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A COMPARISON OF BARLEY, CORN AND WHEAT AS THE GRAIN IN BROILER STARTER RATIONS

by

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ABSTRACT

Growth trials, a digestibility and N-retention trial were conducted using broiler chicks to compare the nutritional value of broiler starter rations based on barley, corn, wheat or combinations of two cereals.

When barley replaced wheat to a maximum level of 50% of the total diet with adjustments to keep diets iso-nitrogenous, feed consumption increased with increasing barley, weight gain fell when barley was used at levels beyond 30% of the diet and feed efficiency fell with increasing barley. However, differences in these parameters were not significant. Feed intakes were 1274, 1292, 1323, 1304, 1311 and 1308 g/bird, weight gains 806.25, 817.50, 826.00, 817.25, 802.75 and 797.50 g/bird and feed/gain ratios 1.58, 1.58, 1.60, 1.60, 1.63 and 1.64 for 0, 10, 20, 30, 40 and 50% barley diets respectively.

When corn replaced wheat to a maximum level of 48.6% of the total diet, feed intake significantly ($P < .01$) decreased while feed efficiency significantly ($P < .005$) improved with increased corn. High wheat diets gave slightly better weight gains than diets high in corn, however best weight gains were achieved when the two cereals were used in a combination of approximate equal proportions. Differences in weight gains were not significant. Feed intakes were 1466, 1440, 1433, 1426, 1386 and 1386 g/bird. Weight gains were 913.00, 912.75, 921.75, 936.25, 902.00 and 901.75 g/bird and feed/gain ratios were 1.61, 1.58, 1.56, 1.52, 1.54 and 1.54 for the 0, 10, 20, 30, 40 and 48.6% corn diets respectively.

When barley replaced corn up to a maximum level of 47% of the diet with adjustments in soybean meal and animal tallow to maintain diets iso-nitrogenous and iso-caloric, there was no significant difference between diets in feed intake, weight gain or feed efficiency although a decline in feed efficiency appeared to occur at 47% barley. Feed intakes were 1349, 1395, 1299, 1404, 1375 and 1394 g/bird, weight gains were 856.62, 885.72, 836.28, 895.25, 863.42 and 874.00 g/bird and feed/gain ratios were 1.58, 1.58, 1.56, 1.57, 1.59 and 1.60 for the 0, 10, 20, 30, 40 and 47% barley diets respectively.

Corn had significantly ($P < .005$) higher digestible dry matter (91.40%) than wheat (88.25%) and barley (87.49%), and barley had significantly ($P < .05$) lower nitrogen retention (71.43%) than corn (77.67%) and wheat (74.03%). No significant difference occurred in the digestible dry matter of diets based on the three cereals but a barley-based diet gave significantly ($P < .005$) lower nitrogen retention (74.03%) than diets based on corn (84.86%) and wheat (83.74%).

It was concluded that no significant difference occurs in weight gain when broilers are fed corn or wheat based diets but corn-based diets give better feed efficiency. Barley-based diets are not practical in broiler feeding due to low metabolizable energy in barley, however, barley in combination with corn or wheat can be successfully used in practical broiler ratios to a level of 30% of the total ration without a significant effect on weight gain and feed efficiency.

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INTRODUCTION

Animal products (meats, milk and eggs) are the best protein sources in human nutrition. About 30% of the total protein consumed by the world population comes from animal sources (FAO, 1964). The need for efficient production of animal products has stimulated changes in animal management practices. Intensive animal production systems have been developed utilizing formulated diets. Cereals are a major component of formulated diets used in animal production, especially poultry and swine which tend to be more dependent on cereals than ruminants since ruminants utilize roughage and can be produced with minimal use of cereals. There is further variation in extent of dependency on cereals between poultry and swine. Swine can utilize a wider range of cereal varieties and by-products as feed ingredients whereas poultry require high energy feed ingredients. In practical formulations, cereals are used to a proportion of about 50% of the total diet. However, the high efficiency of feed utilization by poultry in relation to other types of livestock justifies the use of grain in poultry feeding.

Wheat and corn are the primary cereals for poultry feeds. Due to the high demand for these cereals in the diets of both animals and man, these cereals tend to be expensive. Barley is a cereal which is relatively cheap and has a good potential for increased production. Hence the use of barley in poultry feeds may be a way of diversifying grain types used in feeds as well as reducing production costs, thereby improving the economic efficiency of poultry production. To date, limited use has been made of barley in poultry feeding. Barley-based diets in broiler feeding have been observed to result in poor broiler performance both in growth and feed efficiency (Lindblad et al., 1954; Willingham et al., 1958; Arscott and Rose, 1960a; Anderson et al., 1961; Arscott et al., 1965 and Petersen, 1969).

Most of the work conducted to evaluate barley in broiler feeding was conducted over 10 years ago in which relatively high levels of barley (50% of the diet or more) were used without adjustments for nutrient balance (Arscott et al., 1955; Arscott and Rose, 1960a; Anderson et al., 1961; Arscott et al., 1965 and Petersen, 1969). In most cases, evaluation methods used made comparisons of barley with other cereals on a weight to weight substitution basis. It should be realised that this method of evaluation, while providing the value of one grain relative to the other, does not give an accurate evaluation of the nutritive value of a diet that can be formulated using the grain under consideration. It is also possible that, while a given crop may be of poor nutritional value when used as a sole grain in a diet, partial use of the grain in combination with another grain could provide nutritionally acceptable diets.

Over the years, changes have also occurred in nutrient requirement recommendations, methods of diet formulatation, barley breeding and strains of birds. With these points in mind, a comparative study was designed to evaluate the potential of commercially available feed-grade barley as an ingredient in practical broiler starter rations. The objective of this thesis was to:

1. Conduct a review of literature on the value of barley in poultry feeding and attempt to identify the characteristics that give barley its status in poultry feeding.
2. Conduct growth trials to evaluate the performance of broilers (to 4 weeks of age) fed diets containing varying amounts of barley in combination with wheat or corn in balanced diets.
3. Make comparisons in performance of broilers fed diets based on corn, wheat or barley.

REVIEW OF LITERATURE

A. Classification, Origin, Ecology and Geography

1. Barley

Barley belongs to the tribe Triticeae Dumort, family gramineae and genus Hordeum which occurs both as a wild and as a cultivated plant. The genus Hordeum is divided into sections, cultivated barley together with its closely related wild types belong to the section of Cerealia. Three of the species in the section Cerealia are the cultivated barleys. These include H. vulgare L. a six-rowed barley, H. distichum L. a two-rowed barley and H. irregulare E. an irregular barley (Wiebe and Reid, 1961). All cultivated barleys possesses 7 pairs of chromosomes (Nilan, 1964).

A number of classification schemes for barley have been suggested by a number of workers at species level, none of which appears to be widely accepted as being most appropriate. The classification scheme used above gives the best segregation of barley types. In this work, the term barley will be used to refer to H. vulgare L., H. distichum L. and H. irregulare E., cultivated barley species.

There is a large number of cultivated barley varieties world-wide and these are changing with breeding improvements and changes in cultivation methods. In 1958, about 165 varieties of barley were being grown in North America, approximately 37 were grown in Canada (Wiebe and Reid, 1961). Barley varieties are classified as spring or winter in relation to time of cultivation. In North America the greater part of the barley crop comes from Spring varieties (Weibe and Reid, 1961).

Cultivated barley does not have a clearly traceable origin or path of descent. It is adapted to a very wide range of ecological and climatic conditions. Barley is grown as far north as 65° latitude in the USSR, at elevations of 12,000 feet in the Himalaya mountains to 1,100 feet below sea level at the dead sea (Nilan, 1964), at equatorial latitudes (Helbaek, 1959) and in Australia, in the southern hemisphere.

In spite of the wide distribution of the cultivated barley, the distribution of one of the possible progenitors H. spontaneum is limited to the near East and Western North Africa (Helbaek, 1959) and the other possible progenitor H. agriocrithon has never been observed growing under wild conditions, but was first found as mixtures in cultivated barley seed from Tibet (Schiemann, 1951).

In Canada, barley is produced in many areas across the country, with greater production being carried out in the prairie provinces. The yield in the prairies is in the order of 0.98 to 1.01 tonnes/acre (Agriculture Canada, 1977 and 1978). Canada barley production figures over a five year period (1975-1980) are given in Table 15.

2. Wheat

Cultivated wheat belongs to the tribe Triticeae Dumort, family Gramineae and genus Triticum L. emend. This genus includes diploid, allotetraploid, allohexaploid wheats and diploid, allotetraploid and allohexaploid species of interspecific hybrid origin. There are 10 diploid species, one allotetraploid wheat species of hybrid origin which includes many cultivars, three botanical varieties and one auto-allohexaploid form, one allohexaploid wheat which is a hybrid complex that includes many cultivars, 10 other allotetraploid or allohexaploid species of interspecific hybrid origin and numerous artificial and natural interspecific hybrids (Bowden, 1959).

It is considered that cultivated wheat originated from the middle East since all the four ancestral wild species of wheat (*T. monococcum*, *T. speltoides*, *T. dicoccoides* and *T. aegilops*) are found within the area from Zagros mountains (Iran-Iraq), the Taurus mountains (southern Turkey) to the Galilean uplands (Israel-Transjordan) (Helbaek, 1959; Vavilov, 1950). Wheat production is mainly carried out in areas outside the tropics with major producing areas lying in the northern hemisphere. Wheat is cultivated in North America, Europe and through the middle East region to Asia. In the southern hemisphere, major production is carried out in Australia. Wheat has just been introduced in most tropical regions of the world and major production has not been achieved.

Canada produces red spring wheats and amber durum wheats, with red spring wheats making up the greater part of the crop (Agriculture Canada, 1976-81). Canada wheat production figures over the period 1975-1980 are given in Table 15.

3. Corn

Corn (maize) belongs to the tribe *Maydeae* and family *gramineae*. Due to numerous variations in corn and possible misunderstanding of the nature and relationship of species, the classification of corn at genus and species level is not clear. Whereas *Zea* is usually considered to be the genus name for corn, *mays* has also been used as a genus name for some varieties. *Mays* is usually considered a species name along with many others. There has been a wide divergence of the botanical characteristics of what is suggested to be corn's ancestors and a number of theories have been suggested to explain the origin of corn. Data on the races and lineages suggest that corn had more than one location of origin in Mexico and South America. Corn is cultivated in all continents of the world and appears to be one of the most widely cultivated cereals.

B. Gross Composition of Barley, Corn and Wheat

In general, barley is a high fiber crop compared to wheat and corn. Its crude protein content (11.6%) is higher than corn (8.8%) but lower than wheat (14.1%) (NRC, 1977). The gross energy value of barley (4.43 kcal/g) is lower than corn and comparable to wheat (4.51 kcal/g) (Coates et al., 1977).

The amino acid composition in barley does not differ greatly to that of corn and wheat, all values for amino acid composition fall within the range of corn and wheat. The amino acid composition of barley, corn and wheat is given in Table 16. The lipid content in barley is almost equivalent to wheat and about one-half of corn. Its ash content is higher than both wheat and corn. Barley is slightly lower than wheat and corn in total carbohydrates, it is however higher than both corn and wheat in cellulose, hemicellulose and lignin, and higher than corn in pectins. Barley is lower than both corn and wheat in soluble sugars and starch, providing a lower value than corn or wheat in available carbohydrates (McNab and Shannon, 1974).

The phosphorus content in barley (0.44%, Hayes et al., 1979; 0.36%, NRC, 1977) is almost equivalent to wheat (0.37%, Hayes et al., 1979; and NRC, 1977) and considerably higher than corn (0.27%, Hayes et al., 1979; 0.28%, NRC, 1977) and the phytin phosphorus and tannic acid content in barley (0.25 and 0.018% respectively) is almost equivalent to wheat (0.28 and 0.015% respectively) (Coates et al., 1977). Table 17 shows the gross composition of barley, corn and wheat.

The gross composition of barley can vary with genetic, environmental and cultural conditions. One of the components that can vary considerably is the nitrogen content, which determines the crude protein value. Coates et al. (1977) reported crude protein values of different barley varieties ranging from 10.1 to 14.3%. The nitrogen content of barley can vary with soil nitrogen content, nitrogen fertilization, time of harvesting and to some extent, processing and storage.

The carbohydrate composition can also vary with environmental and cultural practices (Thomke and Hellberg, 1976; Coering et al., 1957). Goering et al. (1957) reported a variation of 19 to 23% in amylose content in 30 barley samples grown under different environmental and cultural practices. The fiber content also varies in barley, Coates et al. (1977) reports values of crude fiber ranging from 3.89 to 7.17% in different barley varieties.

Variation in composition occur in wheat [March and Biely (1973), Protein 9.5 to 22.8%; Coates et al. (1977), Protein 10.2 to 17.3; Nelson et al., (1980), MEn 3.44 to 3.48 kcal/g; Boldaji et al. (1978), ME 3.68 to 3.90 kcal/g.] In a number of major components, similar or greater variations can be observed in wheat as compared to barley. Barley only shows greater variation in crude fiber and ether extractives. Corn shows the least variation in composition. Its crude protein content will range from 8.0 to 9.5%. However, its ME can vary considerably with area of cultivation as well as year of cultivation. Conner et al., (1976), reported significant differences in ME values in corn from different locations as well as years of harvest.

Tables 18 to 23 show the composition of different varieties of wheat and barley produced in Canada in 1972. From these tables it can be noticed that variation in major components between varieties of the two cereals occurred in both cases. Barley varieties showed greater variation in crude fiber and ether extractives whereas wheat varieties showed greater variation in crude protein and nitrogen-free extracts.

C. Nutrient Availability for Poultry

No great differences have been reported in the digestibility of nutrients between barley, corn and wheat except for carbohydrates and some minerals. The digestibility of carbohydrates in barley is considerably less than in corn and slightly less than in wheat. McNab and Shannon (1974) estimated the true digestibility for barley, maize, oats and wheat respectively for crude protein to be 83.6, 82.2, 85.0 and 84.7%, that of crude fat 92.5, 94.9, 95.0 and 92.5% and that of carbohydrates 73.0, 87.2, 52.1 and 81.1%.

There appears to be considerable variation in mineral availability in cereals. Hayes et al. (1979) reported the availability of phosphorus to be 12, 43, 58 and 50% for corn, hard wheat, soft wheat and barley respectively. Closely in agreement with results obtained by Hayes et al., (1979), Trotter and Allee (1979) reported phosphorus availability to be 19 and 48% in corn and wheat respectively. In contrast to the observations by Hayes et al., (1979) and Trotter and Allee (1979), Aw-Yong et al., (1983) reported higher and more uniform phosphorus availability values, the availability of phosphorus was 60.9, 68.8 and 67.5% in corn, barley and wheat respectively. Aw-Yong et al. (1983), reported the availability of other minerals to be as follows: calcium 70.0, 68.9 and 71.0%, magnesium 51.0, 54.9 and 53.5%, manganese 60.0, 54.9 and 48.4%, zinc 57.6, 49.1 and 48.6% and copper 87.2, 77.5 and 78.5% in corn, barley and wheat respectively.

The metabolizable energy value of barley for the chicken does not differ greatly with that of wheat but it is considerably less than that of corn. McNab and Shannon (1974) estimates the metabolizable energy values to be 3.16, 2.91 and 2.66 kcal/g dry matter for corn, wheat and barley respectively. NRC (1977) gives metabolizable energy values corrected for nitrogen for barley, corn and wheat as 2640, 3430 and 2800 kcal/kg respectively.

Davidson et al. (1978) reported ME values of 3.01 and 3.25 kcal/g for barley and wheat respectively and Coates et al. (1977) estimated the mean metabolizable energy values to be 3.05 and 3.47 kcal/g for barley and wheat varieties respectively. The ME value of a crop can vary with variety or area of cultivation. Variations in ME values can also occur with age differences in birds used in the estimation (Zelenka, 1968 and Coates et al., 1977).

There is a significant negative correlation between crude fiber and metabolizable energy values in barley (Sibbald and Price, 1976; Coates et al., 1977). There are also highly significant ($P < 0.01$) correlations between true metabolizable energy and starch (0.833), starch + sugar (0.838), bulk density (0.912) and ash (-0.758) (Sibbald and Price, 1976). The high correlation of component composition to energy values implies variations in metabolizable energy values with variations in factors that affect the gross composition of barley.

D. Barley in Broiler Feeding

Most of the work conducted on the use of barley in broiler rations reveal adverse effects on growth and feed efficiency when barley diets are used, in comparison to corn and wheat, for broilers under 4 weeks of age. Arscott et al. (1965) reported decreased body weights when barley replaced corn at 69.25% and 70.3% of the diet in day old broiler chicks fed to 4 weeks of age. Willingham et al. (1958) reported poor growth and feed efficiency when eight different varieties of barley were fed to chicks. Arscott and Rose (1960a) reported inferior performance efficiency in broilers when fed from day old to 8 weeks on a diet in which barley replaced corn at 61.23% of the diet.

Anderson et al. (1961) observed that the rate of gain of chicks fed on a ration based on yellow corn averaged 17% more than that of chicks fed on a ration based on hulless barley and the gain/feed ratio averaged 12% more with the corn ration. Petersen (1969) reported least growth from barley diets when White Plymouth Rock birds were fed diets containing 50% corn, sorghum, barley, wheat or oats from day old to 53 days.

However, some workers have reported observations which are not exactly in agreement with those of workers just given. Hijikuro and Takemasa (1981) in their study on the palatability and utilization of some whole grains for finishing broilers using barley, wheat, milo and rice observed that feed intake and weight gain was not affected by dietary grain source. Grains were used at 63% of the diet, both as whole grains and as ground grains and diets were adjusted to meet the protein and energy requirements. Birds were fed the diets from 6 to 8 weeks of age.

It should be noted that the period of the experiment only covered the last 14 days of production. The length of the period as well as the age at which the experiment was conducted could have affected the results. It is well known that more rapid growth in broilers will occur in the early weeks of growth. It is also most likely that growth differences can be easier to determine when the growth rate is high and an observation is conducted over a longer period than 14 days. There is a possibility that the method used in the study may have failed to reveal differences in the feeding value of the grains that might occur over an entire growing period.

Lindblad et al. (1954) reported adverse effects on the performance of broilers fed barley-based diets to occur only when the level of barley exceeded 30% of the total diet. This observation suggests that low levels of barley can be used in broiler rations without affecting bird performance. What is not clear is the minimum level of dietary barley which results in adverse effects or the maximum dietary level that will support normal performance. These questions may be difficult to answer since variations can occur in the nutritive value of various barley samples handled by different investigators. Differences in observations made can also occur due to differences in the total composition of the diets as well as differences in bird strains. From the results of the workers given, it can only be said that high levels of barley in broiler diets result in poor bird performance. It should be noted that Hijikuro and Takemasa (1981) reported no adverse effects in 6 week old broilers. This observation might mean reduced sensitivity of broilers to barley-based diets with age.

E. Barley in Layer Feeding

Barley in layer diets does not affect egg production although feed efficiency is affected. Brown and Hale (1965) using diets containing 65% barley, 55% maize and 35% oats observed no significant differences in egg production between diets. However, better feed conversion was obtained on maize diets. Similarly, Anderson et al. (1960) reported good performance in laying hens fed rations with a high level of barley (78 to 80%), egg production was comparable to that obtained with rations containing corn, milo and wheat. However, slightly more feed was required to produce a dozen eggs with the high barley diets. Berg and Bearse (1958) reported equal rates of lay between birds fed corn-based diets and those on barley-based diets although feed efficiency was less with barley-based diets (8% more feed was required per dozen eggs).

Singh and Barsaul (1977) reported relatively poor feed efficiency when 8-week old White Leghorns were fed diets containing 40% grain when the grain was barley as compared to maize, sorghum or pearl millet.

This difference was not however clearly reflected when the diets were fed to Rhode Island Red chickens. Intake values for White Leghorns were 4.73, 6.83, 4.63 and 3.98 kg/kg gained and Rhode Island Reds were 3.98, 4.33, 4.02 and 3.72 kg/kg gained for maize, barley, sorghum and pearl millet respectively.

Better performance in layers on barley-based diets further suggests increased ability of mature birds to utilize barley diets. As observed by Lodhi et al. (1969), the ability of a bird to utilize a given dietary material can vary with age. Lodhi et al. (1969), in a study on the metabolizable energy of rapeseed meal for growing chickens and laying hens, reported increased ability of the chicken to utilize rapeseed meal with age. This increased ability may be due to increased size of the digestive tract, increased microbial populations in the tract, changes in microbial composition, changes in concentrations of digestive enzymes or rate of digestive enzyme secretion.

F. Treatments in Barley Diets

1. Enzyme supplements

Significant improvements in both growth and feed efficiency can be achieved when barley-based broiler rations are supplemented with enzymes. Jensen et al. (1957) reported significant improvements in growth and feed efficiency in broilers, from 1 to 4 weeks of age, when enzymes were supplemented to diets in which barley replaced corn on a weight to weight basis. Arscott and Rose (1960a) reported significant improvements in broiler performance when enzymes were added to rations containing 61.25% barley fed to broilers from day old to 8 weeks. Similar observations were reported by Dobson and Anderson (1958), Willingham et al. (1958), Willingham (1964), Willingham and Earle (1964), Willingham (1959), Daghir and Rottensten (1966), Petersen and Sauter (1968), Herstad and McNab (1975), White et al. (1980), Mannion (1981), Hesselman et al. (1982), and Moss et al. (1983).

The use of enzymes in barley diets has no significant effect on the rate of lay, feed efficiency, total egg production and body weight gain in layers (Berg, 1959 and 1961, and Berg and Bearse, 1958). Arscott and Rose (1960b) also reported no significant effect of enzymes in layer diets on production. The poor response of layers to enzymes may be due to their better ability to utilize barley diets.

No specific enzyme(s) have been identified as being responsible for the improvements observed in broiler performance. Dobson and Anderson (1958) reported improvements with the use of crude fungal and bacterial enzyme preparations. Willingham et al. (1958 and 1959) also reported significant growth responses when enzyme preparations from both bacterial and fungal sources were used. Willingham et al. (1958) observed greater response from a combination of barley malt and fungal amylase, suggesting the possibility of more than one enzyme being involved.

Improved chick growth to 4 weeks can also be achieved by using crude enzyme materials containing amylase, protease, gumase, lipase and cellulase (Petersen and Sauter, 1968), crude amylolytic and proteolytic enzyme preparations (Willingham et al., 1959) or a pectin degrading enzyme (Burnett, 1966).

2. Other treatments

Water soaking of barley grains before using in broiler rations also results in significantly improved bird performance (Dobson and Anderson, 1958; Willingham et al., 1959; Willingham et al., 1960; Willingham 1964 and Potter et al., 1965). A reduction in fecal moisture and increase in body fat occurs in birds fed water soaked barley (Willingham, 1964). Water soaking however, has no significant effect on rate of lay, feed efficiency of egg production or body weight gain in layers (Berg and Bearse, 1958 and Berg, 1959). Other treatments which include the addition of fat (Arscott et al., 1955; Fry et al., 1958 and Arscott and Rose, 1960a), addition of substances with bacitracin-like activity (Willingham, 1964; Willingham and Earle, 1964) or the addition of cottonseed oil (Dobson and Anderson, 1958) also result in improved broiler performance.

The component of the diet affected by the various treatments is not clearly known. However, Leong et al. (1958), Willingham (1964), Potter et al. (1965) and Mannion (1981) reported increased ME values with enzyme treatments. The mechanism of action of the treatments is not clear either. Willingham (1964) suggested the benefits obtained by the use of enzymes or water treatment to be a result of combined action by enzymes and antibiotics which are contained in enzymes or produced during oven drying of a water soaked barley. An assay of treated barley showed it contained approximately 33 g of bacitracin-like activity per ton while untreated barley was without antibiotic activity.

Willingham and Earle (1964) observed significant weight and feed conversion improvements when enzymes with a high level of bacitracin-like activity were used. They suggested that a carbohydrate-protein complex is broken down and improved energy utilization is obtained when an effective enzyme supplement allows a beneficial effect with or without an effective growth stimulating antibiotic.

Burnett (1966), Gohl et al. (1978), Willingham et al. (1980) and Blurn et al. (1980) explain the poor performance of chicks fed barley diets to be due to a viscous component in barley which results in poor digestibility of the barley diet. Gohl et al. (1978) reported a reduction in viscosity in barley with the use of β-glucanase. These workers suggested that enzymes added break up the viscous component whereas water treatment allows hydrolysis by the enzymes in the barley.

Burnett (1966) observed a quick reduction in viscosity of a solution of pectin with the use of a pectin degrading enzyme which also significantly improved the performance of broiler chicks. He also observed that gut extracts from chickens that were fed barley alone were lowered in viscosity by enzyme preparations that were effective in improving the performance of chickens. These enzymes gave similar results with a solution of β-glucan. He concluded that the enzyme responsible for lowering the viscosity was endo-β-glucanase and identified β-glucan and glucan components to give rise to the observed viscosity. Observations made by Burnett (1966) and Gohl et al. (1978) provide evidence in support of the suggestion that poor performance of chicks fed on barley diets is due to a viscous component in barley which results in poor digestibility of barley-based diets.

Since no great differences have been reported in the digestibility of nutrients in barley, except for energy, it can be assumed that the poor digestibility mentioned above mainly affects the energy component of the diet.

In contrast to Burnett (1966), Gohl et al. (1978), White et al. (1980) and Blurn et al. (1980), Coon et al. (1979) reported the correlation coefficient for relative viscosity in barley and chick weight gain to be -0.238, implying that viscosity may not be the main factor affecting chick performance. In agreement with this observation, Gohl and Thomke (1976) observed that the nutritional value of different barleys was not influenced by viscosity.

Arscott et al. (1960) suggested the presence of an enzyme inhibitor in barley, which is removed by water treatment and whose inhibitory action can be overcome by an appropriate enzyme supplement. On the other hand, Dobson and Anderson (1958) and Arscott (1963) reported work which suggested the presence of a beneficial factor in corn. Arscott (1963) reported equal effectiveness by replacing one-eighth to a quarter of the barley with corn, as an amylolytic enzyme supplement considering body weights and feed conversion. This beneficial effect was observed to be lost by autoclaving the corn. The nature of the beneficial factor suggested by these workers is not specified. Whereas one can assume that the beneficial factor is in the form of a substance which improves the feeding value of nutrients in the barley-based diets but is not a nutrient itself, it may however be a nutrient and improves the feeding value of a barley-based diet by contributing to available nutrients.

Dobson and Anderson (1958) achieved a marked improvement in growth and feed efficiency by adding corn, wheat or milo extracts to soaked barley. These workers suggested the presence of a growth factor in the corn extract. The suggested growth factor was not destroyed by boiling for 20 minutes. It should again be realised that an improvement by way of soluble nutrients in the extracts is a possibility.

Coon et al. (1979), using barley selections and cultivars reported low correlation coefficients for chick weight gain and relative viscosity (r = -0.238), catechin content (r = -0.041), lysine (r = 0.142) and threonine (r = 0.448). These workers concluded that the low correlation of chick weight gain with relative viscosity, catechins and amino acid content suggests there are several factors limiting the nutritional quality of barley.

Closely related to this observation is that of Lindblad et al. (1954) who suggested that neither the productive energy nor the digestible protein contents of the high barley rations per se were the limiting factors in the chick's performance, but that palatability of the barley may have been concerned.

If there are several factors limiting the nutritional value of barley, then it may also be that treatments which have been observed to result in improvements in barley diets had their effects brought about in several ways. It should also be realised that reported work has concentrated on observing the effects of the treatments on barley-based diets with little investigations on the effects of the treatments on diets based on other cereals. There is a possibility of achieving benefits from some of the treatments in diets other than barley diets so that the effects could be common to any diet.

3. Amino acid supplements

Little work has been conducted on amino acid supplementation in barley rations possibly due to the fact that observations which have been made do not imply the involvement of amino acids as such. Coon et al. (1979) however reported work on supplementation of threonine and lysine to barley diets. These workers observed that chicks that were fed rations with barleys that supported good body weights did not respond to amino acid supplementation, whereas those that supported poor body weights responded to amino acid supplementation. In fact the barleys that supported the best weights without amino acid supplementation resulted in the lowest weights with amino acid supplementation. However, the correlation coefficient of chick weight gain and amino acid content was low in both supplemented (0.142) and unsupplemented (0.448) diets. Supplementing DL-methionine (at 0.05%) in diets containing 15.25 and 30.5% barley resulted in no significant improvement in growth and feed efficiency (Arscott et al., 1955).

G. Barley Diets and Pancreatic Enlargement

Pancreatic enlargement was observed, by Arscott et al. (1965), when barley-based diets were fed to chicks. Enzyme additions to the diets provided no clear response in the reduction of pancreas size, however a change was observed when the data was expressed as percent of body weight.

Some organs have been observed to undergo modifications in size in relation to their levels of functioning. In most cases organs have been observed to increase in size with increased functioning. This enlargement of the pancreas may be a response to need for increased activity of digestive enzyme secretion due to increased digestive enzyme requirement in the digestion of the barley-based diet.

H. Variation in the Nutritional Value of Cereals

1. Variation in the nutritional value of barley

Besides variation in the gross composition of barley varieties and barley of different geographical localities, differences in the nutritive value of barley in poultry feeding have been reported. Gohl and Thomke (1976) in a digestibility trial with layers observed that barley cultivated in different geographical localities showed differences in the content of ME, in the digestibility of crude protein, organic matter and crude carbohydrates. These workers reported significant decreases in crude protein digestibility with increased geographical latitude. They related the differences in crude protein digestibility to differences in the contents of tannins. Neither the weather conditions, the proximate composition of barleys, the thousand kernal weight nor the viscosity were found to have any influences on the nutritive value.

Daghin and Rotternsten (1966) also reported significant differences in chick weight at 4 weeks when they were fed on diets with barley of different varieties. However, they reported that differences in body weights were not correlated with differences in chemical composition of the varieties tested. Elwinger (1978) reported the protein content of barley to affect weight gain and feed efficiency. On the other hand, Strain and Piloski (1972) observed significant differences due to barley cultivars for shank length but not for average daily gain, although they obtained identical ranking for both traits (r = 0.997). In spite of many reports of variation in barley, Davidson et al. (1978) observed no significant difference in metabolizable energy between 16 barley samples.

Barley grown in the mid-west and eastern North America does not improve chick performance significantly as a response to enzyme supplementation compared to barley grown in the western United States (Willingham et al., 1960). Differences in response to enzyme supplementation by different varieties also occur (Daghin and Rottensten, 1966).

2. Variation in the Nutritional Value of Wheats

Differences have been reported in the feeding value of different wheat varieties. Boldaji et al. (1978) observed variations in metabolizable energy values in varieties of wheat grown in one region ranging from 3.68 to 3.90 kcal/g dry matter. Salmon and Dunkelgod (1974), reported increased growth rate, in day old chicks raised to 8 weeks, as the crude protein content of wheat varieties decreased. Differences were related to dietary amino acid balance of wheats with lower protein and partly due to the higher proportion of soybean meal in lower protein wheats.

In agreement to the observation by Salmon and Dunkelgod (1974), Gardiner and Dubetz (1974) reported significantly lower body weights in chicks fed diets containing high protein wheats compared to those on diets containing low protein wheats.

3. Variation in the Nutritional Value of Corn

Unlike wheat and barley, corn shows little variation in gross composition. Both the location of cultivation and variety have little influence on the gross composition in corn. This should explain the fact that no great variations in the feeding value of corn have been reported.

I. Potential for Nutritional Value Improvement in Barley Through Breeding.

Nutritional value improvements of barley through breeding appears to be possible since a number of types of barley that show considerable differences in some components of nutritional concern have been observed. Some popular characteristics observed in barley are given below.

1. Waxy barley

These are barleys which are different from normal barley in that normal barley has starch in the form of a mixture containing amylopectin and amylose, whereas these barleys have starch which is essentially 100% amylopectin (Moss et al., 1983). Moss et al. (1983) reported better metabolizable energy values for normal barley (12.93 $\pm$ 0.38 kJ/g dry matter) compared to waxy barley (12.76 $\pm$ 0.46 kJ/g dry matter) in non-laying leghorn hens.

Calvert et al. (1976) reported equal performance in rats fed normal and waxy barleys in average gain or protein efficiency ratio. Contrary to this observation, Calvert et al. (1977) reported better rate of gain in rats fed normal barley compared to waxy barley although the difference was not statistically significant. However, feed/gain ratios and protein efficiency ratios were not altered by starch type and there was no difference between diets in retained nitrogen, digestive nitrogen or digestible energy. These workers also showed no significant difference in the performance of pigs fed diets containing the waxy and normal barleys.

2. High amylose barley

Barleys with high amylose have also been discovered. These barleys contain more amylose and less amylopectin in their starch. Newman et al. (1978) reported a high amylose barley to contain more salt-soluble proteins and lysine than a normal barley. These workers reported superior growth and protein efficiency ratios with the use of high amylose barley in weanling rats as compared to normal barley. The biological value of the high amylose barley was also greater than the normal barley, although protein digestibility was higher in normal barley.

However, Calvert et al. (1976) reported higher average weight gains in rats fed the normal barley starch diet compared to rats fed high amylose barley starch diet, although there was no significant difference in feed consumption or feed efficiency. Normal starch diets also produced higher protein efficiency ratio (PER) compared to high amylose starch diets. In another trial these workers reported low digestible nitrogen in high amylose starch diets. But, no differences were observed in retained nitrogen or digestible energy between the two starch type diets.

3. High-lysine barley

These are barley types which have been observed to contain higher levels of lysine than normal barley. But, the composition of these barleys in other components do not differ greatly from that of normal barley. Salomonsson et al. (1980) did not observe any consistent differences in the major constituents of high lysine and normal barleys. These workers considered starch, non-starch polysaccharides, crude protein, lignin and ash.

4. Hulless barley

This is barley without hulls, sometimes known as naked barley. Newman et al. (1980) reported higher protein, ether extract and nitrogen free extract and less crude fiber and ash in hulless barley compared to normal barley. Since the hulls are responsible for high fiber in barley, and since the high fiber in barley has been suspected to contribute to the poor nutritional value of barley in poultry feeding, it may be possible that the use of hulless barley may result in nutritional improvements. Anderson et al. (1961) reported the crude fiber content of a hulless barley to be about 2.2% and the crude protein content about 11.7%. However, these workers reported that rations based on hulless barley were not superior to rations based on regular barley.

MATERIALS AND METHODS

A. Choice of Cereal Source and Birds

To make the evaluation of the cereals on a practical basis, it was decided that all sample ingredients to be used in experimental diets should be obtained from a commercial feed supplier. Cereals used were obtained from Otter Farms Co-op. as ground grain. Birds used in all the experiments were broilers purchased from a commercial hatchery.

B. Formulation of Diets and Mixing

Diets were formulated to meet, at minimum, requirements for a broiler starter (NRC, 1977) in crude protein, lysine, methionine, calcium and phosphorus. Because of the great difference in the metabolizable energy between corn and the other two cereals (wheat and barley) it was realised that attaining the level of 3200 kcal/kg in the diets containing wheat and barley in the substitution with corn, would be difficult, especially as experimental diets were to be of practical nature. To minimize variations in metabolizable energy between diets, a metabolizable energy requirement of 3000 kcal/kg was assumed in the formulations. With this assumption, variations were kept at a minimum possible in Experiments I and II and in Experiment III adjustments in levels of metabolizable energy were achieved by increasing animal tallow. By this procedure, the difference in ME of diets was reduced to a maximum of 194 kcal/kg between extremes in the first experiment, 149 kcal/kg between diets in Experiment II and 61 kcal/kg in Experiment III.

Cereal samples were analysed for crude protein content and tabular values which were used in the formulation of rations were those that best approximated determined values. The total composition of the diets included meat meal, animal tallow, multi calcium phosphate, limestone, a premix, soybean and either of the three cereals (wheat, corn and barley) or a combination of two.

The level of meat meal was kept constant in all diets throughout the three experiments. Animal tallow was also kept constant in the diets of Experiments I and II, but was allowed to vary in Experiment III to maintain almost iso-caloric, iso-nitrogenous diets. The level of soybean meal was adjusted in all diets of the three experiments to provide iso-nitrogenous diets. Diets utilized in the three experiments were 23 $\pm$0.1% calculated crude protein. All diets were mixed in a horizontal mixer. Premixes were prepared in a small mixer before being added into diets.

C. Bird Management

Day-old broiler chicks were purchased from a commercial hatchery and placed in electrically heated Petersime brooder units for the duration of each experiment. The chicks were fed experimental diets from day-old to 4 weeks. Group weekly weights and feed consumption were recorded. Observations for deaths were conducted twice every day, chicks that were found dead were weighed. These weights were used for mortality correction. Chicks that developed leg abnormalities, such that impaired feeding was suspected, were culled and recorded under mortality. Feed and water were supplied ad libitum under 24 hours lighting.

D. Randomization and Experimental Design

A completely randomised design was used in the three experiments. Upon arrival, chicks were randomly selected and weighed in groups of 10. In Experiment I, 300 chicks were obtained as a mixed-sex batch whereas in Experiments II and III, 150 chicks of each sex were purchased. For Experiments II and III, five chicks of each sex were randomly selected to make groups of ten.

Chicks were placed in the middle 4 brooder compartments with the top and bottom compartments unused. The 6 dietary treatments in each experiment were tested in 4 replications. This gave a total of 24 pens assigned to three batteries. The replicates were assigned to brooders such that no two replicates of one treatment shared a common heat source. Batteries were arranged to provide uniform light to all pens.

E. Experiments

1. Experiment I: Growth trial with wheat and barley diets

The objective of this experiment was to evaluate the performance of broilers fed to 4 weeks of age, diets based on wheat or barley, or combinations of these two cereals at various levels.

Six diets, A to F, were formulated with the amount of barley in the diets A to F increasing in units of 10% from 0 to 50%. Barley was introduced in the diets B to F at the expense of wheat, but the percentage of barley added did not correspond to the percentage decrease in wheat since the amount of soybean meal was adjusted with increasing barley to maintain iso-nitrogenous diets.

Meat meal and animal tallow were kept constant throughout the six diets. This method of formulation resulted in a variation of 194 kcal/kg in ME between the diet highest in ME (diet A) and that lowest in ME (diet F). A premix was formulated to meet minimum requirements for a broiler starter (NRC, 1977) in copper, zinc, manganese and vitamins. Methionine and lysine were supplemented as part of the premix to maintain equal dietary levels. The composition of experimental diets is outlined in Table 1. Each experimental diet was fed to 4 groups of 10 chicks of mixed sex for 4 weeks.

2. Experiment II: Growth trial with wheat and corn diets

The objective of this experiment was to evaluate the performance of broiler chicks fed to 4 weeks of age on diets based on wheat or corn, or a combination of these two cereals at various levels.

Six diets were formulated with the amount of corn in diets A to E increasing in units of 10% from 0 to 40%. Corn was introduced at the expense of wheat with adjustments in the amount of soybean to maintain iso-nitrogenous diets. This adjustment resulted in a 8.6% increment in corn, instead of 10% in the last diet (diet F). With this formulation method, a difference of 149 kcal/kg ME occurred between the diet highest in ME and that of lowest ME. Amounts of meat meal and animal tallow were kept constant in the six experimental diets.

A premix was formulated to meet minimum requirements for zinc, copper, manganese and vitamins in a broiler starter (NRC, 1977) and supply methionine and lysine to maintain equal levels. The composition of experimental diets is presented in Table 2. Each of the six

TABLE 1. Experimental diets for Experiment I

Ingredient[1]	A	B	C	D	E	F
			Diets			
Wheat	56.1	45.1	34.1	23.1	12.6	1.6
Barley	-	10.0	20.0	30.0	40.0	50.0
Soybean meal	32.0	33.1	34.1	35.0	35.5	36.5
Meat meal	2.2	2.2	2.2	2.2	2.2	2.2
Animal tallow	6.7	6.7	6.7	6.7	6.7	6.7
Multi calcium phosphate	0.6	0.5	0.5	0.5	0.5	0.5
Limestone	1.4	1.4	1.4	1.5	1.5	1.5
Premix[2]	1.0	1.0	1.0	1.0	1.0	1.0
Composition[3]:						
Calculated CP%	23.00	23.10	23.10	23.00	22.90	22.90
Calculated ME (kcal/kg)	2998	2960	2922	2880	2842	2804
Calculated crude fibre %	2.60	2.88	3.17	3.45	3.72	4.01
Determined CP%[4]	24.30	23.81	23.81	23.85	23.63	23.63

[1]Ingredients given as percent of diets.

[2]Premix was made of a vitamin mix and a mineral mix. Vitamin mix supplied (per kg of diet) retinyl palmitate, 4000 IU., cholecalciferol, 1000 ICU., alpha-tocopherol 25 IU., vitamin B_{12} 0.0132 mg, riboflavin 2.6 mg, pantothenic acid 8.0 mg, niacin 25 mg, choline chloride 400 mg, menadione 1.0 mg and 250 mg of santoquin as an anti-oxidant. Mineral mix supplied (per kg of diet) 50 mg manganese, 30 mg zinc, 3 mg copper and supplemental lysine and methionine to make up for deficiencies in the diets.

[3]All values expressed on air-dry basis.

[4]Determined CP = N x 6.25.

TABLE 2. Experimental diets for Experiment II

Ingredient[1]	Diets A	B	C	D	E	F
Wheat	56.1	44.6	32.6	21.6	9.5	-
Corn	-	10.0	20.0	30.0	40.0	48.6
Soybean meal	32.0	33.5	35.5	36.5	38.5	39.5
Meat meal	2.2	2.2	2.2	2.2	2.2	2.2
Animal tallow	6.7	6.7	6.7	6.7	6.7	6.7
Multi calcium phosphate	0.6	0.5	0.6	0.6	0.7	0.7
Limestone	1.4	1.5	1.4	1.4	1.3	1.3
Premix[2]	1.0	1.0	1.0	1.0	1.0	1.0
Composition[3]:						
Calculated CP%	23.00	22.90	23.10	22.90	22.90	22.90
Calculated ME (kcal/kg)	2998	3029	3057	3091	3119	3147
Calculated crude fibre %	2.60	2.60	2.60	2.60	2.61	2.61
Determined CP%[4]	22.85	23.53	23.44	23.68	23.33	23.53

[1]Ingredients given as percent of diets.

[2]Premix was made of a vitamin mix and a mineral mix. Vitamin mix supplied (per kg of diet) retinyl palmitate, 4000 IU., cholecalciferol, 1000 ICU., alpha-tocopherol 25 IU., vitamin B_{12} 0.0132 mg, riboflavin 3.6 mg, pantothenic acid 10.0 mg, niacin 27.0 mg, Choline chloride 1,300 mg, menadione 1.0 mg and 250 mg of santoquin as an anti-oxidant. Mineral mix supplied (per kg of diet) 55 mg manganese, 40 mg zinc, 4 mg copper and supplemental lysine and methionine to make up for deficiencies in the diets.

[3]All values expressed on air-dry basis.

[4]Determined CP = N x 6.25.

experimental diets was fed to 4 groups of 10 chicks of equal sex composition (5 males and 5 females) for 4 weeks.

3. Experiment III: Growth trial with corn and barley diets

The objective of this experiment was to evaluate the performance of broilers to 4 weeks of age fed on diets based on corn or barley, or combinations of corn and barley at various levels.

Six diets were formulated such that barley was introduced at the expense of corn with amounts of barley increasing by units of 10% in diets B, C, D and E and 7% in diet F. Diet A had no barley (0% barley) and as the levels of barley increased in diets B, C, D, E and F, alterations were made to maintain the diets approximately iso-caloric and iso-nitrogenous by adjusting the amount of soybean meal and animal tallow so that amounts of barley introduced did not correspond to corn removed. This formulation procedure allowed a difference of 61 kcal/kg ME between the diet of highest ME and that of lowest ME.

A premix was formulated to meet minimum requirements for a broiler starter for zinc, copper, manganese and vitamins (NRC, 1977) and supply lysine and methionine to attain equal levels in the diet. The total composition of the experimental diets is shown in Table 3. Each of the six experimental diets was fed to 4 groups of 10 chicks of equal sex composition (5 males and 5 females) for a period of 4 weeks.

TABLE 3. Experimental diets for Experiment III

Ingredient[1]	A	B	C	D	E	F
			Diets			
Corn	52.8	42.0	29.1	18.0	7.0	-
Barley	-	10.0	20.0	30.0	40.0	47.0
Soybean meal	39.0	38.5	39.0	38.5	38.1	37.7
Meat meal	2.2	2.2	2.2	2.2	2.2	2.2
Animal tallow	3.0	4.3	6.7	8.4	9.8	10.2
Multi calcium phosphate	0.7	0.7	0.7	0.5	0.5	0.5
Limestone	1.3	1.3	1.3	1.4	1.4	1.4
Premix[2]	1.0	1.0	1.0	1.0	1.0	1.0
Composition[3]:						
Calculated CP%	23.10	22.90	23.10	22.90	22.90	22.90
Calculated ME (kcal/kg)	3014	2995	3006	3004	2986	2953
Calculated crude fibre %	2.68	2.93	3.18	3.43	3.68	3.87
Determined CP%[4]	22.81	23.61	23.90	23.72	23.83	23.00

[1]Ingredients given as percent of diets.

[2]Premix was made of a vitamin mix and a mineral mix. Vitamin mix supplied (per kg of diet) retinyl palmitate, 4000 IU., cholecalciferol, 1000 ICU., alpha-tocopherol 25 IU., Vitamin B_{12} 0.0132 mg, riboflavin 3.6 mg, pantothenic acid 10.0 mg, niacin 27.0 mg, choline chloride 1,300 mg, menadione 1.0 mg and 250 mg of santoquin as an anti-oxidant. Mineral mix supplied (per kg of diet) 55 mg manganese, 40 mg zinc, 4 mg copper and supplemental lysine and methionine to make up for deficiencies in the diets.

[3]All values expressed on air-dry basis.

[4]Determined CP = N x 6.25.

4. Experiment IV: Digestibility trial and N-retention

(a) Selection of experimental material

After the third week in Experiment III, healthy chicks being fed on a commercial chick starter (20% crude protein) were placed in a battery brooder in groups of four birds per pen. Using these birds, a digestibility trial was conducted on diet A of Experiment II, A and F of Experiment III, ground corn, ground wheat and ground barley. This was done to evaluate the diets that had each of the three grains as a sole grain and test the pure grains. The composition of the three diets is presented in Table 4.

(b) Feeding and sample collection

Feed was withdrawn for a period of 16 hours prior to feeding each of the test materials. Each of the test materials was fed to four replicates of four chicks each for a period of four hours.

A marker diet (chick starter with 0.2% ferric oxide) was supplied before and after feeding each of the test materials until marked excreta showed in fecal pans. Collection of unmarked excreta was started approximately 1 hour after the test material had been withdrawn and was continued until no more of unmarked excreta showed in fecal pans. The excreta was placed in a freezer after collection. Excreta samples were later freeze-dried, weighed and ground for dry matter, nitrogen and gross energy determination.

TABLE 4. Diets used in Experiment IV

Ingredient	DA_2*	DA_3**	DF_3***
Wheat	56.1	-	-
Corn	-	52.8	-
Barley	-	-	47.0
Soybean meal	32.0	39.0	37.7
Meat meal	2.2	2.2	2.2
Animal tallow	6.7	3.0	10.2
Multi calcium phosphate	0.6	0.7	0.5
Limestone	1.4	1.3	1.4
Premix	1.0	1.0	1.0
Calculated CP%	23.00	23.10	22.90
Calculated ME (kcal/kg)	2998	3014	2953
Calculated crude fibre %	2.60	2.68	3.87
Determined CP%	22.85	23.81	23.00

* Diet A of Experiment II.
** Diet A of Experiment III.
*** Diet F of Experiment III.

F. Chemical Analyses

1. Dry matter determination

Samples were weighed and placed in pre-weighed aluminum dishes which had been dried in an oven at 96°C for a period of about 2 hours. The weighed samples were placed in the oven at 96°C overnight and cooled in a desiccator upon removal. Cooled samples were weighed and weight loss was taken as moisture loss.

2. Total nitrogen determination

Total nitrogen was determined by the macro-Kjeldahl method. Approximately 1 g samples were weighed on filter papers and placed in digestion tubes. Two blanks were prepared by placing filter papers in tubes. 10.3 g of a catalyst made up of sodium sulphate with 2.9% copper sulphate was added to each tube and 25 ml concentrated sulphuric acid was added. The samples were then digested on a Buchi digestion unit.

Digested samples were cooled after which 90 ml of distilled water was added to each tube. Tubes were placed on a Buchi 325 N_2 distillation unit, approximately 150 ml 30% sodium hydroxide was added and distillation was done. Nitrogen distilled was collected in 50 ml 4% boric acid with an indicator (0.2% brom cresol green, 0.2% methyl red in ethanol). Approximately 150 ml of the distillate was collected for each tube and distillates were titrated with 0.1052 N hydrochloric acid. The volume of hydrochloric acid used in the titration of blanks was deducted from the volumes used in the titration of samples. Percent nitrogen in the samples was calculated as shown below:

$$\%N = \frac{NHCl \times 14.007 \times mLs\ HCl}{g.wt.\ sample \times 1000} \times 100$$

where: NHCl = normality of hydrochloric acid.

mLs HCl = volume of acid used.

g.wt. = weight in grams.

3. Gross energy determination

Gross energy was determined with a Parr oxygen bomb calorimeter. Pelleted samples were weighed and placed in capsules. The samples were ignited in the bomb filled with oxygen at 25 atmospheres.

Heat liberated from the combustion of the sample was determined and gross energy was calculated by using temperature changes, the water equivalent value and considering corrections for heat production from the ignition wire and sulphur and nitrogen oxidation.

G. Data Analysis

Analysis of variance by F-test was carried out for feed consumption, body weight gain, feed efficiency and digestibility data. Significant differences between means were determined by Duncan's new multiple range test (Duncan, 1955). Correlation between sets of data was determined by Pearson's Product Moment coefficient of correlation as described by Mendenhall (1979).

RESULTS AND DISCUSSION

A. Experiment I

A minor variation was observed in determined total nitrogen values for the six diets (Table 5). A difference of 0.11% total nitrogen occurred between the diet of highest nitrogen, diet A and those of lowest nitrogen, diets E and F. The order of total nitrogen values agreed well with the order of crude protein values calculated on formulation, except diet A which was higher in nitrogen than expected.

Uniformity was also obtained in determined crude protein values of the diets (N x 6.25) which was expected since diets utilized the same ingredient sources and formulations were calculated for 23% $\pm$0.1% crude protein in the six diets (Table 5). The six diets were also fairly uniform in determined gross energy values with a difference of 62.89 kcal/kg between the two extremes (Table 5). There is no clear trend in the order of gross energy values. However, the diet with 50% barley (diet F) gave the highest value and the diets containing 20, 30 and 40% barley gave higher values than the diets with 0 and 10% barley.

Feed consumption (Table 6) expressed as g/bird appeared to increase with increasing barley from 0% to 20%. However, feed consumption after 20% level of barley did not appear to take any consistent order. These values were less than that of 20% barley but greater than those of 0 and 10% barley levels. Analysis of variance by F-test showed no significant difference in feed consumption. This indicates that replacement of wheat by barley up to 50% of the total diet by the procedure followed did not result in dietary differences large enough to significantly

TABLE 5. Determined nitrogen, CP (N x 6.25) and gross energy of experimental diets

Diet	N%	CP%	GE(cal/g)
A	3.89	24.30	4245.82
B	3.81	23.81	4234.62
C	3.81	23.81	4255.50
D	3.82	23.85	4253.23
E	3.78	23.63	4251.84
F	3.78	23.63	4297.51

TABLE 6. Feed intake, weight gain and feed/gain ratios for birds fed wheat and barley-based diets*

Diet	Feed intake (g/bird)	Weight gain (g/bird)	Feed/Gain
A	1274[a]	806.25[a]	1.58[a]
B	1292[a]	817.50[a]	1.58[a]
C	1323[a]	826.00[a]	1.60[a]
D	1304[a]	817.25[a]	1.60[a]
E	1311[a]	802.75[a]	1.63[a]
F	1308[a]	797.50[a]	1.64[a]

*Means of one parameter with a similar superscript are not significantly different ($P \leq .05$).

affect feed comsumption. Even though a difference of 194 kcal/kg was calculated for ME between extremes, this did not appear to have significantly affected feed consumption. The correlation between feed consumption and calculated ME was low (r = -0.65). Calculated ME, feed intake and feed/gain values are given in Table 7.

TABLE 7. Dietary ME (calculated), feed intake and feed/gain ratios for birds fed wheat and barley-based diets

Diet	ME (calculated) (kcal/kg)	Feed intake (g/bird)	Feed/Gain
A	2998	1274	1.58
B	2960	1292	1.58
C	2922	1323	1.60
D	2880	1304	1.60
E	2842	1311	1.63
F	2804	1308	1.64

Correlation: Calculated ME and feed intake r = -0.65.

Weight gains (Table 6) appeared to improve with increased barley in the diet up to the level of 20% in the ration, after which a decline in weight gain occurred. The 50% barley diet gave the lowest weight gain (g/bird) over the 4 week period while that with 20% barley supported the highest, with 10 and 30% barley being second highest. The diet without barley resulted in weight gain which exceeded those of diets containing 40 and 50% barley. Analysis of variance by F-test showed no significant difference between treatment means.

The order of values of feed/gain ratios (Table 6) showed an increase with increasing levels of barley in diets. The 0 and 10% barley diets supported feed/gain ratios of 1.58 and the diet with 50% barley was 1.64. However, the differences were not statistically significant.

These observations are similar to those by Hijikuro and Takemasa (1981) who reported no effect on feed intake or weight gain when diets containing 63% barley adjusted to meet protein and energy requirements were fed to broilers, as compared to wheat. It should however be noted that a higher level of barley and older birds (6 week old) were used by these workers. Furthermore, Lindblad et al. (1954) reported optimum weight gains when wheat was replaced by barley on a pound per pound basis in amounts of up to 30% of the ration. They reported a reduction in weight and feed consumption when barley was included at levels higher than 30% of the ration. Petersen (1969) reported less growth from barley diets in comparison to sorghum, wheat and oats at levels of 50% in the diets. He indicated that weight gain decreased for the diet with 50% barley although not significantly. While Lindblad et al. (1954) mention decreasing feed consumption at high levels of barley inclusion (>30% of ration), results of the present study show increases in feed consumption with increases in barley up to 20% of the diet after which feed consumption shows no consistent order but remains higher than for the wheat based diets. It is emphasized here that differences in feed consumption were not significant in the present study.

A possible reason for differences in observations made in this experiment and results reported by Lindblad et al. (1954) and Petersen (1969) is the fact that substitutions of wheat by barley were on a weight to weight basis, whereas barley was included into diets of this experiment using dietary nutrient balance as the major consideration.

B. Experiment II

Variation observed in determined nitrogen values (percent) and crude protein values (N x 6.25) between diets was low (Table 8). Diets were calculated to provide 23% $\pm$0.10 crude protein, therefore results indicated that ingredient content values were consistent with tabular composition values.

Greater variation in gross energy values of the diets was observed in Experiment II compared to Experiment I. A difference of 134.33 kcal/kg occurred between the diet of highest gross energy and that of lowest gross energy. However, the order of values did not suggest an influence by the two grains, wheat and corn, on the magnitude of gross energy values. The diet which had 20% corn gave the lowest gross energy value while the diet with 30% corn had the highest value.

Feed intake (Table 9) decreased with increased corn in the diet. The diet with 56.1% wheat had 5.7% higher feed consumption than the diet with 48.6% corn, and a diet with 44.6% wheat (10% corn) had 3.86% higher feed consumption than a 48.6% corn diet. Analysis of variance by F-test showed a significant difference ($P < .01$) between treatments and a test of treatment means by Duncan's new multiple range test showed diet A (56.1% wheat, 0% corn) to be significantly different from diets E (40%

TABLE 8. Determined nitrogen, CP (N x 6.25) and gross energy of experimental diets

Diet	N%	CP%	GE(cal/g)
A	3.66	22.85	4479.05
B	3.76	23.53	4416.94
C	3.75	23.44	4366.59
D	3.79	23.68	4500.92
E	3.73	23.33	4376.75
F	3.76	23.53	4411.66

TABLE 9. Feed intake, weight gain and feed/gain ratios for birds fed wheat and corn-based diets*

Diet	Feed intake (g/bird)	Weight gain (g/bird)	Feed/Gain
A	1466^{a}	913.00^{a}	1.61^{c}
B	1440^{ab}	912.75^{a}	1.58^{bc}
C	1433^{ab}	921.75^{a}	1.56^{ab}
D	1426^{ab}	936.25^{a}	1.52^{a}
E	1386^{b}	902.00^{a}	1.54^{ab}
F	1386^{b}	901.75^{a}	1.54^{ab}

*Means with a similar superscript are not significantly different ($P \leq .05$).

corn, 9.6% wheat) and F (48.6% corn, 0% wheat).

Correlation between feed consumption and calculated ME of the diets was high (r = -0.96). This suggests the difference in ME values of the diets E, F and A (a difference of more than 120 kcal/kg) to be a factor that affected feed consumption. Little difference occurred in weight gain (g/bird over 4 week period) between the six diets and the slight difference that occurred did not seem to take any consistent order in favour of either wheat or corn (Table 9). However, diets high in wheat appeared to give slightly higher weight gains as compared to diets high in corn. The diet with 30% corn, 21.6% wheat supported the highest weight gain while diets higher in corn gave slightly lower values than diets lower than 30% in corn. Analysis of variance by F-test showed no significant difference in weight gain.

Feed efficiency (Table 9) improved with an increase in corn. Diets D, E and F supported significantly ($P < .005$) better feed efficiency than diet A. This suggested that diets with 30% corn (or more) were superior to the diet with 56.1% wheat for efficiency of feed utilization. Since no significant difference was observed in weight gain, the difference in feed efficiency was due to variation observed in feed consumption, also similar to feed consumption results, a high correlation was observed between feed efficiency ratios and calculated ME values of the diets (r = -0.84).

Results from this experiment show that diets high in corn ($\geq$30% of the diet) are superior to diets high in wheat ($\geq$30% of the diet) in efficiency although diets high in wheat appear to give slightly higher weight gains than diets high in corn. The best weight gains appear to be achieved when wheat and corn are used in a combination of approximately equal proportions. However, weight gain values are not significantly different, whereas feed efficiency values are significant.

These observations agree with results reported by Reddy et al. (1979) in which poor feed efficiency occurred to 56 days of age, in broilers when maize was replaced with wheat at 53.5% of the diet but not at 25%, both on the basis of equal nitrogen or weight. In contrast to results in Table 9 these workers reported inferior weight gain when wheat was used at 53.5% of the diet compared to a 53.5% corn diet, but not when wheat was used at 25% of the diet in combination with corn. Weight gain for the 25% wheat diet in combination with corn was greater than the 53.5% corn diet. This reflected the compatibility of ingredients to support superior performance.

The superiority of high corn diets to high wheat diets is probably due to high metabolizable energy in the high corn diets, a difference of about 120 kcal/kg occurred in the calculated ME between the high corn diets and the diet containing 56.1% wheat. A high correlation coefficient was obtained between calculated ME and feed consumption (r = -0.96), and feed efficiency ratios (r = -0.84) which further supports the metabolizable energy relationship. Calculated ME, feed intake and feed/gain ratio values are given in Table 10.

TABLE 10. Dietary ME (calculated), feed intake and feed/gain ratios for birds fed wheat and corn-based diets

Diet	ME (calculated (kcal/kg)	Feed intake (g/bird)	Feed/Gain
A	2998	1466	1.61
B	3029	1440	1.58
C	3057	1433	1.56
D	3091	1426	1.52
E	3119	1386	1.54
F	3147	1386	1.54

Correlation: Calculated ME and feed intake $r = -0.96$
Calculated ME to Feed/Gain $r = -0.84$

C. Experiment III

Determined values of total nitrogen and crude protein (N x 6.25 for the six diets appeared fairly close except for diet F, which had a difference of 0.9% CP with the diet highest in crude protein (Table 11). The general trend of determined dietary nitrogen and crude protein agreed well with calculated crude protein values except for diet F which was slightly lower than expected. Variations in determined dietary nitrogen were low enough for the diets to be considered iso-nitrogenous.

Variation in determined gross energy of diets (Table 11) was greater in Experiment III compared to Experiments I and II. There was a difference of 311.44 kcal/kg between the diet of lowest and that of

TABLE 11. Determined nitrogen, CP (N x 6.25) and gross energy of experimental diets

Diet	N%	CP%	GE(cal/g)
A	3.81	23.81	4308.16
B	3.78	23.61	4294.51
C	3.82	23.90	4405.17
D	3.80	23.72	4548.73
E	3.81	23.83	4519.87
F	3.68	23.00	4605.95

highest gross energy. The sequence of gross energy values suggested increased gross energy with decreasing corn and increasing barley. The increase in gross energy values with increasing barley is due to the fact that the high barley diets were maintained adequate in available energy by adding animal tallow while unavailable energy increased with increased barley.

The variation that occurred in feed intake (Table 12) did not suggest any relationship to either of the two cereals, corn and barley, or the energy values of the diets. Feed consumption was highest in the diet with 30% barley and 29% corn. The difference of 61 kcal/kg calculated ME between the diet of highest ME and that of lowest ME was too low to support a significant difference in feed consumption.

Similar to feed consumption, slight differences occurred in weight gain (g/bird over 4 week period), but values showed no definite trend that would suggest the effect of either of the two cereals. The diet

TABLE 12. Feed intake, weight gain and feed/gain ratios for birds fed corn and barley-based diets*

Diet	Feed intake (g/bird)	Weight gain (g/bird)	Feed/Gain
A	1349[a]	856.62[a]	1.58[a]
B	1395[a]	885.72[a]	1.58[a]
C	1299[a]	836.28[a]	1.56[a]
D	1404[a]	895.25[a]	1.57[a]
E	1375[a]	863.42[a]	1.59[a]
F	1394[a]	874.00[a]	1.60[a]

*Means of one parameter with a similar superscript are not significantly different ($P \leq .05$).

with 30% barley had the highest weight gain while that with 20% barley had the lowest. Analysis of variation by F-test showed no significant difference between treatments. Feed efficiency (Table 12) declined slightly at high levels of barley, the diet with 47% barley had the highest feed/gain ratio (1.60) while those with 0% and 10% barley had the lowest (1.58). However, there was no statistically significant difference in feed efficiency between the six diets.

The substitution of barley for corn by the procedure followed in this experiment did not result in differences in either feed intake or weight gain. Even though the feed/gain ratio increased at high levels of barley in the diets, the difference was not statistically significant.

In 1965, Arscott et al. reported decreased body weights in broilers fed to 4 weeks of age on diets in which barley replaced corn at 69.26 or 70.3% of the diet on weight basis. The difference in observations made in this experiment and that by Arscott et al. (1965) could mainly be due to differences in the methods used in the substitution, the barleys used, as well as levels at which the barley was used in the diets. Barley was used to a maximum of 47% of the diet in this experiment and introduced with adjustments to maintain diets iso-caloric and iso-nitrogenous while Arscott et al. (1965) used barley at 69.26 and 70.3% and did a weight to weight substitution.

Earlier in 1955, Arscott et al. reported that replacing corn with barley at 15.25, 26 and 30.5% of the diet resulted in a progressive decrease in growth that was significant at the 30.5% level, while the growth of chicks fed barley at 52% of the diet was retarded. Feed efficiency decreases were observed for all the levels. However, adding 4 to 8% fat to the 26 and 15.25% barley rations resulted in progressive increases in growth and improvements in efficiency of feed conversion that compared favourably with a corn-based diet with or without added fat. Fat in the 52% barley diet resulted in improvements in growth and feed conversion.

An important aspect in the report by Arscott et al. (1955) is the effect of added fat on the nutritional value of the barley containing diets. The improvements resulting from fat may have been realised in this experiment since the levels of animal tallow were increased with increases in the amounts of barley. The fact that the corn diet did not result in any improvements with the addition of fat in the work by

Arscott et al. (1955), suggests the effect on the barley diet to be related to improvements in metabolizable energy which was lowered by the replacement of corn with barley. It is apparent that metabolizable energy is a factor which affects the nutritional value of barley-based diets. Improvements in chick performance with the addition of fat to barley diets were also reported by Fry et al., 1958. and Arscott and Rose 1960a.

D. Experiment IV: Digestibility and N-retention Trial

Corn had significantly higher ($P < .005$) digestible dry matter than both wheat and barley (Table 13). This difference is not totally related to the crude fiber content of the grains since corn and wheat are almost equivalent in crude fiber content while barley is about twice as high in crude fiber compared to wheat and corn, but the dry matter digestibility in wheat was almost equal to that in barley. Corn also had a significantly higher ($P < .05$) nitrogen retention value compared to barley but not to wheat. The nitrogen retention in wheat was intermediate to that of corn and barley and was not significantly different from either. Whereas the digestibility of dry matter and retention of nitrogen in the three cereals is not correlated to crude fiber content, it is possible that crude fibre in barley affected the digestibility of dry matter and retention of nitrogen.

Although corn had a significantly higher digestible dry matter than wheat or barley, diets based on the three cereals showed no significant difference in digestible dry matter (Table 14). This means that the difference that occurred between the cereals in digestible dry

TABLE 13. Apparent ME, dry matter and N-retention of cereals*

Cereal	Crude fiber (%)	AME (kcal/g)	DM dig (%)	N-retention (%)
Wheat	2.4	3.48	88.25[a]	74.03[ab]
Corn	2.5	3.63	91.40[b]	77.67[b]
Barley	5.1	3.45	87.49[a]	71.43[a]

*Means for DM and N-retention with a similar superscript are not significantly different ($P \leq .05$).

TABLE 14. Dry matter and N-retention of diets*

Diet	Crude fiber (%)	DM dig (%)	N-retention (%)
DF_3	3.87	87.95[a]	74.03[b]
DA_2	2.60	89.92[a]	83.74[a]
DA_3	2.68	90.54[a]	84.86[a]

*Means of one parameter with a similar superscript are not significantly different ($P \leq .05$).

matter was not sufficient to be reflected in diets based on either cereal at the levels used and by the method of formulation used. However, the dry matter digestibility in the corn-based diet was higher than the barley-based diet. This trend is in agreement with dry matter digestibility values for individual cereals.

The barley-based diet was significantly ($P < .005$) lower in retained nitrogen than corn and wheat-based diets. The lack of a significant difference in chick performance between the barley- based diet and corn and wheat-based diets in spite of a significant difference in retained nitrogen in the diets implies that the difference in nitrogen retention was not sufficient to cause a significant difference in performance parameters or that N-retention values did not provide an accurate approximation of available protein. It is also noted that a wheat-based diet gave significantly better nitrogen retention than a barley-based diet while nitrogen retention in the two cereals is not significantly different. This situation, together with the fact that the barley diet contained more soybean-nitrogen than the wheat diet suggests that barley affected the availability of crude protein from soybean meal and meat meal.

An attempt was made to determine the apparent metabolizable energy values of the cereals by the total collection method using the same birds on which dry matter and nitrogen retention were determined. As can be seen in Table 13, values of 3.48, 3.63 and 3.45 kcal/g were obtained for wheat, corn and barley respectively. It was realised that the values obtained for wheat and barley were higher than expected, especially that these values were apparent and not true. However, it was also observed that metabolizable energy values reported in the literature vary. Boldaji et al. (1978) reported higher metabolizable energy values for wheat than were obtained in this experiment. These workers reported ME of wheat in the range from 3.68 to 3.90 kcal/g dry matter. It was assumed that ME values in the present study were affected either by prolonged fiber retention in the crops of birds in the case of barley, or by the low accuracy of the method used in the determination.

E. General Bird Performance

Chicks in the three experiments performed well except for leg abnormalities which became evident at about the end of the second week of each experiment. Leg abnormalities were severe starting from the third week of each experiment and this accounted for over 50% of recorded mortality in each experiment. The frequence of leg abnormalities appeared to be less in Experiment II compared to Experiments I and III. Mortality rates were 4.17, 2.08 and 3.75% for Experiments I, II and III respectively. The mortality in the three experiments did not appear to be affected by diets.

Considerable differences in day-old chick weights occurred between the batches for the three experiments. Chicks in Experiment I had an average chick-weight of 36.06 g, those in Experiment II had an average of 42.08 g while those in Experiment III had an average weight of 46.59 g. Whereas the batch that had the lowest day-old chick weights gave the highest mortality, it did not appear that day-old weights affected the mortality rate since the batch that had the highest weights gave a rate almost as high as that of the lightest batch and the intermediate batch gave the lowest mortality rate. Rather than being an indicator of better health, day-old weights may have been related to the degree of dehydration in the chicks or the average size of eggs from which a given batch was hatched.

No difference was observed in water consumption between the different treatments for all the growth trial experiments. Fecal excreta appeared fairly similar in moisture content in all treatments for the three growth trials, but excreta output appeared to vary with levels of feed consumption in Experiment I. Since feed consumption was elevated with increased levels of barley in this experiment, increased fecal excretion can also be related to increases in barley. There was no evident difference in fecal output in the other two experiments.

F. General Discussion

Some of the early work on the evaluation of the nutritive value of barley in poultry feeding may have underestimated the value of barley by using a weight to weight substitution method and only considering high levels of barley (Arscott et al., 1955; Arscott and Rose, 1960a; Anderson et al., 1961; Arscott et al., 1965; Petersen, 1969). When a weight to weight substitution is done in a wheat diet, an increase in barley results in a decrease in both crude protein and metabolizable energy. Because of the substitution, the barley diet may be inferior to the wheat diet in crude protein and available energy. When a similar substitution is done in a corn diet, the barley diet will be considerably lower in available energy. When results obtained from such substitutions are used as a measure of the value of barley diets, an evident bias against barley diets is ignored.

When the aim is to evaluate the potential of a given crop as an ingredient in diets, it is necessary that the crop be incorporated in experimental diets in a way that the crop will be used in practical diets. When this is done, some clear deficiencies of the diets containing the crop under investigation are eliminated. This gives an evaluation of the crop that approaches a practical situation.

Whereas one crop could be inferior to the other as a grain, a similar degree of difference can not be taken to occur between two formulated diets containing the two crops. Improved performance in broilers fed barley containing diets in Experiments I and III compared to some reports in literature is most likely to be due to the fact that the method of substitution of cereals considered nutrient balance. The elevation in soybean meal with increases in barley when barley replaced wheat and in animal tallow when barley replaced corn could be factors that reduced differences in bird performance between diets based on each of the three crops.

It should be noted that, while barley is higher in fiber compared to corn and wheat, differences in the crude fiber of diets based on these cereals were not as pronounced as differences between the cereals. When wheat was replaced by barley in Experiment I, a 54% increase in calculated crude fiber occurred, giving a total of 4.01% crude fiber in the 50% barley diet. Replacement of corn by barley in Experiment III resulted in a 31% increase in calculated crude fiber, giving a total of 3.87% crude fiber in the 47% barley diet. In the replacement of wheat by barley, the 30% barley diet had 22% more calculated crude fiber than the wheat-based diet while the 30% barley diet in the corn replacement had 19% more calculated crude fiber than the corn-based diet. The correlation of dietary calculated crude fiber to weight gain was negative but low in Experiment I ($r = -0.47$) while that in Experiment III was positive and low ($r = 0.19$). Whereas the poor performance of chicks fed on diets based on barley can be suspected to be due to the dilution effect of the fiber, results in the present study did not reveal any clear effect of dietary crude fiber on weight gain. As can be seen above, the correlation of dietary crude fiber to weight gain in the two experiments did not suggest any clear effect of fiber on weight gain.

However, the correlation of crude fiber to feed/gain ratios was 0.96 in Experiment I and 0.51 in Experiment III. This suggests a fiber relationship to feed efficiency. The reduced correlation of dietary crude fiber to feed/gain ratios in Experiment III must be due to greater uniformity in metabolizable energy of diets.

SUMMARY AND CONCLUSIONS

Three growth trials and a digestibility and N-retention trial were conducted to compare the nutritional value of broiler starter diets based on barley, corn, wheat or combinations of two cereals.

1. When wheat is replaced by barley to levels of up to 50% of the diet with adjustments being made to keep the diets approximately iso-nitrogenous.

   (i) Feed consumption increases with increased barley in diets.

   (ii) Weight gain improves slightly to 20% barley level after which it falls.

   (iii) Feed efficiency falls with increased barley.

   However, the differences in all the three parameters are not significant.

   When wheat is replaced by barley by the procedure followed in this study, a level of 30% barley can be used in practical broiler starter rations without adverse effects on weight gain. However, the fact that feed efficiency falls implies that the profitability of such a replacement will be determined by the price difference between the two cereals. Using barley beyond 30% level may also be justifiable in a situation where great differences in prices occur between the two cereals since the decline in weight gain is not significant.

2. When wheat is replaced by corn up to 48.6% of the diet with adjustments being made to keep the diets almost iso-nitrogenous.

   (i) Feed intake significantly decreases with increased corn.

(ii) Weight gain slightly improves to 30% level of corn after which it falls and diets high in wheat give slightly better weight gains than diets high in corn. However, differences in weight gain are not significant.

(iii) A significant improvement occurs in feed efficiency with with increases in corn.

Wheat-based broiler starter diets give better weight gains than corn-based diets but best weights are achieved when the gains are used in combination in approximate equal proportions, and corn diets give better feed efficiency compared to wheat diets. Since the difference in weight gain is not significant whereas differences in feed efficiency are significant, wheat in broiler diets is recommended over corn only when corn is more expensive than wheat.

3. When corn is replaced by barley up to the level of 47% of the diet with diets being maintained iso-nitrogenous and iso-caloric by adjusting the levels of soybean meal and animal tallow.

(i) There is no significant difference in both feed intake and weight gain.

(ii) There is a decline in feed efficiency at levels of barley greater than 40%, however, the decline is not statistically significant.

It is possible to use barley in broiler rations up to 30% of the diet without sacrificing weight gains. Using barley beyond this level to 47% without sacrificing weight gains requires high levels of animal tallow which may not be practical in commercial feed mixing. Where ration formulation is done at farm level, higher levels of animal tallow may be used allowing barley up to 47% of the diet to be used without affecting weight gains. Since a decline in feed efficiency occurs at barley levels greater than 40%, although not significant, this substitution will be justified when barley is cheaper than corn.

4. Corn has significantly higher ($P < 0.005$) digestible dry matter (91.40%) than wheat (88.25%) and barley (87.49%) while barley has significantly ($P < .05$) lower nitrogen retention (71.43%) than corn (77.67%). No significant difference ($P < .01$) occurred in the digestible dry matter of diets based on the three cereals but the diet based on barley gave significantly lower ($P < .005$) nitrogen retention than diets based on corn and wheat.

5. The feeding value of wheat as a sole grain in broiler rations is comparable to that of corn, except that corn is superior in feed efficiency. The closeness of the two crops in nutritional value justifies the use of wheat where corn is more expensive than wheat. The use of barley as a sole grain in a broiler ration is not practical. When barley is used at a level higher than 40% of the total diet, changes have to be made to keep the diet adequate in energy. However, if the level does not exceed 50% of the diet, an increase in animal tallow may be justifiable if barley is relatively cheap and the particular situation enables handling of high fat diets.

6. Barley in combination with wheat or corn can be successfully used in broiler starter rations up to a level of 30% of the diet without affecting bird performance.

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APPENDICES

TABLE 15. Canadian barley and wheat production figures: (1975-1980)[1]

Year	Crop (Thousand tonnes) Barley	Wheat
1975	9,549	13,704
1976	10,545	18,927
1977	11,799	19,862
1978	10,387	21,145
1979	8,460	17,185
1980	11,259	19,158

[1]Agriculture Canada 1976-1981.

TABLE 16. Gross amino acid composition of barley, corn and wheat[1]

Component[2]	Barley		Corn		Wheat	
	McNab & Shannon	NRC	McNab & Shannon	NRC	McNab & Shannon	NRC
Aspartic acid	.66	-	.52	-	.40	-
Threonine	.42	.42	.32	.39	.32	.37
Serine	.44	.42	.40	.40	.34	.63
Glutamic acid	2.80	-	1.82	-	3.40	-
Glycine	.48	.40	.32	.37	.38	.72
Alanine	.56	-	.65	-	.42	-
Valine	.56	.62	.40	.52	.44	.63
Cystine	.19	.19	.19	.15	.22	.26
Methionine	.21	.17	.18	.20	.18	.19
Iso leucine	.42	.49	.32	.37	.41	.58
Leucine	.78	.80	1.06	1.10	.72	.94
Tyrosine	.35	.33	.36	.45	.31	.43
Phenyalanine	.53	.64	.42	.47	.52	.71
Lysine	.42	.40	.27	.24	.38	.40
Histidine	.24	.29	.26	.20	.27	.22
Arginine	.68	.59	.43	.50	.54	.58
Tryptophan	-	.14	-	.09	-	.18

[1]McNab and Shannon 1974; NRC 1977.

[2]All values given as percent of the crops.

(Differences in values between the two sources are due to the fact that McNab and Shannon gave values for single crop samples on dry matter basis whereas values under NRC are means of crop composition on as fed basis.)

TABLE 17. Gross composition of barley, corn and wheat[1]

Component[2]	Barley		Corn		Wheat	
	McNab & Shannon	NRC	McNab & Shannon	NRC	McNab & Shannon	NRC
Fiber	-	5.1	-	2.2	-	2.4
Gross Energy (kcal/g)	-	-	-	-	-	-
Ether Extract	1.5	1.8	3.2	3.8	1.4	1.9
Crude Protein[3]	11.3	11.6	8.2	8.8	10.4	14.1
Ash	2.7	-	1.2	-	1.8	-
Total carbohydrates	73.6	-	75.6	-	75.5	-
Available carbohydrates	55.7	-	65.0	-	62.9	-
Soluble sugars	0.3	-	2.0	-	0.6	-
Starch	54.5	-	59.4	-	57.8	-
Cellulose	1.1	-	0.5	-	0.8	-
Hemicelluse	7.1	-	5.3	-	4.8	-
Pectins	.5	-	.2	-	1.2	-
Lignin	4.4	-	2.9	-	2.0	-

[1]McNab and Shannon 1974; NRC 1977.

[2]All values, except gross energy are given as percent of a crop.

[3]Crude protein = N x 6.25.

(McNab and Shannon values are given as values of single crop samples on dry matter basis whereas NRC values are means of crop composition values on as fed basis.)

TABLE 18. Gross composition of some barley varieties (DM basis)[1]

Barley	Crude fiber %	Gross Energy (kcal/g)	CP% (Nx5.83)	Ether Extract %	Nitrogen-free Extract %
Bonanza	4.83	4.43	11.4	2.21	79.1
Brock	5.73	4.40	12.9	2.24	76.3
Fergus	5.32	4.48	13.9	2.16	75.8
Herta	5.47	4.33	10.1	2.44	79.0
Herta Increase	4.53	4.46	12.8	2.27	77.9
Increase Brock	5.07	4.37	11.9	2.20	78.1
Keystone	6.62	4.52	13.6	2.41	74.4
Sample No. 1	5.89	4.40	11.8	2.70	76.9
Sample No. 2	5.39	4.41	11.1	2.34	78.3
Sample No. 3	7.17	4.43	10.8	3.16	75.0
Sample No. 4	4.99	4.47	11.9	2.43	77.9
Sample No. 5	4.95	4.41	12.2	2.58	77.4
Malting Sample No. 1	4.55	4.44	11.1	2.62	78.9
Malting Sample No. 2	6.29	4.43	12.9	2.55	75.9
Malting Sample No. 5	6.21	4.43	12.7	2.58	75.3
Trent Increase	3.89	4.47	14.3	1.96	77.1
Mean	5.43	4.43	12.2	2.43	77.1
Standard deviation	0.86	0.05	1.2	0.28	1.5

[1]Coates et al., 1977.

TABLE 19. Gross composition of some wheats (DM basis)[1]

Wheat	Crude fiber %	Gross Energy (kcal/g)	CP% (Nx5.83)	Ether Extract %	Nitrogen-free Extract %
Canthatch	3.63	4.53	16.7	2.16	76.0
Cypress	2.91	4.58	16.1	1.99	77.3
Glenlea	3.37	4.47	13.1	2.21	78.2
Hercules	2.35	4.47	12.7	2.37	80.7
Lemhi 53	2.96	4.46	10.6	1.93	82.7
Manitou	3.67	4.55	17.1	2.11	73.8
Neepawa	2.40	4.52	17.3	2.17	76.0
Nugaines	4.18	4.46	10.7	1.75	81.8
Pelissier	2.91	4.45	15.6	2.11	74.4
Pitic 62	2.89	4.44	10.2	2.09	82.9
Pitic 62 National	3.69	4.52	13.8	2.20	78.2
Selkirk	3.00	4.47	14.2	2.20	78.6
Sample No. 1	3.21	4.58	16.1	2.20	76.1
Sample No. 5	3.29	4.56	16.4	2.21	76.1
Stewart	3.68	4.55	16.1	2.05	76.3
Winalta	3.06	4.57	12.6	1.86	80.9
Mean	3.20	4.51	14.3	2.10	78.1
Standard deviation	0.49	0.05	2.4	0.15	2.89

[1]Coates et al., 1977.

TABLE 20. Carbohydrate composition of some barleys (DM basis)[1]

Barley	Acid detergent Fiber %	Starch %	Sugar %	Pentosans %
Bonanza	6.04	66.3	2.7	9.8
Brock	8.67	65.9	2.6	9.5
Fergus	6.53	64.6	2.6	8.2
Herta	6.57	67.9	2.7	10.4
Herta Increase	7.09	65.2	2.6	9.7
Increase Brock	7.52	66.1	2.6	9.4
Keystone	8.81	64.1	2.6	8.4
Sample No. 1	6.50	64.6	2.6	9.4
Sample No. 2	7.23	64.9	2.6	9.5
Sample No. 3	7.74	65.1	2.4	9.6
Sample No. 4	5.90	66.2	2.6	9.4
Sample No. 5	6.09	65.9	2.5	9.5
Malting Sample No. 1	5.64	66.4	2.6	9.7
Malting Sample No. 2	5.64	63.7	2.4	9.4
Malting Sample No. 5	7.10	63.7	2.5	9.4
Trent Increase	7.86	64.6	2.5	8.5
Mean	6.93	65.3	2.6	9.4
Standard deviation	1.00	1.1	0.1	0.6

[1]Coates et al., 1977.

TABLE 21. Carbohydrate composition of some wheats (DM basis)[1]

Wheat	Acid detergent Fiber %	Starch %	Sugar %	Pentosans %
Canthatch	3.69	62.4	2.8	7.7
Cypress	3.98	61.7	2.6	7.4
Glenlea	4.21	67.7	3.0	6.9
Hercules	3.21	62.1	2.6	7.1
Lemhi 53	3.18	68.2	3.6	7.8
Manitou	3.81	63.8	3.1	7.5
Neepawa	3.91	62.5	2.8	6.8
Nugaines	3.35	65.7	3.7	7.4
Pelissier	3.03	64.6	3.0	7.3
Pitic 62	3.47	66.5	2.9	7.2
Pitic 62 National	3.95	67.4	3.0	7.6
Selkirk	3.63	66.7	2.7	7.3
Sample No. 1	4.16	63.5	2.7	7.5
Sample No. 5	4.33	63.1	2.7	7.2
Stewart	3.11	62.9	2.7	7.4
Winalta	3.34	65.6	2.8	7.9
Mean	3.65	64.7	2.9	7.4
Standard deviation	0.42	2.2	0.3	0.3

[1]Coates et al., 1977.

TABLE 22. Ash, phosphorus and tannin content of some barleys (DM basis)[1]

Barley	Ash %	Total Phosphorus %	Phytin Phosphorus %	Tannic acid %
Bonanza	2.51	0.38	0.20	0.016
Brock	2.84	0.41	0.27	0.015
Fergus	2.82	0.42	0.27	0.017
Herta	2.94	0.40	0.25	0.015
Herta Increase	2.52	0.37	0.23	0.014
Increase Brock	2.69	0.43	0.27	0.015
Keystone	2.95	0.44	0.28	0.022
Sample No. 1	2.70	0.38	0.22	0.022
Sample No. 2	2.85	0.42	0.29	0.020
Sample No. 3	3.82	0.46	0.27	0.023
Sample No. 4	2.80	0.43	0.27	0.016
Sample No. 5	2.88	0.39	0.22	0.023
Malting Sample No. 1	2.78	0.35	0.21	0.016
Malting Sample No. 2	2.25	0.34	0.21	0.016
Malting Sample No. 5	3.18	0.45	0.29	0.016
Trent Increase	2.77	0.43	0.26	0.017
Mean	2.83	0.40	0.25	0.018
Standard deviation	0.34	0.03	0.03	0.003

[1]Coates et al., 1977.

TABLE 23. Ash, phosphorus and tannin content of some wheats (DM basis)[1]

Wheat	Ash %	Total Phosphorus %	Phytin Phosphorus %	Tannic acid %
Canthatch	1.54	0.30	0.24	0.015
Cypress	1.67	0.38	0.26	0.013
Glenlea	3.09	0.36	0.23	0.015
Hercules	1.89	0.34	0.24	0.017
Lemhi 53	1.81	0.35	0.25	0.017
Manitou	3.32	0.43	0.33	0.019
Neepawa	2.14	0.44	0.33	0.016
Nugaines	1.51	0.31	0.23	0.011
Pelissier	1.95	0.42	0.33	0.013
Pitic 62	1.90	0.39	0.29	0.015
Pitic 62 National	2.05	0.33	0.23	0.015
Selkirk	1.98	0.44	0.33	0.016
Sample No. 1	2.42	0.46	0.33	0.018
Sample No. 5	2.00	0.43	0.35	0.016
Stewart	1.89	0.36	0.28	0.013
Winalta	1.59	0.36	0.28	0.015
Mean	2.04	0.38	0.28	0.015
Standard deviation	0.49	0.05	0.04	0.002

[1]Coates et al., 1977.

TABLE 24a. Experiment I - Feed intake

Mean feed consumption per bird (g) (1 to 28 days)					
Treatment	Replicate				
(diet)	1	2	3	4	Mean
A	1268	1256	1369	1201	1274
B	1295	1403	1203	1266	1292
C	1304	1334	1357	1296	1323
D	1387	1285	1335	1208	1304
E	1315	1257	1401	1270	1311
F	1337	1300	1299	1296	1308

TABLE 24b. Experiment I - ANOVA on feed intake

Analysis of variance on feed consumption per bird			
Source of variation	df	Mean Square	F[1]
Treatment	5	1,170.50	0.34 N.S.
Replication	3	6,004.72	1.76 N.S.
Error	15	3,417.46	
Total	23		

[1]F-value followed by N.S. is not significant.

TABLE 25a. Experiment I - Weight gain

Mean weight gain per bird (g) (1 to 28 days)					
Treatment	Replicate				
(diet)	1	2	3	4	Mean
A	778	800	867	780	806.25
B	852	861	766	791	817.50
C	800	834	870	800	826.00
D	867	813	829	760	817.25
E	802	776	854	779	802.75
F	820	788	792	790	797.50

TABLE 25b. Experiment I - ANOVA on weight gain

Analysis of variance on weight gain per bird			
Source of variation	df	Mean Square	F[1]
Treatment	5	463.14	0.38 N.S.
Replication	3	2,385.49	1.95 N.S.
Error	15	1,223.19	
Total	23		

[1]F-value followed by N.S. is not significant.

TABLE 26a. Experiment I - Efficiency of gain

Treatment (diet)	Feed/grain ratios (1 to 28 days) Replicate 1	2	3	4	Mean
A	1.63	1.57	1.58	1.54	1.58
B	1.52	1.63	1.57	1.60	1.58
C	1.63	1.60	1.56	1.62	1.60
D	1.60	1.58	1.61	1.59	1.60
E	1.64	1.62	1.64	1.63	1.63
F	1.63	1.65	1.64	1.64	1.64

TABLE 26b. Experiment I - ANOVA on efficiency of gain

Analysis of variance on feed/gain ratios			
Source of variation	df	Mean Square	F[1]
Treatment	5	.0027	2.7 N.S.
Replication	3	.0001	0.1 N.S.
Error	15	.001	
Total	23		

[1]F-value followed by N.S. is not significant.

TABLE 27a. Experiment II - Feed intake

Mean feed consumption per bird (g) (1 to 28 days)					
Treatment	Replicate				
(diet)	1	2	3	4	Mean
A	1480	1452	1449	1481	1466
B	1437	1470	1397	1454	1440
C	1428	1381	1465	1458	1433
D	1465	1437	1392	1409	1426
E	1377	1409	1401	1356	1386
F	1368	1392	1382	1402	1386

TABLE 27b. Experiment II - ANOVA on feed intake

Analysis of variance on feed consumption per bird			
Source of variation	df	Mean Square	F[1]
Treatment	5	3,953.27	4.52**
Replication	3	192.28	0.22 N.S.
Error	15	874.18	
Total	23		

**Significant (P $\leq$.01)

[1]F-value followed by N.S. is not significant.

TABLE 28a. Experiment II - Weight gain

Treatment (diet)	Mean weight gain per bird (g) (1 to 28 days) Replicate 1	2	3	4	Mean
A	925	913	900	914	913.00
B	921	942	868	920	912.75
C	927	874	939	947	921.75
D	951	933	928	933	936.25
E	883	927	934	864	902.00
F	912	922	880	893	901.75

TABLE 28b. Experiment II - ANOVA on weight gain

Analysis of variance on body weight gain

Source of variation	df	Mean Square	F[1]
Treatment	5	679.77	0.94 N.S.
Replication	3	183.28	0.22 N.S.
Error	15	720.74	
Total	23		

[1]F-value followed by N.S. is not significant.

TABLE 29a. Experiment II - Efficiency of gain

Treatment (diet)	Feed/grain ratios (1 to 28 days) Replicate 1	2	3	4	Mean
A	1.60	1.59	1.61	1.62	1.61
B	1.56	1.56	1.61	1.58	1.58
C	1.54	1.58	1.56	1.54	1.56
D	1.54	1.54	1.50	1.51	1.52
E	1.56	1.52	1.50	1.57	1.54
F	1.50	1.51	1.57	1.57	1.54

TABLE 29b. Experiment II - ANOVA on efficiency of gain

Analysis of variance on feed/gain ratios			
Source of variation	df	Mean Square	F
Treatment	5	.0037	5.29 ***
Replication	3	.0003	0.43 N.S.
Error	15	.0007	
Total	23		

***Significant (P $\leq$.005)

N.S. = not significant

TABLE 30a. Experiment III - Feed intake

Mean feed consumption per bird (g) (1 to 28 days)					
Treatment	Replicate				
(diet)	1	2	3	4	Mean
A	1418.31	1280.90	1345.05	1351.43	1349
B	1333.33	1391.95	1415.70	1439.27	1395
C	1336.79	1340.38	1280.55	1236.87	1299
D	1407.03	1347.11	1470.17	1392.24	1404
E	1432.44	1400.50	1297.30	1368.71	1375
F	1451.31	1323.68	1396.64	1402.95	1394

TABLE 30b. Experiment III - ANOVA on feed intake

Analysis of variance on feed consumption per bird			
Source of variation	df	Mean Square	F[1]
Treatment	5	6,325.24	2.28 N.S.
Replication	3	2,479.75	0.89 N.S.
Error	15	2,777.96	
Total	23		

[1]F-value followed by N.S. is not significant.

TABLE 31a. Experiment III - Weight gain

Treatment (diet)	Mean weight gain per bird (g) (1 to 28 days)				
	Replicate				
	1	2	3	4	Mean
A	903.38	842.70	851.30	829.10	856.62
B	865.80	869.97	890.38	916.73	885.72
C	846.07	881.83	853.70	763.50	836.28
D	896.20	869.10	924.03	891.66	895.25
E	912.38	859.20	842.40	839.70	863.42
F	924.40	827.30	872.90	871.40	874.00

TABLE 31b. Experiment III - ANOVA on weight gain

Analysis of variance on body weight gain per bird			
Source of variation	df	Mean Square	F[1]
Treatment	5	1,798.07	1.61 N.S.
Replication	3	1,827.00	1.64 N.S.
Error	15	1,117.23	
Total	23		

[1]F-value followed by N.S. is not significant.

TABLE 32a. Experiment III - Efficiency of gain

Treatment (diet)	Feed/grain ratios (1 to 28 days) Replicate 1	2	3	4	Mean
A	1.57	1.52	1.58	1.63	1.58
B	1.54	1.60	1.59	1.57	1.58
C	1.58	1.52	1.50	1.62	1.56
D	1.57	1.55	1.59	1.56	1.57
E	1.57	1.63	1.54	1.63	1.59
F	1.57	1.60	1.60	1.61	1.60

TABLE 32b. Experiment III - ANOVA on efficiency of gain

Analysis of variance on feed/gain ratios			
Source of variation	df	Mean Square	F[1]
Treatment	5	.0009	.71 N.S
Replication	3	.0019	1.46 N.S.
Error	15	.0013	
Total	23		

[1]F-value followed by N.S. is not significant.

TABLE 33a. Experiment IV - Digestibility percent

Sample	Digestible dry matter (%) for cereals and diets				
	Replicate				
	1	2	3	4	Mean
Wheat	88.37	88.27	87.48	88.87	88.25
Corn	92.24	92.32	89.84	91.19	91.40
Barley	87.49	88.80	88.11	85.55	87.49
Wheat diet (DA_2)	89.39	87.01	91.21	92.08	89.92
Corn diet (DA_3)	90.60	91.08	89.51	90.96	90.54
Barley diet (DF_3)	87.01	84.40	89.57	86.83	87.95

TABLE 33b. Experiment IV - Nitrogen retention

Sample	Nitrogen retention (%) for cereals and diets				
	Replicate				
	1	2	3	4	Mean
Wheat	74.85	73.15	72.70	75.42	74.03
Corn	78.11	80.00	77.67	74.89	77.67
Barley	66.81	75.27	71.04	72.60	71.43
Wheat diet (DA_2)	82.00	79.25	85.62	88.07	83.74
Corn diet (DA_3)	83.98	86.28	83.51	85.67	84.86
Barley diet (DF_3)	74.85	73.15	72.70	75.42	74.03

TABLE 33c. Experiment IV - F-values for DM and N-retention

F-values for dry matter and nitrogen retention	
Component	F-value
Crop dry matter	14.22 ***
Crop nitrogen	6.30 *
Diet dry matter	3.04 N.S.
Diet nitrogen	22.84 ***

* Significant ($P \leq .05$)

** Significant ($P \leq .01$)

*** Significant ($P \leq .005$)

N.S. = Not significant