THE EFFECT OF RYE IN RATIONS
FOR GROWING PIGS

BY

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ABSTRACT

Five experiments were conducted feeding pigs rye, in all stages of growth, as a replacement for wheat or barley. In two experiments with young growing pigs (13-30 kg), rye replaced wheat and the use of different milling fractions (i.e. flour and bran), different protein sources, level of protein, amino acid availabilities and digestibility of protein and energy were studied. With growing pigs (30-65 kg), different levels of rye were fed and performance evaluated, whereas with finishing pigs (65-100 kg), performance, amino acid availabilities, digestible protein and digestible energy values as well as carcass quality were evaluated. In the case of all growing-finishing experiments, rye was used as a replacement for barley.

The addition of rye flour and or rye bran to rations for young growing pigs did not result in any significant differences in pig performance. Similarly, casein and soybean meal as a supplement to rye or wheat - based rations showed no significant difference.

Feeding low (15%) protein rations (both rye and wheat) resulted in lower gains ($p \leq 0.05$) and poorer feed efficiency when compared with the high (18%) protein rations. In comparing rye and wheat as the sole source of grain in rations for young growing pigs at low (15%) and high levels (18%) of protein, no significant differences in pig performance were noted at either level. Pelleting of the low protein rye and wheat rations improved pig performance only slightly over the same rations in mash form.

As a replacement for barley, rye at a level of 84% fed to growing pigs, resulted in decreased feed intake and significantly

lower gains ($P \leq 0.10$). However, the inclusion of rye in rations resulted in improved feed efficiency. When rye replaced barley in finisher rations, superior pig performance was obtained with barrows but slightly lower gains were obtained for gilts,although differences in both cases were not significant. In the case of the grower and finisher experiments, an adaptation period was indicated, as pigs showed better utilization of rye-based rations in the second half of all three growing - finishing experiments. Carcass traits were not affected by inclusion of rye in finishing rations.

Essential amino acid availabilities, digestible protein and digestible energy values were slightly lower for rye - based rations in comparison to wheat based rations fed to young growing pigs. However, these values were higher when compared to the barley-based rations fed to older (65-100 kg) finishing pigs.

DEDICATION

This thesis is dedicated to my wife and children for their encouragement, help, and understanding during the course of my work.

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INTRODUCTION

Although the nutritive value of rye is quite good when compared with other cereals, it has never been extensively used in animal feeding. This may be attributed to the fact that early reports from researchers indicated that rye was not as palatable as other grains in livestock rations. This poort reputation of rye was probably due to the presence of ergot which has been known to lower feed intake and decrease performance.

Over the past fifteen years, research results have continued to be variable. Many authors report rye to be superior to barley and equal to wheat in feeding value and could be used at levels of 50-60% in rations. Others strongly believe that rye should not constitute more than 30% of the ration and sometimes less, whether it be for swine, poultry or cattle.

The contradictory results justify further research on the feeding value of rye. In the study reported here, five experiments were conducted which covered the feeding of rye in all stages for growing and finishing pigs. With the older pigs, crietria used to measure performance were average daily feed, average daily gain, and feed efficiency. Carcass traits were also evaluated in the finishing experiments. Apparent amino acid availabilities were obtained to determine if essential amino acids were utilized to a lesser degree when rye was a major component of the ration.

In reports that have dealt with the feeding of rye grain, usually pigs 30 kg of weight and heavier were used. Therefore, two experiments were conducted where weanling pigs with initial weights of approximately 15 kg were used to determine their performance when rye or rye fractions (i.e. from milling) constituted the major portion of their diet.

In one experiment rye flour and rye bran were compared with wheat flour and wheat bran and their effect upon performance of young growing pigs. In the second experiment, rye and wheat were used as the basal grain and fed at high and low protein levels and in mash and pellet form.

LITERATURE REVIEW

A. Classification

Rye belongs to the grass family, Gramineae. It is a member of the genus, Secale and is species S. cereale. The genus Secale L. which includes cultivated rye, consists of only four to twelve species (depending upon the criteria used for species definition) so detailed comparative studies are not too difficult (Stutz, 1972). Intercrossing is normally rare, but can result in at least partially fertile hybrids. Secale consists of both annual and perennial species. Cultivated rye is of the spring or fall sown annual. In Canada, about 85% of the rye grown is fall rye (Carmichael and Norman, 1970).

Considerably less effort has been expended in the improvement and development of rye varieties than of most other cereal grains (Bushuk, 1976). As a result there are relatively lower numbers of rye varieties when compared to wheat or most other cereals.

B. Origin and Geographic Distribution of Rye

To determine or hypothesize the origin of evolution of a plant species can be a long, tedious process. Secale cereale L. has been no exception, but there is now general agreement with the hypothesis of Vavilov (1917, 1926) that cultivated varieties of rye originated from weedy forms and that these weedy forms were carried to the northern regions and higher altitudes with the main crops of wheat and barley (Khush, 1963). Wheat and barley were weakened by the lower temperatures and higher precipitation but rye, once a weed, gained the upper hand and through mutation and human selection was further improved.

Rye entered northern Europe probably between 2,000 to 2,500 B.C. so that its first domestication must have occurred somewhat earlier; that is between 2,500 to 3,000 B.C. (Khush, 1963). Northern European rye gradually spread throughout most of Europe and was eventually brought to North America and western South America with the settling of these areas by Europeans in the 16th and 17th centuries (Bushuk, 1976).

C. Production Trends

The area of rye production in the world has declined from an average of 27.8 million hectares from 1961-65 to 13.9 million in 1977 (F.A.O., 1977). This represents a 50% decline of land area used for the production of rye. Although there has been a substantial decrease in land under rye cultivation, production has dropped by merely 30% from 33.8 metric tonnes to 23.3 metric tonnes.

The marked decline in area under rye cultivation has been offset to a limited degree by yield increases. From a period of 1963 yields increased annually through to 1973 where the highest yield figure of approximately 1,874 kg/HA was recorded which represents a 62% increase during this time span. This substantial increase was achieved through improvement of agronomic practices, especially in the use of chemical fertilizers and crop rotation and through improvement of varieties and elimination of the use of low fertility land (Bushuk, 1976). Since 1973, a slight decrease in average yield has occurred, most likely due to climatic conditions.

Rye ranks eighth in production relative to other major cereal crops (F.A.O., 1977). Its production is about one-twelfth that of wheat. The ten leading rye producing countries in 1977 are given in Table 1. Poland, the second largest producer of rye, most of which is fall rye, is one of the few countries where the rye acreage still exceeds that of

TABLE 1

Rye Production by Countries

Country	1000 MT	% of Total
U.S.S.R.	8,471	36.5
Poland	6,200	26.7
West Germany	2,538	10.9
East Germany	1,500	6.5
Czechoslovakia	870	3.7
Turkey	715	3.1
U.S.A.	432	1.9
Canada	392	1.7
France	376	1.6

Source: (F.A.O., 1977)

wheat (Carmicheal and Norman, 1970).

D. Uses of Rye and International Trade

The major use of rye has always been that of bread making, and it ranks second to wheat for this purpose (Schaben, 1948; Hunter, 1950; Bushuk, 1976). However, in Canada, only one quarter of the rye crop is used for bread making, while approximately one-third is used by distillers for the production of rye whiskey. The remainder of the rye grain is used for livestock feed or exported.

Unlike wheat, which enters international trade in large quantities, the movement of rye in trade between nations is relatively small, being only approximately 2% of the total production and is limited chiefly to the quantities needed to cover occasional deficits in countries which are themselves large producers (F.A.O., 1977). This was the case in 1977 when the U.S.S.R. and Poland, the two largest producers, were the largest importers of rye. Many European countries frequently import and export rye at the same time, either importing high quality rye for bread making and exporting lower quality grain for feed, or occasionally importing feed rye and exporting bread rye (Schaben, 1948).

Canada, the eighth largest producer in 1977 was the largest exporter of rye.

E. Canadian Situation

In Western Canada, rye ranks sixth and seventh nationally, among major cereals in areas under production (Table 2), making up only 2% of that of the wheat production in Western Canada.

Of the 392,000,000 kg of rye produced in Canada in 1977, over 81% was grown in the Prairie Provinces (Table 3). Saskatchewan, Alberta, and Manitoba were the largest producers of rye in 1977 making up 35,29

Table 2

Crop Production of Western Canada

	Wheat	Barley	Oats	Rapeseed	Flax	Rye
Hectares	9,794,000	4,411,000	1,680,000	1,315,000	575,000	219,000
Yield (kg/HA)	1,780	2,890	3,450	1,490	1,060	1,590
Production (1000 kg)	17,399,000	12,751,000	5,791,000	1,953,000	610,000	349,000

Source: Quarterly Bull. of Agric. Stats. (1978).

Table 3

Provincial Production of Rye in Canada from 1972 and 1977

	1972	1977
SASKATCHEWAN		
Area (HA)	105,000	91,000
Yield (kg/HA)	1,140	1,520
Production (1000 kg)	119,000	138,000
ALBERTA		
Area (HA)	81,000	71,000
Yield (kg/HA)	1,480	1,610
Production (1000 kg)	119,000	114,000
MANITOBA		
Area (HA)	32,000	36,000
Yield (kg/HA)	1,410	1,880
Production (1000 kg)	46,000	69,000
ONTARIO		
Area (HA)	20,000	16,593
Yield (kg/HA)	1,900	1,950
Production (1000 kg)	38,000	32,000
QUEBEC		
Area (HA)	800	4,000
Yield (kg/HA)	1,380	1,560
Production (1000 kg)	1,000	6,000
BRITISH COLUMBIA		
Area (HA)	400	2,400
Yield (kg/HA)	1,880	1,880
Production (1000 kg)	760	4,600

Source: F.A.O. (1977).

and 17% of the Canadian total, respectively. The only other provinces reporting rye production were Quebec, Ontario, and British Columbia, supplying approximately 11% of the total Canadian production.

F. Adaptations

Rye usually stands stronger and taller than oats and barley. On fertile soils it can grow five feet tall or more. The stem terminates with a head or spike. Its roots branch in many directions and can go as deep as six feet.

Currently, intensive rye cultivation is usually confined between the 18° and 20° C isotherms of the northern hemisphere. Rye is cultivated intensively where the annual rainfall is 500-1000 mm. but has been grown in areas between a rainfall range of 100 to 1200 mm./yr. (Szasz, 1962). It is a cool weather plant, not as well adapted to either dry or moist heat as oats and barley.

One of the major advantages of fall rye is that it can be grown in areas of Western Canada where the prospect of growing winter wheat is too great a risk due to severe winters. Since it can be sown in the fall, it takes advantage of the early spring moisture and can be harvested earlier than spring sown crops, helping to distribute farm work more evenly.

Rye can also be grown on poorer soils than any other grain crop. Soils too poor for rye are generally not used for crop production. It can also be grown successfully under distinctly acid soil conditions, but on the other hand, a fairly high degree of alkalinity is not harmful to the crop (Schaben, 1948; Hunter, 1950). Rye produces better on light loams and sandy soil when compared to barley, wheat, or oats. It is more tolerant of dry soils than of wet, poorly drained soils (Briggle,1959).

Fewer diseases and insects attack rye than attack other cereals

(Schaben, 1948; Briggle, 1959).

G. Nutritive Value of Rye

The chemical analysis of rye in comparison to other cereals is given in Table 4. Langborg Hansen et al. (1976) also compared the apparent digestibilities of protein, carbohydrate, and fat of these five grains using pigs as the test animal (Table 4). Based on these results, the metabolizable energy values of rye compare well with those of wheat, maize, and sorghum.

The coefficients of apparent digestibility of dry matter wer higher for rye than for barley (Friend and MacIntyre, 1969; Smith, 1978). Smith (1978) also found that rye had a greater energy digestibility than barley --85.0 versus 80.2%. Friend and MacIntyre (1969) noted that the crude protein of rye was slightly more digestible than that of barley (84.5 versus 82.1%).

Eggum (1973) found the protein quality of barley, oats, and rye to be very much the same when fed to pigs. He found wheat, maize, and sorghum to have a lower biological value since they were lower in lysine, the most limiting amino acid. Biological value (B.V.) for barley was calculated at 80.8, 79.7 for rye, 76.4 for oats, and only 71.2 for wheat. Friend and MacIntyre (1969) and Smith (1978) found little difference in percentage nitrogen retention when pigs were fed rye or barley.

Knipel (1969) indicated that rye when fed to rats had a higher protein efficiency ratio (P.E.R.) that wheat. Zhmakina et al. (1977) obtained similar results with rats reporting P.E.R. values of 1.67 for rye and 0.99 for wheat.

Therefore, these digestibility and utilization studies comparing rye, barley and wheat, clearly demonstrate that lowered digestibility

Table 4

Chemical Composition (% of dry matter) of five cereal grains and apparent digestibility determined in experiments with pigs.

	Protein	Fat	Crude Fiber	NFE	Starch	G.E.
Oats	14.0	5.0	9.2	69.1	55.2	4.52
Wheat	14.8	2.7	2.6	78.0	64.1	4.39
Maize	10.7	4.9	2.7	80.1	72.6	4.46
Sorghum	11.0	3.8	2.6	80.3	71.7	4.40
Rye	11.2	2.7	2.6	81.4	64.2	4.36
			Digestibility			M.E.
Oats	79	67	18	82	100	3.17
Wheat	78	37	27	94	100	3.73
Maize	76	59	53	94	100	3.78
Sorghum	70	51	91	95	100	3.73
Rye	80	33	33	93	100	3.61

G.E.= Gross Energy

M.E.= Metabolizable energy

NFE= Nitrogen free extract

Source: Langborg Hansen et al., (1976)

is not the limiting factor since the apparent digestibility of dry matter and crude protein was highest for rye while nitrogen-retention was similar for rye and barley.

It is well known that genetic as well as environmental factors influence amino acid composition and protein quality of grain. Protein contents ranging between 6.5 and 14.5% have been reported for rye, the higher values usually being obtained under North American conditions of cultivation where nitrogen fertilizer applications are generally higher (Kent-Jones and Amos, 1967). Although, in many cases the level of crude protein in rye equals that of wheat, rye protein contains little gluten, the elastic and distensible substance, important in making bread from wheat, which is formed as a complex of the two proteins, gliadin and glutenin in the presence of water (Hunter, 1950). The protein of rye contains gliadin but little glutenin and therefore, its ability to retain gases is more limited. Even though the nutritive quality of rye bread may equal of exceed that of wheat, it has a distinct sour taste, is flatter and is not as porous as wheat bread.

Rye differs from wheat, barley, and most other cereals in having a comparatively higher proportion of water and salt soluble proteins, both of which have an improved content of the essential amino acid, lysine. In a review, Sauer (1976) indicates lysine and theronine to be the first and second limiting amino acids respectively for barley, oats, rice, rye, triticale and wheat when these cereals were fed to pigs and rats. The amino acid composition of rye protein is claimed to be nutritionally superior to that of most cereals (Bushuk, 1976). This is due, in part, to the higher proportion of lysine and threonine which is found in rye (Table 5).

The mineral and vitamin composition of rye compares favourably

Table 5

Average essential amino acid content of rye, triticale, and wheat as determined by ion-exchange chromatography[a] (gm. of amino acid per 100gm. of total nitrogen; ranges encountered in the literature in parentheses).

Amino Acid	Rye	Triticale[b] (1972-73)	Wheat
Lysine	21.2 (15.1-28.1)	19.6	17.9 (13.1-24.9)
Threonine	20.9 (19.1-23.1)	19.6	18.3 (14.8-22.2)
Arginine	28.6 (18.4-34.4)	38.2	28.8 (23.4-34.4)
Histidine	13.8 (12.5-16.5)	13.3	14.3 (12.5-16.3)
Isoleucine	21.9 (20.0-24.2)	18.7	20.4 (18.8-21.4)
Leucine	38.5 (36.1-40.6)	45.0	41.7 (37.1-45.0)
Methionine	9.1 (5.9-18.1)	6.0	9.4 (6.3-15.6)
Phenylalanine	27.6 (25.0-30.0)	28.6	28.2 (23.4-33.8)
Tryptophan	4.6 (3.4-8.8)	6.3	6.8 (5.1-13.6)
Valine	29.7 (20.6-34.3)	24.2	27.6 (22.8-32.5)

[a]Source: Food and Agriculture Organization (1970) via Hulse and Laing (1974).

[b]Average of data for three advanced triticales produced at CIMMYT, Mexico in 1972-1973.

Source: Bushuk, (1976).

with that of the other cereal grains. Levels of niacin in rye are lower than that found in other cereals. Wojtusiak (1974) reported that nicotinic acid contained in rye is assimilable by rats to a small degree, the values ranging from 11.9 to 35.0%. Since cost of mineral and vitamin supplementation is relatively small when compared to other constituents of the diet, their composition in cereal grains is not of great concern.

H. Use of Rye in Livestock and Poultry Rations

(a) General

Research done in the thirties with livestock and poultry indicated that rye was not as palatable as other grains. Feeding recommendations with the various species suggested that rye should not make up more than 30% of most rations i.e. it should be mixed with other grains. The presence of ergot in rye in varying amounts undoubtedly conditioned these recommendations, but in a number of cases, where apparently lower levels of ergot were present, palatability problems still remained. In the material reviewed here, the emphasis will be on the research data of the past 20 years.

(b) Swine

In order to reduce dustiness and to provide diets with gross energy levels equal to those of maize diets, Hale et al. (1967) added 2.5% tallow to diets where rye completely substituted maize. Pigs fed rye diets with or without added fat grew more slowly (approximately 10-15%) and required more feed to produce a kilogram of live weight gain than pigs fed maize based diets. Hale et al. (1967), therefore concluded that rye is worth only 78 to 80% as much as maize when used as the only grain in a well fortified, 16% protein diet fed to growing - finishing pigs (30-90 kg). In contrast to these results, Danielson (1972) fed rye, in meal form, at levels up to 60% in replacement of corn for growing-finishing pigs without any decrease in growth rate or feed efficiency.

Contrary to earlier reports that rye should not make up more than 30% of the ration, Bowland (1966) indicated that the rate of gain was not affected by the addition of 25 or 50% rye, in replacement for barley and wheat, to rations fed as a mash. Rye was found to be superior to barley but inferior to wheat with regard to gain and feed efficiency and it was suggested that ergot-free rye can be utilized satisfactorily up to levels as high as 50% of the total balanced ration for market pigs above 25 kg in weight. At levels as high as 65%, Smith (1978) found ground rye to be superior to barley in performance when fed to pigs in the 28-63 kg range.

It appears the inclusion of rye in rations does not affect carcass traits (Bowland, 1966; Johnston et al. 1976). Johnston et al. (1976) compared the feeding value of six feed grains (corn, rye, wheat, triticale, barley and milo). No statistical differences were found between the six grain rations for feed conversion, rate of gain, slaughter weight, or various carcass traits associated with carcass composition.

Conversely, from a review of literature, Wieringa (1967) reported that the recommended maximum levels of rye used for pigs were 30% in diets for older pigs, 15% for pigs weighing 30-50 kg and that no rye be used for piglets or sows. Wieringa (1967) also obtained lower growth rates (12%) in mash diets containing 50% rye when compared to diets containing 50% barley when fed to pigs 16-30 kg of weight.

Friend and MacIntyre (1969) reported that the inclusion of 60% rye in growing pig rations reduced rate of gain more in gilts than in barrows. Inclusion of 30% and 60% rye in replacement for barley in rations resulted in decreased feed intake and therefore lower gains.

Very little work has been conducted with rye in diets for gestating or lactating sows. It is known that rye with high levels of ergot should not be fed to gestating sows. Although Wieringa (1967) suggested that rye should not be fed to sows, Delwiche et al. (1940) recommended that bred sow diets could include up to 40% rye. Trials done at the University of Manitoba (1978- unpublished data) found that gestating sows on restricted diets comsumed pelleted rye diets as well as pelleted barley diets. Digestibility coefficients of dry matter and crude protein were higher for rye. During lactation, research at the University of Manitoba (1978 - unpublished data) found that lactating sows fed rye as the sole cereal grain consumed slightly less feed than those on a barley - based ration. Growth of piglets on sows during a 21 day test period fed pelleted rye were slightly inferior to those fed barley suggesting a lower milk production from sows fed rye diets.

(c) Poultry

Proudfoot (1977) indicated that up to 10% ground rye as a replacement for ground wheat may lead to either an equivalent or superior performance with growing chicks. Associated with the feeding of rye in the mash form at levels of 15% or greater was the presence of feed accumulation on the beaks and "sticky feces" which tended to accumulate on the toes of the chickens (Halpin, 1936; Smith and MacIntyre, 1960; Moran et al., 1970; Finzi et al., 1971; Proudfoot, 1977; and Wagner and Thomas, 1978ab). In most cases the material had to be removed so the mobility of the chick was not hampered. Higher mortality rates were reported by Halpin (1936) but not by Proudfoot when ground rye was fed.

Mature roosters utilized pelleted rye more efficiently than chicks (7-12 days of age) according to Moran et al. (1969).

Smith and MacIntyre (1960) supported the fact that up to 60% rye may be safely fed to growing chickens if the entire ration is pelleted. In agreement with these data, Moran et al. (1969) found that additions of 64% rye in place of corn showed a dramatic decrease in growth rate which was largely overcome by pelleting. The large improvement was almost wholly attributed to the overcoming of the problem of feed accumulation on the beaks, however, the problems of feces still existed.

Wagner and Thomas (1978a)found that day old chicks fed 55% rye showed an adaptive response after about eight days. Since the adaptation occurred only in the chicks not supplemented with antibiotics, they suggested that the adaptation was due to changes in the gut population. It has been reported by many researchers that the growth depression in chicks fed a large percentage of rye, is largely overcome by procaine penicillin or by other antibiotics (MacAuliffe and McGinnis, 1971; Fernandez et al., 1973 a,b; Ferndandez et al. 1974; Patel and McGinnis, 1976; and Misir, 1977). Improvement in the growth of chicks fed 55% rye diets containing antibiotic supplements show that the depression otherwise noted, suggests a toxin in rye is not involved (Wagner and Thomas, 1978a). Misir (1977) reported that the detrimental effects of rye can be minimized by supplementing the diet with 160 mg/kg procaine penicillin and a level of good quality protein which exceeded the N.R.C. protein requirement by 3%.

Removal of water soluble fractions of rye gave a significant improvement in chick growth and feed efficiency (MacAuliffe and McGinnis, 1971; Lucas, 1973; Misir, 1977; and Misir and Marquardt, 1978b). It has been suggested that the water soluble pentosans of rye lead to increases in penicillin sensitive, sporeforming organisms which produce large amounts of gas (CO_2 and some NH_3) and butyric acid fermentatively resulting in decreased feed intake and hence decreased gains (Wagner and Thomas, 1978b).

Halpin et al. (1936), attempted to determine the effect of feeding rye to laying hens in mash form, at levels of 15, 30, and 45% of the diet, as a replacement for corn. Egg production was similar for all groups. The fertility and hatchability of eggs from all groups were satisfactory. More recently, Fernandez et al. (1973) reported that rye replacing corn and wheat at a level of 80% in the diet caused a sharp decline in egg production, followed by a subsequent partial recovery, indicating a toxic effect rather than a nutrient deficiency (Fernandez et al., 1973c), which does not agree with the later results of Wagner and Thomas (1978) who suggest a toxic effect is not the cause of the poor performance associated with rye in chick diets.

(d) Ruminants

Baker et al. (1935) reported that finishing calves consumed and gained almost as much when fed ground rye compared to cattle fed ground corn and wheat, but the rye fed calves, lacked finish. Later results obtained by Winter (1975) indicate that up to 60% rye grain can be used in high energy rations for steer calves. There were essentially no effects on feed consumption, weight gains, or feed efficiency of the steers and the rye grain had a feeding value at least equal to that of the barley it replaced. Feeding rye to fattening lambs has produced as good results as wheat or barley (Morrison, 1969).

Cullison (1975) reported that levels of rye as high as 45% of the concentrate may be fed to dairy cows without decreasing performance.

I. Anti - Nutritional Factors in Rye

(a) Ergot

It is now generally understood that levels of ergot exceeding 0.1% in the diet may prove to be detrimental to the performance of animals.

Ergot, which infects the flower and replaces kernels with hard, seed-like fungus bodies called sclerotia is found more often in rye than in any other cereal grain. Ergot sclerotia contain several alkaloids that cause poisoning in humans, animals, and birds (Seaman, 1971). Ergot poisoning has occurred in man in various parts of the world, especially where rye bread is a prominent part of the diet (Bell and Vanterpool, 1952). Species and regional variations observed in the signs of ergotism in domestic animals may depend on the alkaloids produced and on their respective concentrations (Burfening, 1973).

Comparisons between different studies are difficult since many researchers failed to determine the levels of pharmacologically active substances in the ergot used. It is important to know the amount and type of alkaloids present in ergot when attempting to assess the significance of this material as a mycotoxic agent of potential danger to animals in all stages of production. Until more precise evidence is obtained, ergot should still be regarded as a potential danger to growing pigs and to sows during middle and late pregnancy.

Two types of ergotism exist, chronic and acute. Chronic ergotism is the result of continual ingestion of small amounts of ergot for long periods of time while acute ergotism is caused by large amounts of ergot consumed in a short time. More emphasis has been placed on chronic ergotism since many cereal grains, especially rye, contain small percentages of ergot. The cummulative effects of continued eating of small amounts of ergot sclerotia usually causes the capillaries to contract. The result is a diminished blood supply to the limbs, tail, and ears (parts of the body to be first affected) resulting in loss of the extremities (Bezeau, 1966; Seaman, 1971; and Burfening, 1973). Animals tend to experience lameness as the condition worsens.

Effects of ergot when ingested by reproducing animals include increased abortions, reduced vitality of the young, and decreased or minimal milk production. These symptoms are more pronounced in mares, sows, and ewes (Seaman, 1971; Burfening, 1973).

Friend and MacIntyre (1969) found that feeding of No.3 grade rye (0.20% ergot) to growing pigs caused a greater reduction in weight gains as compared to that of No.2 rye (0.03% ergot). Further trials done in 1970 by the same two researchers demonstrated that weight gains decreased as the level of ergot increased from 0.5% to 2.0%. Nitrogen retention values for the control diets were higher than for pigs fed diets containing 0.10% ergot. Similar results were obtained by Whittemore et al. (1976) when they fed wheat with 10% ergot (containing 0.31% total alkaloids), increased urinary excretion of nitrogen resulted in less retained nitrogen. However, in a later experiment (1977) they found 0.5% ergot, also with 0.31% alkaloids, decreased urinary nitrogen losses and improved the efficiency of nitrogen retention.

Nordskog and Clark (1945) found that prolonged feeding of barley ergot as 0.5% of the diet to sows during the later stages of pregnancy caused agalactia and production of weak piglets of low birth weight, all of which died shortly after birth. This is not in agreement with Bailey et al. (1973) who reported no differences in birth weight of young from sows fed control or an ergot ration. Campbell and Burfening (1972) found feeding ergot to female mice at a 0.53% level resulted in a lower pregnancy rate (94 vs. 72% for the control and ergot rations, respectively) and also a reduction in postimplantation embryonic survival rate (96.4 vs. 79.0% for control versus the ergot ration). Bailey et al. (1973) reported the ergot treatment (0.25% ergotamine) did not interfere with maintenance of pregnancy in sows, neither did they have any adverse effects on blastocyst implantation or on organ weights of embryos (at day 30 after pregnancy).

b) Alkyl Resorcinols

Rye is particularly rich in 5-alkyl resorcinols (Wieringa, 1967; Munck, 1969; Evans et al., 1973; Verdeal and Lorenz, 1977) which is toxic to animals.

Table 6 shows that rye, compared to wheat, can contain more than twice as much alkyl resorcinols. Considerable variations exist in alkyl resorcinols content within single samples of rye and also between various varieties (Wieringa, 1967; Evans et al. 1973). Verdeal and Lorenz (1977) reported that bran contained the highest level of alkylresorcinols, shorts contained intermediate amounts, while flour contained relatively low values. For example rye bran, shorts, and flour contained 0.19, 0.12, and 0.03% alkyl resorcinols, respectively.

(c) Pentosans

Contrary to Wieringa (1967) and Munck (1969), Zillman (1973) obtained results suggesting that the alkyl resorcinols content of the grain per se is not detrimental to feed intake or growth rate of growing mice and that the feeding value of rye is superior to that of wheat. Fernandez et al. (1973a) and Misir and Marquardt (1978a) also reported that the growth depressing effect of rye was not due to alkylresorcinols.

Marquardt (1979) reported that the depressing factor in rye is stable (not affected by heating), present in bran or flour, and is partially water extractable. Since the growth depressing factor of rye was present in bran, flour and middlings , alkylresorcinols were ruled out since they are primarily located in the bran and germ fractions (Misir and Marquardt, 1978a). Misir and Marquardt (1978b) hypothesized that the growth depressing factor in rye (believed to be pentosans) interfered with the digestibility of nutrients, notably protein, as well as the absorption of

Table 6

Relative Amounts of Alkyl Resorcinols Present in Rye, Wheat, and Triticale[1]

Cereal	Number of Varieties	Alkyl Resorcinols (units)
Rye (mean and range)	15	161 (129-192)
Wheat (mean and range)	18	69 (56- 79)
Triticale (mean and range)	19	97 (78-124)

[1]Sources: Munck (1972) via Bushuk (1976).

amino acids from the gut. Marquardt (1979) suggested the following mode of action. Pentosans, being viscous, reduce the rate of mixing in the gastrointestinal tract which causes a decreased rate of digestion of nutrients and/or a reduced rate of absorption. This results in increased competition for nutrients by microflora, in the lower portion of the gastrointestinal tract, which can be overcome by antibiotics.

The adverse effects of the utilization of rye can be attributed, in part, to a decrease in availability of all nutrients, especially amino acids and to a lesser extent fat. Although pentosans (arabinoses and xyloses) are believed to be a major contributor to this decrease in availability, other factors are presumed to be involved.

(d) Other Anti-nutritional Factors

Trypsin inhibitors have also been found to occur in rye (Polanowski, 1968; Mikola and Kirsi, 1972). These compounds, which occur mainly in the endosperm, caused a greater inhibition of trypsin than that of the compounds found in wheat and barley. Chymotrypsin inhibitors have also been reported in rye (Madl and Tsen, 1974).

Lewandowski et al. (1975) determined the levels of nitrates present in various grains. The highest level of nitrates, exceeding 0.5% were found in rye bran. In decreasing order, the nitrate levels in bran from different cereals are rye, wheat, barley, maize and oats.

Phytic acid (Myoinositol Hexaphosphoric acid) which occurs in the aleurone layer of rye and other cereals combines with mineral elements to form highly insoluble salts. The phytase of rye has been reported to be more active than that of wheat (Gontzea and Sutzescu, 1968).

A rachitogenic effect of rye has been found when rye made up 40-46% of the diet for turkey poults (MacAuliffe et al., 1976). Severe rickets developed in the birds before they reached two weeks of age. The rachitogenic effect was removed by adding fat or penicillin suggesting that rye interfered with Vitamin D_3 absorption. MacAuliffe and McGinnis (1976) found that the factor which decreased Vitamin D absorption was removed by water extraction or by acid autoclaving.

MATERIALS AND METHODS

In all five experiments Managra-Yorkshire cross-bred pigs obtained from the Glenlea swine research barn were used. Feed and water were available ad libitum. Feed wastage was kept to a minimum since the self-feeders were adjusted and checked daily for optimum output depending on the form of the ration. Pig weights and feed consumption were recorded, at least, weekly. Criteria used to compare pig performance were average daily feed, average daily gain, and feed efficiency. Availability (digestibility) studies were conducted in all experiments except for Experiment No. 1 (growing pigs) and Experiment No. 5 (finishing barrows).

Prior to analysis, feed and feces samples (dried at 62^{o}C) were ground in a Wiley Mill (1 mm. screen). When done, determinations of crude protein (N x 6.25), crude fibre, ash, and fat was by the methods outlined by the Association of Official Agricultural Chemists (1970). Amino acid analyses were conducted according to the procedure of Bragg et al (1966) with modifications described by Giovannetti et al (1970). Methionine and cystine were determined in duplicate according to the method of Hirs (1967). The samples were analyzed on a model 116 - Beckman amino acid analyzer.

Availability (digestibility) studies were carried out toward the completion of each trial. Feed was mixed with 0.5% chromic oxide (CrO_3) and fed seven days prior to feces collection. The determination of the levels of chromic oxide in the feed and feces was by the method of Williams et al.(1962).

Carcass data were collected for the finishing trials.

Statistical evaluations were done according to the randomized complete block design, or in the case of the finishing trials, a one way analysis of variance using a completely randomized design (Snedecor and Cochran, 1967). Treatment differences were subjected to the Student-Newman-Keuls multiple range test (Kirk, 1968).

A. Experiment No. 1

The objective of this experiment was to compare the performance of growing pigs (approximately 30 - 65 kg) on rations containing Fergus barley (control) in comparison to varying levels of rye. Cougar rye containing 0.093% ergot was used.

Twenty four pigs (12 gilts and 12 barrows) were allotted to one of four treatments and fed over a period of six weeks.

The rations were formulated to meet the N. R. C. (National Research Council) requirements for pigs in this weight range. The ration composition is given in Table 7.

B. Experiment No. 2

The major purpose of this trial was to study the feeding value of rations containing rye flour and rye bran in comparision to wheat flour and wheat bran. The effects of two different protein sources (soybean meal and casein) were also studied.

Twenty-five weanlings (15 barrows and 10 gilts) weighing approximately 14 kg were allotted to one of five treatments and fed over a period of four and one-half weeks to a final weight of approximately 30 kg.

Whole wheat, wheat flour, and wheat bran were purchased from Maple Leaf Mills, St. Boniface, Manitoba. Rye flour and rye bran were

TABLE 7

Experiment No. 1: Ingredients and chemical composition of grower rations for pigs fed from 30 - 65 Kg of weight.[1]

	Control	Test (Rye)		
Ingredients (%):				
Barley	83.0	55.0	27.5	----
Rye	----	28.0	56.0	84.0
Soybean Meal (44%)	13.5	13.5	13.0	12.5
Dicalcium phosphate	1.0	1.0	1.0	1.0
Ground limestone	1.0	1.0	1.0	1.0
Trace-mineralized salt	0.5	0.5	0.5	0.5
Premix[2]	1.0	1.0	1.0	1.0
	100.0	100.0	100.0	100.0
Chemical Analysis (5)				
Crude Protein (N x 6.25)	14.6	14.1	14.2	14.3

[1]Rations were steam pelleted (0.5 cm. in diameter).

[2]With wheat middlings as a carrier, the premix supplied 2,200 I. U. Vitamin A, 330 I. U. Vitamin D_3, 11 ug B_{12}, 176 ppm Zinc, and 22 mg of Aureomycin per Kg of feed.

fractionated from Cougar rye (0.093% ergot) by the Canadian International Grains Institute, Winnipeg, Manitoba. A complete amino acid analysis, in duplicate, was run on each fraction prior to the mixing procedure. The wheat and rye flours did not require grinding prior to analysis. The essential amino acid analysis for the individual fractions is given in Table 8.

All diets were designed to meet the 1973 N. R. C. Amino Acid requirements, plus 10%, for this stage of growth. The estimated, actual, and essential amino acid requirements for each ration is shown in Table 9. The composition of rations is given in Table 10. The rations, except for the control, were formulated to be isocaloric. Therefore, the amount of digestible energy in the control ration, the conventional starter ration, was slightly lower than the other four diets (Table 10).

The barrows and gilts were separated into different pens and placed on test rations without allotting any time for adjustment.

Intramuscular injections of Tylocine were given to treat sporadic scouring problems for barrows fed the control ration and the rye flour-rye bran ration. However, some scouring persisted for two barrows on the rye flour-rye bran ration after 22 days till the completion of the trial. Since one of these barrows gained only 2.27 kg and the other 4.56 kg during the 32 day test period, both were sacrificed and analyzed. Swine dysentry was reported to be the cause for the poor performance, therefore, data obtained for these two barrows were discarded.

TABLE 8

Essential amino acid composition of each fraction[1]

	Wheat Flour	Wheat Bran	Wheat Grain	Rye Flour	Rye Bran	Casein	Soybean Meal
Lysine	0.27	0.66	0.35	0.24	0.68	7.12	5.22
Threonine	0.33	0.52	0.38	0.22	0.56	3.40	1.53
Arginine	0.43	1.04	0.54	0.28	1.00	2.57	2.66
Histidine	0.27	0.43	0.29	0.17	0.48	2.50	0.96
Isoleucine	0.50	0.53	0.49	0.31	0.64	4.30	1.94
Leucine	0.92	1.31	0.87	0.50	1.13	7.57	3.31
Methionine	0.35	0.24	0.34	0.15	0.32	0.98	0.37
Phenylalanine	0.67	0.64	0.59	0.42	0.84	4.06	1.89
Valine	0.54	0.79	0.58	0.35	0.86	5.18	2.10

[1] Results in % A. A. on as fed basis.
Each value given is the average of two samples except for wheat flour, which is the average of three samples.

TABLE 9

Estimated, actual, and required levels of essential amino acids.

Ration I

Whole Wheat (80%) A
S B M (17%) B

	A	B	Total	Added	Actual	NRC Plus 10%
Lysine	.28	.50	.78	.09	.90	.82
Threonine	.30	.29	.59		.59	.53
Arginine	.48	.56	1.04		1.06	.24
Histidine	.16	.20	.36		.47	.21
Isoleucine	.48	.48	.96		.72	.58
Leucine	.72	.61	1.33		1.41	.70
S-containing A.A.'s[1]	.54	.24	.78		.60	.58
Phenylalanine	.47	.39	.86		.94	.58
Valine	.48	.37	.85		.98	.58

[1]Amount of methionine and cystine present.

Ration II

Wheat Flour (48%) A
Wheat Bran (32%) B
Casein (6%) C

	A	B	C	Total	Added	Actual	NRC Plus 10%
Lysine	.13	.21	.43	.77	.09	.89	.82
Threonine	.16	.17	.20	.53	.06	.56	.53
Arginine	.21	.33	.15	.69		.71	.24
Histidine	.13	.14	.15	.42		.42	.21
Isoleucine	.24	.17	.26	.67		.66	.58
Leucine	.44	.42	.45	1.31		1.26	.70
S-containing A.A.'s[1]	.34	.21	.08	.63		.71	.58
Phenylalanine	.32	.20	.24	.76		.81	.58
Valine	.26	.25	.31	.82		.96	.58

[1]Amount of methionine and cystine present.

Ration III

Wheat Flour (48%) A
Rye Bran (32%) B
Casein (6%) C

	A	B	C	Total	Added	Actual	NRC Plus 10%
Lysine	.13	.22	.43	.78	.11	.89	.82
Threonine	.16	.18	.20	.54		.52	.53
Arginine	.21	.32	.15	.68		.67	.24
Histidine	.13	.15	.15	.43		.40	.21
Isoleucine	.24	.20	.26	.70		.70	.58
Leucine	.44	.36	.45	1.25		1.24	.70
S-containing A.A.'s[1]	.34	.20	.08	.62		.68	.58
Phenylalanine	.32	.27	.24	.83		.79	.58
Valine	.26	.27	.31	.84		.99	.58

[1] Amount of methionine and cystine present.

Ration IV

Rye Flour (48%) A
Rye Bran (32%) B
S B M (12%) C

	A	B	C	Total	Added	Actual	NRC Plus 10%
Lysine	.12	.22	.33	.67	.20	.84	.82
Threonine	.11	.18	.21	.50	.06	.52	.53
Arginine	.13	.32	.40	.85		.79	.24
Histidine	.08	.15	.14	.37		.34	.21
Isoleucine	.15	.20	.33	.68		.59	.58
Leucine	.24	.36	.43	1.03		1.01	.70
S-containing A.A.'s[1]	.14	.20	.16	.50	.12	.56	.58
Phenylalanine	.20	.27	.28	.75		.59	.58
Valine	.17	.27	.28	.72		.78	.58

[1] Amount of methionine and cystine present.

Ration V

Wheat Flour (48%) A
Wheat Bran (32%) B
S B M (12%) C

	A	B	C	Total	Added	Actual	NRC Plus 10%
Lysine	.13	.21	.33	.67	.20	.79	.82
Threonine	.16	.17	.21	.54		.48	.53
Arginine	.21	.33	.40	.94		.81	.24
Histidine	.13	.14	.14	.41		.40	.21
Isoleucine	.24	.17	.33	.74		.60	.58
Leucine	.44	.42	.43	1.29		1.12	.70
S-containing A.A.'s[1]	.34	.21	.16	.71		.59	.58
Phenylalanine	.32	.20	.28	.80		.78	.58
Valine	.26	.25	.28	.79		.88	.58

[1] Amount of methionine and cystine present.

Table 10

Experiment No.2: Ingredients and chemical composition of starter rations for pigs fed from 15-30 kg of weight.

	Control	Test Rations			
Ingredients (%)					
Whole wheat	80.0	----	----	----	----
Wheat flour	----	48.0	48.0	----	48.0
Wheat bran	----	32.0	----	----	32.0
Rye flour	----	----	----	48.0	----
Rye bran	----	----	32.0	32.0	----
Casein	----	6.0	6.0	----	----
Soybean meal (44%)	17.0	----	----	12.0	12.0
Corn starch	----	6.0	6.0	----	----
Corn oil	----	5.0	5.0	4.0	5.0
Dicalcium phosphate	1.45	1.00	1.00	1.00	1.00
Ground limestone	1.00	1.35	1.35	1.35	1.35
Trace-mineralized salt	0.50	0.50	0.50	0.50	0.50
Alfafloc	0.50	0.15	0.15	1.15	0.15
L-lysine (monohydrochloride)(g)	200	200	250	450	450
DL-methionine (g)	----	----	----	270	----
L-threonine (g)	----	140	----	140	----
Premix[2]	+	+	+	+	+
	100.0	100.0	100.0	100.0	100.0
Chemical Analysis (%)					
Dry Matter	88.0	89.2	89.3	89.2	90.1
Crude Protein (Nx6.25)	17.5	16.7	16.7	14.1	16.6
Ash	4.4	4.4	5.3	5.3	5.3
D.E. (Kcal/kg)	2.92	3.12	3.27	3.26	3.20

[1]Rations were in mash form.

[2]The premix supplied 2,200 I.U. Vitamin A, 330 I.U. Vitamin D_3, 11 ug B_{12}, 176 ppm. zinc, and 2.5 grams mecadox per kg of feed.

C. Experiment No. 3

The objectives of this experiment were: 1) To study the effect on pig performance of low and optimum (1973 N. R. C.) protein levels in rye and wheat based starter rations and 2) Similarly to study the effect on pig performance of pelleting the low protein rations.

Forty-eight weanlings (24 gilts and 24 barrows) with an average weight of 12.9 kg were used; with each sex being divided into groups of four based on weight. Within each sex, each group was randomly assigned to one of six treatments. The pigs were on test for 35 days and reached a final weight of 22.5 kg.

Gazelle rye (0.07% ergot) and Glenlea wheat were the basal grains used in the rations tested.

As a result of a high estimate of rye protein prior to mixing and analysis, the wheat rations had slightly higher protein levels (Table 11). The level of crude protein required for this stage of growth is approximately 17.5%. DL - methionine was added to the high protein rations so they would meet the N. R. C. requirements and also to the low protein, rye, mash ration to equilibrate the level to that of the low protein, wheat, ration. The main ingredients and chemical composition aregiven in Table 11.

D. Experiment No. 4 and No. 5

The purpose of these two experiments with gilts (Experiment 4) and barrows (Experiment 5) was to evaluate the performance of a rye based finishing ration. In addition, a ration including barley and rye in a 50:50 proportion was fed in each experiment. The only differences in the two experiments were:

Table 11

Experiment No. 3: Ingredients and chemical composition of starter rations for pigs fed from 13-27 kg of weight.

Form[1]	Control			Test Rations		
	Mash	Mash	Mash	Mash	Pelleted	Pelleted
Ingredients (%)						
Wheat	78.0		88.0		88.0	
Rye		77.0		87.0		87.0
Soybean Meal (44%)	18.0	18.0	8.1	8.1	8.1	8.1
Alfafloc	1.0	1.0	1.8	0.9	1.0	0.9
Wheat Flour	1.0					
Rageseed Oil		2.0		2.0		2.0
Dicalcium Phosphate	1.5	1.5	1.5	1.5	1.5	1.5
Ground Limestone	0.5	0.5	0.6	0.5	0.6	0.5
Trace-mineralized Salt	0.50	0.50	0.50	0.50	0.50	0.50
DL-methionine (g)	227	681		52		52
Premix[2]	±	±	±	±	±	±
	100.0	100.0	100.0	100.0	100.0	100.0
Chemical Analysis (%)						
Dry Matter	89.3	90.9	88.7	90.7	89.1	91.3
Crude Protein (Nx6.25)	19.7	17.7	16.5	14.3	16.5	13.9
Fat	1.6	3.4	1.7	3.1	1.9	3.3
Crude Fibre	3.9	4.5	4.3	4.1	4.2	4.1
Ash	5.7	5.5	5.7	5.0	4.5	5.0
Calcium	0.5	0.6	0.6	0.6	0.5	0.6
Phosphorous	0.8	0.7	0.8	0.7	0.7	0.7
D.E. (Kcal/kg)	2.74	2.84	2.83	2.82	3.16	3.16

[1] Size of pellets were 0.5 cm. in diameter.

[2] The premix supplied 2,200 I. U. Vitamin, 330 I. U. Vitamin D_3, 11 ug B_{12}, 176 ppm. Zinc, and 2.5 grams mecadox per Kg of feed.

1) There were 12 gilts per treatment and only 5 barrows per treatment and 2) The gilts were started at an initial weight of 62 kg while the barrows were started on test at approximately 70 kg (Both were carried through to a final weight of 100 kg).

The three pelleted rations consisted of a grain which consisted of all Fergus barley or Gazelle rye, or a combination of the two (Table 12). Gazelle rye contained 0.07% ergot which is well below the 0.1% safety level. The rations were formulated to contain the same crude protein content.

Carcass data, with the help of Canada Packers personnel, were collected after termination of both experiments.

TABLE 12

Experiment No. 4 and No. 5: Ingredients and chemical composition of finisher rations for pigs fed from 65 - 100 kg of weight.[1]

	Control	Test Rations	
Ingredients (%):			
Barley	87.1	--	43.3
Rye	----	85.8	43.3
Soybean meal (44%)	10.9	12.2	11.4
Dicalcium phosphate	0.75	0.75	0.75
Ground limestone	0.75	0.75	0.75
Trace-mineralized salt	0.50	0.50	0.50
Premix [2]	1.00	1.00	1.00
	100.0	100.0	100.0
Chemical analysis (%):			
Dry matter	90.5	90.9	90.7
Crude protein (Nx6.25)	14.4	15.3	14.8
Fat	1.7	1.3	1.6
Crude Fibre	5.6	3.7	4.9
Ash	5.3	4.1	4.7
Calcium	0.4	0.4	0.4
Phosphorous	0.6	0.5	0.5
D. E. (Kcal/Kg)	3.08	3.44	3.41

[1]Rations were steam pelleted (0.5 cm. in diameter).

[2]The premix supplied 1,650 I. U. Vitamin A, 176 I. U. Vitamin D_3, 11 ug B_{12}, 176 ppm. Zinc, and 11 mg. of Aureomycin per Kg of feed.

RESULTS AND DISCUSSION

In the interest of continuity of discussion, Experiments 1,4, and 5 will be discussed first as they deal with rye replacing barley. Experiments 2 and 3 are discussed later as they deal with rye/rye fractions substituting wheat/wheat fractions in rations involving pigs in a lighter weight range (starter rations).

A. Experiment No. 1

The performance data of growing pigs fed different levels of rye as a replacement for barley are given in Table 13. These data show a significant difference in average daily gain due to treatment as well as sex ($P \leq 0.10$). The latter (gilts versus barrows) is usually noted in most experiments but the treatment effect (i.e. different levels of rye) show that the highest level of rye fed (84%) gave the poorest results (17% poorer weight gains).

The poorer average daily gain noted with increasing levels of rye can be directly related to the lower levels of feed consumption noted with the increasing levels of rye in feed (2.72 kg per day for barley grower and only 2.12 kg per day for 84% rye grower). However, overall feed efficiency favors the rye rations. The energy level of rye is higher than barley and similar to that of wheat so that an improved feed efficiency could be expected in this experiment. These results agree with those obtained by Wieringa (1967) who reported decreased weight gains, but poorer feed efficiency, feeding 50% rye in replacement for barley to younger pigs (16 - 30 kg).

In contrast to these results obtained by feeding 28% and 56% rye, Bowland (1966) found no differences in weight gain or feed

Table 13

Experiment 1: Performance data for growing pigs (30-65 kg) fed different levels of rye.

Part A: Performance of gilts and barrows.

	Gilts[1]			Barrows[1]		
Ration	Average daily feed (kg)	Average daily gain (kg)	Feed Efficiency	Average daily feed (kg)	Average daily gain (kg)	Feed Efficiency
Barley grower	2.63	0.78[a]	3.35	2.82	0.81[a]	3.46
28% Rye[2]	2.21	0.67[a]	3.31	2.54	0.81[a]	3.12
56% Rye[2]	2.17	0.75[a]	2.91	2.35	0.75[a]	3.15
84% Rye[2]	1.99	0.63[a]	3.17	2.26	0.69[a]	3.27
Overall average	2.25	0.70[3]	3.19	2.50	0.77[4]	3.25

[1]Based on three observations.

[2]Percentage of rye replacing barley, kilogram per kilogram.

[3,4]Means in the same row without a common superscript are significantly different from each other ($P \leq 0.10$).

[a]Means in the same column without a common superscript are significantly different from each other ($P \leq 0.05$).

Part B: Combined data for gilts and barrows.

	Average daily feed (kg)	Average daily gain[1] (kg)	Feed efficiency
Barley grower	2.72	0.79[a]	3.40
28% Rye	2.38	0.74[a]	3.21
56% Rye	2.24	0.75[a]	3.03
84% Rye	2.12	0.66[b]	3.22
Overall average	2.34	0.74	3.22

[1]Based on six observations (gilts and barrows).

[a,b]Means in the same column without a common superscript are significantly different from each other ($P \leq 0.10$).

efficiency feeding rye as a replacement for barley at the 25% and 50% levels. Also, in disagreement with the results obtained in this study with 84% rye, Johnston et al. (1976) found no significant differences for rate of gain or feed conversion when rye replaced all the barley in the ration. Feed conversion ratios obtained by Smith (1978) were similar to the data reported here and rye was reported superior to barley with respect to weight gain at levels as high as 65%.

In general, in this study, gilts were more adversely affected by the inclusion of rye than barrows (Table 13). Similarly, Friend and MacIntyre (1969) found rye rations reduced rate of gain more in gilts than in barrows, but their data were obtained with heavier pigs (52 - 89 kg).

Wagner and Thomas (1978b) reported previously that chicks fed 55% rye diets without antibiotic supplementation would adapt to the diets after about one week. To determine the effect of an adjustment period with growing pigs, performance of the pigs in the two halves of the test were compared (Table 14). In the first half of the test, pigs fed barley had higher average daily gains ($P \leq 0.05$) than pigs fed rations containing rye, whereas no significant differences occurred with respect to treatment in the second half. Both barrows and gilts fed rye showed poorer daily gains in the first half, although it was only significant for barrows ($P \leq 0.05$) due to higher variation found with gilts (Table 14).

It would appear that the rapid change to a rye containing ration resulted in some adverse effects which were compensated for at a later stage. For example, average daily gain is 28% lower for the 84% rye ration compared to the barley ration in the first half compared to only 8%

Table 14

Experiment No. 1: Performance data for growing pigs (30-65 kg) for each half of the test.

A. Performance of the pigs in the first half.

Ration	Average daily feed (kg)	Average daily gain (kg)	Feed efficiency
Barley grower	2.36	0.75[a]	3.14
28% Rye[1]	2.38	0.71[b]	2.86
56% Rye[1]	1.95	0.65[b]	2.98
84% Rye[1]	1.87	0.54[b]	3.47

B. Performance of the pigs in the second half.

Ration	Average daily feed (kg)	Average daily gain (kg)	Feed efficiency
Barley grower	3.08	0.85[a]	3.66
28% Rye[1]	2.66	0.77[a]	3.45
56% Rye[1]	2.57	0.84[a]	3.07
84% Rye[1]	2.39	0.78[a]	3.06

[1]Percentage of rye replacing barley, kilogram per kilogram.

[a,b]Means in the same column without a common superscript are significantly different from each other ($P \leq 0.05$).

C. Average daily gain of gilts and barrows for each half.

i. First half

	Barley	28% Rye	56% Rye	84% Rye
Barrows	0.78[a]	0.78[a]	0.64[b]	0.56[b]
Gilts	0.73[a]	0.64[a]	0.66[a]	0.51[a]

ii. Second Half

	Barley	28% Rye	56% Rye	84% Rye
Barrows	0.85[a]	0.85[a]	0.85[a]	0.82[a]
Gilts	0.84[a]	0.69[a]	0.83[a]	0.75[a]

[a,b]Means in same row without a common superscript are significantly different from each other ($P \leq 0.05$).

lower gains in the second half. Although feed consumption in the two halves of the test did not change greatly relative to that of barley - fed pigs, utilization becomes more efficient i.e. feed efficiency of the pigs fed the 84% rye ration improved in the second half from 3.47 in the first half to 3.06 in the second half.

B. Experiment No. 4

Performance data of the finishing gilts are shown in Table 15. While the differences were not significant, results show that barley - fed pigs had slightly better average daily gains while pigs fed the rye rations showed better feed efficiency. These data agree with the results obtained by Johnston et al. (1976) who found no significant differences in gain when rye and barley were fed to weanlings till they reached a market weight of approximately 100 kg.

In agreement with previous results obtained in Experiment 1 and those of Friend and MacIntyre (1969), pigs on the rye rations had a decreased feed consumption compared to pigs fed the barley rations. However, these data disagree with Bowland (1966) feeding mash, and Friend and MacIntyre (1969) feeding pellets, since pigs in this test fed rye exhibited better feed efficiency than those fed barley.

As was done for experiment 1, performance data for the first and second half of this experiment are given in Table 15 (Part B). In contrast to the overall data, there were significant differences in average daily gain ($p \leq 0.05$) in the first half of the test where the barley fed pigs performed better than the pigs on any of the rye containing rations. There were no signifacant differences in average daily gain in the second half of the test but the rye- fed pigs equaled

TABLE 15

Experiment No. 4: Performance data for finishing gilts (62-100 kg) fed barley and rye.

Part A: Overall data

Ration	Average Daily Feed (kg)	Average Daily Gain[2] (kg)	Feed Efficiency
Barley[1]	2.86	0.77[a]	3.72
Rye[1]	2.64	0.73[a]	3.62
Barley:Rye (50:50)	2.76	0.73[a]	3.75

Part B: Performance data for finishing gilts (62-100 kg) for each half of the test.

a. Performance of the pigs in the first half.

Ration	Average Daily Feed (kg)	Average Daily Gain[2] (kg)	Feed Efficiency
Barley[1]	2.86	0.81[a]	3.48
Rye[1]	2.49	0.70[b]	3.53
Barley:Rye (50:50)	2.72	0.73[b]	3.75

b. Performance of the pigs in the second half.

Ration	Average Daily Feed (kg)	Average Daily Gain[2] (kg)	Feed Efficiency
Barley[1]	2.92	0.70[a]	3.98
Rye[1]	2.85	0.76[a]	3.74
Barley:Rye (50:50)	2.76	0.73[a]	3.76

[1] Constitutes 100% of the grain.

[2] Based on twelve observations/treatment.

[ab] Means in the same column without a common superscript are significantly different from each other ($P \leq 0.05$).

or bettered their gains when compared to the first half of the test while barley-fed pigs gained more slowly.

As well as the data on average daily gains, the feed efficiency data indicate a process of adaptation to rye containing rations already noted in Experiment No. 1. In addition it should be noted that the performance data were similar whether rye replaced 50% or all of the barley in the finishing ration.

Apparent availabilities of essential amino acids, digestible protein and energy values are given in Table 16. In each case, amino acid availability is the lowest for pigs consuming the barley ration. Pigs which consumed the barley - rye - soybean meal ration had the highest availabilities suggesting some interaction taking place between rye and barley resulting in better amino acid availability by the pigs when compared to rye - soybean meal or barley - soybean meal rations. However, the lowered availabilities of essential amino acids and digestible protein has not resulted in a decrease in average daily gain for pigs fed the barley ration. Results by Sauer (1976), showed that lysine in barley was 75.7% available while in this study, lysine in a barley - soybean meal ration was only 63.6% available. There is no apparent explanation for the difference in the values obtained. Results of amino acid availabilities of rye - soybean meal rations reported here using pigs as the test animal are the only ones available to date.

Carcass measurements were collected at the end of the experiment and the results are depicted in Table 17. Bowland (1966), Friend and MacIntyre (1969), and Johnston et al. (1976), indicated little influence of rye on carcass quality which is in agreement with the results obtained in the present study.

TABLE 16

Experiment No. 4: Apparent availabilities of essential amino acids, digestible protein, and digestible energy values for gilts fed barley and rye supplemented with soybean meal.[1]

Ration	Barley[2]	Rye[2]	Barley:Rye[3]
Lysine	63.6[b]	77.1[a]	77.9[a]
Threonine	68.8[b]	78.4[a]	81.2[a]
Arginine	84.0[b]	88.2[a]	87.7[a]
Histidine	83.0[b]	87.8[a]	88.9[a]
Isoleucine	70.8[c]	80.1[b]	87.6[a]
Leucine	76.1[b]	83.2[a]	85.9[a]
Methionine	67.7[b]	77.5[a]	78.8[a]
Phenylalanine	73.7[c]	81.5[b]	85.3[a]
Valine	72.2[b]	82.2[a]	85.2[a]
Digestible Protein	74.4[b]	83.9[a]	84.2[a]
Digestible Energy	78.7[b]	86.9[a]	86.6[a]

[1]Reported as a percent (Dry matter basis).

[2]Constitutes 100% of the grain mixture.

[3]Each grain constitutes 50% of the grain mixture..

[abc]Means in the same row without a common superscript are significantly different from each other ($P \leq 0.05$).

TABLE 17

Experiment No. 4: Carcass measurement of finishing gilts fed barley and rye.[1]

	Barley	Rye	Barley:Rye
Dressing %	79.4	78.9	79.2
Index	102.4	101.8	102.3
Total Fat (cm.)	9.9	10.1	10.0
Carcass length (cm.)	79.2	78.5	79.3
Weight of ham (kg)	8.9	9.0	8.9
Weight of side (kg)	34.6	34.6	34.5
% Ham from carcass	25.8	26.0	25.7
Loin eye area (sq. cm.)	35.0	34.8	36.7
Ham lean (sq. cm.)	133.5	138.1	126.0

[1]Based on twelve observations/treatment.

C. Experiment No. 5

This experiment dealt with the feeding of rye and barley to finishing barrows. The performance data are given in Table 18. First of all, it should be noted that the barrows' performance in the test was quite outstanding. Average daily gain for all pigs was over 0.90 kg with a feed efficiency of approximately 3.65. In agreement with Bowland (1966), results in Table 18 show the rye (100%) fed pigs had the best average daily gain (no significant difference at $p \leq 0.05$) and feed efficiency. Consistent with our previous results from Experiments 1 and 4, pigs fed rye (100%) had a lower feed consumption compared to pigs on the other rations. These data agree with those of Johnston et al. (1976) who reported no significant difference in gain when rye and barley were fed from weanling to finishing. In contrast to Johnston et al. (1976),in this experiment as well as in Experiments 3 and 4 feed efficiency was improved when pigs were fed the 100% rye ration.

The pigs fed the barley - rye ration (50:50) were second best with respect to average daily gain, but their feed efficiency was similar to that of the barley - fed pigs.

As was done with the pigs in Experiments 1 and 4, the experimental data was divided into two halves to determine if an adjustment period was necessary for pigs fed rye. From results of Table 18 (Part B), it is apparent that barrows on the rye ration consumed it in adequate amounts throughtout the test. This is in contrast to finishing gilts (Experiment 4) where feed consumption on the rye based rations was reduced initially and compensated for in the latter part of the test.

TABLE 18

Experiment No. 5: Performance data for finishing barrows (70-100 kg) fed barley and rye.

Part A: Overall data

Ration	Average Daily Feed (kg)	Average Daily Gain[2] (kg)	Feed Efficiency
Barley[1]	3.34	0.87[a]	3.83
Rye[1]	3.16	0.96[a]	3.30
Barley:Rye (50:50)	3.55	0.93[a]	3.81

Part B: Performance data for finishing barrows (70-100 kg) for each half of the test.

a. Performance of the pigs in the first half .

Ration	Average Daily Feed (kg)	Average Daily Gain[2] (kg)	Feed Efficiency
Barley[1]	3.32	0.95[a]	3.51
Rye[1]	3.10	1.08[a]	2.87
Barley:Rye (50:50)	3.36	1.02[a]	3.28

b. Performance of the pigs in the second half.

Ration	Average Daily Feed (kg)	Average Daily Gain[2] (kg)	Feed Efficiency
Barley[1]	3.36	0.80[a]	4.18
Rye[1]	3.24	0.82[a]	3.97
Barley:Rye (50:50	3.78	0.82[a]	4.59

[1]Constitutes 100% of the grain.

[2]Based on five observations/treatment.

[a]Means in the same column without a common superscript are significantly different from each other ($P \leq 0.05$).

Although pigs on all three rations showed similar average daily gains in the final half of the test, barrows on the 100% rye rations did show superior feed efficiency, as was also recorded in the first half of the test.

Carcass data for the barrows are given in Table 19. In agreement with results of Experiment 4 (gilts) and results reported by Bowland (1966), Friend and MacIntyre (1970) there were no significant differences in carcass quality between the rye and barley - fed pigs. The barrows on the combination rye and barley ration had slightly heavier hams, percentage ham, and a greater area of ham lean but the differences were not significant ($P \leq 0.05$) due to the small numbers tested and the variation in the values obtained.

TABLE 19

Experiment No. 5: Carcass measurement of finishing barrows (70-100 kg) fed barley and rye.

	Barley	Rye	Barley:Rye
Dressing %[1]	79.7	79.8	79.7
Index[1]	102.2	104.2	104.6
Total Fat (cm.)[2]	10.4	10.5	9.8
Carcass length (cm.)[2]	79.8	80.0	78.0
Weight of ham (kg)[2]	8.5	8.4	8.9
Weight of side (kg)[2]	34.3	34.3	34.2
% Ham from Carcass[2]	24.6	24.6	26.0
Loin eye area (sq. cm.)[2]	32.9	30.7	32.9
Ham Lean (sq. cm.)[2]	139.4	140.0	148.39

[1]Based on five observations/treatment.

[2]Based on four observations/treatment.

D. Data Comparison of Experiments 1,4, and 5

Comparisons between the data of other researchers and the results obtained here are difficult due to different levels of rye fed, varieties used, levels of ergot present and other environmental conditions as well as size and breed of pigs. Even when comparisons are done between Experiment 1 and Experiments 4 and 5 it should be noted that two different varieties with two different levels of ergot were fed i.e. Cougar rye (0.093% ergot) in Experiment 1 and Gazelle rye (0.07% ergot) in Experiments 4 and 5.

In spite of these differences some general conclusions can be made with respect to these three experiments.

(1). In general, pigs fed from 65 kg to market weight performed better on rye based rations than on barley based rations, but the reverse was true for pigs in the 30-65 kg weight range. These results agree with those reported by Bowland (1966) but are in disagreement with results obtained by Friend and MacIntyre working with finishing pigs and those of Smith (1976) working with growing pigs in the 28-63 kg weight range.

(2). When rye was fed to pigs in the 30-100 kg weight range, gilts were more adversely affected than barrows by the inclusion of higher levels of rye in the ration, which agrees with the results obtained by Friend and MacIntyre (1969).

(3). Detailed examination of the data show that an adaptation process takes place with pigs fed rations containing large amounts of rye. Although feed efficiency usually becomes poorer with age, as was the case with barley - fed pigs in the second half of each experiment,feed efficiency for growing pigs fed 84% rye (Experiment 1) improved . In addition, in experiments 4 and 5 with the finisher rations containing 100% rye - fed pigs showed only slight increases in feed efficiency when compared to the barley fed pigs. These data agree with an adaptation process put forth by Wagner and Thomas (1978) as a result of their work with growing chickens.

(4). Higher digestibility values were obtained for protein and energy for rye - based rations than barley - based rations. These results agree with Friend and MacIntyre (1969) and Smith (1978), who reported higher digestibility values for protein and energy, respectively when rye was compared with barley fed rations.

(5). In general, essential amino acid availabilities were higher for rye - soybean meal rations when compared to barley - soybean meal rations.

(6). Inclusion of rye in the rations did not adversely effect carcass quality, which is in agreement with results obtained by Bowland (1966), Friend and MacIntyre (1969) and Johnston et al. (1976).

E. Experiment No. 2

In this experiment conducted with wheat and rye fractions (flour and bran) there were no significant differences in average daily gain with respect to treatment or protein source ($P \leq 0.05$). However, pigs on the wheat based rations performed slightly better than those on the rye containing rations. Likewise, pigs on the soybean meal supplemented rations gained slightly better when compared to the casein supplemented rations (Table 20).

The data divided for gilts and barrows, are given in Table 21. Average daily gain was highest for the barrows and gilts fed wheat flour and wheat bran (0.54 kg) and lowest for the weanlings fed wheat flour and rye bran (0.39 kg). A significant difference ($p \leq 0.05$) was found between the sexes as the gilts gained better than the barrows. However, it should be noted that barrows on the control and rye flour-rye bran rations consumed less feed and therefore gained less which likely resulted due to sporadic scouring problems which occurred in the experiment. No such explanation can be given for the poorer feed consumption and lower gains found with barrows on the wheat flour-rye bran ration.

Data reported here are in agreement to those reported by Johnston et al. (1976) when he found no significant differences feeding rye or wheat to weanling pigs through to finishing. However, it should be noted that a longer test period was used by Johnston et al. (1976) in comparison to the 32 day test period used for this experiment.

Upon dividing the experimental data into two halves and again comparing performance, no adjustment period similar to that noted for growing pigs in Experiments 1 and 4 was evident.

The essential amino acid availabilities, digestible energy and

Table 20

Experiment No. 2: Performance of young growing pigs (14-30 kg) fed wheat and rye fractions.[1]

Ration	Average daily feed (kg)	Average daily gain (kg)	Feed efficiency
Whole Wheat (80%) Soybean meal (17%) (control)	1.15	0.48[a]	2.42
Wheat flour (48%) Wheat bran (32) Casein (6%)	0.92	0.42[a]	2.20
Wheat flour (48%) Rye bran (32%) Casein (6%)	0.88	0.39[a]	2.26
Rye flour (48%) Rye bran (32%) Soybean meal (12%)	0.99	0.43[a]	2.31
Wheat flour (48%) Wheat bran (32%) Soybean meal (12%)	1.20	0.54[a]	2.25
Overall Average	1.03	0.45	2.29

[1]Five observations (3 barrows and 2 gilts) per treatment except for the rye flour - rye bran - soybean meal ration which had 1 barrow and 2 gilts i.e. data for two barrows omitted due to scouring.

[a]Means in the same column without a common superscript are significantly different from each other ($P \leq 0.05$).

Table 21

Experiment No. 2: Performance of young growing gilts and barrows fed wheat and rye fractions.

	Gilts[1]			Barrows[2]		
	Average daily feed (kg)	Average daily gain (kg)	Feed efficiency	Average daily feed (kg)	Average daily gain (kg)	Feed efficiency
Control Whole wheat, SBM	1.35	0.63	2.13	1.02	0.37	2.73
Wheat flour Wheat bran, Casein	0.92	0.42	2.20	0.92	0.42	2.20
Wheat flour Rye bran, Casein	1.14	0.50	2.25	0.70	0.31	2.28
Rye flour Rye bran, SBM	1.15	0.50	2.27	0.68	0.28	2.40
Wheat flour Wheat bran, SBM	1.18	0.53	2.24	1.22	0.54	2.25
Overall average	1.15	0.52[a]	2.22	0.91	0.39[b]	2.37

SBM - Soybean meal

[1]Based on 2 observations/treatment.

[2]Based on 3 observations/treatment except for rye flour-rye bran-SBM which is 1 observation.

[a,b]Means in the same row without a common superscript are significantly different from each other ($P \leq 0.05$).

protein values are given in Table 22. Lysine was most available in the wheat flour, rye bran ration and least available in the rye flour, rye bran ration (81.0% versus 68.7%). No significant differences in availability between rations were found with regard to threonine and methionine. In most cases, the essential amino acids were more available in the wheat flour - rye bran - casein rations and least available in the rye flour - rye bran - soybean meal rations (Table 22).

Protein was least digestible in the rye flour - rye bran - soybean meal ration (71.7%) and most available in the wheat flour - rye bran - casein ration (83.1%). No significant differences were found with respect to digestible energy values. This is not unusual due to the fact the rations were formulated to be isocaloric.

Although apparent availability of many amino acids and protein were highest in the wheat flour - rye bran - casein ration, performance of these pigs was somewhat lower than that of other groups. The low availability of essential amino acids and digestible protein in the rye flour - rye bran - soybean meal ration did not result in a marked detrimental performance for these pigs (Table 20).

Availabilities obtained with the rye flour - rye bran - soybean meal rations versus the wheat flour - wheat bran - soybean meal ration agree with those of Marquardt et al. (1979) who reported that amino acid availabilities and retention were lower for growing chicks fed rye when compared to values obtained with wheat. However, comparison of amino acid availabilities between the wheat flour - wheat bran - casein ration and wheat flour - rye bran - casein ration show the opposite.

Eggum (1973), feeding rats and pigs and Zhmakina et al. (1977)

TABLE 22

Experiment No. 2: Apparent availabilities of essential amino acids, digestible protein, and digestible energy values for pigs fed wheat and rye fractions supplemented with soybean meal or casein.[1]

Ration	Control Whole Wheat SBM	Wheat flour, Wheat bran Casein	Wheat flour, Rye bran Casein	Rye flour Rye bran SBM	Wheat flour Wheat bran SBM
Lysine	70.0[b]	75.2[ab]	81.0[a]	68.7[b]	68.9[b]
Threonine	62.9[a]	66.6[a]	71.6[a]	59.1[a]	61.3[a]
Arginine	83.8[a]	79.0[a]	82.5[a]	76.8[a]	81.1[a]
Histidine	83.2[ab]	85.1[a]	87.4[a]	76.3[b]	82.6[ab]
Isoleucine	69.6[ab]	74.6[ab]	80.3[a]	66.7[b]	69.7[b]
Leucine	75.1[ab]	79.0[ab]	82.8[a]	67.5[b]	74.2[ab]
Methionine	69.9[a]	68.5[a]	71.3[a]	64.3[a]	71.5[a]
Phenylalanine	79.3[a]	81.8[a]	85.0[a]	68.3[b]	79.3[a]
Valine	71.1[ab]	76.4[ab]	82.0[a]	64.9[b]	73.1[ab]
Digestible Protein	75.8[ab]	79.3[ab]	83.1[a]	71.7[b]	77.8[ab]
Digestible Energy	78.5[a]	74.4[a]	80.8[a]	76.9[a]	76.9[a]

[1]Reported as a percent (Dry matter basis).

[ab]Means in the same row without a common superscript are significantly different from each other ($P \leq 0.05$).

feeding rats found rye protein to have lower digestibility values than those of wheat protein which is in accordance with the data presented here.

It should be noted that results obtained by Sauer (1976) point to the fact that the faecal analysis method is valid for determining amino acid availabilities, but tends to overestimate the availability of threonine due to its relatively large disappearance in the large intestine.

F. Experiment No. 3

This experiment involved the feeding of low protein (in either mash or pellet form) and high protein wheat and rye rations to young growing pigs. When comparing the six treatments (Table 23), significant differences in average daily gain ($P \leq 0.01$) were the result of two different levels of protein. Likewise, pigs on the high protein rations showed a marked improvement in feed efficiency (17%) compared to the ones on the low protein rations.

The barrows on the rye based rations consumed slightly less feed, compared to the barrows on the wheat - based rations, whereas the opposite occurred in two of three similar comparisons with gilts (Table 23). There is no apparent reason for such a decrease in feed consumption for barrows on the rye based rations. The decrease shown by the barrows on the rye, low protein, mash ration was due, in part, to a pig which scoured and recovered during the test.

The combined gilt and barrow performance data are given in Table 24. Similar results were obtained for the high protein rations; wheat fed pigs having slightly better feed consumption, gain, and feed efficiency.

Table 23

Experiment No. 3: Performance of young growing pigs (13-27 kg) fed wheat or rye rations at high and low protein levels

Part A: Data for gilts and barrows[1].

Ration	Gilts			Barrows		
	Average daily feed (kg)	Average daily gain (kg)	Feed efficiency	Average daily feed (kg)	Average daily gain (kg)	Feed efficiency
1. Wheat High protein (MASH)	0.86	0.34	2.58	1.04	0.42	2.48
2. Rye High Protein (MASH)	0.89	0.34	2.62	0.76	0.30	2.52
3. Wheat Low Protein (MASH)	0.70	0.24	2.95	0.85	0.27	3.14
4. Rye Low Protein (MASH)	0.75	0.23	3.24	0.61	0.20	3.05
5. Wheat Low Protein (PELLETS)	0.79	0.25	3.14	0.82	0.27	3.00
6. Rye Low Protein (PELLETS)	0.72	0.23	3.08	0.72	0.24	3.04
Overall Average	0.79	0.27	2.94	0.80	0.28	2.87

[1]Based on 4 observations/treatment.

Part B: Combined data for gilts and barrows; Treatment means for Average Daily Gains.

1	2	3	4	5	6
0.38[a]	0.32[a]	0.25[b]	0.22[b]	0.26[b]	0.24[b]

[a,b,]Treatment means with the same superscript are not significantly different at $P \leq .01$.

TABLE 24

Experiment No. 3: Combined data of gilts and barrows fed wheat or rye rations at high and low protein levels.

Ration	Average Daily Feed (kg)	Average Daily Gain[1] (kg)	Feed Efficiency
Wheat High Protein (MASH)	0.95	0.38	2.53
Rye High Protein (MASH)	0.82	0.32	2.57
Wheat Low Protein (MASH)	0.77	0.25	3.05
Rye Low Protein (MASH)	0.68	0.22	3.15
Wheat Low Protein (PELLETS)	0.80	0.26	3.07
Rye Low Protein (PELLETS)	0.72	0.24	3.06

[1]Based on eight observations (4 gilts and 4 barrows)/treatment.

Feed intake, daily gain, and feed efficiency were similar for all low protein rations, except for the rye mash ration which had slightly poorer values. There was no significant difference between pelleted and mash rations although pelleting showed a slight improvement in pig performance which is in agreement with results reported by Friend and MacIntyre (1969) when they fed pelleted rye rations to finishing pigs.

Therefore, results obtained in Experiment 2 and with low and high protein rations in this experiment show that rye based rations compared favorably with wheat based rations. These results agree with Bowland (1966) feeding levels of 25% rye, and Johnston et al. (1976) feeding 100% rye as the grain in the ration, for both reported that the inclusion of rye in the ration does not significantly alter performance as compared to wheat. However, it should be noted their work was done with finishing pigs, whereas work done here was with young growing pigs.

In agreement with Wagner and Thomas (1978b), pigs on the rye rations showed poorer performance at the start of the test (Table 25). During the first five days, feed consumption was not substantially lower but average daily gain and feed efficiency were poorer for pigs on the rye based rations. Since no significant differences in average daily gain were obtained at the termination of the experiment it appears that there was more efficient utilization of rye as the experiment progressed. This was also noted in the growing-finishing experiments reported earlier.

Essential amino acid availability, digestible protein, and digestible energy values showed significant differences ($P \leq 0.05$) due to treatments (Table 26). In general, essential amino acid availabilities were lowest for the low protein, mash, rye ration.

Table 25

Experiment No. 3: Performance of young growing pigs (13-27 kg) for the first five days on test.

Ration	Average daily feed (kg)	Average daily gain[1] (kg)	Feed efficiency
Wheat High Protein (MASH)	0.55	0.29	1.89
Rye High Protein (MASH)	0.57	0.15	4.14
Wheat Low Protein (MASH)	0.55	0.17	3.19
Rye Low Protein (MASH)	0.50	0.11	4.40
Wheat Low Protein (PELLETS)	0.64	0.14	4.67
Rye Low Protein (PELLETS)	0.60	0.10	5.92

[1]Based on eight observations (4 gilts and 4 barrows)/treatment.

TABLE 26

Experiment No. 3: Apparent availabilities of essential amino acids, digestible protein, and digestible energy values of pigs (13-27kg) fed different levels of protein.[1]

Ration	Wheat High Protein MASH	Rye High Protein MASH	Wheat Low Protein MASH	Rye Low Protein MASH	Wheat Low Protein PELLETS	Rye Low Protein PELLETS
Lysine	59.1[bc]	50.2[cd]	43.7[d]	33.4[e]	73.3[a]	61.9[b]
Threonine	61.1[bc]	53.3[cd]	51.0[d]	45.6[d]	76.0[a]	68.5[ab]
Arginine	84.2[a]	78.2[b]	79.9[b]	73.2[c]	88.2[a]	85.1[a]
Histidine	83.3[ab]	63.7[d]	80.4[abc]	68.5[cd]	88.5[a]	78.9[ab]
Isoleucine	60.5[bc]	55.1[c]	57.1[bc]	46.1[d]	71.0[a]	65.5[ab]
Leucine	69.1[ab]	57.2[c]	59.0[bc]	54.4[c]	74.8[a]	70.5[ab]
Methionine	50.6[b]	43.1[c]	42.0[c]	36.8[c]	76.4[a]	57.4[b]
Phenylalanine	70.9[b]	65.3[bc]	70.0[b]	59.5[c]	80.0[a]	71.5[b]
Valine	57.9[b]	51.1[bc]	54.2[bc]	47.2[c]	70.8[a]	66.5[a]
Digestible Protein	69.6[b]	62.0[c]	69.7[b]	56.7[d]	79.5[a]	69.6[b]
Digestible Energy	71.3[b]	71.9[b]	74.7[b]	72.1[b]	83.3[a]	80.3[a]

[1]Reported as a percent (Dry matter basis).

[abcde]Means in the same row without a common superscript are significantly different from each other ($P \leq 0.05$).

The two pelleted rations had the highest availability/digestibility values with the pelleted wheat ration having a slightly higher percentage availability/digestibility values than the pelleted rye ration.

These results are in agreement with those reported by Marquardt et al. (1979) in that the amino acid availabilities and digestible protein values are lower for rye based rations as compared to wheat based rations.

Lysine, threonine, and methionine showed the lowest availabilities in all treatments, as was the case in Experiment 2. Availability results show that lysine, threonine and methionine(generally the three most limiting amino acids in pig rations) were least available in the rye, low protein, mash ration. A detailed study of the result show low availability values were obtained with gilts for these three amino acids, when compared to those obtained with barrows (i.e. 19.0, 34.5, 29.8%, versus 47.8, 56.7, and 43.7% for lysine, threonine, and methionine, respectively). Since the availability for the six other amino acids did not follow this pattern, no explanation for these results can be given.

In general, amino acids were not as available in the rations where protein requirements were lower than the N.R.C. (1973) requirements. This can be explained by the fact that metabolic faecal nitrogen losses remained relatively constant even though intake was lowered, therefore making up a higher percentage of the loss in the case of the low protein rations.

In general, amino acid availabilities were lower for the two high protein rations in this experiment than those reported for the rye and wheat based soybean meal rations in Experiment 2. Digestible protein and digestible energy values in this experiment for the two high protein rations were also lower (12% and 6% respectively).

Although energy digestibility was significantly higher ($P \leq 0.05$) for the two pelleted rations (approximately 10%) as compared to the mash rations (Table 26), there were no differences in energy digestibility between the rye or wheat based pelleted or mash rations. The large differences in availabilities/digestibilities between pelleted rye and wheat rations and the mash rations were only slightly reflected in pig performance.

SUMMARY

The early reports of poor performance of livestock and poultry when fed rye may have been the result of the presence of ergot. The inclusion of rye in rations may also be subject to species differences since rye often adversely affects the performance of growing chicks whereas with the high levels of rye used in this study, pig performance was not greatly influenced.

In the first experiment with young growing pigs fed rye - based rations, performance was only slightly poorer than for pigs fed a wheat based ration. Amino acid availabilities, protein and energy digestibilities were not significantly lower for pigs fed both rye flour and rye bran when compared to wheat flour and wheat bran. Rye bran in combination with wheat flour and casein gave higher amino acid availabilities, protein and energy digestibilities when compared to the wheat flour-wheat bran-casein ration. The use of casein in place of soybean meal as a supplemental protein source did not affect performance significantly.

Young growing pigs fed the low protein rations resulted in lower gains ($P \leq 0.05$) and 17% poorer feed efficiency when compared to the pigs fed the high protein rations. At low (15%) and high (18%) protein levels, the utilization of rye did not change relative to wheat. Pelleting of rye or wheat based low protein rations improved performance slightly compared to the same rations in the mash form. In this experiment, protein and energy digestibilities and some amino acid availability values were significantly lower ($P \leq 0.05$) for rye-based rations as compared to wheat-based rations. Gilts, especially showed low availability values for lysine, threonine, and methionine (the three most limiting amino acids).

Substituting rye for barley in growing rations at a level of 84% resulted in decreased gains ($P \leq 0.10$) but improved feed efficiency. However, performance of all pigs fed rye improved as the experiment progressed.

Rye in finisher rations as a total replacement for barley was equal to, and in the case of barrows, superior to barley-fed pigs. As was the case with growing pigs, gilts adapted to rye with time, whereas in this experiment, barrows required no adaptation period.

In general, barrows were less adversely affected by the inclusion of rye than gilts in pig in the (30-100 kg) weight range. Carcass quality was not affected by the inclusion of rye in the ration.

Amino acid availabilities, digestible protein and digestible energy values were higher for rye when compared to barley, and slightly higher again when a 50:50 combination of barley and rye was fed.

In summary, early recommended levels of 30% rye or lower for growing and finishing pigs appear too low and the use of ergot-free rye for growing and finishing rations as the sole grain source seem warranted. Similarly, with young growing pigs, rye as the sole basal grain in comparison to wheat, can be used with only slight decreases in performance.

Based on the experimental results reported here, growing-finishing pigs tend to adapt to rye rations, and its utilization becomes more efficient as the feeding period lengthens. Research done with poultry should be compared with caution with research done with pigs as it appears species differences exist in rye utilization.

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