FACTORS AFFECTING RYE UTILIZATION
IN GROWING CHICKS

by

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ABSTRACT

A series of experiments was conducted with growing chicks in an attempt to (1) observe the detrimental effects associated with the feeding of rye, and (2) develop dietary formulations that would either maximize or minimize these effects. Various dietary treatments were administered in feeding trials designed to study the effects of: the substitution of increasing levels of rye for wheat; the incorporation of rye grain fractions in diets containing complementary wheat grain fractions; different levels of a lyophilized water extract of rye; water extracted rye; the addition of ergot bodies; the daily cleaning of chicks' beaks or vents; autoclaving of rye for increasing time periods; the type and the level of dietary fat; two energy levels; increasing levels of vitamin D_3; pelleting of the diets; protein level and source (quality); and increasing levels of procaine penicillin supplementation.

The results indicate that several factors may affect the utilization of rye by growing chicks. A lyophilized water extract of rye was growth depressing; and the water extracted rye was utilized as efficiently as wheat even though it seemed to be less palatable than wheat. The accumulation of feed on the chicks' beaks, vent blockage and feces wetness were associated with feeding the lyophilized water extract of rye. However, the observation that there was no close association between vent blockage and chick performance suggested that growth depression was caused by factor(s) different from those responsible for feed accumulation on the chicks' beaks, vent blockage or feces wetness. The destruction of thermolabile factors following autoclave treatment only slightly corrected

DEDICATION

This thesis is dedicated to my father and mother, and to other farmers of the world who are making a conscious and a deliberate effort to produce food for a hungry world by the application of modern scientific agricultural principles.

ACKNOWLEDGMENTS

The author is indebted to Dr. R.R. Marquardt for the opportunity to learn theoretical and practical aspects of basic agricultural research under his supervision. Dr. Marquardt's suggestions during the periods of planning and experimentation, and his constructive criticism of the manuscript are gratefully acknowledged.

Puma rye and Glenlea wheat samples were obtained from the Glenlea Agricultural Research Station, Glenlea, Manitoba, through the courtesy of the Director, Dr. J.D. Truscott. Milling of the grain samples was accomplished with the help of Mr. J. Watson of the Department of Plant Science, University of Manitoba. Dr. B. Dronzek made arrangements for the analysis of rye fractions for resorcinol content.

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INTRODUCTION

During the last two decades in Canada the increasing use of rye as an animal feed grain has been accompanied by its decline as a human food (bread) grain. Although rye shows chemical composition similar to wheat, the feeding of high levels of rye in diets to domestic animals has shown consistently that rye depresses growth and lowers the efficiency of feed conversion. In addition, problems such as the accumulation of feed on the beaks of chicks, the production of sticky feces and vent blockage have been reported.

Since rye thrives on marginal lands and survives in cold regions, it should be quite feasible to extend the cultivation of rye to the marginal lands in northern Manitoba and other Canadian provinces without affecting the production of other cereal crops. Developing a method to eliminate the growth inhibiting factors of rye will be a necessary first step towards the ready acceptance of rye by feed manufacturers for diet formulation. Therefore, the increased revenue to be derived by elimination of the rye growth inhibitor(s) plus the expected increase in rye production justify an investigation of the problems associated with feeding rye to domestic animals.

Before any meaningful progress could be made in the isolation, identification and characterization of the rye growth inhibitor(s), a suitable bioassay must be developed. The objective of this study was to develop dietary formulations which would maximize the detrimental effects of the growth inhibitor(s) in order to facilitate identification work, or minimize these effects so as to enhance the nutritional value of rye.

LITERATURE REVIEW

A. Classification and Geographical Distribution of Rye

Rye is a member of the grass family, Graminae, which includes such common grain crops as wheat, oats and barley. Cultivated rye is classified botanically as *Secale cereale* L. Plants of the *cereale* species may be spring or winter annuals.

Rye appeared to have evolved in southwestern Asia, the region also reputed to be the centre of origin of wheat, oats and barley (Deodikar, 1963). During the first millenium B.C., rye reached northern Europe and gradually was spread throughout most of Europe. With the settling of the Americas by Europeans in the 16th and 17th centuries, rye was brought to the New World. In the 19th and 20th centuries, it was introduced to Argentina, Uruguay, Australia and South Africa (Bushuk, 1976). This wide geographical distribution of rye has been attributed to its extreme winter hardiness and ability to grow on very marginal soils. Rye is the most drought-resistant of the cereals on account of its extensive root system and its inherent ability to adjust its maturity to moisture conditions (Deodikar, 1963).

Like wheat and other cereal crops, rye thrives on arable land and responds to good soil fertility and moisture conditions; but unlike these crops rye grows well in drier environments, will survive more severe winters and produce larger yields of grain on soils of lower capability. In addition, rye ripens earliest of all the grain crops (Majors, 1951). This combination of agronomic features has been largely responsible for rye being relegated to marginal lands of temperate regions.

In North America most of the rye area is seeded in the fall to winter cultivars on account of their winter hardiness and ability to utilize early spring moisture. Besides, fall seeding enables the farmer to distribute his work-load more evenly between spring and fall, and aids in good soil management by reducing or checking soil erosion by wind. Frequently, fall-sown rye is grazed in the late fall and early spring and then left to produce a grain crop (Bushuk, 1976).

B. Production and Consumption of Rye

Agricultural data for the period 1961 to 1974 indicate an increasing trend in the total world production of cereal grain (F.A.O., 1972, 1974). Compared to 1961, world production rose by 44% in 1974; in Canada the corresponding increase was 47% during the same period. However, total world production of rye showed a drop of 8%. In contrast Canadian rye production fluctuated (Fig. 1). The corresponding production and price per ton in Manitoba are presented in Fig. 2.

Of the major rye producing regions, Europe and the USSR have long dominated production. Their combined production in 1974 accounted for 94% of the total world output (Table 1). The continued importance of rye in the agriculture of these countries has been influenced by climatic factors and the high cost or the low supply of wheat (F.A.O. 1965).

Historically, the chief use of rye has been in bread-making but changing patterns in human consumption of rye bread, especially in Europe, have largely been responsible for the decline in the demand for rye and the resulting decrease in production (F.A.O. 1965). Since the dark bread produced from rye has long been associated with the lower classes consumers have naturally shown a preference for wheat breads which they

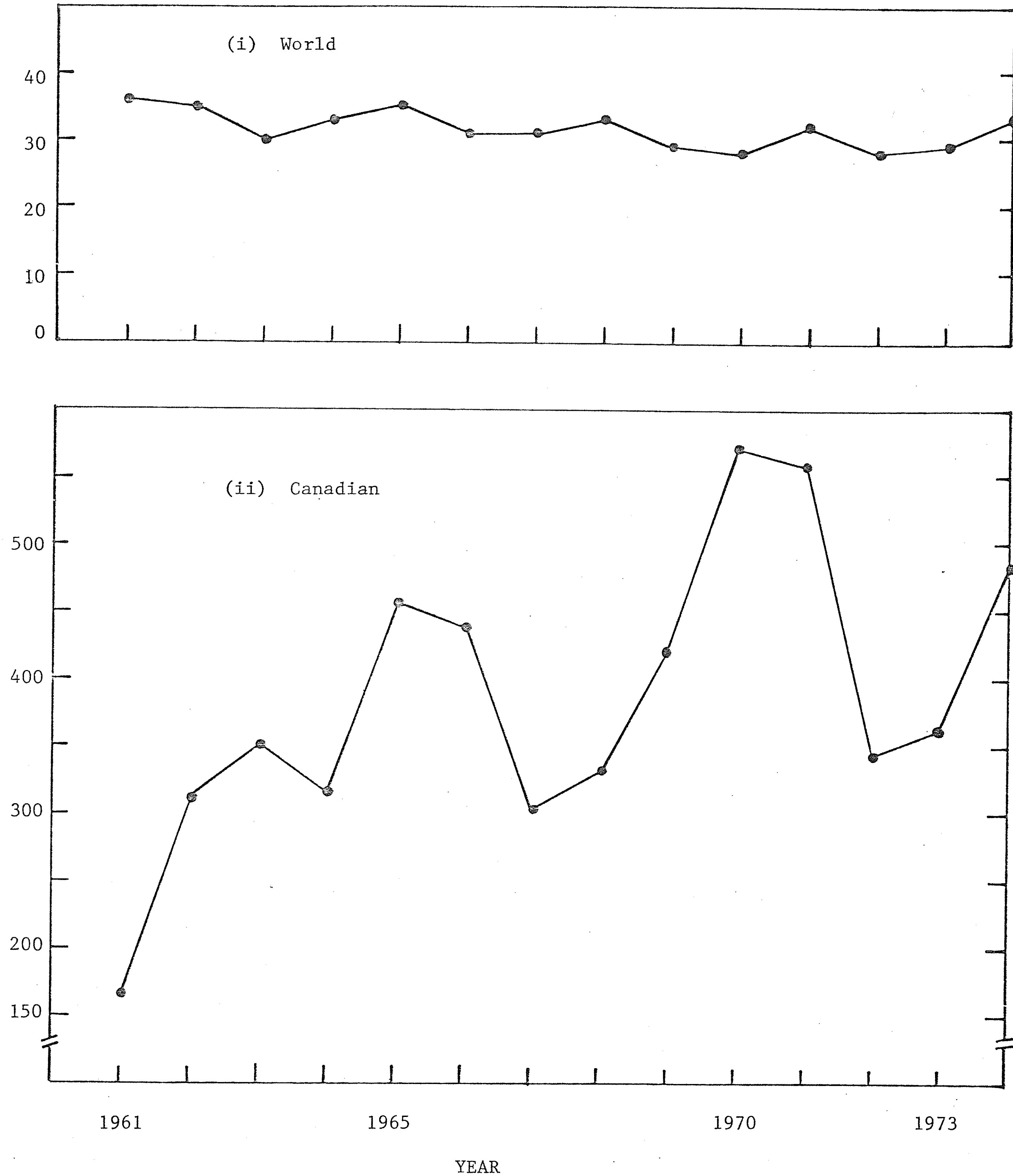

FIGURE 1: Total Rye Production (i) World (ii) Canadian

SOURCE: F.A.O. 1972, 1974

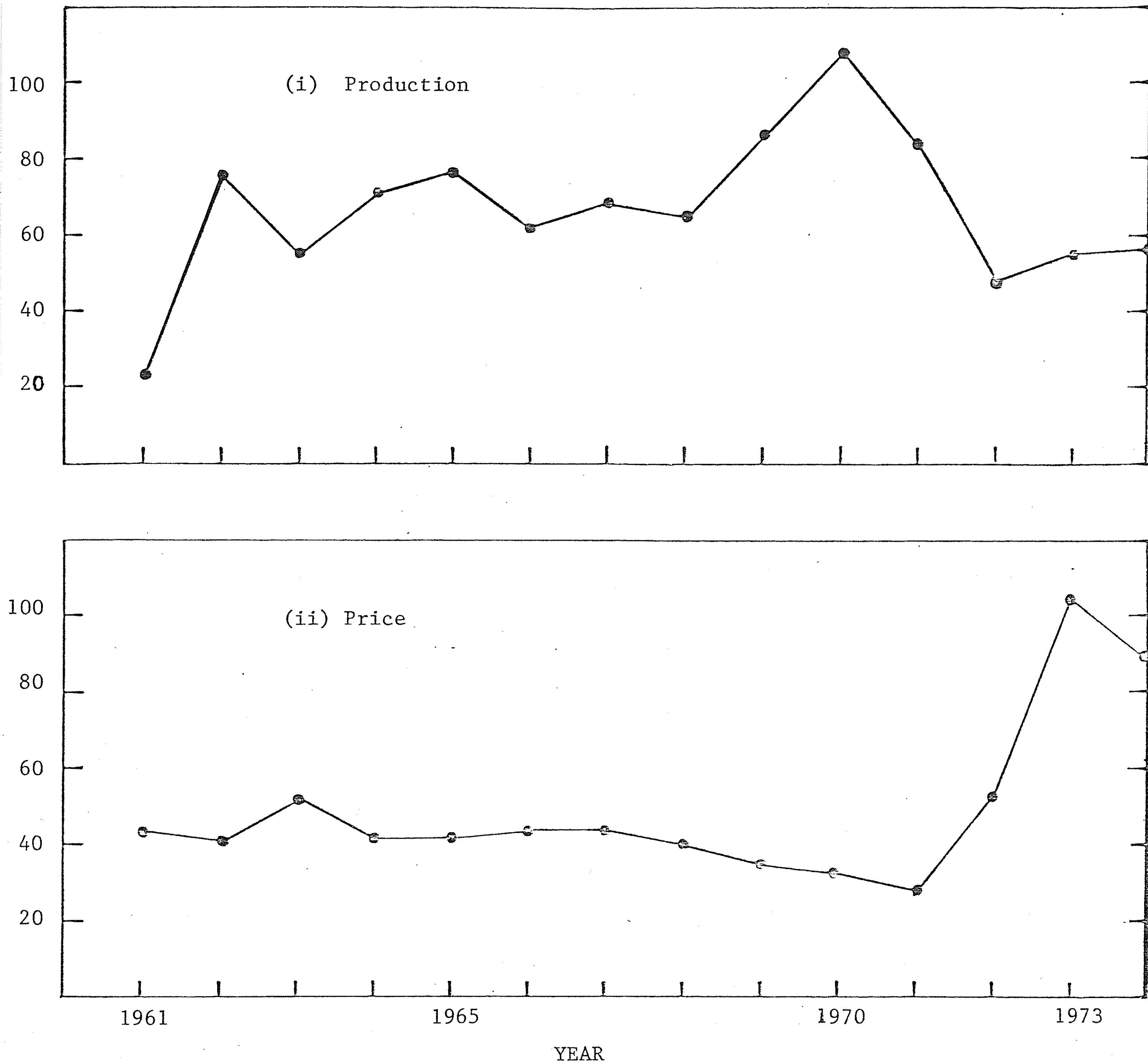

FIGURE 2: Manitoba rye production and price

SOURCE: M.D.A. 1975.

TABLE 1

Area Harvested and Production of Rye in Major Rye-producing Countries.

Region	Area harvested x 10^3 hectares					Production x 10^3 metric tons				
	1961[1]	1964[1]	1967[1]	1970[1]	1974[2]	1961[1]	1964[1]	1967[1]	1970[1]	1974[2]
U.S.S.R.	16,700	16,807	12,418	10,020	9,810	16,716	13,619	12,986	12,972	15,218
Europe	9,856	8,939	8,092	6,666	5,929	16,753	16,507	16,221	12,341	15,470
U.S.A.	624	686	430	577	363	694	825	608	936	490
Canada	227	282	277	411	341	166	314	304	570	481
Others	1,482	1,616	1,425	1,133	1,039	1,181	1,490	1,341	953	952
World	28,889	28,330	22,642	18,807	17,482	35,510	32,755	31,460	27,772	32,611

1 F.A.O. 1972

2 F.A.O. 1974

consider a status symbol. Further, the improvement of wheat through selective breeding, the opening up of new wheat lands and the increasing application of synthetic fertilizers have all contributed to the relative decline in rye production.

The disposal of Canadian rye for three selected time periods is illustrated (Fig. 3). Although the number of tons of rye used for human consumption has remained constant during these periods, the number of tons of rye expressed as a percentage of the total rye consumption in each period actually declined (Commonwealth Secretariat, 1973). Industrial use, mainly the distilling of whiskies, utilized about a quarter of the total. On the other hand the amount of rye used in the manufacture of animal feeds has shown a consistent increase, accounting for over 60% of the total domestic consumption during the last period. The data clearly suggest that rye is a potentially important animal feed grain and therefore research should be directed toward improving the nutritive value of rye as a feed ingredient.

C. Rye as an Animal Feed Ingredient

Modern agricultural practice requires the formulation of balanced livestock and poultry rations containing the correct proportions of all the nutrients essential for optimum performance. Cereal grains are incorporated into rations to serve as the major energy, protein and micronutrient sources.

After reviewing the available literature on the feeding of various cereal grains to cattle, sheep, swine and poultry, Crampton (1933) concluded that the performance of the animals was poorest when rye diets were fed. The adverse effects of rye were more apparent as increasing levels of rye

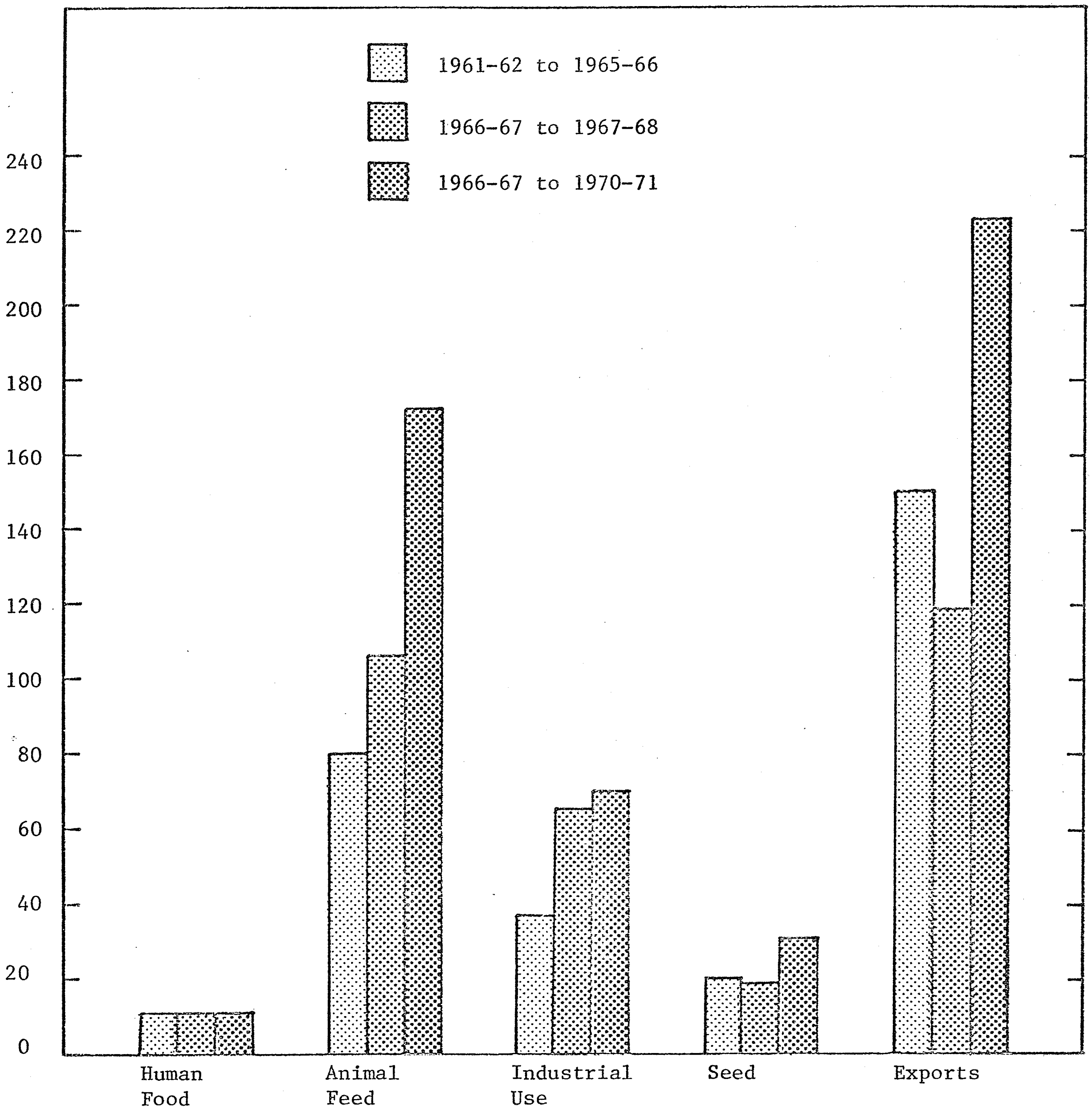

FIGURE 3: DISPOSAL OF CANADIAN RYE DURING THREE SELECTED TIME PERIODS.

SOURCE: Commonwealth Secretariat, 1973

were included in the diets.

The results of feeding trials in which rye has been used to replace other cereal grains in animal rations have been conflicting, and in some instances contradictory. However, it must be recognized that the "rye" samples used in these feeding trials were a heterogeneous assortment of rye cultivars of varying protein contents, and produced in different geographical regions. In addition the experimental animals were of different genera and in different stages of growth and production.

In his review of the literature, Weiringa (1967) indicated that as early as 1900, German researchers had reported detrimental effects of feeding rye to a number of farm animals. These workers had attributed the decreased growth rate observed in rye-fed animals to a reduced feed intake caused by the unpalatability of rye. Weiringa referred to the work of Van Weiringen which suggested that a harmful physiological effect was more to blame for rye-induced growth depression than any palatability factor; and by Dammers who showed that rye bran and grit were more harmful than rye flour.

Feeding rye at levels of up to 45% of the concentrate mixture has proved satisfactory for dairy cows, but higher levels produced a hard, unsatisfactory butter (Cullison, 1975). The rye should be coarsely ground or rolled in order to counteract the hardness of the kernels and to promote better digestion. In one feeding trial conducted by Winter (1975), the inclusion of up to 80% rye in the grain diet for steers did not appreciably reduce feed intake and only slightly reduced weight gain. On the other hand, feeding rye to fattening lambs has produced as good results as barley or wheat (Morrison, 1969).

Bell and Owen (1973) recommended that rye should constitute a maximum of one-third of the final mixed diet for swine. When rye replaced 25% of the wheat or wheat plus barley in a finishing diet, Bowland (1966) found a reduction in growth rate of swine. Weiringa (1967) obtained a 12% lower growth rate in swine fed a diet containing 50% rye as compared to a similar diet containing 50% barley. He indicated that the recommended maximum levels of rye for pigs in the Netherlands was zero for piglets and sows, 15% for pigs weighing 30 to 50 kg. and 30% rye in diets of older pigs.

The performance of pigs fed rye diets has varied greatly. The age and the sex of the animals as well as the physical form of the diets have all influenced results. Friend and MacIntyre (1969) found that feed intake was reduced when pigs were changed from a grower to a finisher diet in which rye replaced barley. Although gilts showed greater weight gains than barrows when fed no rye, the situation was reversed as rye replaced 30 or 60% of the barley in the diet. Number two grade rye promoted greater weight gains in barrows than number 3 grade rye. Pelleting the entire diet improved the feeding value of rye by lowering feed consumption and improving feed conversion.

Rye has never been considered favourably as a poultry feed ingredient. Several researchers have reported poor growth in chicks fed diets containing rye (Halpin and Holmes, 1932: Moran _et al_, 1969; McAuliffe and McGinnis, 1971; Fernandez, Lucas and McGinnis, 1973; Wilson and McNab, 1975). North (1933) noted that rye had a laxative effect on hens but otherwise did not appear to injure their health. Another highly undesirable result observed when feeding rye to chicks has been the excretion of wet and extremely sticky feces resulting in a very damp floor litter (Halpin _et al_

1963).The accumulation of feces on the chicks'vents and feet prevented successful defecation and locomotion respectively. In their never-ending effort to clear their vents and their feet of this hard caked fecal adherence, some feces would invariably collect on the chicks' beaks, thereby limiting their feeding. In general, both adverse performance and excreta problems appeared to be manifested more severely with the young growing than the adult animal.

Many workers have attempted to improve the nutritional value of rye. Fry et al (1958) reported that soaking rye in an equal weight of water overnight followed by drying in an oven at 70° C. gave a significant improvement in chick growth as compared to the untreated rye. However, this treatment did not increase chick growth to levels obtained with other cereal grains such as corn or barley. Smith and McIntyre (1960) could not duplicate these results.

The addition of fermentation enzyme supplements to rye containing diets did not improve the feeding value of rye (Moran et al, 1969). Further, the addition of a mixture of four antibiotics totalling 8.8 mg of antibiotics per kilogram of diet and consisting of equal parts of penicillin, tylosine, chlortetracycline and oleandomycin failed to give a growth increase. However, when the diets were fed in the pelleted form as compared to rations in the mash form, these workers observed an improvement in growth and feed utilization at a dietary rye level of 64%. They attributed these results to a prevention of the accumulation of feed on the beaks of the chicks which could not thereby consume enough feed to grow optimally.

Mac Auliffe and McGinnis (1971) treated rye by adding (1) an equal weight of water to the ground grain, spreading it on trays and oven-drying at 70° C., and (2) an equal weight of water, autoclaving for 15 minutes at

121^{o}C. and then oven-drying at 70^{o}C. Water treatment of rye gave rise to a significant improvement in chick growth and feed efficiency. Alternatively, the harmful effects of rye were largely overcome by addition of antibiotics, terramycin or procaine penicillin G, but not by zinc bacitracin. These researchers suggested that the low nutritional value of rye could be related to a component, possibly high pentose content, which stimulates the growth of adverse microflora in the intestinal tract of the chick.

Mild acid treatment, followed by autoclaving, improved the nutritional value of rye in chick diets; a further improvement was observed when penicillin was added. On the contrary, alkali treatment of rye, followed by autoclaving did not effect improvement. Three commercial enzyme products, Rhozyme H39, Rhozyme CL and Lipase B, improved the utilization of rye by chicks to the same extent as penicillin, but the supplements in combination were not more effective than penicillin alone. Inactivation of the enzyme products by autoclaving destroyed the property of chick growth improvement (McGinnis, 1972).

In a series of experiments, involving young chicks, Fernandez, Lucas and McGinnis (1973) showed that the procaine penicillin supplementation at 50 p.p.m. significantly increased the growth of chicks receiving the rye diet but not the wheat-containing diet. Acetone extraction of rye which would be expected to remove the growth-inhibiting effects of rye as reported by Weiringa (1967) failed to improve the nutritional value of rye. In contrast, water extraction of rye removed the growth inhibiting effects since chicks fed the diet containing water-extracted rye were equal in body weight to those fed the corn diet, and significantly larger than those chicks fed the untreated rye diet. The lyophilized water extract of rye was growth depressing whereas the water-extract dried by heat evaporation did not depress growth. The petroleum ether extract of the distillate of water soluble fraction of rye had no effect on chick growth or feed efficiency. The feces condition was significantly improved by water extraction of rye and the dried water extract of rye caused the characteristic sticky feces condition when added to a diet containing corn as the grain. Clearly, these results indicated that both the growth inhibiting factor(s) in rye and the factor causing feces stickiness were water extractable, but that whereas the former were thermolabile the latter was unaffected by heat.

Using wheat containing diets as controls, Graber et al (1976) reported a dramatic increase in the weight gain of chicks fed a penicillin supplemented rye diet containing 10% meat meal replacing an equivalent percentage of fish meal as compared to a similar rye diet containing only 5% meat meal. Of the antibiotics chlortetracycline, penicillin and zinc bacitracin used to supplement wheat or rye diets, penicillin produced the greatest weight gain in chicks. Thus it would seem that the type of protein (meat meal vs. fish meal) as well as the antibiotic used to supplement rye diets combined to influence the nutritional value of rye.

In view of the limited success achieved in attempting to improve the nutritional value of rye, it was considered that the next best solution to the problem of using rye in practical commercial chick diets was to determine the highest concentration at which this cereal could be fed without adverse effects. For broiler chicks, Moran et al (1970) ascertained that rye could comprise up to 25% of the grain component without adverse effects. Increasing rye in diets above this level resulted in progressively poorer live performance, dressed yield and carcass quality. Sosulski et al (1976) found that feed intakes of male broiler chicks were enhanced at dietary rye levels of up to 50%, but feed efficiency was reduced substantially in a 70% rye diet. In two egg production trials conducted by Halpin et al (1936) the inclusion of up to 45% rye in the diet had no adverse effect on the rate of laying. However, Fernandez, Kim, Buenrostro and McGinnis (1973) found that rye fed at 80% of the diet caused a sharp decline in egg production followed by a subsequent partial recovery, seeming to indicate a toxic effect of the diet rather than a nutrient deficiency.

Working with male Wistar rats averaging 167g initial body weight, Friend (1970) fed ad libitum a basal diet in which 42% of the total diet was provided by (1) ground barley, (2) ground rye, (3) barley flour plus rye bran and (4) rye flour plus barley bran. Those rats fed the diet (3) containing barley flour plus rye bran had the highest feed intake, gained more weight and retained more nitrogen than rats fed the other diets. The poorest performance was obtained in those rats fed the ground rye diet (2) whereas the weight gains in rats fed diet (4) containing rye flour plus barley bran were better than the ground rye diet (2), but less than the values obtained with the other two diets. Rye flour, rather than rye bran, appeared to elicit the lower food consumption associated with diets containing rye grain. This result agrees with that of McDonald et al (1974) who found the addition of rye bran to a wheat-based diet at levels equivalent to 30% and 60% of the wheat flour had no adverse effects on weight gain and feed consumption of weanling male mice. Weiringa (1967) had previously located the growth depressing factor in the pericarp of rye.

D. The Composition of Rye and Related Cereals

Proximate analyses of cereal grains reveal great variation, especially in the protein content. The composition of four common cereal grains, found typically in North America, is presented in Table 2. One striking feature of the cereals is that they are low in protein and high in nitrogen-free extract but there is much variation in the crude fibre content. Rye and wheat are similar in all respects except that rye is slightly higher in crude protein but slightly lower in gross energy. An examination of the average composition of cereal grains shows that rye ranks lowest in niacin, i.e.,1.3 mg/kg as compared to 63.6, 64.5 and 17.8 mg/kg for wheat, barley and oats respectively. (Joint U.S. - Canadian Tables of Feed Composition, 1964). Usually in the formulation of diets used in feeding trials, sufficient niacin is included in the vitamin premix to meet minimum requirements. Yet adverse effects are observed in animals fed high levels of rye in diets made isonitrogenous and isocaloric compared to control diets. Obviously some factor(s) other than a nutrient deficiency must be responsible for these adverse effects.

E. The Quality of Rye Protein

The amino acid composition of whole rye and whole wheat from two independent sources is given in Table 3. Noteworthy is the larger ratio of essential amino acids to non-essential amino acids for rye. This superior quality of rye protein as a whole over the protein in wheat and most other cereals is attributed to the comparatively higher proportion of water-and salt-soluble protein, both of which have an improved content of

TABLE 2

Composition of Common Cereal Grains (Moisture Free Basis)

Component	Barley [1]	Oats [2]	Rye [3]	Wheat [4]
Protein (N x 6.25), %	12.6	12.7	12.8	12.3
Ash, %	3.1	3.9	2.0	2.0
Crude Fibre, %	5.0	11.3	2.3	2.5
Ether Extract, %	1.1	1.9	1.7	1.8
Nitrogen-Free Extract, %	78.3	70.2	81.2	81.4
Energy, Gross-Mcal/kg	-	-	3.75	3.95

Sources [1-3]: National Academy of Sciences, 1971.

[4]: Crampton and Harris, 1968.

[1] Ref. No. 4 08 158

[2] Ref. No. 4 08 161

[3] Ref. No. 4 04 047

[4] Ref. No. 4 04 294

TABLE 3

Amino Acid Composition[1] of Whole Rye and Whole Wheat Grains.

Amino Acids	Rye		Wheat	
Essential	F.A.O. (1970)[2]	Tkachuk & Irvine (1969)[3]	F.A.O. (1972)[2]	Tkachuk & Irvine (1969)[3]
Arginine	28.6	26.2	28.8	24.9
Histidine	13.8	13.1	14.3	13.8
Isoleucine	21.9	22.8	20.4	23.9
Leucine	38.5	37.4	41.7	42.0
Lysine	21.2	18.1	17.9	14.5
Methionine	9.1	7.3	9.4	10.5
Phenylalanine	27.6	28.0	28.2	29.7
Threonine	20.9	20.9	18.3	17.3
Tryptophan	4.6	7.6	6.8	9.6
Valine	29.7	30.6	27.6	27.9
Non-Essential				
Alanine	26.6	23.2	22.6	20.4
Aspartic acid	44.7	40.4	30.8	29.2
Cysteine/cystine	11.9	14.3	15.9	16.2
Glutamic acid	151.1	172.0	186.6	207.0
Glycine	27.1	22.7	25.4	23.5
Proline	58.6	65.0	62.1	69.6
Serine	27.0	26.8	28.7	31.3
Tyrosine	12.0	11.8	18.7	16.7
Essential AA/Nonessential Amino acids	0.6	0.6	0.5	0.5

[1] g Amino acid / 100g sample N.

[2] Average of several samples.

[3] Canadian varieties.

lysine (Bushuk, 1976). While higher in lysine and threonine than wheat rye is somewhat lower in methionine and tryptophan. A comparison of the chemical scores for these four essential amino acids reveals higher values for lysine and threonine in rye than the corresponding values for wheat (Table 4). In spite of its higher lysine content, this amino acid is still likely to be the first nutritionally limiting amino acid in rye, with tryptophan or threonine as the second depending on the sample. On the basis of the chemical scores of the most limiting amino acids, the Canadian rye sample is clearly superior to wheat.

The nutritional superiority of rye, on account of its higher lysine content, has been documented by several workers (Jones et al, 1948; Knipfel, 1969; Kies and Fox, 1970). Higher Protein Efficiency Ratio for rye compared to those of wheat have been obtained. (Sure, 1954; Knipfel, 1969). These observations would suggest that rye should be a nutritionally adequate feedstuff ingredient for animals.

F. Hypotheses to account for the Poor Performance of Animals fed Rye Diets

The presence of naturally-occurring factors in rye is thought to interfere with the digestibility and/or availability to animals of one or more of its nutrient components. As a consequence the performance of these animals is adversely affected. Although the mechanism of the physiological action of these factors is not clearly understood a number of hypotheses has been proposed to provide possible explanations for the poor performance of animals fed diets containing large amounts of rye.

1. The Effects of Naturally-Occurring Nutritional Inhibitors

The presence of these in rye is detected by a lower than anticipated

TABLE 4

Chemical Scores for Whole Rye and Whole Wheat compared with the World Health Organization Standard Reference Pattern. (The data in Table 3 have been used as the basis for calculation.)

Amino Acid	WHO[1] (1973) Standard Reference mg/g protein	Rye		Wheat	
		F.A.O.[2] (1970)	Tkachuk & Irvine[2] (1969)	F.A.O.[2] (1970)	Tkachuk & Irvine[2] (1969)
Lysine	55	62	53	52	42
Threonine	40	84	84	73	69
Methionine & cystine	35	96	100	116	122
Tryptophan	10	74	122	109	154

Source: [1] Hulse and Laing (1974).
[2] Calculated from values in Table 3.

rate of growth in the animals, in relation to the quantity and quality of the nutrients ingested.

(a) Resorcinols

In experiments designed to isolate the growth-inhibiting factor in rye and to develop an analytical method to detect and measure it in "micro quantities", Weiringa (1967) fed Petkuser winter rye to weanling male white Wistar rats. He reported that the growth-inhibiting factor was soluble in petroleum ether and acetone, could be concentrated by solvent fractionation and isolated chromatographically. It was subsequently identified as a mixture of 5-n-alkylresorcinols with odd-numbered side chains of 15-23 Carbon atoms, together with smaller amounts of 5-n-alkenylresorcinols. Although this same group of chemical compounds had been found in the non-saponifiable fraction of wheat bran (Wenckert et al, 1964), Weiringa found that rye resorcinols or wheat resorcinols produced the same degree of growth inhibition in rats. He attributed the higher "valuation" of wheat as a feedstuff ingredient for domestic livestock diets to its lower resorcinol content. Synthetic 5-n-pentadecylresorcinols had only 50 to 60% of the growth-depressing potency of the grain resorcinols. Since hydrogenation of the grain resorcinols did not alter their growth-depressing properties, Weiringa concluded that the difference between the synthetic resorcinols and the grain resorcinols was not due to the alkenyl side chains. Weiringa developed a fluorometric analysis for 5-n-alkyl-resorcinols and by means of this method located the growth-depressing factor in the pericarp of rye grain, and not in the endosperm or the germ. He concluded that the resorcinol content of rye was proportional to the surface area of the kernel. Accordingly, heavier kernels would contain less resorcinols than lighter, more shrivelled ones having a higher bran to endosperm ratio. In experiments with rats Weiringa observed that young animals were more susceptible to the effects of resorcinols than older ones.

The alkylresorcinol content of the grain of spring rye cultivars was found by Evans et al (1973) to be higher than for winter rye cultivars; furthermore there was greater variability in the resorcinol content in spring cultivars than in winter cultivars: 0.046% to 0.322% vs. 0.036% to 0.279% respectively. A high resorcinol content in winter rye was correlated with a low protein content (Munck, 1969). A very high positive correlation (r = .98) was found between the crude fibre and resorcinol contents in wheat grain, again indicating the association of resorcinols with the bran component (Munck, 1972); but the average resorcinol content of rye was more than twice that present in wheat, i.e: 161 "units" compared to 69 "units". This value agrees with the work of Haeberle (1974) who found an average of 36.0 and 17.8 mg/100g for Manitoba rye and wheat cultivars respectively. Recent work by Verdeal and Lorenz (1977) showed that rye contained the highest resorcinol content, wheat the lowest and triticale intermediate. Milling these grains into bran, shorts and flour fractions and subsequent analyses revealed that the bran contained the highest level of alkylresorcinols.

Results contradicting those of Weiringa (1967) were reported by McGinnis (1972) who found that acetone extraction, which was expected to remove any resorcinols present, did not eliminate the growth-depressing effect of rye. Furthermore the acetone extract of rye did not depress chick growth when added to a diet containing wheat. In feeding trials with weanling male white mice conducted by McDonald et al (1974), alkylresorcinols at levels of up to 160 mg/100g of diet had no adverse effects on voluntary feed intake or weight gain. These workers attributed the apparent discrepancy between their results and those of Weiringa (1967) to the lower alkylresorcinol levels in the diets they fed, but these resorcinol levels were comparable to those normally present in diets formulated with Western Canadian triticale or rye. These results were in agreement with those of Haeberle (1974) who found that increasing the rye level from 40 to 80% of the diet failed to affect significantly the growth of weanling male white mice. Consequently Haeberle concluded that the alkylresorcinol content in the rye was not responsible for its poor nutritional status.

(b) Trypsin inhibitors.

Trypsin is one of the proteolytic enzyme systems present in the pancreatic secretion and is essential to the efficient digestion of ingested proteins. Trypsin inhibitors are proteinaceous substances capable of combining with and inactivating trypsin. They have been identified in a wide range of plants including wheat (Learmonth and Wood, 1963), and barley, wheat and rye (Mikola and Kirsi, 1972). The nutritional and physiological effects ascribed to legume trypsin inhibitors include growth depression and hyperthrophy or enlargement of the pancreas (Liener, 1976). Lyman and Lepkovsky (1957) suggested that the growth depression caused by trypsin inhibitor may be the result of the endogenous loss of essential amino acids derived from a hyperactive pancreas which is responding in a compensatory fashion to the effects of the trypsin inhibitor.

Laporte and Tremolieres (1962) reported that cooking wheat flour at 98°C for 4 minutes effectively destroyed its trypsin inhibitory activity, whereas the same treatment reduced the inhibitory activity of rye flour by only 20%. Polanowski (1967) identified a trypsin inhibitor in the aqueous extract of rye. It was located only in the endosperm, and not in the germ or seed coats. Heating the extract at 75°C resulted in loss of inhibitory activity, the inhibitor being completely inactivated after heating for 25 minutes.

The trypsin inhibitory activity of six rye cultivars grown in Saskatchewan was found by Sosulski _et al_ (1976) to range from 22.4 to 52.5%. However, these workers obtained superior weight gains in male broiler chicks fed diets containing 25 or 50% rye compared to a casein control diet. This, coupled with the absence of pancreatic hypertrophy, led those workers to conclude that trypsin inhibitors in rye did not contribute greatly to the overall poor utilization generally attributed to rye. Although autoclaving for 30 minutes destroyed the trypsin inhibitory activity of rye, feeding trials with mice resulted in poorer performance since slight decreases in feed efficiency, protein efficiency ratio and biological value of rye protein were recorded. This failure of autoclaving to improve the nutritive value of rye had also been reported by Moran _et al_ (1969) who found a significant decrease in weight gain of chicks fed autoclaved as compared to raw rye. The results of these feeding trials plus the _in vitro_ experiments of Mikola and Kirsi (1972) would indicate that the trypsin inhibitors in rye do not markedly affect the utilization of rye by domestic livestock.

(c) Rachitogenic factor

The rachitogenic effect of cereals was noted by Mellanby (1922, 1924) who reported that different cereals when fed to puppies interfered with bone calcification to varying degrees. The rachitogenic substance proved to be phytic acid or inositol hexaphosphoric acid (Mellanby, 1950) which together with its derived salts, the phytates, occur in the aleurone cells of rye and many other cereals (Bushuk, 1976). In commercial wheat products phytic acid runs parallel to fibre content and to a large extent is fixed in the form of calcium magnesium phytate (Hay, 1942). Although phytic acid represents 35 to 97% of the total phosphorus in the cereal grains (Gontzea and Sutzescu, 1968), it is a poor source of phosphorus to monogastric animals.

The mechanism of the rachitogenic action of phytic acid depends upon its ability to form insoluble or nearly insoluble compounds with cations including calcium, iron, magnesium and zinc; the resulting phytates are excreted in the feces. The consequent loss of dietary calcium over an extended period results in rickets, whereas loss of the other cations produce characteristic deficiency symptoms.

Both phytic acid and its salts are hydrolyzed by the enzyme phytase to yield inositol and phosphoric acid. Wheat and rye are rich in phytase whose distribution throughout the grain parallels that of the substrate. The phytase of rye is more active than that of wheat (Gontzea and Sutzescu, 1968) but the extent to which the phytic acid of these cereals may be harmful in the diets will depend not only upon its phytic acid content but also upon the extent to which this compound has been acted upon by phytase during preparation of the diet. Therefore, if a diet is adequate in calcium and phosphorus but contains excessive phytic acid, the effect on the animal may be the same as if the diet were too low in calcium and faulty bone formation will take place; in extreme cases, rickets may result. Vitamin D, however, assists in the proper assimilation of calcium and to some extent can counteract the effect of phytic acid (Kent-Jones and Amos, 1967).

The rachitogenic effect of rye in turkey poults was investigated by MacAuliffe et al (1976a) who fed diets containing 40 to 46% rye, and adequate amounts of vitamin D_3, calcuim and phosphorus. Before the birds reached two weeks of age, they developed severe rickets. This condition was significantly reduced when either fat and/or penicillin were added to the diets. The addition of extra vitamin D_3 or penicillin significantly improved growth and increased bone ash content when rye rather than corn was the grain. These results led McAuliffe et al (1976a) to conclude that rye interfered with the utilization of vitamin D_3 by turkey poults. The fact that fat reduced the severity of rickets suggested that rye was probably interfering with vitamin D_3 absorption.

McAuliffe et al (1976b) found that the growth and the bone ash content of broiler chicks were depressed when rye replaced corn in the diet. However, these effects were partially reversed when either fat or procaine penicillin was added to the diet, and completely prevented by feeding 2,000 I.C.U. vitamin D_3/kg diet (10 x normal requirements). Further, water extraction removed the factor responsible for depressed bone mineralization. Acid autoclaving of rye partially destroyed the rachitogenic factor, but a combination of acid autoclaved treatment and penicillin supplementation prevented the depression in bone ash content.

In feeding trials designed to investigate the rye - vitamin D antagonism in growing broiler chicks, MacAuliffe and McGinnis (1976) reported that acid autoclaved treatment inactivated the vitamin D interfering factor, and that water extraction appeared to have removed most of this factor. These results agree with those of MacAuliffe et al (1976b). Furthermore rye was found to interfere with the absorption of vitamin D_3, thereby supporting the previous suggestion of MacAuliffe et al, (1976a) who did similar work with turkey poults. Treatment of the chicks with ultraviolet light in addition to single oral doses of vitamin D_3, indicated that rye was not interfering with vitamin D activation and/or metabolism since its precursor was fully activated after the birds were exposed to ultraviolet light. In consequence, these workers postulated the existence in rye of a factor which blocks or reduces nutrient absorption from the gut rather than a metabolic type of antagonism.

(d) Pectin and related carbohydrates

The reduced growth rate, feed efficiency and characteristically wet, extremely sticky feces associated with feeding chicks diets containing high levels of rye had also been observed in experiments with chicks fed Western barley (Willingham et al 1959; Adams and Naber, 1969). Water treatment of rye gave rise to a significant improvement of growth and feed efficiency of chicks (MacAuliffe and McGinnis, 1971; McGinnis, 1972; Fernandez, Lucas and McGinnis, 1973) and in turkey poults (Fry et al, 1958). Water treatment of barley similarily alleviated these performance reductions in chicks (Jensen et al 1957; Willingham et al 1959; Adams and Naber, 1969). Antibiotic supplementation enhanced the nutritional value of rye (MacAuliffe and McGinnis, 1971; Fernandez, Lucas and McGinnis, 1973; Patel and McGinnis, 1976; Wagner et al, 1976); a combination of water treatment and penicillin supplementation further improved rye to a level equivalent to that of the control (MacAuliffe and McGinnis, 1971; McGinnis, 1972). A similar improvement of barley diets was brought about by adding antibiotics; supplementation with the antibiotic oleandomycin plus enzyme resulted in a further improvement (Moran et al, 1965).

Gums consisting primarily of high molecular weight pentose polymers admixed with proteinaceous material had been isolated from cereal grains by Freeman and Gortner (1932). These workers found that the pentose fraction of these gums could be hydrated to the extent of at least 800 per cent. In their attempt to find substance(s) common to both rye and barley that might explain some of the fecal problems associated with their use in poultry diets, Preece and McKenzie (1952) found that both of these grains contained large amounts of hemicellulose gums, but that whereas barley has a high percentage of 1-glucosans, rye was rich in pentosans. Burnett (1966) reported that fairly viscous conditions could develop in the gut of barley fed chicks, interfering with digestion and absorption of nutrients, and that such a condition could account for the poor nutritional value of untreated barley as well as the associated sticky feces.

Analyses of cereal grains by McNab and Shannon (1974, 1975) indicated highest levels of unavailable carbohydrates in rye followed next by barley, (Table 5). Whereas barley had a high hemicellulose content, rye was the richest source of pectin.

TABLE 5

Percentage Unavailable Carbohydrates in Cereal Grains (Dry Matter Basis)

Cereal	Hemicellulose	Pectin	Total
Barley[1]	7.96	0.56	8.32
Maize[1]	6.00	0.22	6.22
Oats[1]	4.33	0.68	5.01
Rye[2]	3.90	9.30	13.20
Triticale[2]	5.36	0.35	5.71
Wheat[1]	5.38	1.34	6.72

[1] McNab and Shannon, 1974.

[2] McNab and Shannon, 1975.

A beta glucanase isolated from Bacillus subtilis by Moscatelli et al (1961) and Rickles et al (1962) cleaved the hemicellulose fraction of barley and modified the gut contents in barley fed chicks so that the feces appeared normal. Bacterial and fungal crude enzyme concentrates known to be effective in drastically improving performance of Western barley fed chicks and substantially reducing the sticky nature of the feces was found to be ineffective in improving the performance of chicks fed rye diets (Moran et al 1969). The ineffectiveness of treatments and/or supplements with rye which had previously shown responses with barley should not be surprising as the pentosan and glucan gums, though common in many physical properties, have very different requirements for biodegradation (Moran, et al, 1969).

Burnett (1966) had shown that pectin added to a basal barley diet significantly reduced chick performance and the droppings produced were very sticky. A pectin-degrading enzyme quickly reduced the viscosity of a solution of pectin and significantly improved chick performance. Due to the correlation between the relatively high pectin content of rye and the poor growth of chicks fed rye, Wagner and Thomas (1977) speculated that pectin might well be the growth depressing component in rye. Pectin, a polymeric homopolysaccharide of methyl-D-galacturonate (Lehninger, 1975) is known to possess considerable gelling properties and could be responsible for the sticky feces observed when chickens are fed diets containing high levels of rye. Using balanced diets containing simulated rye with and without commercial pectin and formulated according to the analysis of McNab and Shannon (1974), Wagner and Thomas (1977) showed pectin to be growth depressing but non-toxic to chicks. The alleviation of the growth depression by supplementary penicillin led these workers to conclude that pectin brought about some change in the intestinal microflora that was detrimental to the chick. However, the fact that at high pectin concentrations penicillin alleviated only part of the depression in weight gain suggested an involvement of some other factor(s). By analogy the growth depressing effect of rye could be explained by its high pectin content as indicated by McNab and Shannon (1974). The work of Wagner and Thomas (1977) provided no evidence that rye contained some indigenous microorganism which was pathogenic to the chick. However, if the growth depression was due to the proliferation of some microorganism in the intestine, then the microorganism was either resident in the intestine or was derived from dietary components other than rye.

It should be emphasized that the effectiveness of antibiotic supplements in improving the nutritional value of rye lends support to the hypothesis that rye promotes the growth of an adverse microflora in the gut of the chick. Wagner _et al_ (1976) found that the growth of chicks fed rye diets was depressed during the first week but the chicks subsequently became adapted to the rye diets and their growth rate increased. This same adaptive response observed in laying hens by Fernandez, Kim, Buenrostro and McGinnis (1973) adds support to the adverse microflora hypothesis.

2. Toxic Substances

These are produced by infection of the rye grain with microorganisms and include ergot, and to a lesser extent aflatoxin. The tolerence levels of animals are variable but in general are quite low.

(a) Ergot

Ergot results from the infection of the developing rye florets by the parasitic fungus, Claviceps purpurea. The fungus infects the flowers, prevents seeds from developing, and replaces many kernels with hard, seed-like fungus bodies or sclerotia, commonly known as ergot (Seaman, 1971).

Ergot sclerotia contain several alkaloids that cause poisoning in humans, animals and birds. Because the concentration of alkaloids in sclerotia may vary among strains of the fungus, and because animals differ in their tolerance for the poison, it is difficult to specify toxic concentrations of ergot. However, Seaman (1971) advises that feeds containing 0.1% ergot should be regarded as dangerous.

In reviewing the history of ergotism, Friend and McIntyre (1970) noted that the disease dated as far back as 857 A.D. for humans and to 1630 for domestic animals, with a report on pig ergotism in 1690. Friend and McIntyre (1969) had observed greater reduction in body weight gain in pigs fed No. 3 rye (0.20% ergot) than in pigs fed No. 2 rye (0.03% ergot) and attributed this difference to the level of ergot contamination. In another experiment, Friend and McIntyre (1970) fed barley based diets to growing pigs. The inclusion of as low as 0.05% rye ergot in the diet reduced feed intake by 11% compared to the control, probably due to the extreme unpalatability of the ergot in the rye (Bushuk, 1976). Furthermore, pigs fed 0.10% rye ergot retained less nitrogen than the control pigs. This could have been caused by the increased urination in these pigs, triggered no doubt by the high level of dietary ergocristine, the alkaloid present in the ergot sample to the extent of 0.208% (71% of the total alkaloid content) and known to selectively constrict smooth muscles and blood vessels (Goth, 1961).

Feeding graded doses of ergot, O'Neil and Rae (1965) determined that the tolerance of chicks to ergot was 0.30%. Higher levels resulted in growth depression and mortality. Symptoms of ergot poisoning observed included blackening of the nails, toes and shanks, beaks and combs. For laying hens, 0.20 - 0.40% of ergot in the diet appeared to be the critical level with respect to egg production, feed consumption and maintenance of body weight. No mortality was observed even when as much as 9% ergot was fed. However, a level of 1.17% ergot in wheat screenings was lethal within 48 hours to Muscovy ducklings (Rosenfeld and Beath, 1950). In addition to species difference, the evidence suggested a relationship between ergot tolerance and the age or maturity of the animal (Rosenfeld and Beath, 1950; O'Neil and Rae, 1965).

Modern seed-cleaning methods remove many ergot bodies. For research purposes hand-picking, gravity separation and dilution with ergot-free rye are methods currently employed to ensure that the results from feeding trials are not confounded by ergot contamination. Despite these precautions the characteristic reduction in feed intake, body weight gain and feed efficiency in animals fed rye diets have been consistently observed. Consequently, ergot could be ruled out as a cause for the low nutritional value of rye.

(b) Aflatoxin

Mycotoxins produced by mould fungi grow upon the seeds of a wide range of crops including the cereals. A considerable volume of literature has appeared in recent years concerning aflatoxins. Apart from the serious acute and chronic toxicity symptoms attributable to the aflatoxins the presence in grains of the mould fungus, *Aspergillus flavus*, which produces afflatoxin has been shown to reduce significantly the proportion of total amino acids and certain essential amino acids originally present. Other mould fungi may cause a loss of protein quality by selectively destroying some essential amino acids (Hulse and Laing, 1974).

Lafont and Lafont (1970) conducted chromatographic analyses of samples of mixed animal feeds from two factories in France, and the raw materials of which they were composed, taken directly from the storage silos. Detectable levels (in excess of 0.25 ug/kg) of aflatoxin B_1 were found in 19% of the rye samples. However, literature on the effects of afflatoxin when rye is fed to domestic animals is almost non-existent, and thus it is not clear whether aflatoxin has in fact been responsible for the adverse performance so far reported.

3. Nutrient Limitation - Energy Deficiency

Water treatment or enzyme supplementation of Western barley had been shown to improve chick growth and feed utilization. These results would suggest a substantial increase in the utilization of energy. Leong *et al* (1962) found that the addition of an enzyme supplement to barley diets consistently increased the metabolizable energy (ME) of barley and water extraction resulted in a greater increase in ME. This greater improvement was attributed in part to microbial synthesis of antibiotic-like substance(s) during water treatment, since Willingham *et al* (1960) had suggested that an antibiotic supplement increased the ME of a diet.

Rye is known to be low in gross energy (Table 2). In studying the influence of level of substitution of rye for glucose in test diets on its ME value, MacAuliffe and McGinnis (1971) found that feeding rye at levels of 20 and 40% caused growth depression. The observation that at the 40% level the ME of rye was significantly reduced led these workers to conclude that at this level of substitution rye either interfered with digestion of other dietary components or stimulated the growth of intestinal microorganisms that utilized dietary nutrients. Earlier, Moran et al (1969) had found that changing the physical form of the diet from mash to crumbles (pelleted) resulted in significant improvements not only in live chick performance but also in whole diet ME when the birds were fed rye but not corn. Autoclaving tended to lower the ME value of both grains in a manner paralleling the reduction in their respective nutrient values. Further, the rooster was capable of extracting more energy per unit feed than the chick, apparently because of the maturity and consequently increased efficiency of the digestive system. The use of a fungal crude enzyme concentrate resulted in small but consistent increases in ME for rye, but not for corn. A slightly larger ME was measured with an Eastern grown Tetrapetkus rye as opposed to a Western cultivar.

Since the ME value of rye seems to be dependent upon the level of rye in the diet, the variety of rye and the age of the animals fed the rye diets, it is quite possible that, in the formulation of chick diets containing high levels of rye and calculated to meet the minimum NRC recommended levels, the actual ME obtained by the animals was much lower than their minimum requirements. This could help to explain, in part, the low nutritional value of rye observed in feeding trials.

G. Antibiotics in Animal Feeding.

1. The Nature and Role of Intestinal Microorganisms

The routine inclusion of antibiotics in animal feeds can be justified by an understanding of the complex relationships which exist between all animal species and their resident intestinal microorganisms. The presence and nature of these microbes are inextricably linked with the nutrition, age and physiological state of the host (Fauconneau and Michel, 1970).

Much information concerning the role of intestinal microorganisms has been obtained by the use of animals that are either aseptic (gnotobiotic, axenic), contaminated with microorganisms in a controlled fashion, or conventionally contaminated. It is noteworthy that whereas the monogastric animals have a microflora in their alimentary tract, ruminants have a microfauna composed largely of anaerobic protozoans associated with a microflora (Bryant and Burkey, 1953).

The presence of the intestinal microflora modifies the physiology and biochemistry of the intestinal tract in different ways:

(a) Compared with aseptic rats, conventional animals have a thickened intestinal mucosa and a cecum of greatly reduced weight. In the case of the mouse, Lesher et al (1964) found that the presence of an intestinal flora greatly augmented the turnover of epithelial cells in the small intestine. Furthermore, the presence of a microflora stimulated gastric emptying and intestinal peristalsis. On the other hand, the presence of a microflora in the hen aggravated the destruction of certain amino acids, notably methionine, so that re-utilization of amino acids from the secreted endogenous protein would not be the same in aseptic and conventional groups (Miller and Coates, 1966).

(b) The microflora shows a high metabolic activity toward many nitrogenous substances. One likely action of the flora would be to change loss of N in the feces, but reported observations on fecal N are contradictory. In the cecum of the chicken, the flora seems to influence the proteolysis of poorly digestible proteins such as raw soybean (Nitsan, 1965) and deteriorated protein concentrate (Payne et al 1968). The complex enzyme systems provided by the intestinal flora, are capable of degrading all amino acids by decarboxylation or deamination. However, it would appear that the nutritional effects of the presence of the microflora might be more important than the presumed toxic action of the amines formed (Fauconneau and Michel, 1970).

2. The Action of Antibiotics.

The ability of antibiotics to suppress or inhibit the growth of certain microorganisms has been responsible for their use as animal feed additives. Their wide acceptance has been based on their established benefits of increasing growth rate, improving feed conversion and reducing mortality and morbidity from clinical and subclinical infections. The growth-promoting effects of antibiotics appears to be concerned with decreasing the magnitude of a highly variable environmental condition which has come to be recognized as the "environmental-disease level" (Scott et al, 1976). Since this disease level may occur in different forms and in various degrees of severity, it is apparent that no single mode of action can possibly explain all the growth-promoting effects of antibiotics under wide ranges of environmental conditions. At least four modes of actions have been proposed to account for the growth-promoting activity of antibiotics.

(a) Metabolic Effect

Many researchers had shown that metabolic reactions in the host animal were influenced by antibiotics. Braude and Johnson (1953) reported that feeding of chlortetracycline affected water and nitrogen excretion in pigs. Using rat liver homogenates, Brody et al (1954) showed that tetracycline antibiotics inhibited fatty acid oxidation by mitochondria. Thus the bacteriostatic or bactericidal properties of antibiotics could be largely explained on the basis of metabolic effects. However, in view of the nature of the animal responses and the normal tissue levels of the antibiotics when added to the diet at growth-promotant levels, such metabolic effects could hardly account for the growth promotion in animals fed diets supplemented with moderate levels of antibiotics.

(b) Nutrient-sparing Effect

It is well recognized that certain microorganisms synthesize vitamins and amino acids that are essential to animals and that other bacteria require and compete with the host animal for these dietary essential nutrients. Moore et al (1946) reported that streptomycin stimulated the growth or permitted the rapid growth of some yeasts while Anderson et al (1952) found that feeding diets containing penicillin increased the numbers of intestinal coliforms other than Eschericha coli. Such organisms synthesize nutrients that are dietary essentials for the animals. Thus a diet deficient in certain vitamins can be partly corrected by the microbial synthesis.

Beacom (1959a, 1959b) suggested that the level of protein required by pigs for maximum performance was less in the presence of antibiotics. Although the growth rate of young dairy calves was higher on the higher levels of milk (high quality diet) the response to chlortetracycline was greater on the lower milk (poorer quality) diet (Hogue et al, 1957). Stokstad (1954) produced evidence which indicated that the response to antibiotics was greater when they were included in an inadequate diet. The response suggested an improved utilization of nutrients at critical or suboptimal levels. This could be attributed to nutrient syntheses by intestinal microorganisms, reduced competition from bacteria for critical nutrients, or improved absorption of nutrients from the intestinal tract.

(c) Effect on the Intestinal Wall

The inclusion of antibiotics in animal feeds prevents thickening of the intestinal wall, thus facilitating increased absorption of amino acids, fatty acids and other nutrients (Bird, 1968). Catron et al (1953) reported an increased rate of glucose absorption in animals fed rations fortified with antibiotics. Coates (1953) had observed that the gut walls of calves and chicks fed antibiotics were thinner than those of the control animals fed diets containing no antibiotics. Furthermore, feeding chicks the intestinal contents of infected chicks resulted in a thickening of the intestinal wall. The potential for improved absorption of nutrients seem to be a result of the inhibition of the organisms which damage the intestinal wall or produce toxins which in turn damage intestinal tissue.

(d) Disease-control Effect

Perhaps the major benefits derived from the inclusion of antibiotics as routine feed additives result from suppression or control of sub-clinical or non-specific diseases.

Early work on antibiotics as supplements to animal feeds has shown that the degree of response to antibiotics was inversely related to the general well-being of the experimental animals. Day old chicks when kept in clean, new and previously unused starting batteries did not respond to procaine penicillin G supplements for the first three weeks, although there was a marked response for chicks kept in old batteries (Hill et al, 1952). Though other variables such as climatic conditions and different animal species might have influenced animal performance, the relative contamination of buildings has had an important bearing on the response to antibiotics. The gradual build-up of non-specific infection in buildings, continuously used to house animals, can depress the performance in animals with no apparent symptoms of disease. Such is the type of problem which routine antibiotic feeding aids in combatting.

It must be recognized that the use of nutritionally balanced diets and keeping animals in clean quarters reduce the need for antibiotics. However, current practices in large commercial operations involve confining the animals in as small an area as possible in order to release land for alternative uses and to facilitate mechanization of feeding and waste disposal. This increased concentration of animals in a limited space can lead to a higher incidence of clinical and subclinical diseases because of the greater ease of transmittance from one animal to another. The extensive use of antibiotics has contributed to the success of many of these intensive animal operations.

MATERIALS AND METHODS

A. Preparation of Rye Samples

The rye samples used in these experiments were an unknown cultivar(I) obtained from a commercial grain company, or the cultivar "Puma" (II). The 1,000 - kernel weight of these cultivars were 18.8 $\pm$ 0.1g and 25.1 $\pm$ 0.1g respectively. For the wheat diets the utility cultivar "Glenlea" was used. Both the Puma rye and the Glenlea wheat were harvested from plots at the Glenlea Agricultural Research Station, Manitoba by the Department of Plant Science of the University of Manitoba. Unlike the wheat samples which were ergot-free, the rye samples contained a low percentage of ergot bodies. Prior to their incorporation into diets, the grain samples were cleaned by hand-picking of all foreign materials including ergot bodies and partly infested (blackened) grains. However, when the level of ergot in the rye samples was found to have no adverse effects on chick performance, the rye samples were used without cleaning in dietary formulations. All grain samples were ground to pass through a 2mm screen using the facilities at the University's Poultry Shed or Feed Mill.

B. Formulation of Diets.

Generally all the diets were formulated to meet the minimum NRC recommendations (1971) for replacement pullets, unless a nutrient deficiency was tested. The diets were made isonitrogenous by varying the amount of protein supplement, and isocaloric by adding either corn starch or fat to increase the energy content, or alpha-floc to decrease the energy content. The dietary ingredients were mixed by means of a Hobart 3-speed mixer. Unless specifically stated non-pelleted mash diets were fed.

C. Chicks and Management

One day-old chicks were purchased from a commercial hatchery. Broiler chicks were used in experiment I whereas Leghorn cockerels were used in the other experiments. All the chicks were housed in electrically heated, thermostatically controlled batteries with raised wire floors and provided with continuous lighting. From the time of their arrival to the commencement of the growth trials, the chicks were fed commercial chick starter diets containing a minimum protein of 21%.

Prior to the initiation of each experiment the chicks were starved for 4 hours to reduce gastrointestinal tract fill. The chicks were then individually weighed and placed into appropriate small-range weight groups. In order to minimize the variation of the weight of chicks in each pen, only the "median" weight-range groups were used in the experiments. The random selection of birds from each of these representative weight range groups was conducted in such a manner that the group weights of the birds in the various pens were not significantly different. The number of treatments, replicates per treatment and birds per replicate varied from one experiment to another. Feed and water were provided *ad libitum*. The chicks were fasted for 4 hours before the termination of each experiment. At that time the weight of each group (pen) of birds was taken. The amount of feed consumed by each group of birds was determined by subtracting the amount of feed remaining in the feeding troughs plus the spillage, from the total feed supplied to each pen. The difference between the initial and the final pen weight of each group of birds was taken as the gain in body weight. The feed: gain ratio was calculated by dividing the feed intake (g) by the body weight gain (g). Other parameters measured are described for the appropriate experiments.

D. Analyses

The grain and grain fraction samples were analyzed for crude protein (N x 6.25), and the diets for crude protein, fat, crude fibre and ash by the methods of the Association of Official Agricultural Chemists (1970). The analyses for alkylresorcinol were conducted according to the procedure of Evans et al (1973). The determination of chromic oxide was by the method of Williams et al (1963).

Treatment differences obtained from the statistical analysis of the data (Snedecor, 1956) were subjected to the Student-Newman-Keuls multiple range test (Kirk, 1968).

E. Chick Growth Experiments

The experiments involved administering different dietary treatments to growing chicks. Experimental rye-based diets and control wheat diets were fed throughout the growth trials. Since significant responses in the criteria of performance were obtained when the birds were on test for only a week, the duration of the experiments was restricted to periods of 7 to 14 days.

EXPERIMENT I

The Effects of Different Levels of Wheat and Rye on the Growth of Broiler Chicks

(a) Starting Chicks

The experimental design involved four treatments consisting of increasing levels of rye replacing wheat (Table 6) in five replicates; each replicate contained 10 birds. The experiment was initiated when the birds were four days of age and terminated 14 days later. Feed intake and weight gain were determined, and the corresponding feed:gain ratio calculated on both days 7 and 14.

(b) Finishing Chicks

The experimental design involved four treatments of increasing rye levels replacing wheat (Table 7) in seven replicates; each replicate contained six birds. Prior to being put on test, the birds had been fed the control wheat (0% rye) diet as above. The experiment was initiated when the birds were 30 days of age and was terminated 12 days later. The birds had been starved for 12 hours both before being put on test and before the final pen weights of birds were determined.

TABLE 6

Formulas and analyses of starter diets (Experiment Ia).

Ingredients	Diet A	Diet B	Diet C	Diet D
	%	%	%	%
Rye (I)	-	15.0	30.0	60.0
Wheat	60.0	45.0	30.0	-
Basal mixture[1]	40.0	40.0	40.0	40.0
Chemical analyses of diets[4]				
Dry matter	91.4 ± 0.1	92.2 ± 0.0	88.9 ± 0.0	93.7 ± 0.0
Protein (N x 6.25)	25.3 ± 0.0	24.8 ± 0.1	25.1 ± 0.0	23.7 ± 0.1
Fat (ether extract)	4.8 ± 0.0	5.0 ± 0.0	4.8 ± 0.1	4.7 ± 0.0
Crude fibre	2.4 ± 0.0	2.5 ± 0.0	2.3 ± 0.0	2.1 ± 0.0
Ash	5.6 ± 0.0	5.6 ± 0.0	5.8 ± 0.0	5.7 ± 0.0

[1] The composition of the basal mixture (% of the total diet) was: soybean meal, 28.7; fish (herring) meal, 4.0; tallow, 3.0; calcium phosphate, 2.0; calcium carbonate, 0.8; vitamin mix[2], 1.0; and mineral mix[3], 0.5.

[2] The vitamin mix per kg of diet consisted of: retinyl palmitate, 7,500 I.U.; cholecalciferol, 1,000 I.C.U.; alpha-tocopherol, 10 I.U.; menadione, 2.2 mg; thiamine, 2.2 mg; riboflavin, 4.4 mg; pantothenic acid, 14.3 mg; niacin, 33 mg; pyridoxine, 4.4 mg; biotin, 0.13 mg; folic acid, 1.3 mg; choline chloride, 1,320 mg; vitamin B_{12}, 0.011 mg; and anti-oxidant (Santoquin), 250 mg.

[3] The mineral mix (mg/kg of diet) was composed of: manganese, 16 as MgO; zinc, 1.4 as ZnO; iron, 3.1 as $FeSO_4.7H_2O$; copper 2.5 as $CuSO_4.5H_2O$; and iodized NaCl, 4,930.

[4] Analyses represent average dietary composition ± S.E.M. for each diet.

TABLE 7

Formulas and analyses of finisher diets (Experiment Ib).

ngredients	Diet A	Diet B	Diet C	Diet D
	%	%	%	%
ye (I)	-	16.25	32.5	65.0
heat	65.0	48.75	32.5	-
asal mixture[1]	35.0	35.00	35.0	35.0
hemical analyses of diets[3]				
ry matter	91.4 ± 0.0	92.6 ± 0.3	91.8 ± 0.0	92.3 ± 0.0
rotein (N x 6.25)	22.1 ± 0.0	21.4 ± 0.1	21.2 ± 0.1	19.7 ± 0.1
at (ether extract)	6.3 ± 0.0	6.2 ± 0.0	6.6 ± 0.1	6.4 ± 0.0
rude fibre	2.9 ± 0.0	2.9 ± 0.0	2.9 ± 0.0	2.8 ± 0.0
sh	5.9 ± 0.0	5.6 ± 0.0	5.6 ± 0.0	5.5 ± 0.0

The composition of the basal mixture (% of the total diet) was: soybean meal, 22.0; fish (herring) meal, 2.0; dehydrated alfalfa, 2.0; tallow, 4.5; calcium phosphate, 2.2; calcium carbonate 0.8; vitamin mix[2], 1.0; and mineral mix[2], 0.5.

The vitamin and the mineral mixes were the same as those used in Experiment 1a.

Analyses represent average dietary composition ± S.E.M. for each diet.

EXPERIMENT II

The Effects of Different Milled Fractions of Wheat and Rye

Samples of cleaned wheat and ergot-free rye were subjected to "scouring" in a machine which removed dust and other light particles. The grains were next tempered to achieve a final moisture content of 16.5% for wheat and 14.5% for rye. The tempered grains were stored overnight in large covered tin cans before being ground 24 hours later in a Buhler mill to produce flours, middlings and brans. Recovery of the combined weights of the three milled fractions expressed as a percentage of the untempered grain were respectively 90% for wheat and 89% for rye.

In the formulation of diets, the grain fractions were combined in the same proportions as obtained in milling of the rye sample rather than the wheat sample (Table 8). This was considered necessary in view of the stated objectives of this study.

The experiment was a completely randomized design involving 10 treatments with six replicates of five birds each. Five-day old birds were put on test which lasted nine days. All the diets were pelleted in order to reduce or eliminate the accumulation of feed on the chicks' beaks ("beak impaction") noted in the previous experiments, where high levels of rye were fed. To facilitate pelleting 10% water was added to the diets which were then thoroughly mixed. A superior Templewood pelleting machine equipped with a No. 2 die was used. After pelleting, the diets were spread thinly (1 cm) on sheets of brown paper and air-dried at 24°C for two days. The composition of the diets is given in

Table 9. In addition to the feed intake and body weight gain, the "feces condition" was measured. This was done by an arbitrary visual inspection of the amount of moisture ("degree of wetness") of the feces present on the paper-lined collection trays below each pen. An index of 1 to 3 was employed with a high number indicating feces with high moisture content.

TABLE 8

Yield of Bran, Middlings and Flour obtained from Milling Wheat and Rye (I)

Fraction	Wheat	Rye
	%	%
Bran	19.2	25.4
Middlings	9.0	17.9
Flour	71.8	56.7

Formulas and analyses of diets (Experiment II).

Ingredients	Diet A	Diet B	Diet C	Diet D	Diet E	Diet F	Diet G	Diet H	Diet I	Diet J
	%	%	%	%	%	%	%	%	%	%
Rye (I) bran[1]	-	-	-	-	14.00	-	14.00	14.00	14.00	14.00
Rye (I) middlings[1]	-	-	-	10.08	-	10.08	10.08	-	10.08	10.08
Rye (I) flour[1]	-	-	31.92	-	-	31.92	-	31.92	31.92	29.12
Wheat bran	14.00	14.00	14.00	14.00	-	14.00	-	-	-	-
Wheat middlings	10.08	10.08	10.08	-	10.08	-	-	10.08	-	-
Wheat flour	31.92	29.12	-	31.92	31.92	-	31.92	-	-	-
Alpha-floc	-	2.80	-	-	-	-	-	-	-	2.80
Basal mixture[2]	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00
Chemical analyses of diets[4]										
Dry matter	90.4±0.0	91.3±0.0	91.1±0.1	91.5±0.0	91.2±0.0	91.3±0.1	91.1±0.0	91.4±0.0	91.1±0.1	91.3±0.0
Protein (N x 6.25)	26.0±0.1	25.8±0.0	23.9±0.1	26.6±0.0	26.8±0.0	24.4±0.0	26.0±0.1	24.5±0.1	23.8±0.0	23.2±0.0
Fat (ether extract)	6.4±0.1	6.8±0.2	6.6±0.0	6.1±0.0	5.5±0.3	5.5±0.6	5.3±0.6	5.9±0.0	5.9±0.1	5.5±0.1
Fibre	3.6±0.0	5.7±0.0	3.6±0.0	3.6±0.0	3.1±0.0	3.8±0.1	2.9±0.0	3.5±0.1	3.2±0.0	5.3±0.0
Ash	6.3±0.0	6.2±0.0	6.3±0.0	6.2±0.0	6.3±0.0	6.4±0.0	5.8±0.0	6.1±0.0	6.0±0.0	5.8±0.0

[1] Hand picked, ergot-free rye samples were used in milling to obtain rye fractions. After formulation of the diets, 10% water was added to facilitate pelleting.

[2] The composition of the basal mixture (% of the total diet): soybean meal, 31.7; fish (herring) meal, 4.0; soybean oil, 4.0; calcium phosphate, 2.0; calcium carbonate, 0.8; vitamin mix[3], 1.0; and mineral mix[3], 0.5.

[3] The vitamin and the mineral mixes were the same as those used in Experiment la.

[4] Analyses represented average dietary composition ± S.E.M. for each diet.

EXPERIMENT III

The Effects of a Lyophilized Water Extract of Rye, Water Extraction or Two Processing Methods

Rye was extracted by adding five parts of distilled water (by weight) to one part of ground rye in a 50-litre plastic pail and mixing at two-hour intervals using a plastic stirrer. The pail containing the rye-water mixture was covered and allowed to stand overnight. The clear brown supernatant was filtered through several layers of fine cheese cloth into a flat stainless steel tray of 5 cm depth. The insoluble rye suspension was centrifuged at 20,000 x g for 15 minutes in a Sorvall Superspeed RC2-B centrifuge. Following this, the insoluble material was resuspended in three parts of distilled water and subjected to the same extraction procedure as described above. All the supernatant fractions were pooled, poured into similar trays, and placed in a Virtis Research freeze-drier for 72 hours. A brown, fluffy, hygroscopic solid representing 18% of the original ground rye was obtained. The insoluble extracted rye was spread thinly (1 cm) on sheets of brown paper and air-dried at 24°C for two days. The water extracted rye thus obtained represented 81% of the original ground rye. Just before inclusion in the diets, the lyophilized water extract of rye was carefully ground in a water-cooled Chemical Rubber Company grinder. The dried water extracted rye was ground in a Wiley Mill equipped with a 2 mm screen.

Autoclaving of the ground rye samples was carried out prior to their incorporation into the diets. The samples were spread in porcelain trays to a depth of 2 cm and autoclaved at 121°C for 10 or 30 minutes.

Pelleting of one diet was by the same procedure as described in experiment II.

(a) Diets containing One Level of the Lyophilized Water Extract of Rye, One Level of Water Extracted Rye and Rye subjected to Two Processing Methods

A completely randomized design involving six treatments with six replicates of five birds each was employed. The experiment was initiated when the birds were five days old and was terminated after eight days. The formula and analyses of the diets are given in Table 10. The percentage of the lyophilized rye extract added to a wheat diet was in excess of that obtained upon water extraction. (i.e: 22%[1] vs. 18%) Parameters measured were feed intake, weight gain, feces condition, beak impaction and vent blockage. The last two factors were determined by arbitrarily assigning a score to indicate the degree of feed accumulation on the chicks' beaks, or the amount of feces adhering onto their vents. A scoring index of 1 to 3 was employed: a high score denoted a high degree of beak impaction or vent blockage.

(b) Dietary Treatments Containing Two Levels of the Lyophilized Water Extract of Rye, One Level of Water-Extracted Rye and Rye subjected to Two Autoclaving Periods.

The experimental design involved seven treatments in six replicates, each of which contained five birds. The experiment was conducted using four-day old birds and lasted seven days. Two levels (6%, 12%) of

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[1] $\frac{\text{12.5\% rye extract added}}{\text{57.4\% grain in the diet}} \times 100\% = 21.8\%$

TABLE 10

Formulas and analyses of diets (Experiment IIIa).

Ingredients	Diet A	Diet B	Diet C	Diet D[1]	Diet E[1]	Diet F[1]
	%	%	%	%	%	%
Rye[2] (I)	–	–	–	57.4	57.4	57.4
Water-extracted rye[2]	–	–	57.4	–	–	–
Water extract of rye[2] (lyophilized)	–	12.5	–	–	–	–
Wheat	32.6	32.6	–	–	–	–
Corn starch	24.8	12.3	–	–	–	–
Basal mixture[3]	42.6	42.6	42.6	42.6	42.6	42.6
Chemical analyses of diets[6]						
Dry matter	91.4±0.1	89.9±0.0	89.6±0.0	90.1±0.1	90.2±0.2	90.9±0.0
Protein (N x 6.25)	23.1±0.1	25.3±0.1	20.6±0.0	23.0±0.0	23.1±0.0	23.0±0.0
Fat (ether extract)	4.5±0.1	4.4±0.0	5.1±0.0	4.9±0.1	6.1±1.0	5.0±0.0
Crude fibre	2.7±0.1	2.6±0.0	3.3±0.0	3.0±0.0	3.0±0.1	3.0±0.0
Ash	7.2±0.0	7.7±0.1	6.6±0.0	7.2±0.0	7.1±0.0	7.0±0.0

[1] Diet D contained unprocessed rye; diet E was pelleted; diet F contained rye that was autoclaved for 30 minutes at 121°C.

[2] Hand picked, ergot-free rye samples were used.

[3] The composition of the basal mixture (% of the total diet) was: soybean meal, 28.0; fish meal (herring), 6.0; soybean oil, 3.0; calcium phosphate, 1.8; calcium carbonate, 1.8; vitamin mix[4], 1.0; mineral mix[4], 0.5; and chromic oxide-methionine mix[5], 0.5.

[4] The vitamin mix and the mineral mix were the same as those used in Experiment 1a.

[5] The chromic oxide-methionine mix (% of the total diet) consisted of: chromic oxide, 0.2; DL-methionine, 0.1; and wheat bran, 0.2.

[6] Analyses represent average dietary composition ± S.E.M. for each diet.

lyophilized water extract of rye were added to diets containing wheat as the cereal in order to assess the influence of these levels on chick performance. Diets containing water-extracted rye or rye autoclaved for 10 or 30 minutes were also fed (Table 11).

EXPERIMENT IV

The Effects of Ergot, Procaine Penicillin Supplementation, Pelleting of the diets or Treatment of the Chicks in Two Different Ways.

Five-day old chicks were used in this 14 day growth trial. A completely randomized design involving eight treatments with six replicates of 10 birds each was employed. The formulas and analyses of the diets are given in Table 12. The effects of feeding diets containing uncleaned rye, uncleaned rye plus 2% "ergot bodies" or ergot-free rye were compared to the effects of feeding wheat diets. A total of five diets was prepared from the ergot-free rye. The first of these diets was fed in the non-pelleted (mash) form; the second was pelleted and the third was non-pelleted and supplemented with 50 mg/kg procaine penicillin. The beaks of all the birds fed the fourth diet were cleaned daily whereas the vents of the firds fed the fifth diet were cleaned daily. These last two treatments were administered in order to evaluate the effects of the daily cleaning of these organs on the chicks' performance. The parameters measured were feed consumption, weight gain and feed:gain ratio; in addition the degree of beak impaction, vent blockage and feces condition were determined.

TABLE 11

Formulas and analyses of diets (Experiment IIIb).

Ingredients	Diet A	Diet B	Diet C	Diet D	Diet E[1]	Diet F[1]	Diet G[1]
	%	%	%	%	%	%	%
Rye[2] (II)	–	–	–	–	55.0	55.0	55.0
Water-extracted rye[2]	–	–	–	55.0	–	–	–
Water extract of rye[2] (lyophilized)	–	6.0	12.0	–	–	–	–
Wheat	55.0	55.0	55.0	–	–	–	–
Corn Starch	3.0	1.0	–	–	2.3	2.3	2.3
Alpha-floc	3.6	3.3	2.1	–	2.0	2.0	2.0
Soybean meal	26.7	23.0	19.2	32.3	28.0	28.0	28.0
Soybean oil	4.0	4.0	4.0	5.0	5.0	5.0	5.0
Other ingredients[3]	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Crude protein content[6] (N x 6.25)	21.5±0.0	22.0±0.0	21.4±0.0	21.3±0.1	21.5±0.0	22.0±0.1	22.0±0.1

1 Diet E contained unprocessed rye; diets F and G contained rye that had been autoclaved at 121°C at a depth of 2 cm for 10 and 30 minutes, respectively.

2 Hand picked, ergot-free samples were used.

3 The percent fish (herring) meal, calcium phosphate, calcium carbonate, vitamin mix[4], mineral mix[4], and amino acid mix[5] added to each diet was 2.0, 1.7, 2.0, 1.0, 0.5 and 0.5, respectively.

4 The vitamin and the mineral mixes were the same as those used in Experiment 1a.

5 The amino acid mix was composed of (% of the diet): L-lysine HCl, 0.1; DL-methionine, 0.2; and corn starch, 0.2.

6 Average dietary composition ± S.E.M. for each diet.

TABLE 12

Formulas and analyses of diets (Experiment IV).

Ingredients	Diet G	Diet H	Diet I	Diet J[1] – M	Diet N
	%	%	%	%	%
Rye, uncleaned[2] (I)	-	56.9	54.9	-	-
Rye, hand picked ergot-free (I)	-	-	-	56.9	56.9
Ergot-bodies[3]	-	-	2.0	-	-
Wheat	32.6	-	-	-	-
Corn starch	24.8	0.5	0.5	0.5	-
Procaine penicillin mix[4]	-	-	-	-	0.5
Basal mixture[5]	42.6	42.6	42.6	42.6	42.6
Chemical analyses of diets[8]					
Dry matter	91.0±0.1	90.9±0.0	90.9±0.0	90.9±0.0	90.9±0.0
Protein (N x 6.25)	22.4±0.3	23.2±0.0	23.2±0.0	23.2±0.0	23.2±0.0
Fat (ether extract)	4.4±0.0	4.8±0.0	4.8±0.0	4.8±0.0	4.8±0.0
Fibre	2.4±0.0	2.6±0.1	2.6±0.1	2.6±0.1	2.6±0.1
Ash	7.1±0.0	7.1±0.0	7.1±0.0	7.1±0.0	7.1±0.0

1 Diet J was unpelleted; diet K, pelleted; the beaks of the chicks consuming diet L were cleaned daily; the vents of the chicks consuming diet M were cleaned daily.

2 Contained 1.4% ergot bodies plus partly infested (blackened) grains.

3 Obtained by handpicking of the uncleaned rye samples. The blackened grains accounted for in excess of 95% of these "ergot bodies".

4 PRO-PEN (50% procaine penicillin) used in diet N was supplied by Merck, Sharp and Dome. Two grams of PRO-PEN was added to 98g corn starch. Seventy-five grams of this mixture was added to make up a 15kg diet. The resulting concentration of procaine penicillin was 50 mg/kg.

5 The basal mixture consisted of (% of the diet): soybean meal, 28.0; fish (herring) meal, 6.0; soybean oil, 3.0; calcium phosphate, 1.8; calcium carbonate, 1.8; vitamin mix[6], 1.0; mineral mix[6], 0.5; and chromic oxide-methionine mix[7], 0.5.

6 The vitamin and the mineral mixes were the same as those used in Experiment 1a.

7 The chromic oxide-methionine mix was composed of (% of the diet): chromic oxide, 0.2; methionine 0.1; and corn starch, 0.2.

8 Analyses represent average dietary composition ± S.E.M. for each diet.

EXPERIMENT V

The Effect of Diets Containing Rye Autoclaved for Increasing Time Periods.

Ground uncleaned rye was autoclaved as described for Experiment III for increasing periods of time (0,5,10,15,25 and 50 minutes). A completely randomized design involving six treatments (autoclaving times) with six replicates of eight birds each was employed. The experiment was initiated when the birds were five days of age and was terminated seven days later. The composition of the diets is given in Table 13.

TABLE 13

Formulas and analyses diets (Experiment V).

Ingredients	Diets[1] A - F
	%
Rye (II)	70.0
Meat meal	23.0
Soybean oil	5.0
Vitamin Mix[2]	1.0
Mineral mix[2]	0.5
Amino acid mix[3]	0.5
Crude protein content[4] (N x 6.25)	21.0 ± 0.0

[1] Prior to mixing the diets, ground rye was spread in porcelain trays to a depth of 2 cm and autoclaved at 121°C for 0, 5, 10, 15, 25 or 50 minutes.

[2] The vitamin and the mineral mixes were the same as those used in Experiment 1a.

[3] Amino acid mix was composed of (% of diet): L-lysine HCl, 0.1; DL-methionine, 0.3; and corn starch, 0.1.

[4] Average dietary protein composition ± S.E.M.

EXPERIMENT VI

The Effect of Fat and Energy

(a) Diets Containing Two Levels and Two Types of Fat.

Eight treatment combinations were obtained by a 2 X 2 X 2 factorial arrangement of two grain types (rye or wheat), two fat type (soybean oil or tallow) and two fat levels (2% or 5%) with six replicates of six birds each. The experiment was initiated when the birds were six days old and was terminated eight days later. The diets were calculated to be iso-nitrogenous and isocaloric (Table 14). However, the energy content was calculated to be slightly below (by 7%) the recommended NRC requirements.

(b) Diets Containing Two Energy Levels.

A 2 X 2 factorial arrangement of treatments with six replicates of eight birds each was used to evaluate the two grains (rye or wheat) and two energy levels (low or high). The low and high energy levels were respectively calculated to be 9% below and 7% above the recommended NRC requirements (Table 15). The age of the birds and the duration of the experiment were the same as in VI(a) above.

TABLE 14

Formulas and analyses of diets (Experiment VIa)

Ingredients	Diet A	Diet B	Diet C	Diet D	Diet E	Diet F	Diet G	Diet H
	%	%	%	%	%	%	%	%
Rye(II)	54.4	54.4	54.4	54.4	-	-	-	-
Wheat	-	-	-	-	50.4	50.4	50.4	50.4
Corn starch	7.0	8.0	-	3.0	7.5	8.5	0.5	3.5
Alpha-floc	1.0	-	5.0	2.0	4.5	3.5	8.5	5.5
Soybean oil	2.0	-	5.0	-	2.0	-	5.0	-
Tallow	-	2.0	-	5.0	-	2.0	-	5.0
Basal mixture[1]	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6
Calculated analyses								
Crude protein (N x 6.25), %	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9
Fat, %	4.2	4.2	7.2	7.2	4.2	4.2	7.2	7.2
M.E. (Kcal/kg)	2706	2703	2719	2732	2708	2705	2721	2734

[1]The composition of the basal mixture (% of the diet) was: soybean meal, 29.0; fish (herring) meal, 1.0; calcium phosphate, 1.8; calcium carbonate, 1.8; vitamin mix[2], 1.0; mineral mix[2], 0.5; and chromic oxide-methionine mix[3], 0.5.

[2]The vitamin and the mineral mixes were the same as those used in Experiment 1à.

[3]The chromic oxide-methionine mix was made up of (% of the diet): calcium oxide, 0.2; DL-methionine, 0.2; and wheat middlings, 0.1.

TABLE 15

Formulas and analyses of diets (Experiment VIb).

Ingredients	Diet A	Diet B	Diet C	Diet D
	%	%	%	%
Rye (II)	60.0	60.0	-	-
Wheat	-	-	55.0	55.0
Corn starch	5.0	3.0	6.0	4.0
Alpha-floc	4.0	-	8.0	4.0
Soybean oil	2.0	8.0	2.0	8.0
Basal mixture[1]	29.0	29.0	29.0	29.0
Chemical and calculated analyses of diets:				
Dry matter[4]	93.0±0.0	93.1±0.0	92.5±0.0	93.1±0.0
Protein (N x 6.25)[4]	21.5±0.1	21.5±0.1	21.6±0.2	21.9±0.0
Fat (ether extract)[4]	5.9±0.1	11.8±0.0	5.8±0.1	10.2±0.1
Metabolizable Energy (kcal/kg)[5]	2647	3111	2648	3112

[1]The basal mixture (% of the diet) consisted of: meat meal, 27.0; vitamin mix[2], 1.0; mineral mix[2], 0.5; and amino acid mix,[3] 0.5 .

[2]The vitamin and the mineral mixes were the same as those used as in Experiment 1a.

[3]Amino acid mix consisted of (% of the diet): L-lysine HCl, 0.1; DL-methionine, 0.3; and corn starch, 0.1.

[4]Average dietary composition ± S.E.M. for each diet.

[5]Calculated.

EXPERIMENT VII

The Effect of Vitamin D

(a) Diets with or without Added Vitamin D_3

A 2 (rye or wheat) X 2 (no added vitamin D_3 or 5 X NRC vitamin D_3 recommended level) factorial arrangement of treatments was designed, with six replicates of five birds each. The formulas and analyses of the diets are given in Table 16. Five-day old birds were used in this 14 day growth trial. Feed consumption was determined on both day 7 and day 14, when the experiment was terminated.

(b) Diets with Three Levels of Excess Vitamin D_3

A 2 X 3 factorial arrangement of treatments was designed to evaluate two grain types (rye or wheat) and three increasing levels of excess vitamin D_3 (5X, 100X, or 1,000X NRC recommendation). Each treatment combination consisted of six replicates of six birds each. The experiment was initiated when the birds were six days of age and was terminated eight days later. The formulas and analyses of the diets are given in Table 17.

TABLE 16

Formulas and analyses of diets (Experiment VIIa).

Ingredients	Diet A	Diet B	Diet C	Diet D
	%	%	%	%
Rye (II)	-	-	64.4	64.4
Wheat	60.4	60.4	-	-
Alpha-floc	4.0	4.0	-	-
Vitamin mix (complete)[1]	1.0	-	1.0	-
Vitamin mix, less vitamin D_3[2]	-	1.0	-	1.0
Basal mixture[3]	34.6	34.6	34.6	34.6
Chemical analyses of diets				
Dry matter	89.4±0.0	89.6±0.0	90.6±0.0	90.5±0.0
Protein (N x 6.25)	21.0±0.0	21.1±0.0	20.9±0.0	20.7±0.1
Fat (ether extract)	5.6±0.0	3.7±0.0	4.3±0.0	4.1±0.0
Fibre	5.7±0.0	5.7±0.0	3.0±0.0	2.8±0.0
Ash	6.7±0.0	6.5±0.0	7.2±0.0	7.2±0.0

[1] Same as that used in Experiment la.

[2] Same as above except that no vitamin D_3 was included.

[3] The composition of the basal mixture (% of the diet) was: soybean meal, 26.0; fish (herring) meal, 2.0; tallow, 2.0; calcium phosphate, 1.8; calcium carbonate, 1.8; mineral mix[4], 0.5; and chromic oxide-amino acid mix[5], 0.5.

[4] The mineral mix was the same as that used in Experiment 1a.

[5] The chromic oxide-methionine mix consisted of (% of the diet): chromic oxide, 0.2; DL-methionine, 0.1; and corn starch, 0.2.

TABLE 17

Formulas and analyses of diets (Experiment VIIb).

Ingredients	Diet A	Diet B	Diet C	Diet D	Diet E	Diet F
	%	%	%	%	%	%
Rye (II)	54.4	-	54.4	-	50.4	-
Wheat	-	50.4	-	54.4	-	50.4
Corn starch	8.0	8.5	8.0	8.0	8.5	8.5
Alpha-floc	-	3.5	-	-	3.5	3.5
Vitamin mix[1]	1.0	1.0	1.0	1.0	1.0	1.0
Basal mixture[2]	36.6	36.6	36.6	36.6	36.6	36.6
Calculated analyses of diet						
Protein (N x 6.25)	19.9	19.9	19.9	19.9	19.9	19.9
Vitamin D (ICU/kg diet)	1,000	1,000	20,000	20,000	200,000	200,000

[1]The vitamin mix was the same as in Experiment 1a except for level of vitamin D included in the mix. The amounts of cholecalciferol added in this mix are indicated under calculated analyses of diet.

[2]The composition of the basal mixture (% of the diet) was: soybean meal, 29.0; fish (herring) meal, 1.0; tallow, 2.0; calcium phosphate, 1.8; calcium carbonate, 1.8; mineral mix[3], 0.5; and chromic oxide-methionine mix[4], 0.5.

[3]Same as those used as in Experiment 1a.

[4]The chromic oxide-methionine mix (% of the diet) was made up of chromic oxide, 0.2; and DL-methionine, 0.2; wheat middlings, 0.1.

EXPERIMENT VIII

The Effects of Grian Type, Protein Source and Level, and Form of the Diets.

(a) The Interaction of Grain Type, Protein Source and Form of The Diets

The arrangement of the treatments was a 2 (grain type) X 3 (protein sources) X 2 (forms of diet) factorial, with four replicates of eight birds each. Seven day old chicks were used in this seven day growth trial. The dietary formulations and analyses are in Table 18.

(b) The Interaction of Grain Type, Protein Level and Form of the Diets.

A 2 X 2 X 2 factorial experiment was designed to assess the effects of two grain types (rye or wheat), 2 protein levels (21% or 26%), and 2 forms of the diets (non-pelleted or pelleted) in four replicates each consisting of eight birds. This experiment which was run cuncurrently with VIII(a) involved the use of seven day old birds, and lasted for seven days. The formulas and analyses of the diets are given in Table 19.

(c) Interaction of Grain Type, Protein Source and Protein Level

Rye or wheat were supplemented with meat meal or fish meal in diets containing 18% or 26% of protein in a 2 X 2 X 2 factorial arrangement of treatments. Each of the eight treatments consisted of six replicates of eight birds each. Dietary formulations and analyses are in Table 20. The experiment was initiated when the birds were four days old and was terminated seven days later.

TABLE 18

Formulas and analyses of diets (Experiment VIIIa).

	Diets - Non-pelleted and pelleted[1]					
gredients	A	B	C	D	E	F
	%	%	%	%	%	%
e (II)	57.4	57.4	57.4	-	-	-
eat	-	-	-	53.1	53.1	53.1
rn starch	-	4.0	4.5	0.5	4.5	5.0
pha-floc	-	10.4	3.1	3.8	14.2	6.9
ybean meal	32.0	-	-	32.0	-	-
sh (herring) meal	-	20.0	-	-	20.0	-
at meal	-	-	28.0	-	-	28.0
ybean oil	5.0	5.0	5.0	5.0	5.0	5.0
lcium phosphate	1.6	0.5	-	1.6	0.5	-
lcium carbonate	2.0	1.2	-	2.0	1.2	-
tamin mix[2]	1.0	1.0	1.0	1.0	1.0	1.0
neral mix[2]	0.5	0.5	0.5	0.5	0.5	0.5
ino acid mix[3]	0.5	-	0.5	0.5	-	0.5
ude protein content (N x 6.25), %	22.6±0.1	20.8±0.1	21.7±0.1	21.9±0.0	21.1±0.0	21.8±0.0

ne-half of each diet was mixed with 10% water and was pelleted. The pelleted diets ere spread as a thin layer (1 cm in depth) and were dried at 24°C for 4 days.

ame as in Experiment 1 a.

ne amino acid mix contained (% of the diet): L-lysine HCl, 0.1; DL-methionine, 0.2; l corn starch, 0.2.

TABLE 19

Formulas and analyses of diets (Experiment VIIIb)

Ingredients	Diets - Non-pelleted and pelleted[1]			
	A	B	C	D
	%	%	%	%
Rye (II)	57.4	57.4	-	-
Wheat	-	-	53.1	53.1
Corn starch	4.0	0.5	4.5	1.0
Alpha-floc	10.4	7.4	14.2	11.2
Fish (herring) meal	20.0	28.0	20.0	28.0
Soybean oil	5.0	4.0	5.0	4.0
Calcium phosphate	0.5	-	0.5	-
Calcium carbonate	1.2	1.2	1.2	1.2
Vitamin mix[2]	1.0	1.0	1.0	1.0
Mineral mix[2]	0.5	0.5	0.5	0.5
Crude protein content (N x 6.25)	20.8±0.1	26.4±0.1	21.1±0.0	26.0±0.0

[1] One-half of each diet was pelleted as described under Experiment VIIIa.

[2] Same as those in Experiment la.

TABLE 20

Formulas and analyses of diets (Experiment VIIIc).

Ingredients	Diet A	Diet B	Diet C	Diet D	Diet E	Diet F	Diet G	Diet H
	%	%	%	%	%	%	%	%
Rye(II)	55.0	55.0	55.0	55.0	-	-	-	-
Wheat	-	-	-	-	51.0	51.0	51.0	51.0
Corn starch	9.0	8.3	-	0.5	9.4	8.7	0.4	4.0
Alpha-floc	7.4	11.3	-	10.5	11.0	14.9	3.6	10.8
Fish (herring) meal	-	14.5	-	26.0	-	14.5	-	26.0
Meat meal	20.6	-	37.0	-	20.6	-	37.0	-
Soybean oil	6.0	6.0	6.0	5.5	6.0	6.0	6.0	5.7
Calcium phosphate	-	1.5	-	-	-	1.5	-	-
Calcium carbonate	-	1.4	-	1.0	-	1.4	-	1.0
Vitamin mix[1]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mineral mix[1]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Amino acid mix[2]	0.5	0.5	0.5	-	0.5	0.5	0.5	-
Crude protein content, %	18.3±0.0	17.6±0.0	25.5±0.1	26.0±0.0	17.9±0.1	18.0±0.1	26.0±0.2	26.7±0.0

[1] Same as those used in Experiment 1a.

[2] The composition of the amino acid mix (% of the diet) for diets A and E was 0.2% L-lysine HCl and 0.3% DL-methionine. The premix for remaining diets (% of the diet) was 0.1% DL-methionine and 0.4% corn starch.

EXPERIMENT IX

Tryptophan Supplementation of a Rye Diet

A completely randomized design involving two treatments with six replicates was employed. Each replicate contained eight birds. Five-day old chicks were used in this seven day feeding trial. The composition of the control rye diet was the same as those in Experiment V (Table 13). The tryptophan supplemented rye diets was formulated by adding 0.2% L-tryptophan to a diet having the same composition as the control diet. The experiment was initiated when the birds were five days old and was terminated after seven days.

EXPERIMENT X

The Effects of Increasing Levels of Procaine Penicillin and Two Protein Sources.

(a) Increasing Levels of Procaine Penicillin

(i) The experiment involved four treatments: a wheat control diet and three rye (I) diets supplemented with 0, 50 or 100 mg/kg procaine penicillin (Table 21). Each treatment consisted of six replicates of 10 birds each. Five-day old chicks were used in this 14 day growth trial. In addition to feed consumption, gain in body weight and feed: gain ratio, beak impaction, vent blockage and feces condition were measured.

(ii) Rye (II) diets were supplemented with 0, 10, 20, 40, 80 or 160 mg/kg procaine penicillin (Table 22). A completely randomized design involving these six treatments with six replicates of eight birds each was employed. The experiment was initiated when the birds were five days of age and was terminated after seven days.

(b) The Interaction of Procaine Penicillin and Protein Sources

Eight treatment combinations were obtained in a 2 (rye or wheat) X 2 (meat meal or fish meal) X 2 (0 or 160 mg/kg procaine penicillin) factorial arrangement in six replicates of eight birds each. The formulas and analyses of the diets are given in Table 23. This seven day experiment involved the use of six-day old chicks. Apart from measuring the feed

TABLE 21

Formulas and analyses of diets (Experiment Xa(i).

Ingredients	Diet A	Diet B	Diet C	Diet D
	%	%	%	%
Rye(I)	-	56.9	56.9	56.9
Wheat	32.6	-	-	-
Corn starch	24.8	0.5	-	-
Procaine penicillin mix	-	-	0.5[1]	0.5[2]
Basal mixture[3]	42.6	42.6	42.6	42.6
Calculated crude protein content (N x 6.25), %	22.0	21.9	21.9	21.9

[1]PRO-PEN (50% procaine penicillin) was supplied by Merck, Sharp and Dome. 2 g PRO-PEN was added to 98 g corn starch; 75 g of this mixture was added to make up a 15 kg diet. This was equivalent to 50 mg/kg diet.

[2]75 g of a mixture of 4 g PRO-PEN and 96 g corn starch was added to make up a 15 kg diet. This was equivalent to 100 mg/kg diet.

[3]The composition of the basal mixture (% of the diet) was: soybean meal, 28.0; fish (herring) meal, 6.0; soybean oil, 3.0; calcium phosphate, 1.8; calcium carbonate, 1.8; vitamin mix[4], 1.0; mineral mix,[4] 0.5; and chromic oxide-methionine mix[5], 0.5

[4]Same as those used in Experiment la.

[5]The chromic oxide-methionine mix consisted of (% of the diet): chromic oxide, 0.2; DL-methionine, 0.1; and corn starch, 0.2.

TABLE 22

Formulas and analyses of diets (Experiment Xa(ii).

Ingredients	Diets A - F
	%
Rye(II)	70.0
Meat meal	23.0
Soybean oil	5.0
Vitamin mix[1]	1.0
Mineral mix[1]	0.5
Amino acid mix[2]	0.5
Penicillin mix[3]	
Crude protein content (N x 6.25), %	20.9 ± 0.1

[1]Same as those used in Experiment 1a.

[2]Same as those used in Experiment 6.

[3]The penicillin (PEN-P) used to prepare the penicillin mix was supplied as Penicillin G Procaine salt by the Sigma Chemical Co., St. Louis, Mo., U.S.A. and contained 1,000 units/mg. A 1-kg stock sample of PEN-P was prepared by mixing 20 g PEN-P and 980 g corn starch. An aliquot of this stock solution was then added to each of the different diets so that the final concentration of penicillin in the diets A to F were 0, 10, 20, 40, 80 and 160 mg/kg diet respectively.

TABLE 23

Formula and analyses of diets (Experiment Xb).

Ingredients	Diet A	Diet B	Diet C	Diet D	Diet E	Diet F	Diet G	Diet H
	%	%	%	%	%	%	%	%
Rye(II)	63.0	63.0	-	-	63.0	63.0	-	-
Wheat	-	-	64.0	64.0	-	-	64.0	64.0
Corn starch	0.8	0.8	1.8	1.8	-	-	1.0	1.0
Alpha-floc	-	7.4	-	7.4	-	7.4	-	7.4
Fish (herring) meal	-	18.6	-	18.6	-	18.6	-	18.6
Meat meal	28.5	-	28.5	-	28.5	-	28.5	-
Soybean oil	6.0	6.0	4.0	4.0	6.0	6.0	4.0	4.0
Calcium phosphate	-	1.0	-	1.0	-	1.0	-	1.0
Calcium carbonate	-	1.5	-	1.5	-	1.5	-	1.5
Vitamin mix[1]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mineral mix[1]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Chromic oxide	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Penicillin mix[2]	-	-	-	-	0.8	0.8	0.8	0.8
Chemical analyses of diets[3]								
Dry matter	93.5±0.3	93.2±0.1	92.7±0.3	92.8±0.2	93.5±0.3	93.2±0.1	92.7±0.3	92.8±0.2
Protein (N x 6.25)	21.2±0.0	21.9±0.1	22.0±0.0	22.3±0.1	21.2±0.0	21.9±0.1	22.0±0.0	22.3±0.1

[1]Same as those used in Experiment 1a.

[2]Source was the same as used in Experiment Xa(ii). The final dietary concentration of penicillin in diets E to H was 160 mg/kg of diet.

consumption and gain in body weight from which were calculated the corresponding feed:gain ratios, the feed dry matter and protein retention for each diet were determined. Excreta collections for nutrient retention evaluations were initiated after the birds were three days on test. The feces which were allowed to accumulate in the trays under the pens for the last four days were air-dried at 24^{o}C for three more days; traces of feathers and spilt feed were removed. The fecal material from each pen (replicate) was ground and stored frozen (-20^{o}C) in polyethylene bags until analyzed. The percent of dietary nutrient retained equalled grams nutrient per gram of diet minus grams nutrient per gram of excreta times Cr_2O_3 in the diet divided by Cr_2O_3 in the excreta X 100.

RESULTS

For each experiment, the performance criteria data in each table are presented on an average chick basis.

EXPERIMENT I(a)

Feed consumption, body weight gain and feed:gain ratios of young broiler chicks fed diets containing varying levels of wheat and rye are presented in Table 24. At the end of the first week, the results show that feed consumption was the same for the rye diets but significantly ($P<0.01$) lower than for the wheat diets. There were however no differences in consumption of any of the diets by the end of the second week, indicating that the birds became adapted to consuming high levels of rye in the diets. At the end of each week, the gain in body weight was progressively reduced as increasing levels of rye were substituted for wheat in the diets: the all-rye diets depressed weight gain by 21% and 26% in weeks 1 and 2 respectively. The efficiency of feed conversion followed a pattern similar to that of weight gain.

EXPERIMENT I(b)

This study which was similar in design to Experiment I(a) was conducted with finishing broiler chicks. The data presented in Table 25 and Fig. 4 reveal no significant differences in consumption of the four diets. In contrast, body weight gains decreased and feed:gain ratio increased as the level of rye in the diet increased ($P<0.01$), the corresponding changes being - 27% and + 42% respectively for the all-rye as compared to the all-wheat diet.

TABLE 24

The effects of feeding different levels of wheat and rye on the growth of starting broiler chicks (Experiment Ia)

Treatment[1]	Response criteria[2]					
	Feed intake		Weight gain		Feed:gain	
	Week 1	Week 2	Week 1	Week 2	Week 1	Week 2
	g	g	g	g	g/g	g/g
60% wheat, 0% rye	178 A	516	135 A	335 A	1.32 B	1.54 C
45% wheat, 15% rye	165 B	506	122 B	303 B	1.35 B	1.67 B
30% wheat, 30% rye	167 B	507	121 B	299 B	1.38 B	1.69 B
0% wheat, 60% rye	166 B	509	106 C	249 C	1.57 A	2.04 A
SEM	2.4	6.2	1.7	4.0	0.02	0.02

[1]The number of pens in each of the four treatment groups was 5. The number of birds in each pen was 10. Average initial bird weight was 65.8 ± 0.2 SEM. This experiment was initiated when the birds were 4 days of age.

[2]Means for those response criteria not sharing a common postscript letter within each column were significantly different at P<0.01.

TABLE 25

The effects of feeding different levels of wheat and rye on the growth of finishing broiler chicks (Experiment 1b).

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
65.0% wheat, 0% rye	1215	553 A	2.20 C
48.75% wheat, 16.25% rye	1255	535 A	2.35 BC
32.50% wheat, 32.50% rye	1250	476 AB	2.63 B
0% wheat, 65.0% rye	1268	406 B	3.12 A
SEM	22	19	0.08

[1]The number of pens in each of the four treatment groups was 7. The number of birds in each pen was 6. Average initial bird weight was 823.6 $\pm$ 1.1 SEM. The experiment was initiated when the birds were 30 days of age.

[2]Means for those response criteria not sharing a common postscript letter within each column were significantly different at P<0.01.

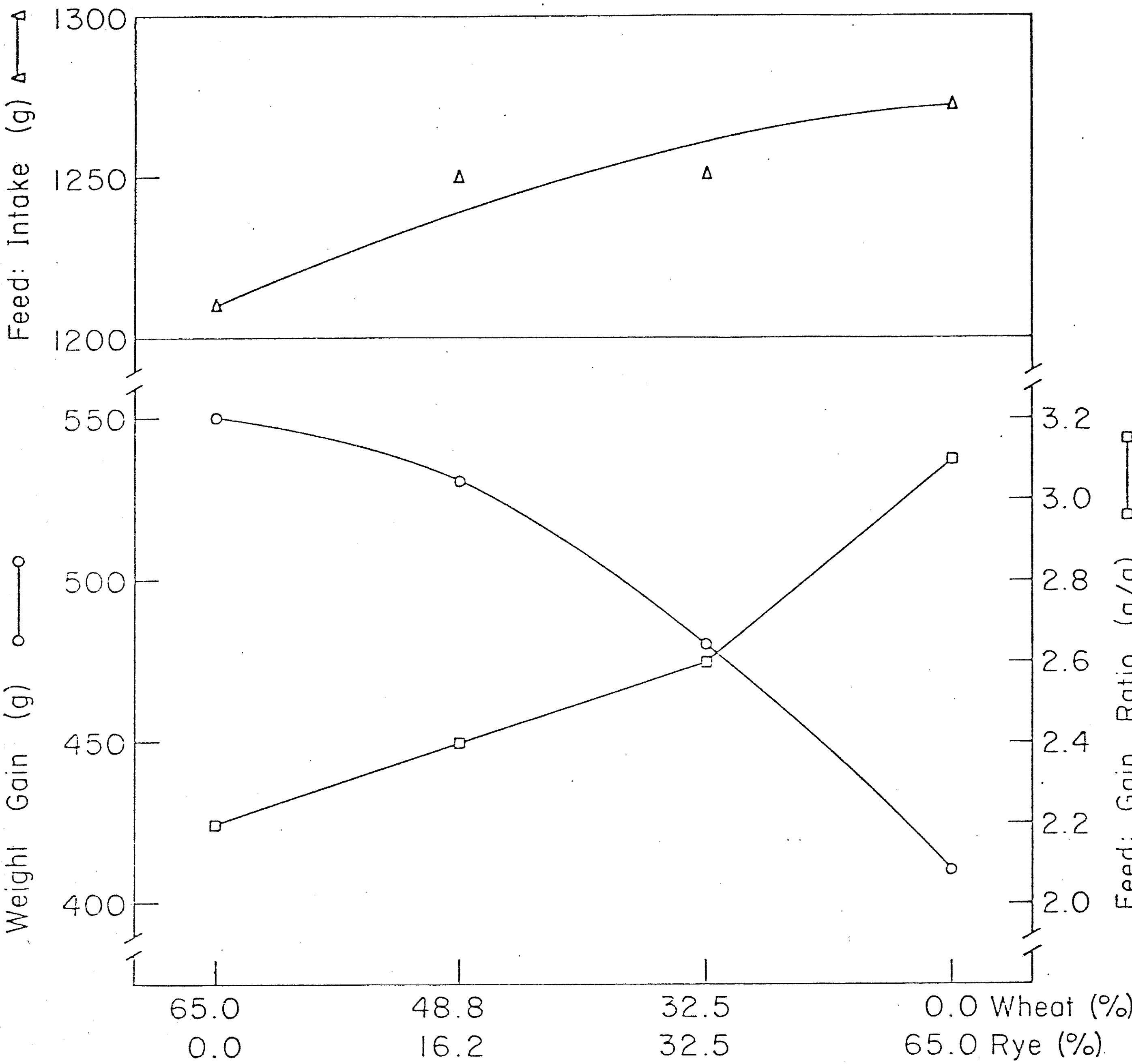

FIGURE 4: Effect of feeding different levels of wheat and rye on the growth of finishing broiler chicks.

EXPERIMENT II

In this study leghorn cockerels were fed diets containing various milled fractions of wheat and rye. The data in Table 26 indicate that the chicks on the different dietary treatments consumed the same amounts of feed. However, the chicks fed diets containing only the rye fractions were significantly smaller ($P<0.01$) than those fed the other grain combinations. The data on feed efficiency indicate that the diets containing the three rye fractions, or rye middlings plus rye flour were poorly utilized compared to the other diets. The degree of feces wetness was greatly increased as a result of the birds consuming diets containing all three rye fractions or a combination of one wheat fraction and two rye fractions, notably rye flour.

The alkylresorcinol content was highest in the rye bran, intermediate in rye middlings and lowest in rye flour (Table 27). The chicks fed diets containing rye bran in combination with wheat middlings and wheat flour, showed performance criteria not significantly different ($P<0.01$) from those of the chicks fed all three wheat fractions.

EXPERIMENT III(a)

The feed intake and weight gain of the chicks fed diets containing a lyophilized water extract of rye, water-extracted rye or rye subjected to two different methods of processing were not significantly different at $P<0.01$. (Table 28) The efficiency of feed conversion was lower for the rye diets than for the wheat control diet ($P<0.01$). Processing of rye did not affect the efficiency with which it was utilized by the chicks.

TABLE 26

The performance of Leghorn cockerels fed diets containing various milled fractions of wheat and rye (Experiment II).

Treatment[1]	Response criteria[2]			
	Feed intake	Weight gain	Feed:gain	Feces condition[3]
	g	g	g/g	1-3
WB, WM, WF	140	80 A	1.75 C	1.1 D
WB, WM, WF, C	139	77 AB	1.80 BC	1.1 D
WB, WM, RF	139	76 AB	1.83 BC	1.4 CD
WB, RM, WF	136	77 AB	1.77 C	1.3 CD
RB, WM, WF	135	79 AB	1.71 C	1.4 CD
WB, RM, RF	138	75 AB	1.84 BC	2.3 B
RB, RM, WF	134	75 AB	1.79 C	1.6 C
RB, WM, RF	138	72 ABC	1.92 AB	2.7 A
RB, RM, RF	138	71 BC	1.94 AB	3.0 A
RB, RM, RF, C	136	67 C	2.03 A	3.0 A
SEM	2.2	1.6	0.03	0.1

[1]The number of pens in each of the 10 treatment groups was 6. Number of birds in each pen was 5. Average initial bird weight was 53.8 ± 0.1 SEM. Letter designations are: WB, wheat bran; RB, rye bran; WM, wheat middlings; RM, rye middlings; WF, wheat flour; RF, rye flour; and C, alphafloc.

[2]Means for those response criteria not sharing a common postscript letter within each column were significantly different at $P<0.01$.

[3]An index of 1 to 3 was employed with a high number indicating feces of a high degree of wetness.

TABLE 27

Alkylresorcinol Content of Whole Rye Grain and Rye Grain Fractions.

Item	% Alkylresorcinol[1]
Ground Whole Rye	0.186 ± 0.003
Rye Bran	0.357 ± 0.044
Rye Middlings	0.161 ± 0.013
Rye Flour	0.045 ± 0.004

[1]Average percent ± S.E.M. for each item.

TABLE 28

The performance of Leghorn cockerels fed diets containing a lyophilized water extract of rye, water-extracted rye, or rye subjected to two different methods of processing (Experiment IIIa)

Treatment[1]	Response criteria[2]					
	Feed intake	Weight gain	Feed: gain	Beak impaction[3]	Vent blockage[3]	Feces condition[3]
	g	g	g/g	1-3	1-3	1-3
Wheat	114	68	1.68 B	1.0 C	1.0 B	1.0 D
Wheat + lyophilized water extract of rye (12.5%)	117	66	1.77 AB	3.0 A	1.3 AB	2.2 C
Water-extracted rye	120	65	1.85 A	1.0 C	1.0 B	1.0 D
Rye, unprocessed	116	64	1,80 A	1.7 B	1.5 AB	2.6 B
Pelleted rye	120	69	1.75 AB	1.0 C	1.1 AB	3.0 A
Autoclaved rye, 30 minutes	121	67	1.80 A	1.2 C	1.6 A	2.8 AB
SEM	2.3	1.2	0.02	0.1	0.1	0.1

[1] The number of pens in each of the 6 treatment groups was 6. The number of birds in each pen was 5. Average initial bird weight was 54.1 ± 0.2 SEM.

[2] Means for those response criteria not sharing a common postscript letter within each column were significantly different at $P<0.01$.

[3] Scores of 1 to 3 were assigned. A high score indicates a high degree of beak impaction, vent blockage or feces with a high degree of wetness.

Variable degrees of beak impaction were observed in the birds fed the different diets, with the highest degree of beak impaction occurring in the birds fed the diet containing wheat plus the lyophilized water extract of rye, followed by the unprocessed rye. No vent blockage resulted from the feeding of wheat or water-extracted rye diets, but there was slight vent blockage in the birds fed the other diets. Markedly wet feces were excreted by those birds fed diets containing rye or wheat plus the lyophilized water extract of rye.

EXPERIMENT III(b)

The feed intake, gain in body weight and feed:gain ratio of chicks fed diets containing two levels of a lyophilized water extract of rye, water extracted rye, or rye autoclaved for two different time periods are presented in Table 29. Feed intake was lowest in chicks fed the water-extracted rye and was not significantly different ($P<0.01$) from the feed intake of chicks fed diets containing 12% lyophilized water extract of rye or unprocessed rye. Comparable feed intake values were observed for the autoclaved rye diets, wheat plus 6% lyophilized water extract of rye or the wheat control diet. The weight gain followed the same trend as the feed intake. Growth depression relative to the control diet were 5%, 16% or 18% respectively for birds fed diets containing 6% or 12% of the lyophilized water extract of rye or unprocessed rye. The feed:gain ratio pattern was similar to that for weight gain. However, there was no difference ($P<0.01$) among the feed:gain ratios for the control wheat, wheat plus 6% lypohilized water extract of rye or the water-extracted rye

TABLE 29

Comparison of the performance of Leghorn cockerels fed diets containing two levels of a lyophilized water extract of rye, water-extracted rye, and rye autoclaved for two different time periods (Experiment IIIb)

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Wheat	82 AB	42.5 A	1.92 C
Wheat + lyophilized water extract of rye (6%)	81 AB	40.5 AB	2.00 BC
Wheat + lyophilized water extract of rye (12%)	77 BC	35.5 C	2.17 AB
Rye, water extracted	74 C	37.2 BC	1.99 BC
Rye, unprocessed	77 BC	34.9 C	2.20 A
Rye, autoclaved (10 minutes)	85 A	40.5 AB	2.10 ABC
Rye, autoclaved (30 minutes)	83 AB	39.0 ABC	2.13 ABC
SEM	1.4	1.0	0.04

[1]The number of pens in each of the 7 treatment groups was 6. The number of birds in each pen was 5. Average initial bird weight was 44.4 ± 0.1 SEM.

[2]Means for response criteria not sharing a common postscript letter within each column were significantly different at $P<0.01$.

diets.

EXPERIMENT IV

The results of this experiment designed to test the effects of ergot, pelleting, daily cleaning of the chicks' beaks or vents, and procaine penicillin supplementation are presented in Table 30. The feed consumption was greatest in chicks fed the pelleted ergot-free rye diets; this value was significantly higher ($P<0.05$) than the corresponding value for the wheat control diet. Chicks fed diets containing wheat, uncleaned rye or uncleaned rye plus "ergot bodies" consumed slightly less feed than chicks fed ergot-free rye diets, but the maximum variation between extreme values was only 6%. The daily cleaning of the beaks or the vents of the chicks fed the ergot-free rye diets resulted in no difference in feed intake, weight gain or feed:gain ratio. Pelleting the diet or supplementing it with 50 mg/kg procaine penicillin produced growth responses comparable to that obtained for the wheat diet ($P<0.01$). Procaine penicillin supplementation significantly increased the efficiency of feed utilization compared to the other rye diets. This value was intermediate to those obtained with the rye and wheat diets. All traces of beak impaction were completely eliminated by pelleting. There was no problem due to vent blockage since whatever traces of feces adhered onto the vents of birds fed rye diets, soon hardened and dropped off into the collection trays below each pen. Wet feces were produced by chicks fed all the rye diets, but not for the wheat diet; this condition seemed to be slightly alleviated by procaine penicillin supplementation.

TABLE 30

The performance of Leghorn cockerels fed rye diets with or without ergot bodies and procaine penicillin (Experiment IV).

Treatment[1]	Response criteria[2]					
	Feed intake	Weight gain	Feed: gain	Beak[3] impaction	Vent[3] blockage	Feces[3] condition
	g	g	g/g	1-3	1-3	1-3
Wheat	230 b	134 A	1.72 C	1.0 B	1.0	1.0 D
Rye, uncleaned	230 b	120 C	1.92 A	1.5 A	1.1	2.7 AB
Rye, uncleaned + 2% "ergot bodies"	228 b	119 C	1.91 A	1.4 A	1.1	2.4 B
Rye, ergot free	233 ab	121 BC	1.92 A	1.5 A	1.1	2.7 AB
Rye, ergot free (pelleted)	243 a	128 AB	1.90 A	1.0 B	1.0	2.9 A
Rye, ergot free - chicks' beaks cleaned daily	232 ab	123 BC	1.88 A	1.5 A	1.1	2.6 AB
Rye, ergot free - chicks' vents cleaned dails	234 ab	122 BC	1.91 A	1.5 A	1.1	2.7 AB
Rye, ergot free + 50 mg/kg procaine penicillin	233 ab	127 ABC	1.83 B	1.7 A	1.1	2.1 C
SEM	2.8	1.5	0.01	0.06	0.04	0.98

1 The number of pens in each of the 8 treatment groups was 6. The number of birds in each pen was 10. Average initial bird weight was 48.4 ± 0.1 SEM.

2 Means for response criteria not sharing a common large postscript letter within each column were significantly different at $P<0.01$; means not sharing the same common small letter within each column were significantly different at $P<0.05$.

3 A scoring index of 1 - 3 was employed with a high number indicating a high degree of beak impaction, vent blockage or feces of high moisture content.

EXPERIMENT V

In this experiment rye was autoclaved for varying time periods prior to being incorporated into chick diets. Of the response criteria examined, only feed intake was significantly increased ($P<0.01$) with heat treatment (Table 31.) The greatest increase of 12% was observed for the diet containing rye autoclaved for 25 minutes. Generally, autoclaving seemed to result in a non-significant increase in the feed: gain ratio probably due to the destruction of thermolabile amino acids.

EXPERIMENT VI(a)

Two types and two levels of fat were incorporated into isocaloric chick diets that contained either rye or wheat. The results of this experiment clearly show the superiority of wheat over rye as an animal feed ingredient for all the parameters measured (Table 32). Feed intake, weight gain and feed efficiency for the rye diet as compared to the wheat diet were lower by 8%, 25% and 23% respectively. The level of fat had no effect on feed intake or gain in body weight but was more efficiently utilized ($P<0.01$) by the chicks than the 2% level. Fat type produced response criteria similar to those for fat level, with soybean oil appearing to be slightly better than tallow. There was also an interaction between grain and fat for weight gain and feed:gain ratio (Table 32, footnotes). Diets containing wheat plus either fat were utilized in a similar manner. In contrast, the diet containing rye plus soybean oil was more efficiently utilized than a corresponding diet that contained tallow.

TABLE 31

The Performance of Leghorn cockerels fed diets containing rye subjected to increasing autoclaving time periods (Experiment V).

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Rye, 0 minutes autoclaving	56 B	17.6	3.18
Rye, 5 minutes autoclaving	58 AB	17.6	3.30
Rye, 10 minutes autoclaving	61 AB	20.7	2.97
Rye, 15 minutes autoclaving	60 AB	18.5	3.33
Rye, 25 minutes autoclaving	63 A	19.3	3.31
Rye, 50 minutes autoclaving	62 A	19.0	3.26
SEM	1.3	0.9	0.10

[1]The number of pens in each of the 6 treatment groups was 6. Number of birds in each pen was 8. Average initial bird weight was 60.0 ± 0.1 SEM.

[2]Means for response criteria not sharing a common large postscript letter within each column were significantly different at $P<0.01$.

TABLE 32

Comparison of the performance of Leghorn cockerels fed diets with two types and two levels of fat (Experiment VIa).

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Grain			
Rye	113 B	46 B	2.48 A
Wheat	123 A	61 A	2.01 B
Fat type			
Soybean oil	118	54	2.20 B
Tallow	118	52	2.29 A
Fat level			
2%	117	52	2.28 A
5%	119	54	2.21 B
SEM	1.8	1.2	0.03

[1] The number of pens in each of 8 treatment groups was 6. The number of birds in each pen was 6. Initial average weight per bird was 56.3 ± 0.1 SEM.

[2] Means for response criteria not sharing a common postscript letter within a column were significantly different at $P<0.01$. There was an interaction at $P<0.05$ between fat type and grain for weight gain and feed:gain ratio. The weight gain and feed:gain ratio for chicks fed the rye-soybean oil, rye-tallow, wheat-soybean oil, and wheat-tallow diets were: 47g and 2.41; 41g and 2.55; 61g and 1.99; and 61g and 2.02, respectively.

EXPERIMENT VI(b)

Feed intake, weight gain and feed:gain ratio data obtained in chicks fed rye or wheat diets formulated to meet energy levels 9% below or 7% above NRC recommendation are presented in Table 33. Compared to the wheat diet, the feed intake, weight gain and feed efficiency were respectively lowered by 15%, 36% and 32% for the rye diet. Energy level had no effect on feed consumption and weight gain but the high energy diet was more efficiently utilized than the low energy diet ($P<0.05$). However, the magnitude of this increase (5%) was not proportional to the increase in calculated metabolizable energy values (16%).

EXPERIMENT VII(a)

This study compared the effects of feeding rye or wheat diets with or without supplemental vitamin D_3 on the growth of Leghorn cockerels. The data in Table 34 consistently show the superiority of wheat over rye as a feed ingredient. Although average chick performance was not affected by the omission or inclusion in the diets of added vitamin D_3, individual diets were affected in a differential manner (Table 34, footnotes). Vitamin D_3 supplementation of the rye diets resulted in a slight increase in the feed: gain ratio (+5%) whereas vitamin D_3 supplementation of the wheat containing diet resulted in a slightly reduced feed:gain ratio (-3%).

EXPERIMENT VII(b)

In this experiment 5-, 100- or 1,000- times the NRC recommended levels

TABLE 33

The effect of two energy levels on the growth of Leghorn cockerels fed diets containing wheat or rye (Experiment VIb).

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Grain			
Rye	62 B	21.5 B	2.89 A
Wheat	73 A	33.5 A	2.19 B
Energy			
Low	68	27	2.61 a
High	68	28	2.47 b
SEM	1.2	0.8	0.05

[1] The number of pens in each of the 4 treatment groups was 6. The number of birds in each pen was 8. Initial average weight per bird was 46.1 ± 0.1 SEM.

[2] Means for response criteria not sharing a common postscript letter within a column were significantly different. Large letters denote $P<0.01$ and small letters denote $P<0.05$. There were no interactions ($P<0.05$) between different treatment groups.

TABLE 34

Effect of feeding rye diets with or without added vitamin D_3 on the growth of Leghorn cockerels (Experiment VIIa).

Treatment[1]	Response criteria[2]			
	Feed intake (2 wk period)	Weight gain (1 wk period)	Weight gain (2 wk period)	Feed:gain (2 wk period)
	g	g	g	g/g
Grain				
Rye	220 B	36 B	88 B	2.49 A
Wheat	225 A	55 A	124 A	2.06 B
Vitamin				
(-) vitamin D_3	239	46	107	2.27
(+) vitamin D_3 (5X)	237	45	106	2.29
SEM	3.0	1.0	1.5	0.03

[1] The number of pens in each of the 4 treatment groups was 6. The number of birds in each pen was 5. Initial average bird weight was 54.4 ± 0.1 SEM.

[2] Means for response criteria not sharing a common postscript letter were significantly different at $P<0.01$. There was an interaction ($P<0.01$) for feed: gain ratio between grain type and vitamin level. The feed:gain ratio values for chicks fed rye without vitamin D_3 rye with vitamin D_3 wheat without vitamin D_3 and wheat with vitamin D_3 were 2.43, 2.55, 2.10, and 2.03 respectively.

of vitamin D_3 were added to rye or wheat diets. The data presented in Table 35 show that there was a difference between grain type and among vitamin D_3 levels for feed intake and weight gain (Fig. 5) and feed:gain ratio. There was also an interaction between grain and vitamin D_3 levels for all three performance criteria. The performance of chicks fed a rye diet containing increasing levels of vitamin D_3 was not effected whereas feed intake and weight gain of chicks fed wheat diets supplemented with increasing levels of vitamin D_3 were depressed, and the corresponding feed: gain ratio increased.

EXPERIMENT VIII(a)

The objective of this study was to compare the performance of chicks when fed diets containing rye or wheat supplemented with different protein sources and processed in two different ways. The analysis of variance data in Table 36 show highly significant responses ($P<0.01$) in all the criteria of performance for grain and protein source. Weight gain and feed:gain ratios were significantly affected ($P<0.05$) by form (non-pelleted vs. pelleted) of the diet. There was significant interactions ($P<0.05$) between grain and form of the diet, between protein source and form of the diet, and among grain, protein source and form of the diet for feed:gain ratio. Table 36 gives individual values of the three-way interactions; the values for the feed:gain ratio are illustrated in Fig. 6. This graph shows a differential response in feed:gain ratios to pelleting of the diets. Pelleted as compared to non-pelleted wheat diets gave a similar pattern of response. In contrast, the response to pelleting of rye diets was very different. Pelleting of a rye-soybean meal diet resulted in a reduction of the feed:gain ratio whereas pelleting of a rye diet that contained meat meal, or fish meal, resulted in

TABLE 35

The effect of feeding rye or wheat diets with increasing levels of Vitamin D_3 on the growth of Leghorn cockerels (Experiment VIIb).

Treatment[1]	Response criteria		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Rye, 5 X vitamin D requirement	111	43	2.60
Rye, 100 X normal Vitamin D requirement	109	43	2.56
Rye, 1000 X normal Vitamin D requirement	112	43	2.63
Wheat, 5 X normal Vitamin D requirement	124	60	2.07
Wheat, 100 X normal Vitamin D requirement	115	54	2.15
Wheat, 1000 X normal Vitamin D requirement	114	49	2.31
SEM	1.5	1.0	0.04

[1] The number of pens in each of the 6 treatment groups was 6. The number of birds in each pen was 6. Initial average bird weight was 56.3 ± 0.1 SEM.

Summary of Analysis of Variance (Experiment VIIb)

Source	d.f.	Feed intake		Weight gain		Feed:gain	
		Mean square	F	Mean square	F	Mean square	F
Grain	1	15,834	34**	43,264	185**	1.5750	197**
Vitamin	2	2,901	6**	2,963	13**	0.0678	8**
Grain X vitamin D_3	2	3,251	7**	3,053	13**	0.0356	4*
Error	30	465		234		0.0080	

** Significant at $P<0.01$.

* Significant at $P<0.05$.

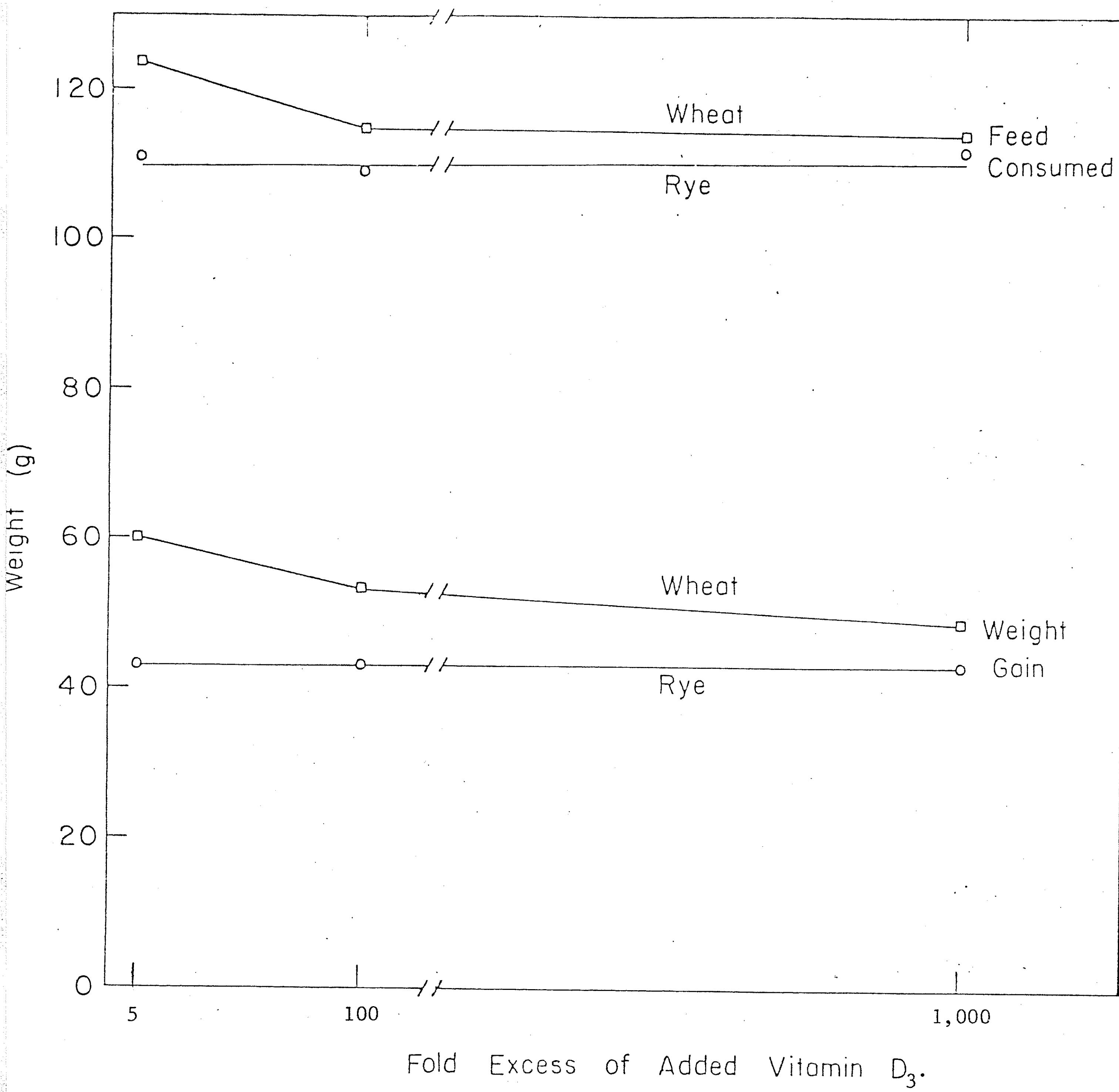

FIGURE 5: Feed consumption and weight gain of Leghorn cockerels fed wheat or rye diets containing varying levels of added vitamin D_3

TABLE 36

Evaluation of protein source on the growth of Leghorn cockerels fed non-pelleted or pelleted rye or wheat diets (Experiment VIIIa).

Treatment	Response criteria		
	Feed intake	Weight gain	Feed:gain
	g	g	g
Rye, meat meal, non-pelleted	72.4	30.6	2.37
Rye, meat meal, pelleted	76.1	31.3	2.43
Rye, soybean meal, non-pelleted	89.9	42.0	2.14
Rye, soybean meal, pelleted	87.2	42.2	2.06
Rye, fish meal, non-pelleted	94.7	48.6	1.95
Rye, fish meal, pelleted	95.4	43.0	2.22
Wheat, meat meal, non-pelleted	91.6	48.2	1.90
Wheat, meat meal, pelleted	89.4	46.9	1.91
Wheat, soybean meal, non-pelleted	95.5	55.0	1.73
Wheat, soybean meal, pelleted	92.6	53.1	1.74
Wheat, fish meal, non-pelleted	100.4	59.8	1.68
Wheat, fish meal, pelleted	97.0	57.8	1.68
SEM	2.2	1.3	0.03

[1] The number of pens in each of the 12 treatment groups was 4. The number of birds per pen was 8. Initial average bird weight was 51.0 ± 0.1 SEM.

Summary of Analysis of Variance (Experiment VIIIa)

Source	d.f.	Feed intake		Weight gain		Feed:gain	
		Mean square	F	Mean Square	F	Mean Square	F
Grain	1	55,081	44**	146,523	312**	2.1336	455**
Protein source	2	54,689	44**	45,556	97**	0.3413	73**
Grain X protein source	2	11,757	9**	1,524	NS	0.0184	NS
Form of diet	1	954	NS	2,054	4.4*	0.0234	5.0*
Grain X form of diet	1	2,133	NS	3	NS	0.0200	4.3*
Protein source X form of diet	2	806	NS	900	NS	0.0297	6*
Grain X protein source X form of diet	2	566	NS	698	NS	0.0333	7*
Error	36	1,240		469		0.0047	

* Significant at P<0.05.

** Significant at P<0.01.

NS Not significant P≤0.05.

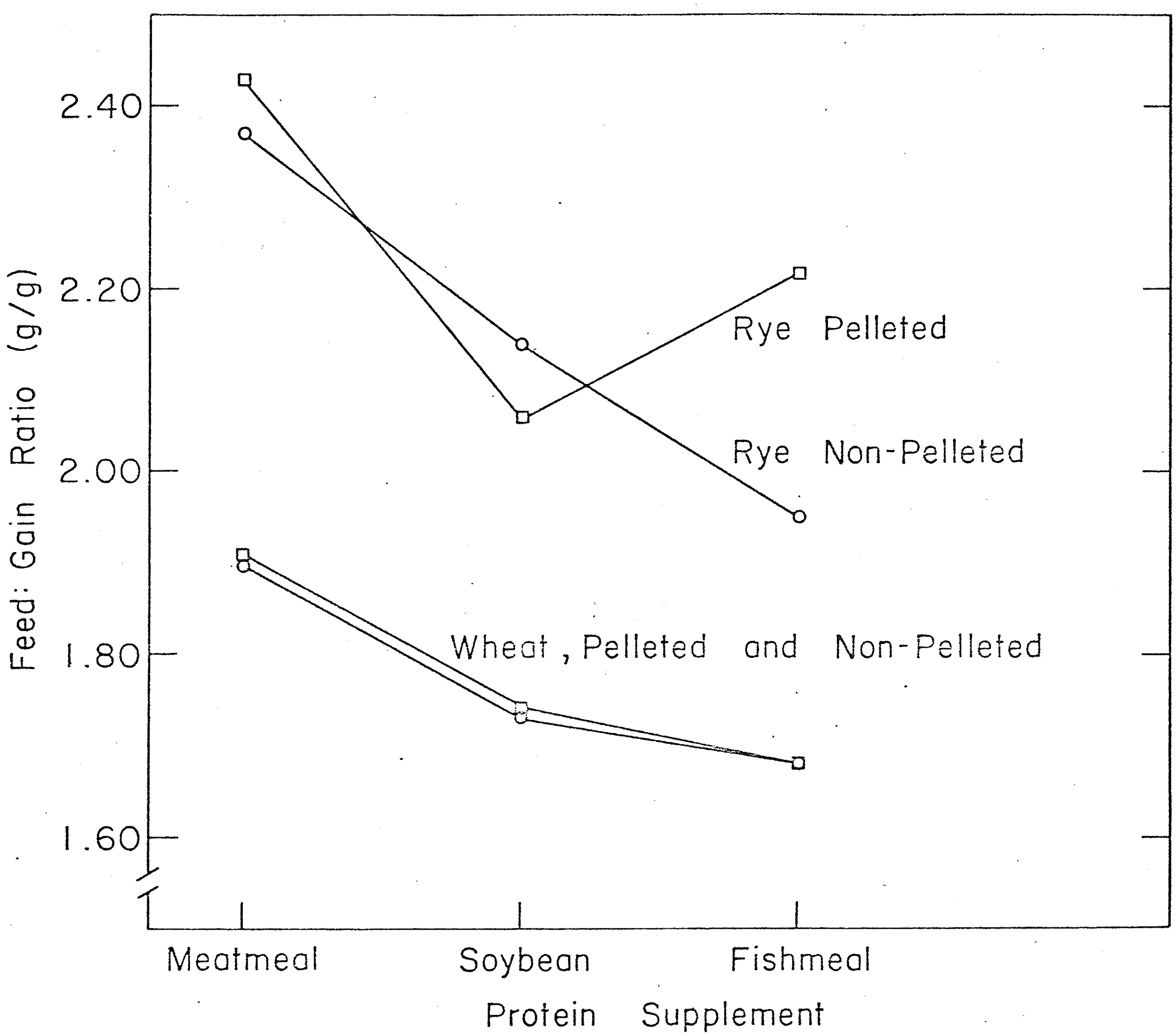

FIGURE 6: Interactions among grain, protein source and form of diet for feed:gain ratio.

an increase in the feed:gain ratio.

EXPERIMENT VIII(b)

The results of this experiment designed to evaluate the effects of grain type (rye or wheat), level of dietary protein (21% or 26%) and form of diet (non-pelleted or pelleted) on chick performance are presented in Table 37. The weight gain was significantly reduced ($P<0.01$) and the feed: gain ratio significantly increased ($P<0.01$) in the birds fed rye rather than wheat diets. The 26% protein diets supported significantly greater ($P<0.01$) body weight gain and significantly reduced the feed:gain ratio ($P<0.01$) compared to the 21% protein diets. There was a significant interaction between grain and form of the diet for weight gain ($P<0.01$) and feed:gain ratio ($P<0.01$). Pelleting of the wheat containing diets did not affect chick performance whereas pelleting of the rye containing diets resulted in a reduced level of chick performance. The effect on the feed: gain ratio is illustrated in Fig. 7. There was also an interaction between grain and protein level for feed:gain ratio. The results illustrated in Fig. 7 demonstrate that the response in feed:gain ratio for chicks fed increasing levels of protein was much greater for diets containing rye as compared with those containing wheat.

EXPERIMENT VIII(c)

The purpose of this study was to investigate the effects of feeding

TABLE 37

Performance of Leghorn cockerels fed non-pelleted and pelleted rye or wheat diets containing two levels of protein (Experiment VIIIb)

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Grain			
Rye	95	50 B	1.91 A
Wheat	99	61 A	1.62 B
Protein level			
21%	97	52 B	1.88 A
26%	97	59 A	1.64 B
Form of diets			
Non-pelleted	98	58 A	1.72 B
Pelleted	96	54 B	1.81 A
Interaction (grain x form)			
Rye, non-pelleted	96	54	1.81
Rye, pelleted	93	47	2.00
Wheat, non-pelleted	100	62	1.63
Wheat, pelleted	98	61	1.61
SEM	2.2	1.3	0.01

[1]The number of pens in each of the 12 treatment groups was 4. The number of birds in each pen was 8. Initial average bird weight was 51.0 ± 0.1 SEM.

[2]Means for response criteria not sharing a common postscript letter within a column were significantly different at $P<0.01$. There was a significant interaction between grain and form of the diet for weight gain ($P<0.01$) and feed:gain ratio ($P<0.01$). In addition to above indicated interactions, there was an interaction ($P<0.01$) between grain and protein level for feed:gain ratio (Fig. 7), and between protein level and form of the diet for feed:gain ratio ($P<0.05$).

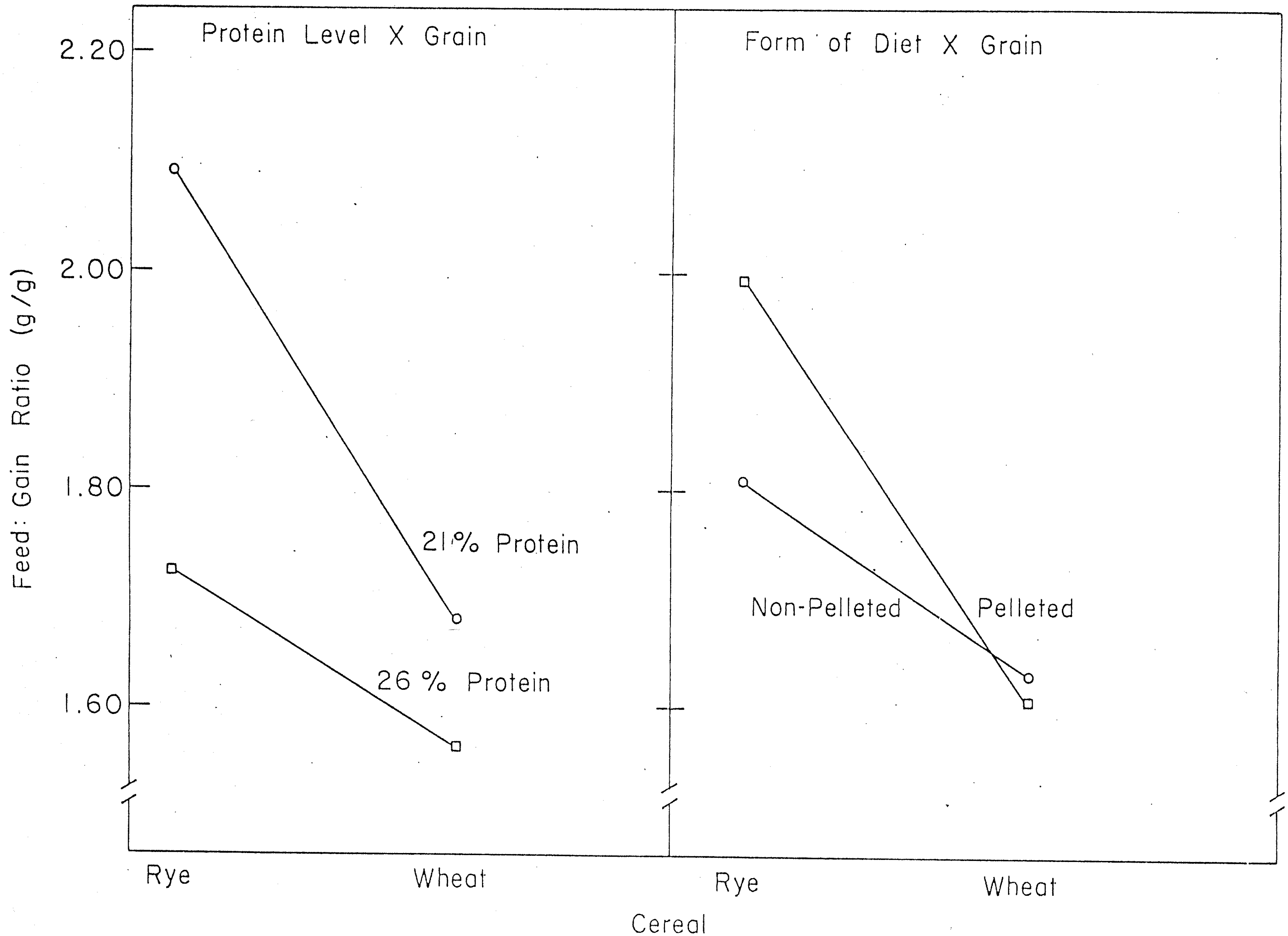

FIGURE 7: Interaction between (i) protein level and grain for feed:gain ratio, and (ii) form of diet and grain for feed:gain ratio.

chicks rye or wheat diets containing 18% or 26% protein derived from meat meal or fish meal. The analysis of variance data in Table 38 show highly significant responses for grain, protein source and protein level ($P<0.01$); and the interactions between grain and protein source ($P<0.05$), grain and protein level ($P<0.01$), protein source and protein level ($P<0.01$), and among grain, protein source and protein level ($P<0.01$). The individual treatment values are given in Table 38 for the interaction among grain, protein source and protein level; the data for weight gain are illustrated in Fig. 8. Clearly, the magnitude of the response was markedly influenced not only by the type of protein but also by the level of dietary protein and the type of cereal. An improvement in weight gain for birds fed increasing levels of low quality protein (meat meal) was observed only for the wheat diet (24%) but not for the rye diet. In contrast when a high quality protein (fish meal) was fed, increasing the level of protein resulted in an opposite trend with 50% chick growth improvement with the rye diet compared to only 9% improvement for the wheat diet.

EXPERIMENT IX

Supplementation of the rye diet with tryptophan significantly increased feed intake ($P<0.01$) and gain in body weight ($P<0.05$), thereby suggesting that this amino acid might be limiting in rye (Table 39). The feed:gain ratio was greater for the un-supplemented rye diet but the difference was not significant.

TABLE 38

The effects of two sources and two levels of protein on the growth of Leghorn cockerels fed rye or wheat diets (Experiment VIIIc)

Treatment[1]	Response criteria		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Rye X meat meal X 18% protein	66	20	3.31
Rye X meat meal X 26% protein	55	20	2.72
Rye X fish meal X 18% protein	74	28	2.64
Rye X fish meal X 26% protein	80	42	1.92
Wheat X meat meal X 18% protein	74	29	2.58
Wheat X meat meal X 26% protein	72	36	2.01
Wheat X fish meal X 18% protein	89	44	2.04
Wheat X fish meal X 26% protein	82	48	1.71

[1] The number of pens in each of the 8 treatment groups was 6. The number of birds per pen was 8. Initial average weight per bird was 46.1 ± 0.1 SEM.

Summary of Analysis of Variance (Experiment VIIIc)

Source	d.f.	Feed intake		Weight gain		Feed:gain	
		Mean Square	F	Mean Square	F	Mean Square	F
Grain	1	87,894	151**	104,720	411**	3.8250	286**
Protein source	1	152,776	263**	151,425	595**	4.0310	301**
Grain X protein source	1	3,169	5*	261	NS	0.2961	22**
Protein level	1	10,325	18**	30,402	119**	3.6686	274**
Grain X protein level	1	444	NS	147	NS	0.1250	9**
Protein source X protein level	1	7,500	13**	5,590	22**	0.0078	NS
Grain X protein source X protein level	1	21,760	38**	11,970	47**	0.1018	8**
Error	40	580		255		0.0134	

* Significant at $P<0.05$.

** Significant at $P<0.01$.

NS Not significant at $P\leq 0.05$.

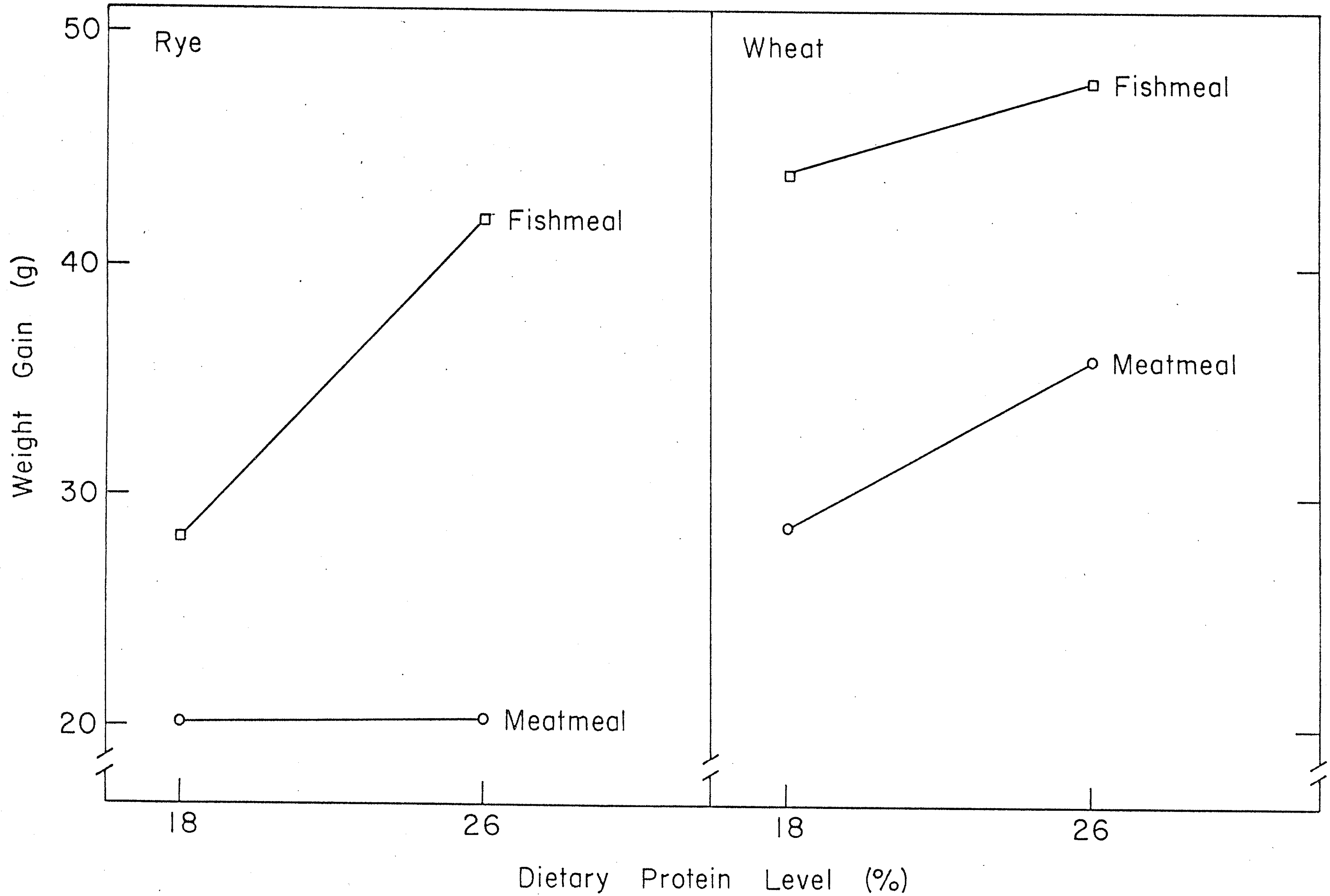

FIGURE 8: Interactions among grain, protein source and protein level for weight gain.

TABLE 39

Effect of tryptophan supplementation on the growth of Leghorn cockerels fed rye diets (Experiment IX).

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Rye	56.8 B	18 b	3.17
Rye + tryptophan	62.6 A	21 a	2.96
SEM	1.0	0.8	0.08

[1]The number of pens in each treatment group was 6. Number of birds in each pen was 8. Average initial bird weight was 47.1 ± 0.1 SEM.

[2]Means for response criteria not sharing the same capital postscript letter within each column were significantly different at $P<0.01$; means for response criteria not sharing the same small postscript letter were significantly different at $P<0.05$.

EXPERIMENT X (a) (i)

The effect of feeding chicks rye (I) diets supplemented with increasing levels of procaine penicillin was studied in this experiment. The intake of the rye diets was the same regardless of the level of procaine penicillin supplementation, and significantly higher ($P<0.05$) than the intake of the wheat diet (Table 40). The weight gain of the chicks fed rye plus 100 mg/kg procaine penicillin was significantly greater ($P<0.01$) than those fed the unsupplemented rye diet but not different from the weight gain of the chicks fed the other two diets. Procaine penicillin supplementation (100 mg/kg) significantly reduced the feed:gain ratio but this value was still significantly higher than that for the wheat diet ($P<0.01$). A slight degree of beak impaction was observed in the birds fed the rye diets (Table 40). There was no problem of vent blockage in the treatments since whatever feces accumulated around the vents of the rye-fed chicks soon dried and dropped off into the collection trays. Marked fecal moisture was observed only for the rye-fed birds and this condition was slightly alleviated by procaine penicillin supplementation (Table 40).

EXPERIMENT X (a) (ii)

With increasing levels of procaine penicillin supplementation of the rye (II) diets, there was a progressive increase in feed intake which was significantly greater at the 160 mg/kg level ($P<0.01$), at the 80 mg/kg and 160 mg/kg levels ($P<0.05$) compared to the unsupplemented rye diet (Table 41). The data also show dramatic and progressive increases in body weight gain and

TABLE 40

The performance of Leghorn cockerels fed rye diets supplemented with increasing levels of procaine penicillin (Experiment X a (i)).

Treatment[1]	Response criteria[2]					
	Feed intake	Weight gain	Feed: gain	Beak[3] impaction	Vent[3] blockage	Feces[3] condition
	g	g	g/g	1-3	1-3	1-3
Wheat	234 b	129 AB	1.82 C	1.0 B	1.0	1.0 D
Rye + 0 mg/kg procaine penicillin	246 a	122 B	2.02 A	1.3 A	1.3	2.9 A
Rye + 50 mg/kg procaine penicillin	246 a	124 AB	1.98 A	1.4 A	1.3	2.6 B
Rye + 100 mg/kg procaine penicillin	248 a	131 A	1.89 B	1.4 A	1.2	2.6 B
SEM	3.1	1.6	0.01	0.1	0.1	0.1

1 The number of pens in each of the four treatment groups was 6. Number of birds in each pen was 10. Average initial bird weight was 57.0 ± 0.1 SEM.

2 Means for response criteria not sharing a common postscript were significantly different: A, B, C at $P<0.01$; a, b, c at $P<0.05$.

3 A scoring index of 1 - 3 was employed. A high number indicates a high degree of beak impaction, vent blockage and feces with a high moisture content.

TABLE 41

The performance of Leghorn cockerels fed rye diets supplemented with increasing levels of procaine penicillin (Experiment Xa(ii))

Treatment[1]	Response criteria[2]		
	Feed intake	Weight gain	Feed:gain
	g	g	g/g
Rye, 0 mg/kg procaine penicillin	55.8 B c	17.6 C c	3.17 A a
Rye, 10 mg/kg procaine penicillin	57.1 B bc	18.6 BC bc	3.07 AB a
Rye, 20 mg/kg procaine penicillin	57.3 B bc	18.4 BC bc	3.11 AB a
Rye, 40 mg/kg procaine penicillin	58.2 B bc	18.7 BC bc	3.11 AB a
Rye, 80 mg/kg procaine penicillin	61.5 B b	21.9 AB b	2.81 AB ab
Rye, 160 mg/kg procaine penicillin	67.2 A a	25.7 A a	2.63 B b
SEM	1.2	0.9	0.10

[1]The number of pens in each of the six treatment groups was 6. The number of birds in each pen was 8. Average initial bird weight was 47.0 ± 0.1 SEM.

[2]Means for response criteria not sharing a common large postscript letter within each column were significantly different at $P<0.01$; means not sharing a common small postscript letter within each column were significantly different at $P<0.05$.

corresponding decreases in feed:gain ratio (Fig. 9) with increasing levels of procaine penicillin supplementation.

EXPERIMENT X (b)

This study was designed to evaluate the effects of feeding chicks rye or wheat diets containing meat meal or fish meal with or without supplementation with 160 mg/kg procaine penicillin. The analysis of variance data (Table 42) reveal highly significant differences ($P<0.01$) due to grain, protein source and procaine penicillin, and the interaction of grain and protein source, for all the parameters measured. In addition a highly significant interaction for grain and procaine penicillin was obtained for all the parameters except protein retention. Further, there was an interaction between protein source and procaine penicillin for feed intake ($P<0.05$) and feed:gain ratio ($P<0.01$); and among grain, protein source and procaine penicillin for feed intake ($P<0.05$), feed:gain ratio ($P<0.01$) and dry matter and protein retention ($P<0.05$). Individual treatment values are given in Table 42. For all the parameters, the improvement in chick performance as a consequence of supplementation of diets with a high quality protein or procaine penicillin was more pronounced when the chicks were fed rye-based diets rather than wheat-based diets. Thus, for rye diets containing meat meal and zero level of procaine penicillin compared to similar wheat diets, the changes in feed intake, weight gain, feed:gain ratio, dry matter retention and protein retention were respectively -30%, -55%, +56%, -21% and -36%; for meat meal rye diets without procaine penicillin supplementation compared to fish meal rye diets without procaine

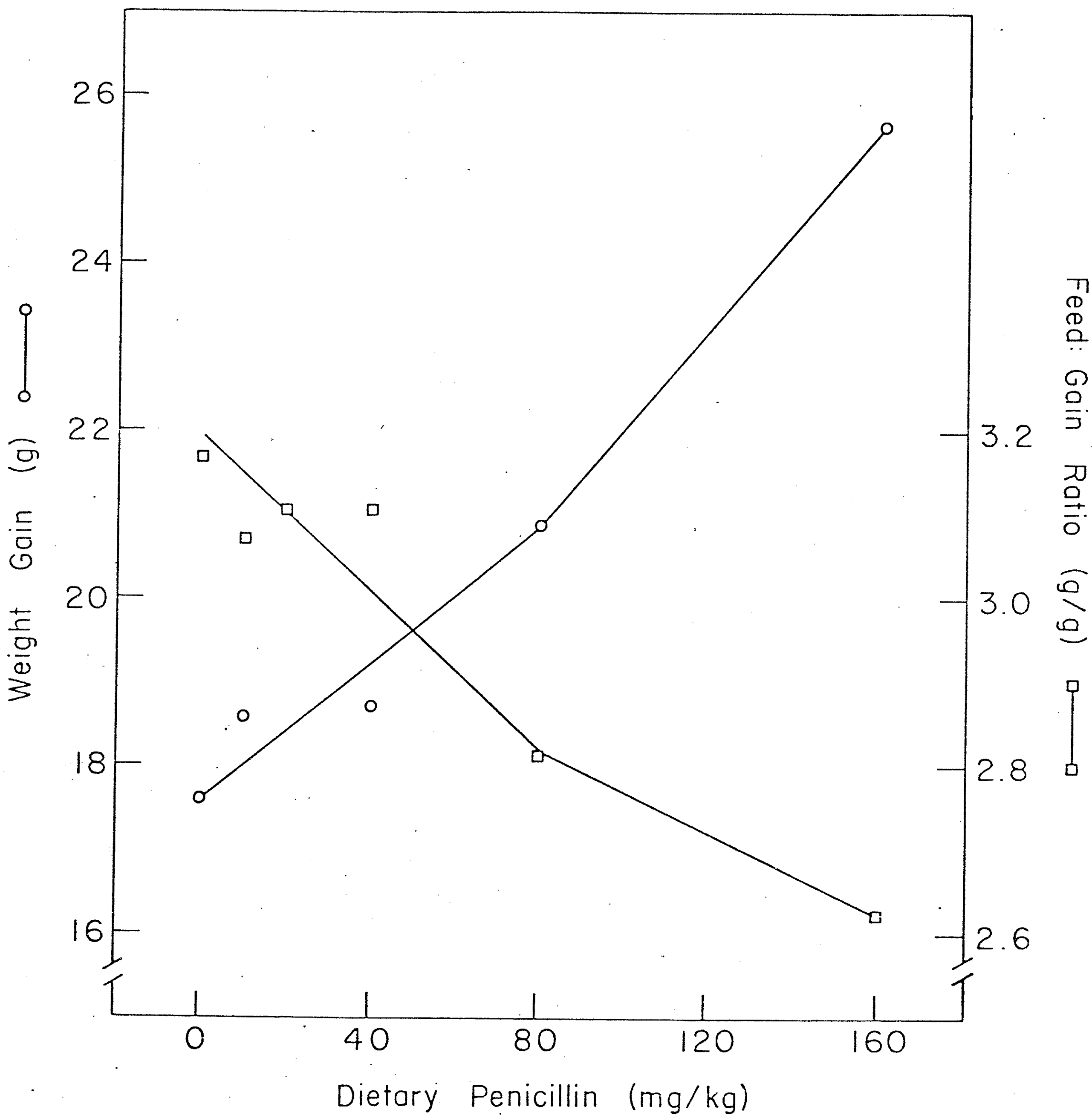

FIGURE 9: Weight gain and feed:gain ratio of Leghorn cockerels fed rye diets supplemented with increasing levels of procaine penicillin.

TABLE 42

Comparison of the effects of two protein sources with or without procaine penicillin supplementation on the growth of Leghorn cockerels fed rye or wheat diets (Experiment Xb).

Treatment[1]	Response criteria: Feed intake	Response criteria: Weight gain	Response criteria: Feed:gain	Retention data: Dry matter	Retention data: Protein
	g	g	g/g	%	%
Rye, meat meal, 0 pro. penicillin	62	19	3.26	55.3	28.1
Rye, meat meal, 160mg/kg pro. penicillin	77	30	2.54	59.3	39.7
Rye, fish meal, 0 pro. penicillin	79	36	2.18	59.9	49.1
Rye, fish meal, 160 mg/kg pro. penicillin	84	42	1.99	61.3	51.4
Wheat, meat meal, 0 pro. penicillin	88	42	2.09	69.6	43.9
wheat, meat meal, 160mg/kg pro. penicillin	91	47	1.96	69.3	46.9
Wheat, fish meal, 0 pro. penicillin	88	49	1.81	67.8	51.8
Wheat, fish meal, 160 mg/kg pro. penicillin	92	53	1.75	69.0	57.2
SEM	1.4	1.1	0.05	0.5	1.7

[1] The number of pens in each of the eight treatment groups was 6. The number of birds per pen was 8. Initial average bird weight was 50.9 ± 01. SEM.

Summary of Analysis of Variance (Experiment Xb)

Source	d.f.	Feed intake: Mean square	Feed intake: F	Weight gain: Mean square	Weight gain: F	Feed:gain: Mean square	Feed:gain: F	Retention data, Dry matter: Mean square	Retention data, Dry matter: F	Retention data, Protein: Mean square	Retention data, Protein: F
Grain	1	159,735	218*	186,377	400**	4.21	269**	1192	563**	752	44**
Protein source	1	32,085	44**	84,924	182**	3.33	212**	17	8**	1940	113**
Grain X protein source	1	24,798	34**	12,002	26**	0.95	61**	59	28**	159	9**
Procaine penicillin	1	33,867	46**	30,755	66**	0.91	58**	30	14**	373	22**
Grain X pro. penicillin	1	6,746	9**	3,451	7**	0.39	25**	16	7**	24	NS
Protein source X procaine penicillin	1	3,905	5*	1,485	NS	0.27	17**	1	NS	36	NS
Grain X protein source X procaine penicillin	1	4,941	7*	1,112	NS	0.16	10**	12	6*	101	6*
Error	40	734		465		0.02		2		17	

* Significant at P<0.05 ** Significant at P<0.01. NS Non-significant at P<0.05.

penicillin supplementation, the corresponding values were -22%, -47%, +49%, -8%, and -43%. However, procaine penicillin supplementation of meat meal rye diets compared to similar diets without procaine penicillin supplementation resulted in the following values for the corresponding parameters: +24%, +58%, -28%, +7% and +41% respectively. In effect this means that the influence of a good quality protein (fish meal) plus procaine penicillin on the performance of chicks fed a rye diet were +46%, +105%, -77%. +15% amd +84% respectively for feed intake, gain in body weight, feed: gain ratio, dry matter retention and protein retention.

Figure 10 illustrates the interaction of grain, protein source and procaine penicillin for feed:gain ratio. The graphs show that improvement in the efficiency of feed utilization was much greater when rye diets rather than wheat diets were supplemented with procaine penicillin. Furthermore, the response to procaine penicillin supplementation was magnified when meat meal (low quality protein) as compared to fish meal (high quality protein) was incorporated into the diets. These results which are consistent with those of the previous experiments would suggest the presence in rye of factor(s) responsible for the reduction of nutrient utilization, particularly protein utilization. Increasing the level of protein, improving its quality or supplementing the rye diets with procaine penicillin have all influenced chick performance in the same way.

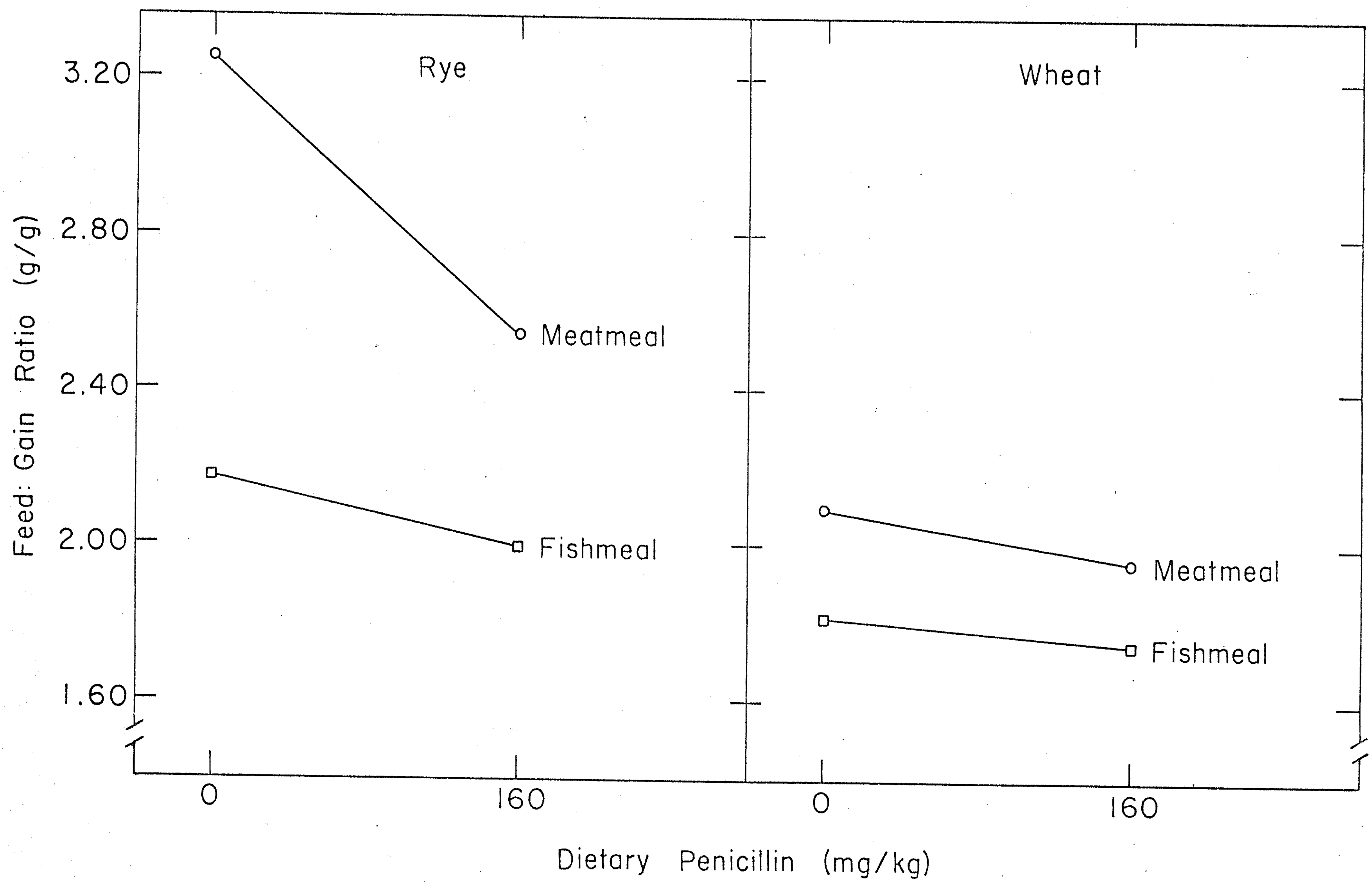

FIGURE 10: Interactions among grain, protein source and penicillin level for feed:gain ratio.

DISCUSSION

The proximate analysis data for rye and wheat (Table 2) would suggest that as an animal feed ingredient rye should support growth to the same extent as wheat. This view is substantiated by the amino acid composition data for these two cereals (Table 3) and the published results of several workers (Jones et al, 1948; Sure, 1954; Knipfel, 1969; and Kies and Fox, 1970), all of which attest to the superior quality of rye protein or the nutritional superiority of rye on account of its higher lysine content compared to wheat. However, feeding trials have demonstrated that when rye has been incorporated into animal diets the rate of growth of the animals has generally been depressed relative to a control group in which other cereals such as wheat or corn has been utilized (Halpin et al, 1936; Moran et al, 1965; Bowland, 1966; Weiringa, 1967; Moran et al, 1969; Friend, 1970; MacAuliffe and McGinnis, 1971; Fernandez, Lucas and McGinnis, 1973; and Wilson and McNab, 1975).

The results of the first of this series of experiments showed that when the 60% wheat in a diet was replaced by rye, the gain in body weight and the efficiency of feed utilization by young broiler chicks were depressed by 26% and 32% respectively after being on test for two weeks. Even replacing as low as 15% wheat in the diet with rye significantly depressed chick growth and feed efficiency. A rather similar trend was observed in older broiler chicks. Replacing the 65% dietary wheat by rye depressed growth and feed efficiency by 27% and 42% respectively.

The data obtained in feeding different combinations of rye and/or wheat fractions gave no indication as to which rye fraction contained the growth-inhibiting substance(s). However, alkylresorcinol seemed to have had no adverse effects on chick preformance since rye bran added to diets containing wheat middlings plus wheat flour or rye middlings plus wheat flour produced results similar to those obtained in feeding chicks diets containing all three wheat fractions. This finding is in contradiction to that of Weiringa (1967) who observed resorcinols to be growth inhibiting to rats, but supports those of Haeberle (1974) and McDonald et al (1974) who worked with mice.

The incorporation of a lyophilized water extract of rye into a wheat containing diet (Experiment IIIb) resulted in depression of chick growth and feed efficiency. Feed intake, in contrast, was not affected. The actual amounts of water-extractable compounds in rye was 18%, and therefore the amounts of added rye extract were respectively equivalent to 69% (Experiment IIIa), 33% or 67% (Experiment IIIb) of as fed rye. The growth depression caused by the addition of a 12% rye extract to a wheat containing diet was less than that obtained by feeding an equivalent amount of dietary rye. This would suggest that either all of the growth inhibiting substance(s) were not completely extracted from rye or that the growth inhibiting potential of the extract was reduced by the extraction procedure.

The incorporation of water extracted rye in diets yielded variable results in two experiments. In Experiment IIIb, feed intake and weight gain of chicks were similar to those obtained in feeding chicks the unprocessed rye; the efficiency of feed utilization, however, was similar to that obtained with the all wheat diet. These results would suggest that the chicks could utilize the extracted rye as efficiently as wheat but that it was much less palatable than wheat. It appeared that rye might contain two factors: a water-soluble factor that depressed feed utilization, and a water-insoluble factor which depressed feed consumption.

As indicated above, the results obtained in feeding chicks the water extracted rye from Experiment IIIa were different from those obtained in Experiment IIIb. In the former experiment the feed:gain ratio was similar to those observed in chicks fed the all rye diets and was higher than that obtained in feeding the wheat diet. Part of these apparently inconsistent results may be explained by the fact that the extracted rye used in each experiment was prepared from a different rye sample, and that the protein level of the extracted rye diet in Experiment IIIa was much lower relative to the other diets, whereas in Experiment IIIb the diets had similar protein contents. The depressed weight gain observed in this latter experiment was probably due to the low feed consumption, but such results might not have been typical since Fernandez, Lucas and McGinnis (1973) obtained similar growth in chicks fed diets containing water-extracted rye or corn.

The magnitude of the difference in chick performance between wheat and rye diets in Experiment IIIa and IIIb, expecially the former, was much less than that obtained in some of the subsequent experiments in this study. Such results do suggest that the growth depressing effect of rye may be modified by nutritional factors including the level of dietary protein relative to the animals' requirements. This is exemplified by the fact that the protein levels in diets (Experiment IIIa) were much in excess of required levels (23% vs. 21%) whereas in Experiment IIIb the protein levels were closer to but still higher than the NRC recommended levels.

Autoclaved treatment of rye before incorporation into diets increased feed consumption by the chicks but weight gain and feed:gain ratio were unaffected. The optimum autoclaving of 10 minutes would suggest that compounds of low thermosensitivity, such as proteins, were being affected, resulting in increased palatability. Heat treatment did not seem to affect the factors associated with vent blockage or feces wetness but beak impaction was considerably reduced (Experiment IIIa).

It has been hypothesized that the adverse effects of rye might be caused by reduced feed intake due to beak impaction (Moran _et al_, 1969), vent blockage, or sticky feces which gave rise to a very damp floor litter that presented serious management problems (Halpin , _et al_, 1936). Under the conditions in which these experiments were conducted, i.e., low relative humidity, room temperature of approximately 25^{o}C and housing the chicks in cages equipped with raised wire floors, no differences in performance criteria were observed in feeding rye diets to chicks whose beaks or vents were cleaned daily (Experiment IV). In general it seemed that pelleting rye diets eliminated beak impaction and autoclave treatment eliminated or greatly reduced it. Dietary fat in excess of 6% seemed to eliminate both beak impaction and vent blockage.

The factor responsible for beak impaction, vent blockage and feces wetness was present in the lyophilized water extract of rye (Experiment IIIa). This factor is probably a complex polysaccharide such as pectin (Wagner and Thomas, 1977) or pentosans (Preece and McKenzie, 1952) whose ability to cause feces wetness was considerably reduced by water extraction but uneffected by heat (Experiment IIIa). Procaine penicillin supplementation had no effect on beak impaction or vent blockage but slightly reduced feces wetness, probably by the proliferation of intestinal bacteria which promoted the enzymolysis of the complex polysaccharide causative factor. Fernandez, Lucas and McGinnis (1973) and Patel and McGinnis (1976) had noted that procaine penicillin supplementation or rye diets resulted in increased stickiness to the feces.

Ergot levels in excess of those present in the rye samples did not influence chick growth and consequently could be ruled out as a growth inhibiting factor in these experiments.

The type and level of fat in diets calculated to be isocaloric did not have a great effect on chick performance. The interaction between grain and fat type indicated that soybean oil rather than tallow was utilized more efficiently in rye diets, but there was no difference in feed efficiency between the wheat diets supplemented by each of the two fats. The cause of this effect was not established but might be related to a difference in essential fatty acids in rye and wheat or the relative rates of absorption of rye and wheat consituents in the intestinal tract. There was an increase in feed efficiency for the high energy diets but this improvement (5%) was not proportional to the increased energy content

16%). The fat contents of the low-fat and the high-fat diets were 4.2% and 7.2% respectively. Therefore, it would seem that utilization of higher levels of dietary fat was impaired by a component in rye.

No difference in chick performance was obtained by feeding diets with or without added vitamin D_3. However, the interaction of grain and vitamin D_3 indicated that vitamin D_3 added to rye or wheat diets respectively increased or decreased the feed:gain ratio, but this difference was only 8%. The lack of a greater response might have been due to the short treatment period and/or high levels of dietary calcium and phosphorous. The addition of greatly excessive levels of vitamin D_3 (100 X 1,000 X requirements) depressed feed consumption, gain in body weight and increased the feed:gain ratio for the wheat diets but not for the rye diets. These observations would suggest the presence in rye of a complexing agent which reduced the potency of vitamin D_3. MacAuliffe *et al* has found that rye affected the utilization of vitamin D_3 by turkey poults (1976a) and broiler chicks (1976b), probably by stimulating the growth of an adverse microflora in the intestinal tract that could interfere with the absorption of vitamin D_3. In addition, the utilization of other nutrients, appeared to be reduced when rye was present in the diet. This latter conclusion is supported by the results of subsequent experiments in this study.

Pelleting of the diets eliminated beak impaction in the chicks (Experiments IIIa, IV). Besides, pelleting the rye diets increased the feed:gain ratio (Fig. 6). This latter effect seemed to be related to the quality of the dietary protein supplement and the grain since the most marked response was observed for the fish meal rye diet.

As mentioned earlier, the magnitude of the difference in chick performance when rye or wheat diets were fed seemed to be modified by nutritional factors, including the level of dietary protein relative to the animal's requirements. The results of Experiments VIII(a), (b) and (c) also provide clear evidence that chick performance was greatly influenced by grain type and protein level. Supplementation of a rye diet with 26% protein as compared to 21% protein gave a more dramatic decrease (17%) in the feed:gain ratio than corresponding wheat diets (7%). This observation (Fig. 7) would suggest the presence in rye of a certain factor which interfered with protein utilization in the chick, thereby causing protein to become a limiting nutrient in a rye diet containing protein at or slightly above the NRC recommended level. Furthermore, the quality (source) of the protein added to the diet influenced chick performance: the lowest gain in body weight of the chicks was obtained by feeding rye diets supplemented with a low quality protein (meat meal) whereas the best performance in rye fed chicks was obtained by supplementing the diets with a high level (26%) of a good quality protein (fish meal) (Fig. 8). However, this best performance in the rye fed chicks was equivalent to that obtained in chicks fed a wheat diet containing a low level (18%) of fish meal, again indicating that rye contains a factor which interferes with protein utilization.

The response of the chicks to penicillin supplementation of rye diets seemed to indicate that a dietary level of 160 mg/kg or greater was needed to achieve maximum response. Other workers had obtained optimum chick growth improvement when only 50 mg/kg procaine penicillin was used to supplement rye diets MacAuliffe and McGinnis (1971) and Fernandez, Lucas and McGinnis (1973). The observation that penicillin had no effect on beak impaction and vent blockage would lend support to the proposal that these conditions are not directly responsible for the low nutritional value of rye.

The highly significant interactions of several factors in Experiment Xb (Table 42) would indicate that as a feed ingredient the nutritional value of rye in a diet formulated to meet minimum NRC nutrient requirements was greatly influenced by the quality of the protein as well as by procaine penicillin supplementation. The interaction of grain type (wheat vs. rye), protein source (meat meal vs. fish meal), and procaine penicillin level (0 vs. 160 mg/kg) in conjunction with the individual treatment values would suggest that the nutritional value of rye for growing chicks could be greatly enhanced by supplementing it with a good quality protein or 160 mg/kg procaine penicillin. However, an even greater improvement could be obtained by supplementation of a rye diet with a good quality protein in conjunction with 160 mg/kg procaine penicillin. The results for feed intake and weight gain obtained by supplementing a meat meal rye diet with procaine penicillin were greater, as compared to the rye diet without procaine penicillin supplementation but were somewhat lower than those obtained by supplementing the rye diet with fish meal protein. Both dry matter retention and protein retention were significantly affected but greater protein retention increases were obtained by supplementing the rye diets with procaine penicillin or a good quality protein. However, the rye diet supplemented with both fish meal and procaine penicillin resulted in only a slight increase in dry matter retention and protein retention compared to the rye diet supplemented with fish meal alone. The improvement in the nutritional value of rye by procaine penicillin supplementation of the diets had been documented by several workers including MacAuliffe and McGinnis (1971) and Fernandez, Lucas and McGinnis (1973) who used protein supplements consisting of 27% soybean meal, 5% fish meal and 5% meat meal. By replacing the fish meal with meat meal and supplementing the wheat or rye diet with 50 mg/kg procaine penicillin, Graber et al (1976) observed a dramatic increase (45%) in weight gain for the rye diets compared to only 1% for the wheat diets. Consequently it may be hypothesized that penicillin has a sparing effect in reducing the chicks' requirements for proteins. The mode of action of penicillin seems to be the inhibition or suppression of the growth of deleterious intestinal microorganisms which compete with the host for dietary protein, and whose growth seems to be promoted by a component in rye.

SUMMARY AND CONCLUSIONS

Several factors seem to affect rye utilization by growing chicks:

1. A water-soluble growth inhibiting factor seems to be located in both the middlings and flour but not in the bran fraction of the grain. It is not clear whether water-extraction removed all the growth-inhibiting effects of rye.
2. Beak impaction, vent blockage and feces condition may be caused by one or more complex carbohydrates, probably pectin and/or pentosans, which are also water extractable.
3. There does not appear to be a close association between the degree of vent blockage and the level of chick performance, thereby indicating that the complex carbohydrates per se may not be growth inhibiting.
4. Both the level and the quality of the protein supplementing rye diets modify the effects of the growth inhibitor(s) in rye.
5. Procaine penicillin supplementation of rye diets affects chick performance in a manner similar to the supplementation of rye diets with a high level of a good quality protein.
6. The mode of action of penicillin appears to be the inhibition or suppression of intestinal microorganisms which compete with the host for dietary nutrients particularly protein, and whose growth seems to be promoted by a component in rye.
7. The type of fat as well as the level of energy in the rye diets may not be responsible for the growth depression associated with the feeding of rye.
8. Vitamin D seems to affect chick performance but this effect might have

been more pronounced if the experiments were conducted over longer time periods, and if the dietary calcium and phosphorus levels were not in excess.

9. Resorcinols do not appear to have any adverse effects on the utilization of rye in growing chicks.

It is clear therefore that the detrimental effects of the growth-inhibiting substance(s) in rye could be maximized by the supplementation of a rye diet with a low level of a poor quality protein, or minimized by supplementation with a high level of a good quality protein plus 160 mg/kg procaine penicillin.

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