size of comb and wattles for Pp hens, heat losses and hence energy requirements are less. In another study (Merat et al., 1979) it was also found that white hens (I/I, I/i) consumed significantly less (140.8g) feed than coloured hens in a 28-day period. They could not, however, assign

any plausible explanation.

Significant variations in residual feed consumption within genetic lines were found by Bordas and Merat (1974), Watenabee et al. (1975) and Hagger (1977). Conversely Arboleda (1971) and Lee and Nordskog (1975) failed to find such variation in the White Leghorn lines that they were studying.

On the other hand, between line differences in residual feed consumption exist in chickens. Bordas and Merat (1981), comparing 2 brown egg strains, observed highly significant differences between sire families in both strains. Wing and Nordskog (1982) estimated the heritability of residual feed consumption in two populations of White Leghorns consisted of 4909 birds to be 0.29 ± 0.07 and 0.15 ± 0.06 respectively. These moderately high heritability estimates indicates that individual feed consumption records should be considered in relation to selection for efficiency of egg production.

Quite a number of studies have so far measured feed consumption in chickens in relation to such environmental factors as group size and density (eg. Feldkamp and Adams, 1973; Jensen et al., 1976). In these studies group size ranged from 1 to 5 birds and densities were between 350 and 1400cm^2 per bird. Jensen et al. (1976) reported that hens housed alone ate more than groups of three kept in the same area. Ouart and Adams (1982) conducted two experiments to compare the effects of cage shape, feeder space, cage design, bird density, level of feeding, and feeding period on feeding behavior and bird movements. They found that feed consumption was significantly affected by bird density. Hens housed 2 per cage consumed 10.5g more feed per bird daily than those housed 3 per cage. Furthermore, they also concluded that increased feeder space is important in reducing feeder competition during feeding time.

Social rank and feeding behavior may have considerable influence on the amount of feed consumed and feed spilt. The social rank and priority in feeding was investigated by Candland et al. (1968). Within a restricted environment there exists a strong correlation between the two variables. In their study they used paired comparison technique, a limited feeding period and food deprived chickens, and found that individuals having high social rank spent a longer time in feeding than low ranked birds. Longer feeding requires more energy expenditure. On the other hand Syme and Syme (1974) observed whole group competition for feed in a pen environment having 7 to 8 birds per pen and obtained a poor correlation between the peck order and time spent in command of the feed box.

When animals feed in groups, another kind of social influence is also operative: social facilitation (Craig, 1981). Social facilitation is the repetition of an act performed by one individual by other individuals (Arbi, 1978). Thus, the two kinds of social influences act in opposite directions, social facilitation influence feeding activity, whereas agonistic behavior is likely to reduce feeding by subordinates.

Social interactions can be drastically affected by putting opaque spectacles on laying hens and blocking their frontal vision. Cumming and Epps (1976) reported the effect of spectacles on the feed consumption of 4000 Leghorn-Australorp cross laying hens. They found that hens wearing 'specs' consumed 6% less total feed than control hens and there was also an improvement in feed efficiency as measured by g of egg per kg of feed consumed. Arbi (1978) studied the feeding behavior of hens wearing specs and reported that control hens spent much time in playing with the feed, flicking it around, filing it up or

pecking at the feed trough. Spec hens tended to eat rather than play with the feed. They ate quickly, reduced time spent in feeding activity, and wasted less feed than control hens. He concluded that because of the reduction in feeding time spent by spec hens, energy expenditure due to feeding activities was also reduced.

Another advantage of specs is to reduce feather pecking and feather loss. Emmans and Charles (1976) indicated that maintenance ME (Metabolizable Energy) requirement by hens with extensive feather loss is much higher. Hens with a large amount of feather loss may lose up to 40% more heat from their exposed surface than fully feathered hens. Karunjeewa (1977) reported that the use of specs significantly reduced feather loss in pullets and resulted in a 6.6% reduction in total ME intake.

A study of feed consumption by pullets under cage or floor situations was conducted by Stappers (1969). Pullets in cages consumed 5.6% less energy than pullets in floor pens.

The feed consumption of laying hens is also affected by a host of other factors such as intensity of egg production, body weight, and light schedule (Bordas and Merat, 1981; McDonald, 1978 and Nys and Morgin, 1981)

4. Body weight

Commercial poultry breeders strive to develop small bodied varieties of chickens (White Leghorn strains) that lay at a high rate (Nordskog and Briggs, 1968). The purpose of doing this is to reduce feed requirement for maintenance. Nordskog (1960) demonstrated that an increase of body weight of layers by 454g (1lb) above the mean decreased income, but similar increase in body weight in birds below the mean was beneficial economically. These results

lead to the conclusion that a satisfactory body weight in laying hens is important for economic gain. Nordskog and Briggs also emphasized the importance of an optimum body weight in layer strains. They showed that lowering body weight by 100g per bird from over all mean of 1500g decreased hen-housed egg production by 18 eggs in a production period of 332 days.

It has been reported that body weight or gain in body weight are normally distributed and are affected by many genes each with a small effect and also by many environmental factors (McCarthy, 1977).

Adult body weight of chicken is a highly heritable trait (Clayton and Robertson, 1966). Kinney (1969) summarised most of the published heritabilities of mature body weight obtained by paternal half-sib correlation method. The values obtained averaged 0.52 for light breeds and 0.49 for heavy breeds. These heritability estimates are indicative of the highly heritable nature of this trait. For this reason body weight responded well to selection and has been one of the important factors in selective breeding (McCarthy, 1977).

Body weights of chickens vary according to breed. Standard weight of Rhode Island Red adults and that of White Leghorn adults are reported to be 3856g vs 2722g respectively for males and 2948g vs 2041g respectively for females (Nesheim et al., 1979). On the other hand, reports on differences in body weight gain between strains of White Leghorns are conflicting. Significant variations in weight gain of commercial layer strains were reported by Aitken et al. (1973), Lee and Bolton (1976) and also by Hill (1977). Conversely, Cunningham and Ostrander (1982) found no such variation in body weight gain of 2 strains of White Leghorn layers.

Genetic studies regarding the effect of a single gene on body weight of

chickens were conducted by several authors using different gene loci. Bullerman (1981) compared the body weight of dwarf hens (caused by the effect of a sex-linked recessive gene, dw, Hutt, 1953) with their normal non-dwarf (Dw^+) counterparts in two temperatures (normal 18 °C-20 °C and high 32 °C). From 17 week of age, half of 74 dwarf and 80 normal sized hens were kept in individual cages at 18-20 °C and the others also in cages but at 32 °C. For dwarf hens at the two temperatures respectively, body weight at 91 week of age averaged 1356 and 1131g vs 1958 and 1523g for normals. The reduction in body weight of the dwarf hens was 30% of that of the normal hens in the moderate temperature and the corresponding value in the high temperature condition was 24%. In another study of layers Koroleva et al. (1980) demonstrated that dwarf birds from 20 week of age to the age of first egg (176 days) gained on an average of 13.33g per bird per day compared to 16.93g for normal hens. Touchburn et al. (1980) also reported 27% reduction in body weight gain of dwarf chicks at 5 week of age compared with their normal counterparts. Other gene loci do not seem to have as much influence in causing variation in body weight gain of chickens. For example, the pea comb (Pp) gene was studied by several authors (Kan et al., 1959; Smith, 1961; Siegel and Dudley, 1963; and Williums et al., 1977) but no relationship was found between this locus and body weight in chickens.

Studies concerning bird density on body weight of egg laying strains are variable and the results are inconclusive. In most of the studies group size and area per bird were confounded. In those studies some have observed reduced body weight gain as bird density increased (Grover et al., 1972; Wilson et al., 1967; Foss and Carew, 1974; Dorminey and Arscott, 1971; Jensen et al., 1976, Hill, 1977 and Cunningham and Ostrander, 1982), others observed increased body

weight gain in multiple caged birds compared to individually caged birds (Lowe and Haywang, 1964; Tower et al., 1967; Aitken et al., 1973) and still others found no effect of bird density on body weight gain (Cook and Domnicki, 1966; Champion and Zindel, 1968). Besides, in one study in which group size and area per bird were varied systematically and independently (Wells, 1973), a reduction in space allowance, at a given group size, resulted in a lower weight gain. The group sizes used in this particular experiment were 3, 4, 5 or 6 birds per cage. On the other hand, varying group size, at a given space allowance, had no effect on weight gain. The space provided was 387, 465 and 581cm^2 per bird.

5. Fertility

Fertility in the general meaning of the term is the ability of individuals to become parents. Many factors, both genetic and environmental in origin are reported to affect fertility in domestic fowls.

The evidence that fertility in chickens is a hereditary trait was not realized before the work of Jull (1935), who reported a significant correlation of 0.19 ± 0.05 between fertility of dams with their daughters. Blow et al., (1951) reported that fertility in Standard Bronze turkey was influenced by heredity. These authors estimated heritability of fertility to be as high as 0.81. Another later report (Abplanalp and Kosin, 1953) also confirmed their findings. In New Hampshire chickens Crittenden et al. (1957) reported heritability of fertility to be very low (0.02). Using the same breed (New Hampshire) as Crittenden et al. used , Gilbreath et al. (1962) obtained heritability of fertility to be 0.02, 0.21 and 0.14 according to sire, dam and full-sib correlations respectively. Buckland (1971) estimated the genetic variance of this trait and obtained heritability of fertility to be 0.21, 0.31

and 0.22 for three measures of fertility such as duration of fertility, percent fertility and percent hens fertile. In one more study (Salonia and Shushu, 1972) reported heritability values of 0.25 and 0.44 for fertility in two lines of chickens.

The above reports indicated that in chickens heritability estimates of fertility varied from low (0.02) to high (0.81) with intermediate values (0.20-0.40) being more frequent. These results suggest that fertility in avian species is partly under hereditary control and selection for its improvement could be effective.

Breed differences in male fertility have been reported in the literature (Parker, 1961; Soller et al., 1965). These authors obtained significantly lower fertility in Cornish males than in Delware, New Hampshire and White Rock males. They attributed this to the failure of Cornish males to mate naturally, since there was no significant differences in fertility between breeds when artificial insemination was used. Fertility of White Wyandotte, White Leghorn and Rhode Island Reds was compared by Hutt (1940). He found lower fertility in White Wyandotte than in the other two breeds. Furthermore, differences between strains (Bhagwat and Craig, 1975), between individuals (Soller et al., 1965) and whether or not the males and the females were related (Dunn, 1927) have been reported to have significant effects on fertility. The presence of a certain gene may also affect fertility. Buckland and Haws (1968) reported lowered fertility in pea comb (Pp) and rose comb (RR) chickens compared to birds with single combs.

Adams et al (1978) found that fertility was significantly affected by flock size. They tested two experimental strains of White Leghorn chickens housed in cages at a constant density of 534cm^2 per bird either in small flocks

(1♂:10♀♀) or in large flock (2♂♂:20♀♀). From 20-44 week of age the mean fertility of the birds was 39.4% for small flock vs 55.5% for large flock. In this study they further reported that fertility of individual flocks varied from 0 to 100%. In another study involving birds in larger flocks (8♂♂:80♀♀), Hughes and Holleman (1976) reported fertility of 94%. It is evident, therefore, that the larger the size of the flock (with a constant male-female ratio), the higher the fertility rate. This may be due to male-male competition for mating within the flock.

There is some evidence that fertility in chickens is affected by social rank or peck order of the birds. Guhl and Warren (1946) suggested that the social rank or peck order of the hens to which males are introduced affects their mating behavior. Males tend to mate more frequently with the hens which are intermediate in social rank but not with the highest or lowest ranking hens. The same authors also stated that when three or more males are put together in a pen, both the frequency of mating and fertility are highest for the top-ranking males. The lowest ranking males mate less frequently with few females, because of interference from the highest ranking males.

It was reported in several studies that the age of a pullet has an effect on the fertility of eggs produced. Sunde and Bird (1959) reported that eggs laid by pullets which had just reached sexual maturity did not hatch as well as later eggs presumably due to infertility. Tomhave (1958) also found greater variation in percentage of fertile eggs from pullets of early maturity and late maturity groups. Garwood and Lowe (1982) reported that in the early maturity group (1st egg on 159 days) first fertile egg was found two days after the first egg but in the late maturity group (1st egg on 174 days) one day after.

This difference was not significant.

Other factors affecting fertility are season, state of nutrition and health (Lake, 1974; Lorenz, 1959).

II. Parameters measuring stress

1. Feather pecking

Feather pecking in Gallinaceous birds is a behavioral phenomena (Ottel, 1873), more often this term is confused with aggressive pecking and sometimes with cannibalism. Generally, feather pecking and cannibalism are quite different from aggressive behavior (Wennrich, 1974). Feather pecking is the loss of feathers due to pecking by other birds sometimes associated with hemorrhaging of skin (Hughes and Duncan, 1972). Aggressive pecking is the vigorous and quick pecking activity of a bird at the head of another bird (Wennrich, 1974). On the other hand, feather and cannibalistic pecks are performed much less vigorously and quickly and generally not directed towards the need of the penmates. Feather pecking in most of the cases does not result in bloody wounds, but the bloody wounds caused by cannibalism are usually due to feather pecking. Allen and Perry (1975) also reported that cannibalism in birds is influenced by feather pecking and they are independent phenomena with additive effects.

Various causative factors that can influence feather pecking in birds have been classified by Hughes and Duncan (1972). The main factors involved are dietary composition, environment, hormones and psychic factors. Whether feather pecking is under genetic control is still controversial.

The influence of inheritance or heredity on the occurance of feather pecking has been investigated by several authors. Ritcher (1954) found

considerable strain differences in the incidence of feather pecking. He concluded that, feather eating is a hereditary characteristic. Hughes and Duncan (1972) and Charles (1976) also observed differences between strains for feather loss due to pecking, wear, or both, in laying hens. They did not analyse the causal factors and genetic basis of this 'trait'. However, they suggested that, irrespective of the cause, certain genetic factors may be involved in modifying the individual susceptibility to these causes. Similarly Cuthbertson (1980) stated that feather pecking behavior when identified in a suitable way, has an inherited component and that selection to reduce its occurance should be feasible.

Allen and Perry (1975) reported that in chicken feather pecking occurs in birds by the end of the rearing period, but continuation of its occurance during laying period is influenced by group size and density per bird. Adams et al. (1978) demonstrated that birds housed 22 (2♂♂ and 20♀♀) per group had significantly poorer feathering than those housed 11 (1 ♂ and 10♀♀) per group. Hughes and Duncan (1972) also found a significant group size effect on feather damage with more severe damages in groups of 8 growing pullets housed in cages than in groups of 4. According to Kivimae (1976) high density of layers in battery cages had a negative effect on the plumage. Similarly, Hoffmeyer (1969) observed that high density and flock size in combination increased feather pecking in pheasants.

Type of housing or design of cages may also influence feather pecking in birds. Simenson et al. (1980) reported that birds housed in wire floor had significantly higher feather damage than those housed in litter floor. Similar results were also observed by Duncan and Hughes (1973) and Touson (1977).

Both found that housing system influenced the infegument of the birds.

The use of specs in laying hens was effective in controlling feather pecking and cannibalism (Arbi, 1978). Pecking damage scores were 3.3 for control hens vs 1.2 for spec-hens. This difference was highly significant. Cumming and Epps (1976) also reported that spec-hens were better feathered after 11 months of lay than control hens, but no quantitative data were presented.

2. Adrenal weight

The adrenal glands play a central role in the fowl's response to stress (Siegel, 1971). In mature birds, increases and decreases in adrenal weight frequently occur in response to seasonal and environmental changes, and these variations usually reflect for the most part growth and atrophy of the adrenocortical tissue (Holmes and Cronshaw, 1980). On the other hand, a number of studies have reported the significance of genetic influence and social density on the response of adrenal gland in domestic fowl.

Siegel and Siegel (1969) compared adrenal weights in six different genetic stocks of chickens in two trials. Adrenal glands were excised at 57 days of age of the chicks. In both of their trials they observed significant differences among stocks for adrenal weight expressed as mg per 100g body weight. In one trial adrenal weight for males and females ranged from 7.63-10.30mg and 6.87-8.81mg respectively. In the other trial, the same varied from 6.74-8.95 in males and 6.82-8.20 in females. In a more recent experiment, Ali and March (unpublished data) studied two commercial egg laying strains and one broiler strain for adrenal weights of chicks at ages from one day to thirty five days. The glands were monitored at day 1, 14, 21 and 35. A consistent and highly significant strain difference was evident in all days of measurements

(expressed as mg per g of body weight) with an exception for day 1 where it was found not to be significantly different. Lowest adrenal weight was from broiler strain. Bareham (1972) on the other hand, found no significant difference in adrenal response of 2 layer strains reared either in battery cages or in deep litter pens.

Adrenal gland size may also be influenced by social density. Siegel (1960) demonstrated the effects of crowding on the adrenal weight of White Leghorn cockerels aging from 7-17 weeks. The densities provided were 929.0, 743.0 557.0 and 371.6cm^2 per bird. No consistent effects of housing density were observed up to 11 weeks. Whereas heavier adrenals were found beyond this age. Birds housed 371.6cm^2 per bird compared with 929cm^2 per bird had significantly heavier adrenals. From these results, the author stated that in higher population densities such as 371.6cm^2 per bird, symptoms of adaptation, associated with physiological stress were produced. Another study (Siegel and Siegel, 1969) involving 6 genetic stocks, housed at two bird densities of 464.5 and 929cm^2 per bird resulted in no significant effects of density on adrenal weights. Three other studies also reported no effect of density on this gland (Bareham, 1972; Bolton et al., 1972; and Pesti and Howarth, 1983). These non-significant results were obtained presumably because, the densities used were not critically below the physiological limit imposed by the birds general well-being.

Social interaction between individuals within a flock not necessarily associated with crowding may also influence adrenal gland weight. Flickinger (1961) reported that cockerels in uncrowded colonies establish dominance hierarchies as sexual maturity approaches. The adrenal gland weight then

becomes correlated reciprocally with the social rank of each individual.

It is well known that adrenal gland weight response to stress (Freeman, 1971). Arbi (1978) demonstrated that wearing specs (see pages 2 & 3 for description) in laying hens reduced stress associated with agonistic acts and feather eating. This was also reflected by a reduction in adrenal gland weights. When specs had been on for thirteen and a half months, the adrenal gland weight of the spec-hens were significantly lighter in comparison with control hens (hens without specs). This result indicates that controlling vision in layers may be associated with a reduction in stress due to less agonistic and feather pecking activities.

3. Corticosterone

The major secretion of the adrenal gland of most avian species is corticosterone (Assenmacher, 1973). It had been used as one of several objective measures of stress (Eskeland, 1978). Stressors are typically mediated via ACTH secretion by the hypothalamus (Chester, 1957) and results in an elevated corticosterone level. As stated by Selye (1976) a rise in corticosterone is a very constant characteristic of stress.

The consequences of increased level of corticosterone are manifolds. Birds which are more stressed are susceptible to various types of diseases (Gross and Colmano, 1971; Gross, 1972; and Brown and Nestor, 1973). Increased corticosterone induces osteoporosis in adult birds (Siegel and Latimer, 1970). Although increased corticosterone level increases the potential for short term survival under acute stress, growth and development of young birds are depressed, if such high level is maintained over extended period of time. There are also losses in body weight and reduced reproductive capacity (Bartov et al., 1980).

Brown and Nestor (1973) found that turkeys selected for low adrenal cortical secretory activity improved egg production, growth rate and reduced mortality.

It has been reported that the plasma concentration of corticosterone in unstressed birds irrespective of lines or strains selected for high or low levels of corticosterone are not very different and that the differences become apparent only if the birds were stressed (Brown and Nestor, 1973 and Edens and Siegel, 1975). Freeman and Manning (1975) reported Rhode Island Reds to be more sensitive to stress than Light Sussex. On the other hand, Siegel and Siegel (1966) found non-significant differences in the responsiveness of 4 strains of chickens they studied to ACTH.

The reported estimates of normal concentration of plasma corticosterone in avian species vary according to the method of quantitation (Etches, 1976). Three methods - Fluorometric, Competitive Protein Binding, and Radioimmunoassay were commonly used (Beuving, 1980). A detailed discussion of the use of these methods and their relative effectiveness have been provided by Etches (1976) and by Beuving (1980). Normal plasma corticosterone in laying hens was assayed by Culbert and Wells (1975) who found values in the range of 7 to 20ng per ml of plasma. An astonishing high value (about 100ng per ml) in 21-day-old chicks was reported by Nir et al. (1975), but Buckland and Blagrave (1973) obtained a value of only 5ng per ml in 39 day-old chicks.

The evidence that plasma concentration of corticosterone in laying hens follows a daily rhythm was provided by Beuving and Vonder (1977). They housed White Leghorn layers (25-30 weeks old) in individual cages and examined the plasma corticosterone every 3 hours for 24 hours and found considerable individual variations and also a clear daily rhythm. A maximum (2.3ng per ml)

was found at the end of the night (5:30) and a minimum (0.5ng per ml) at the beginning of the night (20:30). Their findings also confirmed that a rise in corticosterone occurs just prior to oviposition.

It has been observed that corticosterone levels of laying hens are increased by intensive husbandry practices (Gross and Siegel, 1973). But until the work of Mashaly et al. (1982) it was not fully realized. These workers studied the response of adrenal glands of laying hens under different cage densities by radioimmunoassay for costicosterone from serum of samples. The birds were housed 3, 4 or 5 birds per cage at 19 weeks of age in 12' x 20' cages. After 48 hours subsequent to housing average corticosterone concentrations for 3, 4 or 5 birds per cage were 1.038, 1.599 and 2.058ng per ml respectively. This result is an indicator of a positive correlation between number of birds per cage and the initial response of the adrenal glands. In another more recent study with broiler chicks to determine the effects of population density on the growth, feed efficiency and plasma corticosterone, Pesti and Hawarth (1983) brooded chicks in batteries at 116, 232, 348 and 697cm^2 per bird. They observed significantly higher plasma corticosterone for chicks kept at 697 (14.5ng per ml) and 348 (12.2ng per ml) cm^2 per chick than at 232 (4.9ng per ml) or 116 (5.4ng per ml) cm^2 per chick at 3 weeks. The results obtained by Pesti and Hawarth were opposite to that of Mashaly et al. It could be attributed to differences in age of the birds and/or to differences in bird densities used by these authors.

Furthermore, in one experiment, Barnett and Bartlett (1981) studied the effects of spectacles (polypeepers) on the concentration of plasma corticosterone in White Leghorn (WL) and crossbred (XB) hens. WL was housed

either in cages or on litter, but XB only in cages. From day 1 of the experiment up to 14-day all birds were without spectacles. On day 15 of the experiment specs were fitted to half of the birds. Blood samples were collected from all birds on days 1, 3, 7, 11 and 14 for the first half and on days 15, 17, 21, 25 and 28 for the second half of the experiment. The overall mean corticosteroid concentration in XB was significantly ($P<0.01$) higher than WL in cages. The mean corticosteroid concentration on day 1-14 for WL in cages and on litter were 0.88 ± 0.08 and 1.32 ± 0.10ng per ml respectively. They did not find any significant effect of specs on plasma level of corticosterone.

4. Leukocytes

Leukocytes are agents in the defence of the body against infection and are able to remove particles and micro-organisms foreign to the body (Hodges, 1974). It is known that, leukocyte count in birds varies according to breed, age of the birds and sex. Barger et al. (1958) reported that fowl's blood contains from 15000 to 30000 white blood cells per ml of blood. Schermer (1967) has summarised values obtained by different authors and showed that the range is from 9300 to 32000 with an average of 20000. These figures demonstrate a great deal of variations in the estimation of leukocyte numbers in chickens. In part, these discrepencies may be attributed to the method of making the count, and in many cases, to the small number of birds used (Sturkie, 1976). A detailed description of different counting methods for leukocyte can be found in Lucas and Jamroz (1961), and Schermer (1967).

Studies with effects of breed, sex and age of the birds on total leukocyte counts are not numerous. Most estimates of leukocyte counts in chickens are from White Leghorn breed (Fenstermacher, 1932; Biely and Palmer, 1935; Twisselmann,

1939 and Lucas and Jamroz, 1961). Lucas and Jamroz (1961) reported total white blood cells (per ml) to be 35787 in Rhode Island Red females; comparative figures for males were not given. They also reported that White Leghorn male contains 16615 leukocytes compared to 29397 in females. Blein (1928) reported leukocytes to be 18630 in dominique chickens. Total leukocyte counts in turkeys' appeared to be higher than what is reported for chickens. McGuire and Cavett (1952) found total leukocyte counts (per ml) to be 38700 in turkey blood. Sex difference in leukocyte counts in adult chickens was observed by Olson (1937) but not in chicks. Cook (1937) reported no significant variation in the count attributable to sex in chickens aging from 26 to 183 days. Young chicks and quails usually have slightly lower counts than adults (Sturkie, 1976). Barton and Harrison (1969) demonstrated that the blood of the neonate chicks is low in leukocytes and changes rapidly during the growing period. By 3 weeks of age, the cell numbers increase and reach essentially the adult level.

Freeman (1971) stated that changes in leukocyte count could possibly be used as stress indicators in chickens. Wolford and Ringer (1962) concluded that leukocyte response were particularly sensitive to stress and perhaps was the best indicator of stress for the fowl. Leukocyte count may also be a reliable index of adrenocortical hyperactivity (Newcomer, 1958). Leukocytes are found to be very sensitive to stressors such a corticotrophin (Siegel, 1968). It is generally agreed that there is a leukocytosis following injection of ACTH (Huble, 1955; Newcomer, 1958). An increase in leukocyte number due to stress may probably be associated with increased demand for immune response of the stressed animal's body system so that it could cope with the stress (Selye, 1963).

The response of leukocytes after an injection of ACTH was studied by Davison and Flack (1981) using 3-week old Rhode Island Red chickens. Number of leukocytes were counted at various intervals over an extended period of 32 hours after the injection. They observed a biphasic response of leukocytes. There was an 18% decrease in the number of leukocytes one hour after the injection and 40 to 50% increase between 4 and 8 hours after the injection. A significant leukocytosis was still in evidence after 12 hours but the counts returned to normal 24 hours after the injection.

Environmental factors such as restraint, handling, cold and starvation cause a change in leukocyte numbers similar to treatment with ACTH (Huble, 1955; Newcomer, 1958; Wolford and Ringer, 1962 and Sturkie, 1976). Olson (1937) showed that adult birds raised in batteries within a building had 17000 leukocytes compared to 23600 for those raised outside. However, very little is known concerning the effect of bird density on the change of leukocyte count. One recent study (Pesti and Howarth, 1983) with 3-week old female broiler chicks demonstrated no significant differences in leukocyte counts as density increased from 697cm^2 per bird to 116cm^2 per bird.

Other factors such as diet (Goff et al., 1953), drugs (Hunt and Hunt, 1959) and exposure to X-rays (Lucas and Demington, 1957) also play a significant role in changing leukocytes.

METHODS

I. Experimental animals

Data were obtained from two genotypic classes of chickens maintained at the Avian Genetics Laboratory, The University of British Columbia. One type was heterozygous for the autosomal recessive gene 'rc' and has sight vision. The other genotype is homozygous for 'rc' and is blind. Detailed description of the genotypes was outlined by Cheng et al. (1980).

II. Rearing conditions of birds before start of experiment

The chicks for this experiment were of two age groups. The first group was hatched on August 24, 1982 and the second hatched two weeks later on September 7, 1982. Immediately after each hatch all the chicks were wing-banded for identification and brooded in Jamesway battery chick brooders at densities of 335cm^2 per bird and group sizes of 50 chicks per group. The two genotypes from each hatch were kept separated but raised under similar conditions by assigning chicks to randomized sections of the brooders. Brooding heat was provided up to 4 weeks after hatching. Chick starter containing 21% protein was supplied ad libitum during the entire brooding period with free access to water.

At the end of the 4th-week, brooder space for each group of 50 chicks was doubled to allow for the increase in body size. When the birds attained 7 weeks, they were moved to littered floor pens. Eighty birds (20♂♂ and 60♀♀) from each genotype and age group were kept (4 groups). Each group was kept in a 3.2m x 5.9m pen (approximate density of 2350cm^2 per bird). The birds remained in these pens until finally being moved into the experimental pens on

January 25, 1983. During the entire growing period a grower ration (18% protein) and water were provided ad libitum. All the birds were under 14L/10D light schedule during entire brooding and growing periods.

III. Management of experimental birds

At the time birds were put into the experimental pens the first hatch was 22-weeks old and the second hatch was 20-weeks old. All the birds were fed a commercial layer ration containing 16% protein. Feed and water were provided ad libitum. However, feeder space and water space were standardised at eight centimeters each per bird. Wood shaving 10-12cm deep were used as litter. They were replaced from time to time as and when necessary. All the birds received a standard photoperiod of 14 hours of artificial light in a 24-hour day.

IV. Experimental design

The design of this experiment was a 2 x 2 x 2 x 2 factorial with two hatches (replications), two genotypes, two densities and two flock sizes. The two hatches were two weeks apart in terms of age but were put into the experimental pens at the same time. The two densities used in this experiment were of 1000cm^2 per bird (high density) and 2000cm^2 per bird (low density). These densities were used in the light of what other workers used under experimental situations of high and low density levels. For example, Simmenson et al. (1980) used 714cm^2 and 1428cm^2 per bird for high and low density conditions respectively. The birds used were White Leghorn type layers. Normal body weight of White Leghorn type pullets during housing at 20 weeks is about 1406g (McClung and Jones, 1973). On the other hand, the birds used in this experiment were Rhode

Island Red type having much higher body weight (average body weight of pullets at housing 1865g) compared to White Leghorn types. Therefore more space was allowed per bird to compensate for the bigger body size. The two flock sizes used were one of 5 birds (1♂ and 4♀♀) per flock (small flock) and 20 birds (4♂♂ and 16♀♀) per flock (large flock). Although it is desirable to have larger number of birds in the large flocks to approximate commercial production situations, the size of floor pens available limited the size of the experimental flocks. The duration of the experiment was 8 weeks.

V. Parameters measured

The parameters considered in this experiment were:

i) Number of eggs collected

ii) Egg weight

iii) Amount of feed taken from feed trough

iv) Body weight gain

v) Fertility of eggs

vi) Feather pecking and comb damage scores

vii) Leukocyte count

viii) Plasma corticosterone level

ix) Adrenal gland weight

1. Number of eggs collected and egg weight

Egg number and egg weight were recorded daily. Eggs from each treatment pen were collected twice a day (at 10:00 and 16:00 hr) to minimize the number of broken eggs due to pecking and trampling. The collected eggs were

each marked according to date and pen number. The collected data were then converted to egg production on a hen-day basis after adjusting for mortality whenever necessary. After each days collection, eggs from each treatment pen were weighed together to the nearest gram using a 'Toledo' balance. Broken eggs were included in egg production data, however, they were not weighed. Egg weights were converted to mean weight per egg for statistical analysis.

2. Amount of feed taken from feed trough

The amount of feed taken from the feed troughs in different treatment pens was recorded separately. The feed troughs were filled twice a day after egg collection. Each sack of feed used for a particular pen was weighed (kg) and marked according to pen number for identification. The left over feed at the end of the experiment was weighed and subtracted from the total feed given. The feed data were then converted to kg feed per hen per day. These data were also adjusted for mortality whenever necessary.

3. Body weight gain

Individual body weight (g) of all the experimental birds were measured twice during the whole experimental period. The first weight was taken immediately before placing the birds into the experimental plots. This weight constituted the 'initial body weight'. The birds were weighed again at the end of the experiment (March 21, 1983) and 'final body weight' was recorded. The gain in body weight was then calculated by subtracting 'initial body weight' from 'final body weight'.

4. Fertility of eggs

Eggs from three sample periods during the experiment were incubated

in a Jamesway 252 electric forced air incubator to test for fertility. The three sample periods were: (1) days 8-17, (2) 28-37 and (3) 48-57. Eggs saved for fertility test were stored in a cool room at a temperature of 55°F and a relative humidity of 65%. For each period a total of 10 days cumulating stored eggs were set for incubation at the same time. Eggs were incubated for 8-10 days. After that incubation period all the eggs were candled and fertility determined. All the 'infertile' eggs were broken out to determine whether they were truly infertile or early embryonic death (Kosin, 1944). Fertility was measured as a percentage of total eggs set for incubation.

5. Feather pecking and comb damage scores

Feather and comb damages of the experimental birds due to pecking were rated by visual estimation. Back, rump, comb, wing and tail were considered for evaluation of such damages. Back and rump feather losses were evaluated by the procedure described by Hughes and Duncan (1972) and is shown in Table 1. The method used to measure the comb damage scores was as presented in Table 2.

Wing and tail feather losses of the birds were evaluated by:

a. Birds with no broken, no missing feather scored 0

b. Subjectively scored 1-3 according to degree of feather loss

c. Birds with skin damage and/or bleeding scored 4

Feather and skin damages of the experimental birds were measured two times during the experimental period. The first measurement was made just prior to placing the birds into the experimental plots and finally at the end of the experiment. No comb damage was recorded during the first measurement

Table 1. Scoring method to assess the degree of pecking damage to back and rump

Score	Description
0	No denuded area of skin
1	Denuded area less than 1 cm^2
2	Denuded area less than 25 cm^2
3	Denuded area more than 25 cm^2
4	Skin damage (haemorrhage, scab) regardless of size of denuded area

Table 2. Scoring method to assess the degree of pecking damage to the comb

Score	Description
0	No sign of pecking damage
1	A single mark of pecking damage
2	Two to three marks of pecking injuries on both sides of the blade
3	More than three marks of pecking on the comb
4	Severe injuries, bleeding, extensive damage to the comb

nor wing and tail feather losses.

6. Leukocyte count and plasma corticosterone level

Immediately after the end of the two months experimental period blood samples for leukocyte counts and corticosterone analysis were collected from a total of 80 birds, taking 5 (1♂ and 4♀♀) from each treatment pen. The birds from large flocks were picked at random. From each bird two samples of 2ml each were collected into two heparinized test tubes by the method of venepuncture of the wing vein. Blood samples were collected for a period of 8-days from 1:00pm to 1:30pm each day. This was done to minimize the effect of time difference, since corticosterone level in laying hens is known to change during the day (Beuving and Vonder, 1977). The time required between catching the bird and bleeding varied from 40 seconds to one minute in most cases. The first collected sample from each bird was used for corticosterone analysis and the second one for leukocyte count. Immediately after blood collection, all the collected samples were brought into the laboratory. Blood samples for corticosterone were centrifuged in a Sorval GLC-I General Laboratory Centrifuge for 15 minutes at 2000rpm. The separated plasma was then stored at a temperature of -20 $^{\circ}$ C pending shipment to the University of Guelph, Canada, where it was analysed by radio-immunoassay technique outlined by Etches (1976). Leukocyte number was counted using haematocytometer under the light microscope at magnification of 40x. The White Blood Cell (WBC) diluent used for leukocyte count was prepared according to the following recipe recommended by Schermer (1967):

Crystal violet	10.0mg
Sodium citrate	3.8g
Formalin	0.4ml
Distilled water	100.0ml

The dilution rate of blood and WBC diluent was in the ratio of 1:100. Leukocyte number was expressed as the number of leukocytes per ml of blood. The method used for counting was described in Ministry of Agriculture, Fisheries and Food, Reference Book 365 (1978). The formula used for total leukocyte number was = (number counted in 4 squares of the haematocytometer ÷ 4) x depth of the haematocytometer x dilution rate.

7. Adrenal gland weight

The number of birds from which adrenal glands were excised and weighed was the same as leukocyte counts. From each large flock 5 birds (1♂ and 4♀♀) were randomly drawn independently of birds used for leukocyte counts. All the birds in the small flock were used. One week after the blood samples were drawn, birds were sacrified, dissected and both the right and left adrenal glands were excised. Connective and fat tissues were carefully trimmed from all the glands by the same person. The glands were then weighed using a sensitive balance (Mettler H-10 Analytical Balance). Glands were kept moist until and during weighing.

VI. Data analyses

Data were analysed by Analysis of Variance using either flock means or individual measurements. Analysis of Variance with Repeated Measures (Steel and Torrie, 1980) was applied to traits measured repeatedly at different periods or ages. In these situations hatches, genotypes, bird densities and flock sizes were the main plot factors, while periods or weeks was the sub-plot factor. All data in percentages were arcsin transformed before statistical tests. Duncan's Multiple Range Tests were performed to test

for differences among individual means when treatment involving more than one degree of freedom were found to be significantly different. Analysis of Covariance (Steel and Torrie, 1980) was used to test body weight gain with 'initial body weight' as the covariate. The general statistical model is as follows:

$$Y_{ijklm} = \mu + R_i + G_j + D_k + F_l + (GD)_{jk} + (GF)_{jl} + (DF)_{kl} + (GDF)_{jkl} + E1_{ijkl} + T_m + (GT)_{jm} + (DT)_{km} + (FT)_{lm} + (GDT)_{jkm} + (GFT)_{jlm} + (DFT)_{klm} + E2_{ijklm}$$

and $i = 1, 2$; $j = 1, 2$; $k = 1, 2$; $l = 1, 2$; and $m = 1,\ldots,x$; where Y_{ijklm} = one of the dependent variables. Y_{ijklm} is the mean for the parameter in the ith replication involving birds of the jth genotype housed under kth bird density and lth flock size, measured during the mth period, μ = the theoretical population mean, R_i = effect of the ith replication, G_j = effect of whether the bird involved was blind or sighted, D_k = effect of high or low density, F_l = effect of large or small flock size, T_m = effect of measurements made during the mth time period, $(GD)_{jk}$, $(GF)_{jl}$, $(DF)_{kl}$, $(GT)_{jm}$, $(DT)_{km}$, $(FT)_{lm}$ = two-factor interactions, $(GDF)_{jkl}$, $(GDT)_{jkm}$, $(GFT)_{jlm}$, $(DFT)_{klm}$ = three-factor interactions, $E1_{ijkl}$ = error term for main plot comparisons, and $E2_{ijklm}$ = sub-plot error term.

This general model was slightly modified for analysis of each parameter. The analyses were conducted with the aid of a computer program, 'UBC - MFAV' (Lee, 1980), at the University of British Columbia Computer Center.

Since the scoring for feather and comb damage are considered as rank data, a parametric analysis cannot be applied (Steel and Torrie, 1980). Instead, such

data were analysed by the Kruskal-Wallis one-way analysis of variance (Siegel, 1956) appropriate for ranked data. The formula for this analysis is:

$$H = \frac{\frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_i^2}{n_j} - 3(N+1)}{1 - \frac{\Sigma T}{N^3 - N}}$$, distributed as chi-square with df k-1

where H = the statistic used in the Kruskal-Wallis test defined by the formula, n_j = number of observations in jth sample, $N = \Sigma n_j$, R_i = sum of ranks in jth sample, $\sum_j^k$ = sum over the k samples, $T = t^3 - t$, where t = number of tied observations. Because of similarity in nature, back and rump feather scores from each individual were added together and the mean calculated. The calculated mean scores were then ranked for the Kruskal-Wallis test. Similar treatment for wing and tail feather losses was also done.

The only known independent variation between the two replications is that there was a two week difference in the age of the birds. In order to determine whether this variation caused significant differences between the two replications, data for number of eggs collected, egg weight and amount of feed taken from feed trough (where weekly data were obtainable) were re-analysed after correcting for the age differences between the two replications. This was done by matching data taken during weeks 3 to 8 from replication 2 (younger birds) with data taken during weeks 1 to 6 from replication 1 (older birds). In other words, data collected during week 3 from birds in replication 2 and week 1 from replication 1 would be from birds of the same age. In these analyses, data collected during weeks 7 and 8 from replication 1 and weeks 1 and 2 from replication 2 were not utilized.

RESULTS

I. Number of eggs collected

Analysis of variance (ANOVA) table for percent hen-day egg production is presented in Table 17 (Appendix). Significant ($P < 0.05$) differences were found between genotypes with blind chickens producing higher number of eggs compared to sighted chickens. The mean rate of production was 54.0% for blind birds compared to 41.3% for sighted birds (Table 3).

Density effect on egg production was not significant (Table 4), neither was the effect of flock size (Table 5). However, when corrected for the differences in ages of the two hatches, flock size became a significant ($P < 0.05$) factor. Percent hen-day production for small flocks was 58.5% compared to 48.9% for large flocks. The difference between small and large flocks was 9.6% (Table 19 in Appendix). There was no significant two-way or three-way interactions involving genotype, density or flock size.

The results on percent hen-day egg production over different weekly periods demonstrated highly significant ($P<0.001$) period effect (Table 6). Egg production increased from 15.4% in the first week to 58.0% in the fourth week, but remained stable after the fourth week. The TXG interaction was not significant. Blind chickens had higher production rate in all weeks of production in the experimental pens (Figure 1). From Figure 1, it could be seen that egg production in blind chickens was uniformly better over all weeks compared to sighted ones.

The effects of the two hatches (replications) on egg production are shown in Table 7. The mean for the first hatch was 52.3% against 43.2% for the

Table 3. Effects of genotype on parameters measured

Parameters	Genotype means		Difference between genotypes
	Sighted	Blind	
Apparent mean egg production (hen-day %)	41.30± 6.90	54.00± 4.30	12.70*
Mean egg weight (g)	46.82± 4.88	46.07± 4.07	0.75
Apparent feed requirement (g, per bird per day)	179.40± 29.00	135.30± 14.00	44.10***
Body weight gain (g, females only)	263.30±158.90	267.10±234.80	3.80
Fertility (%)	84.20± 5.00	48.20± 17.10	36.00*
Leukocyte count (1,000 per ml)	19.27± 4.96	20.19± 4.56	0.92
Adrenal weight (mg per 100g body weight)	7.30± 1.66	6.69± 1.19	0.61
Corticosterone level (ng per ml of plasma)	1.22± 0.59	1.04± 0.74	0.18

*$P < 0.05$

***$P < 0.001$

Table 4. Effects of density on parameters measured

Parameters	Density means		Difference between densities[1]
	High	Low	
Apparent mean egg production (hen-day %)	42.20± 7.40	49.80± 4.50	7.60
Mean egg weight (g)	46.04± 4.50	46.85± 4.48	0.81
Apparent feed requirement (g, per bird per day)	154.40± 26.00	160.40± 38.00	6.00
Body weight gain (g, females only)	263.40±121.90	267.10±256.30	3.90
Fertility (%)	58.80± 18.50	75.70± 9.50	16.90
Leukocyte count (1,000 per ml)	19.52± 4.63	19.94± 4.93	0.42
Adrenal weight (mg per 100g body weight)	7.08± 1.30	6.90± 1.63	0.18
Corticosterone level (ng per ml of plasma)	1.23± 0.73	1.03± 0.60	0.20

[1] None of the differences were significant at 0.05 level.

Table 5. Effects of flock size on parameters measured

Parameters	Flock size means		Difference between flocks
	Small	Large	
Apparent mean egg production (hen-day %)	52.30± 6.60	43.00± 5.00	9.30
Mean egg weight (g)	46.55± 4.77	46.34± 4.24	0.21
Apparent feed requirement (g, per bird per day)	173.60± 35.00	141.10± 18.00	32.50***
Body weight gain (g, females only)	330.90±209.00	199.60±165.20	131.30**
Fertility (%)	62.80± 21.10	72.10± 7.80	9.30
Leukocyte count (1,000 per ml)	19.15± 4.80	20.31± 4.70	1.16
Adrenal weight (mg per 100g body weight)	6.75± 1.09	7.23± 1.75	0.48
Corticosterone level (ng per ml of plasma)	1.09± 0.67	1.16± 0.68	0.07

**$P < 0.01$

***$P < 0.001$

Table 6. Effect of time on egg production and egg weight of the experimental birds

Parameters[2]	Week[1] Means							
	1st	2nd	3rd	4th	5th	6th	7th	8th
Apparent mean egg production (hen-day %)	$15.40^{a}\pm5.40$	$31.20^{b}\pm3.20$	$42.70^{c}\pm2.50$	$58.00^{d}\pm2.00$	$58.80^{d}\pm1.20$	$60.70^{d}\pm2.80$	$63.60^{d}\pm4.20$	$54.70^{d}\pm5.20$
Mean egg weight (g)	$39.50^{a}\pm2.50$	$42.20^{b}\pm3.10$	$44.70^{c}\pm2.00$	$46.30^{d}\pm2.60$	$48.10^{e}\pm2.50$	$48.90^{e}\pm2.10$	$50.10^{f}\pm1.80$	$51.70^{g}\pm1.90$

[1] Time measured since the initiation of the experiment.

[2] In comparing subclass means within each parameter, means with similar superscripts are not significantly different. Means with different superscripts are significantly different ($P<0.05$) by Duncan's Multiple Range Tests.

Figure 1. A comparison of weekly egg production between sighted and blind chickens

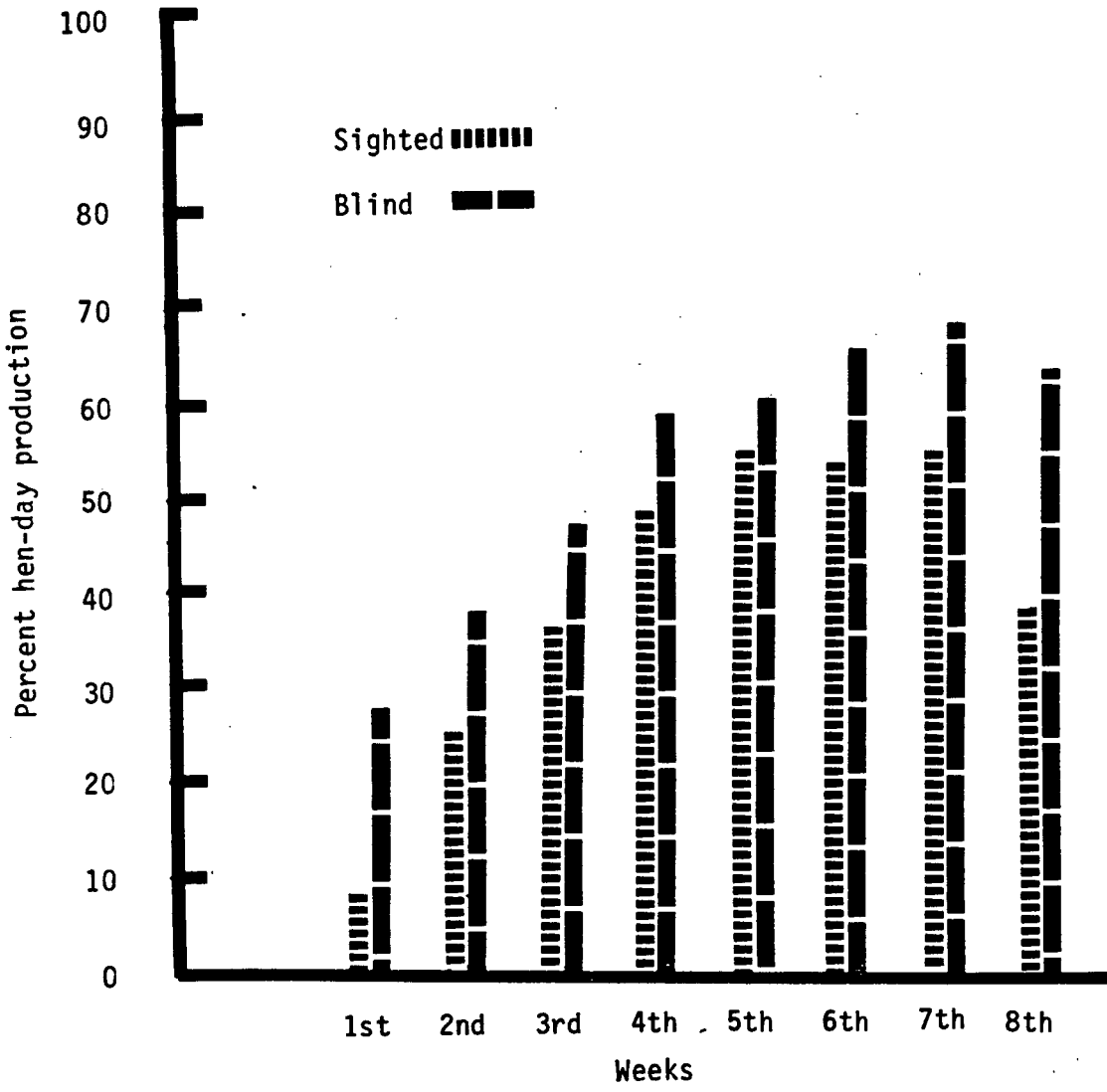


Table 7. Effects of replication (hatch) on parameters measured

Parameters	Hatch means		Difference between hatches
	First	Second	
Apparent mean egg production (hen-day %)	52.30± 5.00	43.20± 6.60	9.10
Mean egg weight (g)	47.46± 3.66	45.43± 5.02	2.03**
Apparent feed requirement (g, per bird per day)	154.40± 28.00	162.30± 36.00	10.00
Body weight gain (g, females only)	192.20±164.60	338.30±205.10	146.10***
Fertility (g)	75.10± 8.80	58.60± 19.10	16.50
Leukocyte count (1,000 per ml)	18.72± 4.81	20.74± 4.54	2.02
Adrenal weight (mg per 100g body weight)	6.84± 1.72	7.15± 1.17	0.31
Corticosterone level (ng per ml of plasma)	1.07± 0.66	1.19± 0.68	0.12

**P< 0.01

***P< 0.001

second hatch. The difference (9.1%) however was not significant.

ANOVA of same parameter after adjusting for the differences in age of the birds in the two hatches did not reveal any conflicting trends (see Tables 18 and 19 in Appendix) compared to the previous analysis.

II. Egg weight

ANOVA for data on egg weight is presented in Table 20 (Appendix). No significant differences were observed for genotype, density or flock size. However, there was a significant ($P<0.001$) density by flock size interaction. This interaction is reported in Table 8. From Table 8, it could be seen that the heaviest egg weight was from chickens in small flocks at low density (48.00g) and the lowest from small flocks at high density (45.11g). On the other hand, there was no significant difference between low density (45.76g) and high density (46.97g) for chickens kept in large flocks.

The two hatches differed highly significantly ($P< 0.01$) in mean egg weight (Table 7). The first hatch averaged 2.03g more (weight per egg) than the second hatch. Egg weight was apparently affected by age of the birds. During the first week of production in the pens, egg weight averaged 39.51g. Thereafter it increased at a rapid rate. In the following weeks of 2, 3, 4, 5, 6, 7 and 8, mean egg weight was 42.18, 44.69, 46.33, 48.11, 48.94, 50.09 and 51.71 g respectively. Duncan's Multiple Range Tests indicated that any two means (except between 5 and 6 weeks) in the above weeks were significantly ($P< 0.05$) different from each other (Table 6). The effect of replication (hatch) became non-significant after adjustment for the age differences (see Table 21 and 19 in Appendix). From the above results, it could be concluded

Table 8. Significant DXF interaction for egg weight of experimental birds

Density	Flock Size	
	Small	Large
High	45.11^{ab}	46.97^{bc}
Low	48.00^{c}	45.70^{b}

Means with different superscripts are significantly different ($P < 0.05$) by Duncan's Multiple Range Test .

that, during the experimental period, egg weight increased with age of the birds.

III. Amount of feed taken from feed trough

ANOVA table for this trait is presented in Table 22 (Appendix). Highly significant ($P < 0.001$) difference was found between the two genotypes. Mean amount of feed taken by the blind birds was 135.3g per bird per day compared with 179.4g by the sighted birds (Table 3). The difference between the two genotypes in the mean feed requirements was 44.1g per bird per day. There was also a significant GXF interaction. The feed requirements for various combinations of genotypes and flock sizes are shown in Table 9. From Table 9, it could be seen that sighted birds took more feed per bird daily when kept in small flocks (202.0g) than when kept in the large flocks (156.8g). The same pattern was also apparent for blind birds kept in small and large flocks (145.2g vs 125.4g respectively). The difference between sighted and blind chickens, however, was much bigger in small flocks (56.8g) than in large flocks (31.4g).

Flock size was highly significant ($P < 0.001$) in affecting feed requirements of the birds. Chickens in small flocks took more feed per bird daily (173.6 g) than birds in large flocks (141.1g). On the average, birds in small flocks took 32.5g more feed per bird per day compared to birds in large flocks (Table 5). Density as a main effect was not significant in feed requirements of the birds. However, the interaction term DXF was significant ($P<0.05$). This has been tabulated in Table 10. From Table 10 it could be seen that birds kept in small flocks at low density took the highest amount of feed (183.5g) and birds in large flocks at the same density the lowest (140.1g). Feed taken by birds in small flocks at high density was 163.7g compared to 145.0g by birds kept in

Table 9. Significant GXF interaction for feed taken from feed troughs by experimental birds

Genotype	Flock Size	
	Small	Large
Sighted	202.00^{c}	156.80^{b}
Blind	145.20^{b}	125.40^{a}

Means with different superscripts are significantly different ($P<0.05$) by Duncan's Multiple Range Test.

Table 10. Significant DXF interaction for feed taken from feed troughs by experimental birds

Density	Flock Size	
	Small	Large
High	163.70[b]	145.00[a]
Low	183.50[c]	140.10[a]

Means with different superscripts are significantly different ($P<0.05$) by Duncan's Multiple Range Test.

large flocks at the same density. The difference in feed requirements between birds in small flocks and large flocks was greater at low bird density (43.4g) than in high bird density (18.7g).

The effect of hatch on this trait was not significant (Table 7). ANOVA after removing age effect of the two replications did not show any difference in trends (see Tables 23 and 19 in Appendix).

IV. Body weight gain

Body weight gain of the experimental hens during the experimental period was subjected to analysis of covariance with initial body weight being the covariate (see Table 24 in Appendix). No differences were observed between the two genotypes (Table 3). The effect of flock size, however, was highly significant ($P<0.01$). Hens in small flocks gained more weight than those in large flocks. On the average, each hen in small flocks gained 131.3g more than their counterparts in large flocks over the 2-month period (Table 5).

The effect of density was not significant for this trait, but the interaction term DXF was significant ($P<0.01$). This could have rendered the main effect non-significant. The various combinations of densities and flock sizes affecting body weight gain of hens are reported in Table 11. As can be seen from Table 11 that hens in small flock-low density conditions gained the most weight (392.7g) and those in large flock-low density conditions the least (141.5g). On the other hand, under high density conditions, flock size was not significant in affecting weight gain.

Furthermore, the two hatches used in this experiment differed highly significantly ($P<0.001$) in body weight gain. The first hatch (older birds)

Table 11. Significant DXF interaction for body weight gain of experimental hens

Density	Flock Size	
	Small	Large
High	269.00^{b}	257.70^{b}
Low	392.70^{c}	141.50^{a}

Means with different superscripts are significantly different ($P<0.05$) by Duncan's Multiple Range Test.

gained 146.1g per bird less than the second hatch (younger birds).

Regression of body weight gain on initial body weight was not significant. Although covariance analysis removed the effect of initial body weight (body weight taken before start of experiment) difference on the body weight gain of the hens, it did not reveal whether there was any difference in initial body weight. This was tested by an ANOVA on initial body weight. No significant difference was found in any of the main factors involved or their interactions thereof (see Table 25 in Appendix) except the GXDXF interaction.

Because of very small sample sizes (8 per group) body weight gains of roosters were not analysed statistically. However, means were calculated and are presented in Table12. The mean weight per bird of blind and sighted, low and high densities, large and small flocks and older and younger hatches were 339 and 142g, 277 and 204g, 253 and 228g, and 83 and 398g respectively.

V. Fertility of eggs

Fertility of eggs from the experimental birds was determined over three different periods during the experiment. Except for genotype, none of the main effects nor their interactions was significant (Table 26, Appendix). The mean fertility for the sighted birds was 84.2% compared to 48.2% for the blind birds (Table 3). This difference was significant ($P < 0.05$).

Period had a highly significant ($P < 0.01$) effect on fertility. Fertility was lowest (50.9%) during the initial period (days 8 to 17). It increased by 20.2% (to 71.1%) and 28.2% (to 79.1%) respectively during the second (days 28 to 37) and the third (days 48 to 57) periods. All interaction terms involving period as a factor were not significant.

Table 12. Mean body weight gain, adrenal weight and leukocyte count of experimental roosters[1]

Factors		N	Parameters		
			Weight gain (g)	Adrenal weight (mg per 100g body weight)	Leukocyte count (1,000 per ml)
Hatch	First	8	83	7.36	16.64
	Second	8	398	7.32	22.42
Genotype	Sighted	8	142	7.74	20.63
	Blind	8	339	6.99	18.43
Density	High	8	204	6.89	20.29
	Low	8	277	7.74	18.77
Flock size	Small	8	228	7.11	19.68
	Large	8	253	7.54	19.38

[1] Not tested statistically.

VI. Leukocyte count, plasma corticosterone level and adrenal gland weight

Analysis of leukocyte count per ml of blood from experimental hens indicated no significant effects of genotype, bird density, flock size or hatch (Table 27, Appendix). The only significant effect observed for this trait was the interaction term GXF. This interaction is presented in Table 13. Analysis by Duncan's Multiple Range Test shows that blind birds in small flocks had the lowest counts and is significantly lower than counts for blind birds kept in large flocks. Between these two extremes were the counts for sighted birds kept in small flocks and large flocks. However, neither counts for the blind birds were significantly different from counts for the sighted birds (Table 13).

The effects of different factors on leukocyte counts of roosters are presented in Table 12. Although not tested for level of significance (due to small sample sizes) the means presented in Table 12 showed large differences in leukocyte counts in most of the cases.

The adrenal gland weight was measured as mg per 100g of body weight. For this trait, the data from roosters and hens were also separately presented. The ANOVA Table for experimental hens is presented in Table 28 (Appendix). This Table showed that none of the main effects nor their interactions was significant. The means and standard deviations of this trait for two hatches, two genotypes, two bird densities and two flock sizes can be found in Table 7, 3, 4 and 5 respectively.

The mean adrenal weights of roosters are presented in Table 12. There appears to be little variation in mean adrenal weights of roosters from different treatment groups.

Table 13. Significant GXF interaction for leukocyte count of experimental hens

Genotype	Flock Size	
	Small	Large
Sighted	19.96^{ab}	18.59^{ab}
Blind	18.35^{a}	22.02^{b}

Means with different superscripts are significantly different ($P < 0.05$) by Duncan's Multiple Range Test.

The plasma corticosterone level (ng per ml of plasma) of roosters and hens was analysed jointly. The ANOVA Table (Table 29, Appendix) indicated no significant effects of hatch, genotype, density and flock size. The means calculated for each level of hatch, genotype, density and flock size for corticosterone data are reported in Tables 7, 3, 4 and 5 respectively. All two-way and three-way interactions involving genotype, density and flock size were not significant.

VII. Feather pecking and comb damage scores

Means and level of significance for feather loss and comb damage scores are presented in Table 14. Observations from initial back and rump scores indicated highly significant ($P<0.001$) genotype effect. Blind birds scored 0.0063 per bird against 0.2000 for sighted birds. Back and rump feather losses scored at the end of the experiment also had highly significant ($P<0.001$) genotype effect. The mean scores per bird were 0.0316 for blind and 1.1948 for sighted birds.

Wing and tail feather losses scored at the end of the experiment also had a highly significant ($P<0.001$) genotype effect. Blind chickens had score of 0.1646 per bird compared to 0.5649 for sighted ones. Density or flock size effect on feather scores of the two combined areas were not significant nor was the interaction term involving the two factors.

Comb damages were significantly ($P< 0.001$) higher in sighted birds compared to blind birds. Mean score for sighted birds was 0.8961 per bird as against 0.3544 for blind ones. In addition to a significant genotype effect, there was also significant GXD and GXF interactions for comb damage scores. The GXD interaction is presented in Table 15; similarly the GXF interaction in Table 16.

Table 14. Mean feather loss and comb damage scores of the experimental birds

Period[1]	Body area	Factors								
		Genotype		Difference	Density		Difference	Flock size		Difference
		Blind	Sighted		High	Low		Small	Large	
Initial:	Back and rump	0.0063	0.2000	0.1937***	-	-	-	-	-	-
Final :	Back and rump	0.0316	1.1948	1.1632***	0.6538	0.5577	0.0961	0.5781	0.6129	0.0348
	Wing and tail	0.1646	0.5649	0.4003***	0.3462	0.2500	0.0962	0.1875	0.3266	0.1391
	Comb	0.3544	0.8961	0.5417***	0.7051	0.5385	0.1666	0.2188	0.7258	0.5070***

[1] Initial period refers to score taken prior to start of the experiment.

Final period refers to score taken at the end of the experiment.

*** $P < 0.001$

Table 15. Significant GXD interaction for comb damage scores of experimental birds

Genotype	Density	
	High	Low
Sighted	1.13^{c}	0.67^{b}
Blind	0.30^{a}	0.41^{a}

Means with different superscripts are significantly different ($P < 0.05$) by Kruskal-Wallis k-sample Test.

Table 16. Significant GXF interaction for comb damage scores of experimental birds

Genotype	Flock Size	
	Small	Large
Sighted	0.31^{b}	1.05^{c}
Blind	0.13^{a}	0.41^{b}

Means with different superscripts are significantly different ($P < 0.05$) by Kruskal-Wallis k-sample Test.

Regarding GXD significant interaction, sighted birds kept in high density had more comb damage scores than when they were kept in low density. On the other hand, blind birds kept in high or low density had no difference in comb damage scores. Even when blind birds were kept in high density conditions, their comb damage scores were significantly lower than sighted birds kept in low density conditions. Significant GXF interaction indicated that, both genotypes kept in large flocks had higher comb damage scores than when they were kept in small flocks. The difference between sighted and blind chickens was bigger in large flocks than in small flocks. The important point is that, when blind birds were kept in large flocks their comb damage scores were only similar to sighted birds kept in small flocks.

Density as a main factor did not affect comb damage scores, but flock size significantly ($P<0.001$) affected this parameter. Large flocks suffered more damage (0.7258) per bird than small flocks (0.2188).

The above results on feather loss and comb damage scores considered together indicate that sighted birds suffered more feather and comb damages than blind birds. Histograms depicting the distribution of birds in the two genotypes with relationship to severity of feather and comb damages are presented in Figure 2 and 3 for initial and final 'back and rump' feather scores, in Figure 4 for final 'wing and tail' feather scores and finally in Figure 5 for final comb damage scores.

Figure 2. A comparison of initial back and rump feather damage between sighted and blind chickens

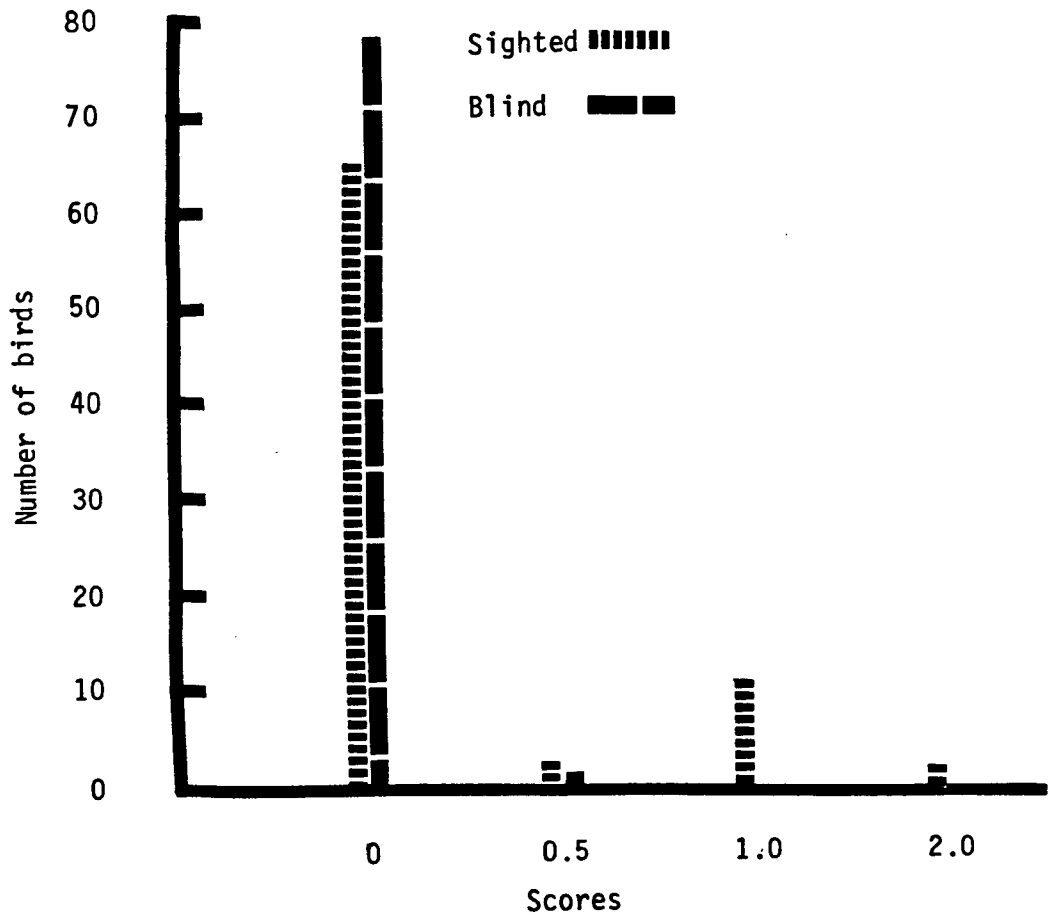


Figure 3. A comparison of final back and rump feather damage between sighted and blind chickens

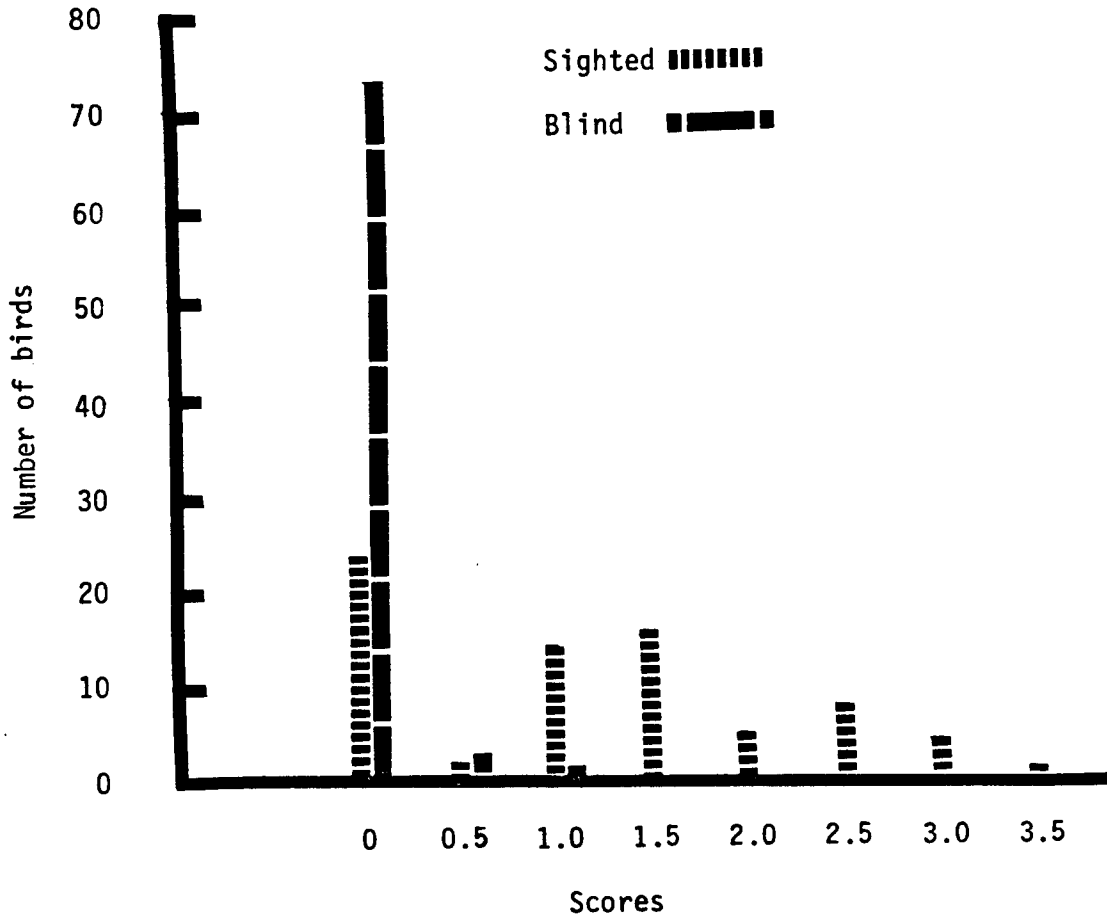


Figure 4. A comparison of wing and tail feather damage between sighted and blind chickens

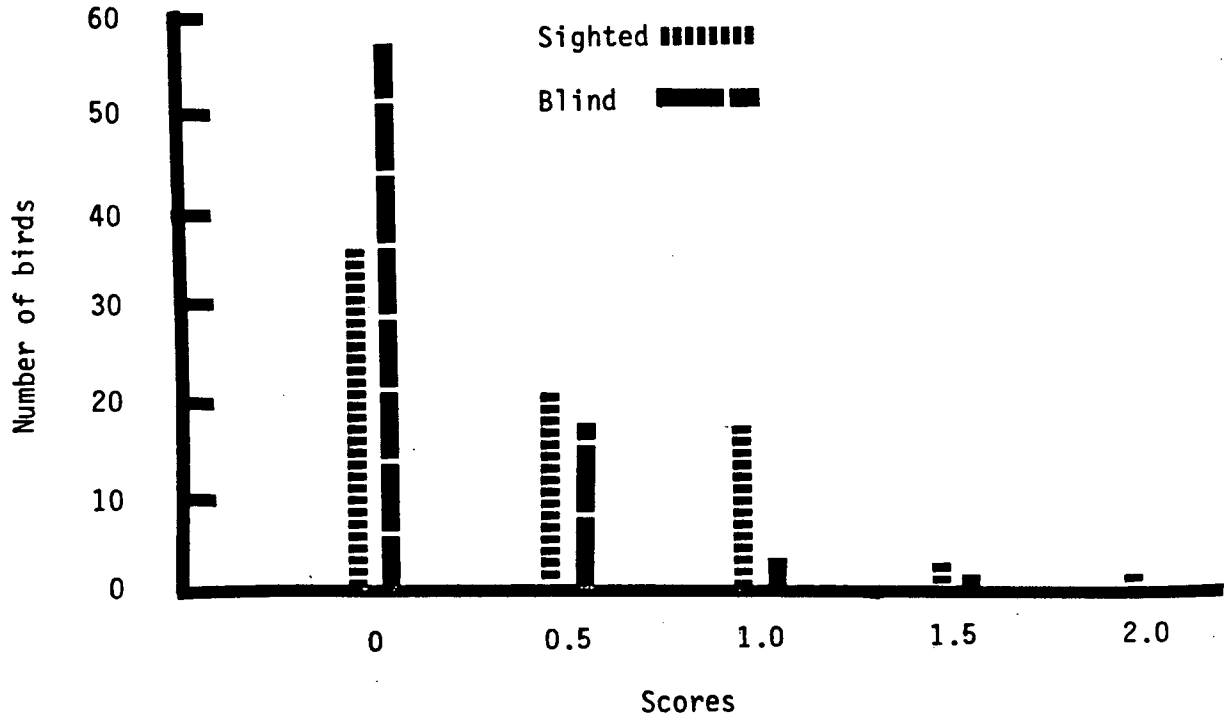
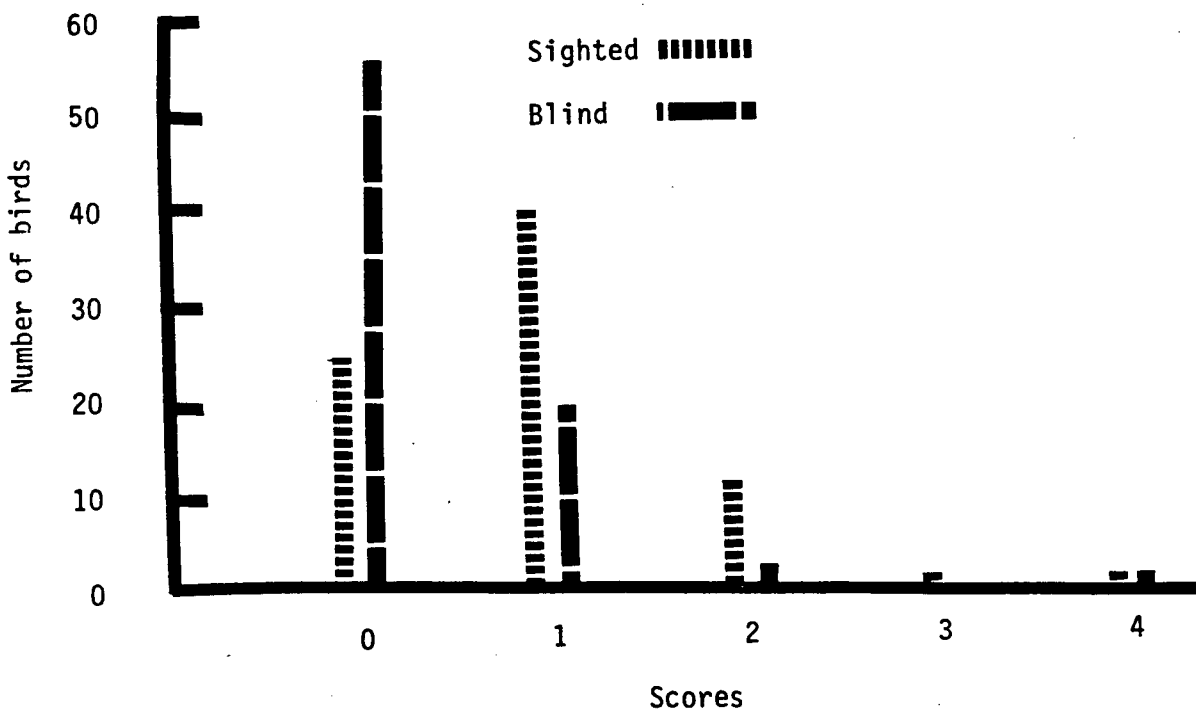


Figure 5. A comparison of comb damage between sighted and blind chickens



DISCUSSION

I. Performance of blind chickens

This study was undertaken to determine the effects of sight or the lack of it on the performance of chickens under two different densities and two different flock sizes. It has been reported that a reduction of frontal vision reduced stress when hens were wearing specs (Arbi, 1978). It might be that total elimination of sight would lead to further reduction of social stress by breaking down social hierarchy which might contribute to the increased productivity per bird. It was also suspected that the lack of sight might interfere with feeding and other maintenance activities of the bird which in turn may abolish any potential advantage gained by reduced social stress experienced by these chickens. Keeping in mind these conflicting tendencies, a null hypothesis was developed which stated 'The lack of vision did not result in better performance for the blind birds compared to the sighted ones through decreased social interactions because blindness interfered with feeding and other maintenance practices'. The objective of this study was therefore to gather evidence either to support or to reject the null hypothesis through a study of nine parameters related to productivity and stress of the birds.

Sighted and blind chickens were compared as per their relative performance in the parameters measured. Based on the results of this experiment, a number of statements can be made and arguments for or against each statement can be discussed.

1. Statement number 1

'Under the conditions of the experiment blind chickens out-performed sighted ones in egg production.'

a) Number of eggs collected from pens with blind chickens were significantly higher than the number of eggs collected from pens with sighted chickens. For a 56-day test period blind hens had a production rate of 54.0% compared to 41.3% for sighted hens. The calculated egg numbers per hen for this period were 30.24 (56 days x 0.540) and 23.13 (56 x 0.413) for blind and sighted hens respectively. Therefore, there was a difference of 7.11 eggs per hen for the 2-month study period. There was no significant interaction between genotype and density nor between genotype and flock size in egg production, indicating that the blind chickens out-performed the sighted ones in both types of densities and flock sizes.

b) The mean egg weight of the two groups was not different statistically. Although egg production can be evaluated by using number of eggs collected as a criterion, this may not accurately reflect total egg mass output. Total egg mass may be changed either by changing the number of eggs or by changing the mean egg weight (Wills, 1974). It is therefore important that the differences exhibited by the two groups of birds in egg number and egg weight need to be properly balanced against each other to demonstrate the relative egg mass output. Because of the significant difference in the number of eggs collected from each genotype, the total egg mass collected from each blind hen was calculated to be 1485.30g (30.24 x 46.07) compared to 1082.95g (23.13 x 46.82) from each sighted hen. From the above estimations it is apparent that total egg mass collected from blind chickens was

heavier (402.35g per hen) than from sighted ones.

The above facts and figures suggest egg production to be higher in blind chickens. On the other hand, because sighted birds were observed to be breaking and eating eggs more freqently than blind birds, it could be argued that the number of eggs collected did not reflect egg production in these birds. However, eggs were collected at least twice a day from all pens to minimize egg breaking and eating and it seems unlikely that the difference in the number of eggs collected can totally be accounted for by the number of eggs broken and eaten by the sighted birds. Moreover, it was observed that birds in only one pen (pen A5; sighted high density-large flock rep. 1) developed this habit. Egg breaking by sighted birds in other pens was very slight if at all. After excluding data from this particular pen there was still a difference (not statistically tested) in the means; egg production percentage for the sighted birds, however, increased from 41.13 to 45.36%. The mean difference between the two genotypes was still large (8.64%). Since egg eating is a learned behavior in chickens, it takes time to develop this habit in a group. If egg eating was the only reason for difference in egg production between these two genotypes, sighted birds could have at least equal or higher production rate during the early weeks before this habit was developed. It could be seen from Figure 1 that the weekly productivity of blind chickens was uniformly better over all weeks. There was not a single week in which productivity was better in sighted chickens. This indicates that egg production in sighted hens may indeed be inferior to blind hens.

From the above observations, it could be argued that under the conditions of the experiment egg production in blind chickens was at least equal but may

indeed be better than sighted ones. It is therefore, worthwhile to investigate how blind chickens would perform in cages under more intense conditions.

Egg quality is an important aspect of egg production. Although no measurement was made, the eggs from blind hens seem to be comparable to those produced by sighted ones. Further studies are required to compare the internal and external qualities of eggs from both groups of chickens under similar environmental conditions.

Another aspect of future research is how well blind hens will perform over a full year production. This requires the computation of genetic correlation between early rates of production with annual rates. Such computations were made in the recent past. Lowe and Garwood (1980) estimated the genetic correlations of rate of egg production between early records and annual records and obtained a correlation coefficient of 0.77. Another study (Kinney et al., 1968) also reported such correlation to be high (0.80). These correlations reported by the above authors among many others suggest that the individuals which had higher egg production in the early period of lay will tend to have higher egg production in the annual rate of lay. In this connection, it would be interesting to compare annual egg production of blind chickens with sighted ones to see if the duration of egg production is affected by the blindness which may alter the amount of photostimulation received by these birds.

2. Statement number 2

"Under the conditions of this experiment blind chickens consumed less feed than the sighted chickens."

The amount of feed taken from the feed troughs by the blind chickens (135.3g per bird per day) was significantly less than the sighted birds (179.4g).

Such a large difference in feed requirements suggests differences in the utilization of feed by the two genotypes.

Of the differences exhibited by the two genotypes in the amount of feed taken, a substantial amount of which could be attributed to feed spillage with more spillage by the sighted birds than by the blind ones. Arbi (1978) reported reduced feed spillage by hens wearing specs particularly when the feed troughs were filled. He also noticed that spillage by the control hens increased with an increase in the amount of feed placed in the feed troughs. Observations from this experiment supported Arbi's findings. Sighted birds were observed frequently to scratch and spill feed out of troughs leading to feed wastage. Such behavior was rarely observed in the blind chickens. Therefore, feed spillage could account for part of the variation in the amount of required feed between the two genotypes.

Flock size was a significant factor in affecting the amount of feed taken from the feed troughs. Daily feed requirement per bird in the small flock was higher compared to large flock (see Table 5 and also later discussion on effects of flock size on performance). The interaction term GXF for required feed was also found to be significant ($P<0.05$). Although blind chickens took significantly less feed than sighted ones in both the small and large flock situations, the difference in feed taken between the two genotypes was much bigger in small flocks situation than in the large flocks situation. Al-Rawi *et al*. (1976) stated that genotype X housing environment interactions are likely to be detected when strains and environments greatly affect productivity. The largest amount of feed taken per bird by the sighted chickens associated with small flocks may be attributed to greater feed spillage and also higher

consumption per bird. Previous research indicated that when birds were housed singly they ate significantly more feed than those housed 3 to a group (Jensen et al., 1976), and 2 birds per group consumed significantly higher feed compared to 3 birds per group (Ouart and Adams, 1982). Therefore increased feed spillage and increased feed consumption by the sighted chickens in small flocks may be responsible for the significant increase in amount of feed taken from the trough.

At this point, it should be pointed out that body weight gains of the blind and sighted chickens during the experimental period were not significantly different. Nor did the body weight measured just prior to the start of the experiment significantly differ between the two genotypes. The Analysis of Covariance also demonstrated that there was no significant regression of body weight gain on initial body weight. Although it is valid to anticipate that sighted chickens will put on more weight than the blind ones due to a higher feed consumption and less egg mass output, this was not reflected in the results. Emmans (1974) demonstrated that the energy required for growth and egg production not only depends on the energy contents of the weight gain and egg produced but also on the efficiency with which dietary energy is converted to carcass and egg mass.

3. Statement number 3

'Higher activity level and feather damages in flocks of sighted chickens lead to higher energy cost not related to productivity.'

Although feed spillage could be a factor contributing to the difference in feed requirements between the two genotypes, the impact of social interaction and stress is also important. This is reflected in the amount of increased

social activity shown by sighted birds as evidenced from higher pecking damages (Table 14) to the combs of birds in this group. Wennrich (1974) stated that pecking in chickens is usually directed at the head of the individuals. When roosters grasp hens in a mating attempt, they also grasp hens by the comb or by the back of the head. Thus the combs of the birds are affected the most. Again, when a bird pecks another bird, the latter tries to escape or fight. This leads to increased bird movement (Hughes and Black, 1974). Behavioral observations on the same experimental birds in this study by Cheng (unpublished data) also demonstrated that there were significantly more social interactions by sighted birds compared to blind ones. Wilson et al. (1959) demonstrated that any kind of physical activity increases energy expenditure. Although such energy expenditure may vary considerably, it represents a substantial proportion of maintenance requirements (Morrison and Leeson, 1978) and is usually 50% of the basal metabolism (Card and Nesheim, 1967). It is therefore logical to assume that more activity in the sighted birds was accompanied by higher energy expenditure which, in turn, led to higher feed consumption to compensate for the extra energy expenditure.

In addition to a significant genotype effect for comb damage scores, there were also significant GXD and GXF interactions observed for this trait. Sighted birds in high density conditions had higher comb damages than in low density conditions. Blind chickens, however, were not affected by a change in density. This GXD significant interaction might have rendered the main density effect non-significant. Al-Rawi and Craig (1975) and Polley et al. (1974) observed increased social interactions as area per bird decreased. A later study (Simmonsen et al., 1980) also confirmed the same tendencies. The rise

in social activities (as evidenced from higher comb damage scores due to increased density observed in the present experiment) of sighted birds may presumably be associated with increased physical contact because of reduced individual distances.

A significant GXF interaction observed for this trait (Table 16) indicated that, although sighted birds had more social interactions than blind birds, both sighted and blind chickens had higher activity levels in large flocks compared to small flocks. However the difference between sighted and blind birds was much bigger in large flocks than in small flocks. Al-Rawi et al. (1976) observed higher agonistic behavior in groups of 8 and 14 birds compared to 4 birds. Hughes and Black (1974) also reported more pecking damages in groups of 4 birds than in groups of 2 birds. Perry (1977) reported that large flocks provide more opportunities for agonistic behavior than small flocks. Sighted birds, therefore, were more affected by the difference in flock size, because, lack of sight in blind birds hindered intense social interactions.

The difference in the amount of feather loss as evidenced in this experiment (see Table 14 and also Figures 2, 3 and 4) could be another reason for the variation in feed requirements of the two genotypes. Feather loss was far more severe in sighted birds compared to blind birds. Practically, by the end of the experiment, all blind birds were still fully feathered. Emmans and Charles (1976) reported that heat loss from exposed surface under extensive feather loss may be up to 40% more than fully feathered hens. Lee et al. (1983) found that when hens were defeathered they had significantly higher heat loss compared to fully feathered hens. Another study using naked

neck (na/na) fowls (Touchburn et al., 1980) observed inferior thermochemical efficiency in these birds compared to normal feathered ones. Still another report (Ernst and Boas, 1933) indicated that 'frizzle (F/f or F/F) fowl' with scanty plumage had a high basal metabolism and increased feed consumption. It is therefore, obvious that more heat was lost from exposed surface of the sighted birds compared to blind ones. The extra heat loss by the sighted birds must therefore be compensated by increase in feed consumption. Leeson and Morrison (1978) also stated that poor feather cover is associated with increased feed consumption to compensate for extra heat loss.

It has been demonstrated that hens wearing specs had higher egg production and lower feed consumption than controls (Cumming and Epps, 1976 and Arbi, 1978). These authors concluded that the phenomenon was partly because of reduced incidence of stressful situations encountered by hens wearing specs. Wells and Wright (1971) suggested that regardless of feather cover, stressful situations could also alter thermoregulatory responses in chickens and render them less efficient. It is not conclusive whether in this study, the sighted birds experienced more stress than the blind ones. Circumstantial evidence, however, indicates that this may be true because sighted birds suffered more skin and feather damages than blind birds. The difference could be even more drastic had pine tar not been applied to all wounds caused by pecking in order to avoid unnecessary suffering by the experimental birds. Pine tar tends to deter further pecking on the wounds because of its bitter taste. Despite this remedy, three birds from the sighted groups died because of pecking injuries during the experiment but none from the blind groups died. There was no significant difference between the two genotypes in leukocyte count, adrenal

weight and plasma corticosterone level. However, the means for adrenal weight and plasma corticosterone level were both lower for the blind genotype. Each of the four factors taken separately may not be meaningful, but taken together, they indicate that the sighted birds were under more stress than the blind chickens.

Although unlikely, the gene 'rc' could also be causing differences in feed requirements of the two genotypes through gene actions other than those causing blindness in the homozygotes. Differences in feed utilization because of single gene differences has been observed by Merat et al. (1979). Their white hens (I/i, I/I) consumed significantly less feed compared to coloured hens (i/i). Although it is not fair to compare the results of this study with that of Merat et al. (because of a lack of similarity in the experimental conditions and type of birds used) it nevertheless, does indicate that genotypic difference at one locus could cause a significant variation in feed utilization through unknown mechanisms.

4. Statement number 4

'Blind chickens may have better feed efficiency than normal chickens.'

Based on arguments presented under the first three statements, one can conclude that when compared in terms of feed efficiency, blind birds were more efficient in using feed. Because, while they consumed less feed they produced higher egg mass. Moreover, there was no difference in body weight gain between blind and sighted hens. Further indication that blind birds were utilizing feed more efficiently can be found by examining the body weight gain of roosters (Table 12). Although the means were not statistically tested, blind roosters on the average gained more than double in body weight compared to sighted ones.

This indicates that blind chickens were efficient converters of feed into products. However, it is worthwhile to further explore the potential of blind chickens under modern system of management practices.

5. Other considerations

Whatever may be the reason for higher number of eggs collected and less amount of feed taken by the blind birds compared to sighted ones, the former would still be beneficial in farm yard situations. In a recent review of 'Global Poultry Industry', Jasper (1979) reported that changes in the cost of living and other factors have revived, to a small degree, the backyard flock. As a matter of fact, many developing countries of Asia, South America and Africa have not developed an intensive and modernized poultry industry. In those countries poultry is predominantly a backyard enterprise. Under those conditions blind birds would be more economical, because other things being equal, the farmers would still collect more eggs for less feed compared to sighted ones.

II. Additional observations from experiment

1. Fertility

A particular behavior or component of a behavior exhibited by an animal is considered its phenotype. As such, it is affected by both genetic and environmental factors. Learning usually involve the interactions of both the auditory and visual modalities. Blind animals can be useful for studying learning in animals, because they allow the experimenter to hold constant the sensory input from one modality while studying the other.

A thorough search in the literature has failed to turn up with any

instances of previous research dealing with mating behavior of genetically blind animals. This could be due to lack of availability of experimental animals which are genetically blind. The blind chickens used in this experiment would provide a good opportunity to study such behavioral patterns. Previous casual observations (Cheng, personal communication) of blind chickens did not indicate that blind birds could mate successfully under natural mating situations. For propagation of this line artificial insemination was used.

From Cheng's observations, it is anticipated that very low or no fertility could be expected through natural mating from blind birds. Contrary to this expectation, the results obtained in the present study were surprising. Percent fertility of eggs from the blind chickens was 48.2% compared to 84.2% for the sighted birds (Table 3).

Adams et al. (1978) reported the fertility of two strains of White Leghorns (normal vision) kept with a male to female ratio of 1:10 to be 48.7% and 36.2% respectively. Under this particular situation, the performance of blind chickens in the present study was not too much out of line in comparison.

Moreover, fertility of eggs from different pens of the blind birds varied considerably. The fertility of eggs from one particular pen (Pen A3 low density-small flock) was 85% during the first period (8-17 days), 92% during the second period (28-37 days) and 100% during the third period (48-57 days). Fertility from a pen of sighted birds under the same conditions was only 64.4%, 78.3% and 77.3% respectively for the first, second and third periods. However, fertility of eggs from blind birds was usually lower than from sighted birds. In one particular pen (pen B2, high density-small flock) fertility was 0% throughout the experiment.

As evidenced from the results (see page 55), fertility in different periods increased over time. In the first period, the mean fertility of sighted and blind birds was 50.9%, in the second, 71.1% and in the third 79.1%. These increases in fertility may be attributed to learning experience of the roosters. Adams et al. (1978) also reported higher fertility from experienced males compared to inexperienced males.

The variability observed for fertility parameter among blind birds in different pens, reflect that blind roosters may vary considerably in learning ability to successfully mount females. As evidenced, some could learn more quickly than others. Therefore, it would be of interest to (a) examine situations where successful mating can be enhanced and (b) determine whether frequency of successful mating can be increased through selective breeding.

Observations in this experiment indicate that the blind chicken would be a good model for behavioral studies.

2. Flock size and density

Most of the earlier studies involving bird density and flock size were not well designed to separate the effects of these two factors. Hughes (1975) reviewed a wide range of literature dealing with 'stocking density' and stated that much of the earlier work was poorly designed in that it mostly confounded colony size (number of birds per cage) and area per bird. More recent studies have attempted to separate the effects of these two factors but little emphasis have been given on the importance of interactions involving these two factors (Adams and Jackson, 1970; Al-Rawi et al., 1976; Perry, 1977). In view of the above facts, this study was planned in an attempt to separate the effects of flock size and bird density upon the parameters measured and also to examine

the interaction between these two factors.

Flock size significantly affected some of the parameters studied. Percent hen-day egg production was significantly higher ($P<0.05$) in small flocks compared to large flocks. Higher egg production obtained from the small flocks confirmed the work of Al-Rawi et al. (1976) who, working with group sizes of 4, 8 and 14 birds per group, found lowest production rate in group size of 14. Production declined as group size increased. Similar results on group size effect can be found in Hill and Binns (1973) and Aitken et al. (1973). No explanation however, was provided by these authors for such results.

The effect of flock size on feed consumption, body weight gain and comb damage (pecking activity) of the experimental birds were highly significant ($P<0.001$). Birds in small flocks had higher feed intake, gained more weight, and less comb damages. A higher feed requirement by birds in small flocks could be accounted for increases in the number of total collectable eggs and higher body weight gain. How much of this excess feed consumption in small flock was accounted for by increases in egg number and body weight gain was not quantitated in this study. However, previous research indicated that feed consumption decreases as bird number per group increases (eg. Jensen et al., 1976; Ouart and Adams, 1982).

Higher body weight gain by birds in the small flocks as observed in this study is in agreement with that of Cunningham and Ostrander (1982). These authors found significantly higher body weight gain in groups of 4 birds compared to 5 birds. From their results it appeared that body weight gain could be related to group size. The present study with a bigger difference in group sizes (5 vs 20) confirmed Cunningham and Ostrander's findings. Significantly higher comb

damage in the large flocks indicated higher agonistic and sexual activities in those flocks. Al-Rawi and Craig (1975) observed a positive relationship between group size and individual frequencies of aggression with flocks of 4, 8, 14 and 28 birds. The level of aggression varied directly with group size and was most evident during feeding time. Therefore, it is possible that feeding interruptions occur under those conditions more frequently in large flocks than in small flocks. Due to a reduced interruption in feeding, birds in small group sizes have the opportunity to eat more and perform better.

Flock size was not only the factor which affected these traits, density also played a significant role. Although density as a main factor was not significant in any case, 4 out of 9 parameters studied showed significant interactions involving density as a factor. A significant GXD interaction for comb damage scores has already been discussed earlier (see page 74). Aside from this interaction, all others were involving density and flock size. Significant DXF interactions were observed for egg weight, feed consumption and body weight gain. In all of these interactions a general and convincing trend was noticed in that small flocks in low density took the highest feed, had the heaviest egg weight and had the most gain in body weight. On the other hand, for large flocks in low density, the results were the opposite (Table 8, 10 and 11). The differences exhibited by these two flock sizes in low and high density situations were greater in low density than in high density. From these results it could be concluded that flock size as a factor is not as important in high density as in low density. Therefore, it could be suggested that when birds are to be housed in low density they should be housed in small group sizes.

The above discussions emphasised the need of examining interactions in

a factorial experiment like the present one for a valid interpretation of the effect of each factor involved. For example, in this study, if the interactions between genotype and density or density and flock size were not examined and separated from the main effects, the results could be misinterpreted because these interactions masked the significance of density as a main effect. However, there could be other reasons for density effect being not significant. It may be that the two densities used in this experiment were not different enough to cause a clear separation of density effects. The sample sizes used were often quite small leading to greater sampling variations reflected in the higher standard deviations for most traits (Table 4).

SUMMARY

The impact of visual contact or lack of it was accessed in two genetic groups of chickens maintained at the Avain Genetics Laboratory of the University of British Columbia. Each of the two genotypic groups (sighted and blind) were reared in two floor densities and two flock sizes. A total of nine parameters was measured to compare the relative performance of each genetic group under these experimental conditions.

Although it was originally suspected that blindness will interfere with feeding and other maintenance practices, there was no such indication from data collected in this experiment. Moreover, blind birds performed better than sighted ones in the number of total collectable eggs and had lower feed requirements while body weight gain was similar. Total egg mass output was also higher in blind birds. All these factors in combinations indicated that blind birds were more efficient in utilizing feed for body weight gains and egg production.

From other parameters measured in this experiment, possible reasons for the better performance in blind chickens can be offered. Although sighted birds were apparently breaking and eating eggs more frequently than blind ones, the difference in number of eggs collected cannot be totally attributed to this factor. Rather, sighted birds may be utilizing more energy for other purposes than egg production, because, they were seemingly more active and may also be under more stress compared to blind birds. Though no conclusive evidence to support this claim can be derived from this experiment, the sighted birds were observed to suffer more feather and skin damages than blind birds. In addition, although not statiscally significant, mean adrenal weight and corticosterone

level for sighted birds were higher than blind ones.

Higher amount of feed taken from the feed troughs by the sighted birds was partly due to feed spillage and partly due to increased activity level in that group. Another possible reason for higher feed requirements by the sighted chickens could be attributed to increased skin and feather damages. Under those situations, heat losses from exposed surface of the bared skin would increase energy requirement.

Although fertility from natural mating was much lower in blind birds compared with sighted ones, and may be considered as an adverse effect due to the lack of sight, it was surprising that they did show successful mating behavior and learned how to mount females. These blind birds could be useful animal models for studying learning behavior in those aspects such as feeding, drinking, resting and reproductive behaviors.

Under the conditions of the experiment, the results obtained suggest that blind birds were at least as good as or better than sighted birds in terms of efficiency in feed conversion. It could therefore be concluded that lack of sight did not interfere with feeding and other maintenance processes (except mating behavior). Therefore, the null hypothesis that 'lack of sight will interfere with feeding and other maintenance processes which may interfere with the normal performance of the birds' can be rejected.

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APPENDIX

Table 17. Analysis of Variance for percent hen-day egg production[1] of experimental birds

Source	df	SS	MS	F
Replication	1	889.58	889.58	4.54
Genotype (G)	1	1715.40	1715.40	8.75*
Density (D)	1	7.83	7.83	0.04
Flock size (F)	1	919.35	919.35	4.69
GXD	1	202.26	202.26	1.03
GXF[2]	1	0.00	0.00	0.00
DXF	1	8.61	8.61	0.04
GXDXF	1	284.65	284.65	1.45
Error 1	7	1372.20	196.03	
Week (W)	7	12182.00	1740.30	20.35***
WXG	7	358.12	51.16	0.60
WXD	7	597.06	85.30	1.00
WXF	7	390.18	55.74	0.65
WXGXD	7	144.65	20.66	0.24
WXGXF	7	643.15	91.88	1.07
WXDXF	7	209.24	29.89	0.35
Error 2	63	5386.70	85.50	
Total	127	25311.00		

[1] Arcsin transformation applied to the data before analysis.

[2] SS is equal to 0.0032.

*$P < 0.05$

***$P < 0.001$

Table 18. Analysis of Variance for percent hen-day egg production[1] of experimental birds with adjustment for age differences between replications

Source	df	SS	MS	F
Replication	1	67.55	67.55	0.65
Genotype (G)	1	875.74	875.74	8.39*
Density (D)	1	159.62	159.62	1.53
Flock size (F)	1	734.22	734.22	7.04*
GXD	1	14.92	14.92	0.14
GXF	1	0.03	0.03	0.00
DXF	1	7.35	7.35	0.07
GXDXF	1	180.48	180.48	1.73
Error 1	7	730.29	104.33	
Week (W)	5	4762.80	952.55	22.44***
WXG	5	314.94	62.99	1.48
WXD	5	226.13	45.23	1.07
WXF	5	214.34	42.87	1.01
WXGXD	5	242.15	48.43	1.14
WXGXF	5	219.01	43.80	1.03
WXDXF	5	40.06	8.01	0.19
Error 2	45	1910.40	42.45	
Total	95	10700.00		

[1] Arcsin transformation applied to the data before analysis.

*$P < 0.05$

***$P < 0.001$

Table 19. Apparent mean percent hen-day egg production, egg weight (g) and apparent feed requirements (g) of birds with adjustment for age differences of birds between replications

Factor		Egg production	Egg weight	Feed requirements
Replication:	First	52.3±4.4	46.07±2.98	155.6±30
	Second	55.2±2.3	27.68±3.38	163.1±38
	Difference	2.9	1.66*	8.0
Genotype :	Sighted	48.4±4.3	47.21±3.67	182.8±31
	Blind	58.9±2.1	46.54±2.80	136.0±16
	Difference	9.5*	0.67	48.8***
Density :	High	57.7±4.0	46.42±2.81	156.1±27
	Low	51.4±2.7	47.33±3.64	162.6±40
	Difference	6.3	0.91	3.9
Flock size :	Small	58.5±3.8	46.95±3.76	174.5±37
	Large	48.9±2.6	46.80±2.72	144.2±23
	Difference	9.6*	0.15	30.0***

*$P < 0.05$

***$P < 0.001$

Table 20. Analysis of Variance for egg weight of experimental birds

Source	df	SS	MS	F
Replication	1	132.57	132.57	14.41**
Genotype (G)	1	18.41	18.41	2.00
Density (D)	1	21.12	21.12	2.30
Flock size (F)	1	1.50	1.50	0.16
GXD	1	18.73	18.73	2.04
GXF	1	1.39	1.39	0.15
DXF	1	138.73	138.73	15.08***
GXDXF	1	6.99	6.99	0.76
Error 1	7	64.42	9.20	
Week (W)	7	1908.70	272.68	108.69***
WXG	7	24.44	3.49	1.39
WXD	7	21.42	3.06	1.22
WXF	7	11.67	1.67	0.66
WXGXD	7	7.67	1.10	0.44
WXGXF	7	8.68	1.24	0.49
WXDXF	7	23.40	3.34	1.33
Error 2	63	158.06	2.51	
Total	127	2567.90		

**$P < 0.01$

***$P < 0.001$

Table 21. Analysis of Variance for egg weight of experimental birds with adjustment for age difference between replications

Source	df	SS	MS	F
Replication	1	61.99	61.99	7.00*
Genotype (G)	1	10.83	10.83	1.22
Density (D)	1	19.64	19.64	2.22
Flock size (F)	1	0.50	0.50	0.06
GXD	1	10.02	10.02	1.13
GXF	1	2.98	2.98	0.34
DXF	1	125.17	125.17	14.13**
GXDXF	1	4.38	4.38	0.49
Error 1	7	62.00	8.86	
Week (W)	5	594.90	118.98	73.12***
WXG	5	5.15	1.03	0.63
WXD	5	16.35	3.27	2.01
WXF	5	13.90	2.78	1.71
WXGXD	5	3.22	0.64	0.40
WXGXF	5	2.87	0.57	0.35
WXDXF	5	7.60	1.52	0.93
Error 2	45	73.23	1.63	
Total	95	1014.70		

*$P < 0.05$

**$P < 0.01$

***$P < 0.001$

Table 22. Analysis of Variance for amount of feed taken from feed troughs by experimental birds

Source	df	SS	MS	F
Replication	1	0.00040	0.00040	3.65
Genotype (G)	1	0.00778	0.00778	71.42***
Density (D)	1	0.00014	0.00014	1.33
Flock size (F)	1	0.00423	0.00423	38.84***
GXD	1	0.00004	0.00004	0.34
GXF	1	0.00064	0.00064	5.89*
DXF	1	0.00075	0.00075	6.93*
GXDXF	1	0.00017	0.00017	1.55
Error	7	0.00076	0.00011	
Total	15	0.01491		

*P< 0.05

***P<0.001

Table 23. Analysis of Variance for amount of feed taken from feed troughs by experimental birds with adjustment for age differences between replications

Source	df	SS	MS	F
Replication	1	0.0013	0.0013	1.69
Genotype (G)	1	0.0525	0.0525	66.67***
Density (D)	1	0.0010	0.0010	1.27
Flock size (F)	1	0.0220	0.0220	27.94***
GXD	1	0.0003	0.0003	0.36
GXF	1	0.0033	0.0033	4.16
DXF	1	0.0051	0.0051	6.51*
GXDXF	1	0.0014	0.0014	1.76
Error 1	7	0.0055	0.0008	
Week (W)	5	0.0013	0.0003	1.10
WXG	5	0.0012	0.0002	0.98
WXD	5	0.0006	0.0001	0.51
WXF	5	0.0009	0.0002	0.74
WXGXD	5	0.0007	0.0001	0.56
WXGXF	5	0.0004	0.0001	0.33
WXDXF	5	0.0012	0.0002	1.00
Error 2	45	0.0108	0.0002	
Total	95	0.1095		

*$P < 0.05$

***$P < 0.001$

Table 24. Analysis of Covariance for body weight gain of experimental hens

Source	df	SS	MS	F
Replication	1	346320	346320	13.43***
Genotype (G)	1	1586	1586	0.06
Density (D)	1	769	769	0.03
Flock size (F)	1	282400	282400	10.95**
GXD	1	11900	11900	0.46
GXF	1	478	478	0.02
DXF	1	220510	220510	8.55**
GXDXF	1	63623	63623	2.47
Error	54	1392700	25792	
Total	62	2320286		

**P< 0.01

***P< 0.001

Table 25 . Analysis of Variance for initial[1] body weight of experimental hens

Source	df	SS	MS	F
Replication	1	2197.3	2197.3	0.06
Genotype (G)	1	84463.0	84463.0	2.36
Density (D)	1	21572.0	21572.0	0.60
Flock size (F)	1	7119.1	7119.1	0.20
GXD	1	5166.0	5166.0	0.14
GXF	1	11963.0	11963.0	0.33
DXF	1	10635.0	10635.0	0.30
GXDXF	1	530170.0	530170.0	14.83***
Error	55	1966500.0	35754.0	
Total	63	2639800.0		

[1] Body weight taken before start of experiment.

***P<0.001

Table 26. Analysis of Variance for percent fertility[1] of experimental birds

Source	df	SS	MS	F
Replication	1	1364.60	1364.60	1.54
Genotype (G)	1	6151.50	6151.50	6.93*
Density (G)	1	1294.30	1294.30	1.46
Flock size (F)	1	383.92	383.92	0.53
GXD	1	1203.10	1203.10	0.28
GXF	1	2.75	2.75	0.00
DXF	1	303.36	303.36	0.34
GXDXF	1	367.47	367.47	0.41
Error 1	7	6216.40	888.06	
Period (P)	2	2524.90	1262.50	9.36**
PXG	2	312.32	156.16	1.16
PXD	2	344.44	172.22	1.28
PXF	2	100.77	50.39	0.37
PXGXD	2	107.10	53.55	0.40
PXGXF	2	101.24	50.62	0.38
PXDXF	2	449.57	224.79	1.67
Error 2	18	2428.60	134.92	
Total	47	23656.00		

[1] Arcsin transformation applied to the data before analysis.

*$P < 0.05$

**$P < 0.01$

Table 27. Analysis of Variance for leukocyte count of experimental hens

Source	df	SS	MS	F
Replication	1	65675000	65675000	3.07
Genotype (G)	1	13443000	13443000	0.63
Density (D)	1	2847700	2847700	0.13
Flock size (F)	1	21199000	21199000	0.99
GXD	1	5299200	5299200	0.25
GXF	1	101460000	101460000	4.74*
DXF	1	22069000	22069000	1.03
GXDXF	1	12105000	12105000	0.57
Error	55	1177100000	21403000	
Total	63	1421200000		

*P< 0.05

Table 28. Analysis of Variance for adrenal weight of experimental hens

Source	df	SS	MS	F
Replication	1	1.5252	1.5252	0.68
Genotype (G)	1	5.9231	5.9231	2.65
Density (D)	1	0.5123	0.5123	0.23
Flock size (F)	1	3.6864	3.6864	1.65
GXD	1	0.0030	0.0030	0.00
GXF	1	0.2207	0.2207	0.10
DXF	1	0.1189	0.1189	0.05
GXDXF	1	0.0007	0.0007	0.00
Error	55	123.1300	2.2388	
Total	63	135.1200		

Table 29. Analysis of Variance for plasma concentration of corticosterone of experimental birds

Source	df	SS	MS	F
Replication	1	0.2771	0.2771	0.62
Genotype (G)	1	0.6344	0.6344	1.42
Density (D)	1	0.7940	0.7940	1.77
Flock size (F)	1	0.0854	0.0854	0.19
GXD	1	0.8137	0.8137	1.82
GXF	1	1.0848	1.0848	2.42
DXF	1	0.0001	0.0001	0.00
GXDXF	1	0.0100	0.0100	0.02
Error	71	31.8070	0.4480	
Total	79	35.5060		